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Local-scale mapping of benthic habitats to assess representation in a marine protected area

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Abstract. Macrobenthic habitat types were classified and mapped using a compact video array at 78 sites spaced 5 km apart in Moreton Bay, Australia. The area mapped was about 2400 km^2 and extended from estuarine shallow subtidal waters to offshore areas to the 50-m isobath. Nine habitat types were recognised, with only one on hard substrate, and their representation within an existing marine protected area was assessed. Only two habitat types were represented in highly protected (no-take) zones, with less than 3% of the total area of each habitat type included. The habitat mapping characterised several habitat types not previously described in the area and located deep-water algal and soft coral reefs not previously reported. Seagrass beds were encountered in several locations where their occurrence was either unknown or had not previously been quantified. The study represents the most spatially comprehensive survey of epibenthos undertaken in Moreton Bay, with over 40 000 m^2 sampled. Derived habitat maps provide a robust basis for inclusion of representative examples of all habitat types in marine protected area planning in, and adjacent to, Moreton Bay. The utility of video data to conduct a low-cost habitat survey over a comparatively large area was also demonstrated. The method used has potentially wide application for the survey and design of marine protected areas.

Extra keywords: benthic habitat classification, Moreton Bay, video survey.

Introduction

Design of marine protected areas (MPAs) over the last decade has increasingly adopted representation of all habitat types as a major criterion for selection of candidate areas and drawing of management boundaries (e.g. IUCN 1994; Agardy 1995; Great Barrier Reef Marine Park Authority 2003). Decisions about the scale at which elements of biodiversity should be represented, and therefore the resolution of mapping to support the design process, are complex (Levin 1992). A recent trend has been to use habitats as surrogates for biodiversity (Ward *et al.* 1999). Representativeness *sensu stricto* (Stevens 2002) logically and practically requires habitat mapping at the scale at which management provisions and protected-area boundaries are drawn. Most commonly, this is at the local scale (10 km) or finer (Kelleher *et al.* 1995). Even within the world's largest MPA, the *c.* 350 000 km^2 Great Barrier Reef Marine Park, boundaries of highly protected areas (IUCN Category I or II) are drawn at this scale (Stevens 2002).

Habitat mapping at the relevant scale allows planners to design MPAs or MPA systems that incorporate samples of every habitat type existing in the candidate area, typically through the use of optimisation techniques (e.g. Possingham *et al.* 2000; Villa *et al.* 2002). In existing reserves, representation can be assessed and habitat types that are not well represented can be highlighted for inclusion or particular management provisions. A habitat map in this context is defined as a model of relative homogeneity at a nominated spatial scale, such that points within a single polygon are more similar than points in different polygons (Stevens 2002). However, design of MPAs to include representative samples of the range of habitats occurring in the area (among a range of other criteria, Jones 1994) has been hampered by a lack of mapping at the requisite scale, largely owing to the perceived costs of underwater survey. Often, maps have been constructed from abiotic surrogates, but there are clearly inaccuracies resulting from this approach, especially in distinguishing variation in soft-bottom communities (Hirst 2004; Stevens and Connolly 2004).

Underwater videography, either diver operated (Christie *et al.* 1996; Sweatman 1997) or remotely deployed (e.g. Starmans *et al.* 1999; Bax and Williams 2001; Parry *et al.* 2003) has emerged as an effective, non-destructive and data-rich method for surveying benthic communities over relatively large areas. The widespread use of this technology has been limited by the logistical constraints of depth and endurance for SCUBA divers, or the size, complexity

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and therefore expense of remotely deployed equipment and the required support vessels. Recently, Stevens and Connolly (2003, 2004) demonstrated the quantitative use of an inexpensive video array using off-the-shelf components and compact enough to be deployed from a small (6-m) vessel.

Moreton Bay Marine Park is a relatively complex example of a meso-scale MPA, zoned to reduce conflicts between competing users and to preserve high-profile marine habitats and threatened 'iconic' species, especially seagrass beds, coral reefs, dugong and marine turtles (Anon 1997). Established in 1993, the planning process for the park predated the emergence of representativeness as a major criterion in MPA design. Park zoning plans are subject to periodic review and alteration where necessary. The Moreton Bay Marine Park zoning plan is due for review shortly (L. Harris, personal communication).

The aims of this study were: (*i*) to map marine habitat types in Moreton Bay and adjacent offshore areas at the local (10-km) scale, using an inclusive habitat classification as a basis for MPA design; and (*ii*) to assess the extent to which each derived habitat type is represented within the existing MPA zones.

Materials and methods

Study site

Moreton Bay (27°15′S, 153°15′E) on the east coast of Australia, is a shallow, coastal embayment, covering approximately 1500 km^2 (Fig. 1). The bay is roughly triangular in shape, about 35-km wide in the north and narrowing in the south into a maze of mangrove-lined waterways. It is protected in the east by large sand islands; its main ocean entrance is in the north east and there is a smaller entrance in the east. Most of the bay is less than 15-m deep, but reaches depths greater than 25 m in the north-eastern part, adjacent to the main ocean entrance. The western parts of the bay are heavily influenced by terrestrial inputs (Costanzo *et al.* 2001), principally from the Brisbane River (Eyre *et al.* 1998) and smaller river systems. The eastern side is essentially under oceanic influence (Udy and Dennison 1997). The offshore portion of the study area extends seaward from the two large sand islands to the 50-m isobath. In general, the bottom is of soft substrate and slopes quite evenly away from the ocean beaches. The north-eastern extremity of each island is formed by a rocky headland with associated offshore outcrops. In the north-eastern part of the study area, a sandstone platform provides a substrate for Flinders Reef, a coral-reef community of surprisingly high diversity given its latitude (Davie 1998; Harrison *et al.* 1998).

The bay and adjacent offshore waters are included within Moreton Bay Marine Park (Fig. 1), a zoned, multiple-use MPA declared in 1993 and managed to 'provide for the ecologically sustainable use of Moreton Bay Marine Park and to protect its natural, recreational, cultural heritage and amenity values' (Anon 1997, page 9). The park covers about 3800 km^2 and extends from highest astronomical tide to between 3 and 20 km offshore and a maximum depth of about 150 m.

Field methods

Data were collected using a compact towed video array designed specifically for the survey. The general arrangement follows the design principles of Barker *et al.* (1999), but much reduced in size and complexity. The array was towed on a 10-m tether behind a 20-kg drop weight suspended beneath the survey vessel approximately 2 m above the substrate. The array was slightly positively buoyant and 'flew' a constant and adjustable distance above the substrate by using the trailing-chain method, which allowed the array to self adjust to irregularities on the bottom. This arrangement can be used on rough substrates and is smaller (0.5 m × 0.5 m × 0.3 m) and lighter (<10 kg) than comparable sled-based equipment. The array was successfully deployed to a maximum depth of 52 m.

The sensor was a high resolution (480 lines) colour 'lipstick' camera mounted in a PVC housing at a 45° angle to the substrate. The unit was powered, and the video signal returned to the surface, via a 3-core cable. The video signal was recorded on a SONY Digital 8 'handycam' (Sony Corporation, Tokyo), which doubled as a video monitor with its 6-cm LCD screen. Two laser diodes mounted parallel to each other projected dots onto the bottom a constant 0.5 m apart, allowing calibration of the video images and checking for correct orientation and elevation of the array.

Sample sites were set out in a staggered 5-km-spaced array covering the central, eastern and southern parts of the bay, and offshore waters to the 50-m isobath (Fig. 1). The 5-km spacing was chosen to facilitate construction of polygons of relative similarity at the local (10-km) scale. Budgetary constraints prevented surveying offshore components at the northern and southern ends of the marine park; this will be addressed in planned future studies. The western portions of the bay and the constricted waterways in the south were not surveyed because they were generally too turbid for video-based survey.

The sampling design was a single 500-m transect at each site. Although this approach permits no assessment of within-site variability,

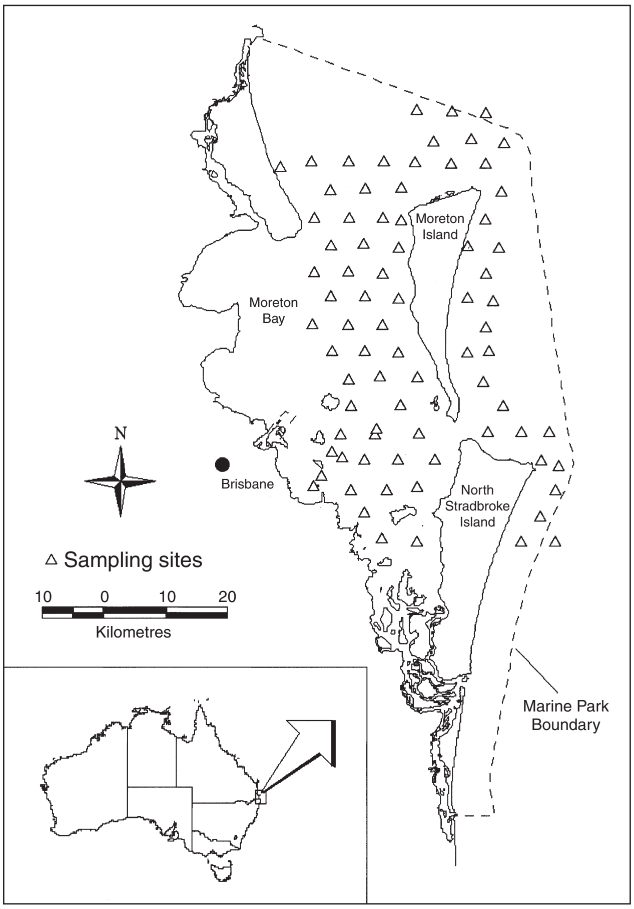

Fig. 1. Study area showing sampling sites with the marine park boundary.

this was acceptable in this case since it was determined *a priori* that such variability is regarded as patchiness at a scale smaller than the target resolution. Transect start and finish points were located using GPS, which gave sufficient positional accuracy (about 15 m) compared to the target-mapping scale (10 km). Implicit in the sampling design is that habitat elements with linear dimensions less than 5 km may not be captured, and that variability at the 500-m scale is treated as patchiness within habitats.

Data extraction

Digital video was captured at 1 frame every 2–5 s, the frame rate giving maximum coverage without frame overlap. The resultant frame series was stored as a Quicktime (Apple Computer Inc., Cupertino, CA; www.apple.com/quicktime, verified January 2005) movie file, and digital image enhancement was carried out where necessary to enhance clarity and contrast.

Overlay layers were added to the Quicktime movies to facilitate data extraction. A calibrated 1-m^2 frame was overlaid, within which all solitary or discrete colonial organisms were counted, as well as a 9-point array for calculating percentage cover. For each frame, the taxa present at each of the nine points were recorded, as was the number of individuals of each taxon in the whole frame. Presence and abundance of bioturbating organisms was quantified by scoring variables for occurrence of biogenically worked sediment surfaces, and counts of burrows or holes in three size classes.

Data were pooled for all frames in a transect. Percentage cover was calculated from point data and density was calculated from count data and bioturbation indicators. The three datasets (but not individual taxa) were standardised to the range 0–1 and combined to allow point, count and bioturbation indicator data to be analysed as a single dataset. The resulting data matrix (morphospecies and bioturbation indicators by sites) was then analysed using multivariate techniques.

Classification and mapping

Similarity matrices were constructed using Bray–Curtis similarity because it does not derive similarity from conjoint absences (Clarke and Warwick 1994). Relationships between sites were visualised using non-parametric multidimensional scaling (MDS) ordination supplemented with cluster analysis and pairwise inter-group similarity using the SIMPER (similarity percentage breakdowns) module in the PRIMER package (PRIMER-E Ltd, Plymouth; www.pml.ac.uk/primer/, verified January 2005).

Preliminary analyses compared classifications from the untransformed dataset to those from log $(x + 1)$, 4th-root- and presence/absence-transformed datasets. The results were broadly similar, and the 4th-root transformation was selected for subsequent analyses because it allows rarer taxa to influence discrimination between groups without discarding abundance information.

Habitat maps were constructed by spatial agglomeration, that is, allocating sites into groups of relative similarity, based on consistently occurring groups of sites. The number of groups defined was determined initially by site clusters in the MDS and verified by calculating analysis of similarity (ANOSIM) Global R values across a range of group-number solutions to confirm that the target group-number solution corresponded to the highest Global R value; that is, the between-group difference is highest. A few very depauperate sites (only 1 or 2 taxa and very low densities) had consistently low Bray–Curtis similarities and therefore tended not to associate with any group or with each other. This was resolved by conducting a subsequent analysis using a non-zero constant, which aided in determining the group to which they were most similar.

Representation in the existing MPA

The study area comprises about 2400 km^2 (outer boundary based on a 2.5-km buffer, that is, half the nominal site spacing, around each sample site) and constitutes approximately 60% of the marine park. For analysis of representation in the MPA, habitat polygons were constructed using Voroni tessellation, a technique that draws polygons whose boundaries define the area that is closest to each point relative to all other points (Watson and Philip 1984).

Representation of the derived habitat types within the parts of the marine park covered by the study area was assessed by overlaying the derived habitat groups on the digital zoning plan. The analysis was conducted using both point and polygon habitat data to address biases inherent to both. Point data assume no spatial extrapolation of the habitat information from a single point in space (in this case, the transect centroid) and therefore underestimates representation in smaller zones. On the other hand, polygons derived from Voroni tessellation assume a habitat boundary at the midpoint between sites in different groups and assume homogeneity between sites within a group, and may therefore overestimate representation in small zones. Considering both types of analysis together gives a more balanced assessment of representation.

Results

Description of dataset

A total of 78 sites was surveyed between September and December 2002. Over 40 km of video transect was recorded, and 16 373 individual frames were analysed. Mean frame number per transect was 202 (range 53–435). Relative abundances (as percentage cover or density) of 114 morphospecies were recorded, as well as four indicators of bioturbation (Appendix 1).

Of the 114 morphospecies, 24 occurred in only one site, 64 contributed less than 0.1% each to total standardised abundance and 101 contributed less than 1% each. Five taxa (Table 1) were very common, each contributing more than 10% to total standardised abundance and, in total, represented over 61%. These common taxa were not widespread over the study area and none occurred in more than 20% of sites. No taxon was ubiquitous. The most frequently occurring taxon (the acorn worm *Balanoglossus carnosus*) occurred in just under 50% of sites, but contributed only 0.4% to total standardised abundance.

Bioturbation was common, with small burrows (<3-cm diameter) occurring in 55% of sites. Biogenic working of surface sediments was evident in 47% of sites.

Table 1. Taxa contributing more than 10% to total standardised abundance

Percentage frequency is the number of sites in which the taxon occurs, as a percentage of the total number of sites. Number of sites = 78, number of frames = 16 373

Taxon	Percentage total abundance	Percentage frequency
Anemone sp. 4	14.5	17
Halophila spinulosa	12.9	19
Zostera capricorni	12.0	6
Cerianthus sp.	11.9	17
Encrusting algae	10.0	6

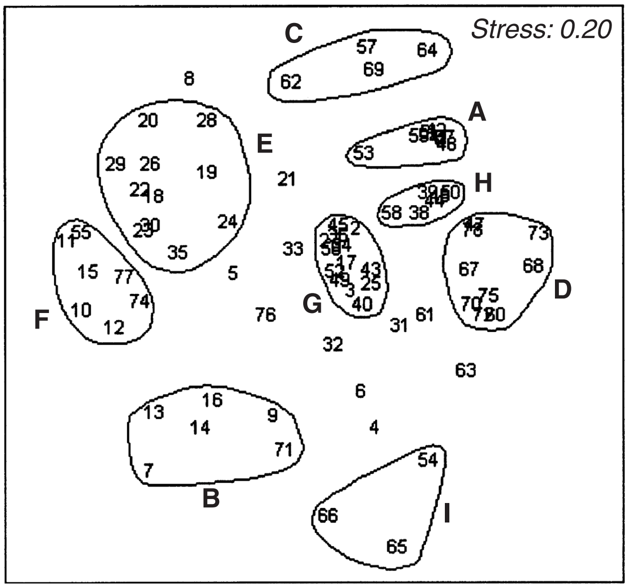

Fig. 2. Multidimensional scaling ordination plot of all sites with selection of core groups.

Derived habitat classification

Several groups of sites (termed 'core groups') formed consistently across differently weighted MDS analyses (4th root shown in Fig. 2). Stress levels in two-dimensional MDS plots were relatively high (0.20), so group composition was not determined purely from the MDS plots, but groups agreed well with corresponding cluster analyses. Although stress levels in three-dimensional MDS plots were lower (0.15), the large number of sites in the plots made interpretation unworkable. Sites within these core groups (Fig. 3) were aggregated and pairwise SIMPER analysis was used to determine the similarity between the remaining single points and the core groups. On the first pass, single sites with Bray–Curtis similarities of 40% or above were allocated to the group with which they were most similar. Examination of the raw data showed that the three sites left after this pass had consistently low Bray–Curtis similarities because they were depauperate, rather than because they had multi-taxon assemblages very different to the remainder of sites. A parallel analysis using an additional very small (10^{-10})

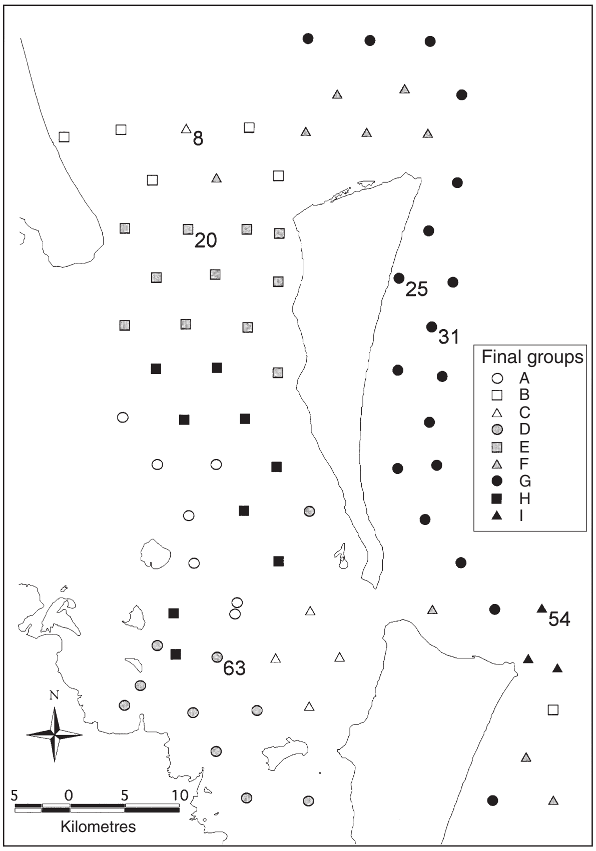

Fig. 3. Study area showing derived habitat groups. Numbers denote sites referred to in the text. Letters refer to habitat groups as follows: A, bioturbated mud; B, sparse on rubble and sand; C, seagrass dominated; D, inshore algae and sponge; E, diverse sandy; F, depauperate sandy; G, offshore sparse but diverse; H, bioturbated sparse; I, reefal.

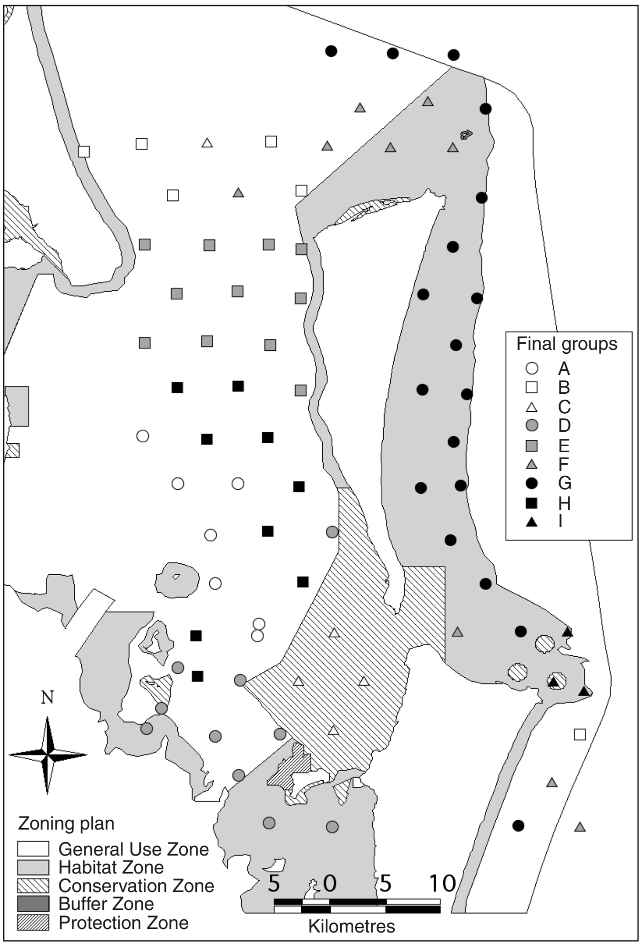

Fig. 4. Habitat group points superimposed on the Moreton Bay Marine Park zoning plan. Letters refer to habitat groups as for Fig. 3.

constant term (post transformation) improved Bray–Curtis values without changing the overall relationships or composition of the core groups, and clarified the groups to which these sites should be allocated (Fig. 4). ANOSIM analysis verified that the derived groups were significantly different from each other (Global $R = 0.84$, $P = 0.001$, pairwise tests all significant $P \geq 0.018$). ANOSIM Global R values were calculated for solutions from 2 to 12 groups ($P < 0.001$ in each case). Global R values increased approximately linearly from two groups (0.56) to highest values at 8 and 9 groups (both 0.84). At larger numbers of groups, Global R values declined, although only slightly (12 groups, Global $R = 0.82$). The 9-group interpretation therefore represented maximum between-group difference.

Description of groups

Two groups (Table 2) stood out as being taxon rich: D (42 taxa) and G (28 taxa). These groups were at opposite ends of the estuarine–oceanic continuum. Group D covered ten sites in the southern portion of Moreton Bay, where it begins to narrow into a maze of mangrove-lined waterways. Macrobenthos of group D was dominated by algae and sponges but was very diverse, with significant contributions from solitary ascidians, anemones and seagrass. Of the 42 taxa, 19 (45%) contributed more than 1% each to the total similarity within the group. Group G was the largest group, covering 18 sites that were essentially oceanic. Most sites were deeper than 30 m. Although very diverse, with 10 of the 28 taxa (36%) contributing more than 1% each to the total similarity within the group, abundances were generally low, with little cover (except at site 31, see below) and most taxa sparsely distributed. Occasional clumps of the seagrass *Halophila spinulosa* were found at about 25-m depth in several sites.

At the other extreme in terms of taxon richness, were groups A and F. These two groups also represented a contrast of inshore and offshore environments. Group A was a muddy inshore environment dominated by bioturbators, whereas F was offshore, sandy and depauperate, with sparse populations of the acorn worm *Balanoglossus carnosus* responsible for 83% of the overall similarity within the group.

Of the remaining groups, C and I were both cover dominated. Group C sites were seagrass beds and, notably, the group included site 8, where seagrass beds have not previously been mapped. Group I was the only reefal group in the classification, dominated by encrusting algae, soft corals and sponges.

Group E highlighted an assemblage that had not previously been documented in Moreton Bay, dominated by very high-density patches (transect maximum 0.85 individuals

Table 2. Composition and features of derived groups

Group	No. sites	No. taxa	Dominant taxa or bioturbation indicator (>10% CTGS)	No. taxa >5% CTGS	No. taxa >1% CTGS
A Bioturbated mud	7	5	Small burrows (54%) Medium burrows (35%)	3	3
B Sparse on rubble and sand	6	8	Bivalve unidentified (36%) Sponge unidentified (28%) Echinoid unidentified (14%)	5	8
C Seagrass dominated	5	19	*Halophila ovalis* (33%) *Halophila spinulosa* (17%) Zostera capricorni (13%)	5	9
D Inshore algae and sponge	10	42	Worked sediment (16%) Phaeophyta sp. 1 (11%) *Psammocinia* sp. (11%)	7	19
E Diverse sandy	11	18	*Cerianthus* sp. (33%) *Balanoglossus carnosus* (23%) Echinoid unidentified (10%)	5	8
F Depauperatesandy	9	4	*Balanoglossus carnosus* (83%)	3	4
G Offshore sparse but diverse	18	28	Worked sediment (39%) Small burrows (27%)	4	10
H Bioturbated sparse	9	19	Worked sediment (39%) Small burrows (20%) Anemone sp. 4 (12%) Medium burrows (11%)	5	8
I Reefal	3	17	Encrusting algae (20%) Digitate soft coral (16%) Macroalgae unidentified (15%) Fan-forming soft coral (11%) White ridge sponge cf. *Callyspongia manus* (10%)	5	17

CTGS = Contribution to total-group similarity, derived from SIMPER analysis. CTGS for each dominant taxon is given in parentheses.

per m^2, frame maximum 125 individuals per m^2) of cerianthid anemones. Group H was similar to group G in that it was dominated by bioturbators, but was clearly distinguished by having fewer taxa, and supporting an array of taxa not found in group G including the seagrass *Halophila ovalis* and an unidentified sand anemone occurring in high-density patches (transect maximum 0.1 individuals per m^2, frame maximum 38 individuals per m^2). Group B was a relatively depauperate group characterised by low densities of mobile macroinvertebrates, such as echinoids, crinoids, bivalves and occasional sponges and soft corals attached to patches of rubbly substrate.

Exceptional or unusual features

Several sites contained features of unusual diversity or abundance (Fig. 3) while still grouping with one of the core groups on the second pass.

At site 31 and, to a lesser extent, site 25, part of the transect covered a macroalgal reef on boulder outcrops. Cover was dominated by several taxa of macroalgae, including large brown algae such as *Ecklonia* sp. and *Sargassum* sp. The remainder of the transect was quite depauperate, so overall abundance was not sufficiently high to prevent this site from falling within Group G.

Site 54 contained an unusual deep-water (48–52 m) reef assemblage dominated by encrusting algae, soft corals, seawhips, sponges and crinoids. Examination of the SIMPER tables showed that this site was included with Group I on the second pass on the basis of encrusting algal cover and soft coral. It is likely that these were actually different taxa but, because of the deep-water location, samples were unable to be recovered, so the dominant taxa had to be assigned to general categories. This resulted in the site being allocated to Group I, with which it was most similar, as the only reefal group.

Site 63 contained the only significant stands of soft coral reef observed inside the bay but was included within Group D on the basis of associated sponge and macroalgae taxa.

Representation in existing MPA

Representation was assessed using both point (Fig. 4) and polygon (Fig. 5) analyses. In each type of analysis, the habitat information was overlaid on the Moreton Bay Marine Park zoning plan to derive the percentage frequency (points – Fig. 4) or percentage area (polygons – Fig. 5) of occurrence of each habitat type in each zone. The information is also presented in terms of IUCN protected area categories (IUCN 1994). Briefly, the zones represent a rising scale of levels of protection from ‘General Use’ zones (IUCN Catagory VI), within which most activities including dredging and trawling are permissible, to ‘Protection’ zones (IUCN Catagory II), within which no extractive or destructive uses are allowed. In the intermediate zones (all IUCN Catagory IV), varying levels of disturbance or extraction are permitted (for details see Anon 1997).

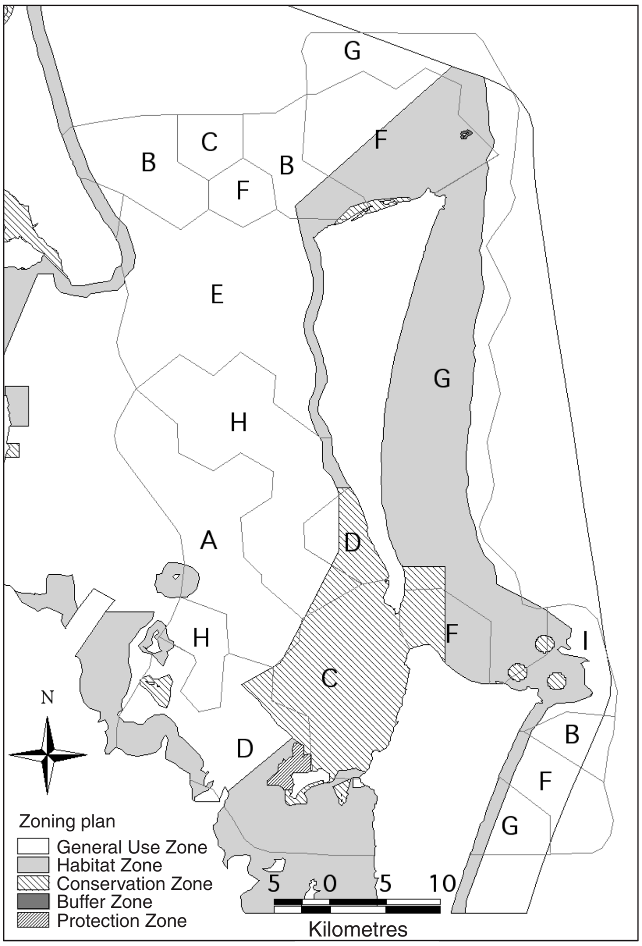

Fig. 5. Habitat group polygons derived from Voroni tessellation superimposed on the Moreton Bay Marine Park zoning plan. Letters refer to habitat groups as for Fig. 3.

The results of point (Table 3) and polygon area (Table 4) analyses are comparable, although the point analysis is biased by the location of the samples, for instance no sample sites are located in Protection zones. Four of the nine habitat types are not represented in a zone managed for protection of the habitat or particular values (IUCN Catagory IV or below). Alternatively, the polygon area analysis concluded that only two of the nine habitat types are represented within a Protection zone and of these, less than 3% of the total area of each habitat type is represented. All habitat types have some representation in a zone managed for protection of the habitat or particular values and in three of the nine habitat types, less than 10% of the total area of each habitat type is represented.

Discussion

The derived habitat groups illustrate consistently occurring associations of sites, plus the three very depauperate sites. Interpreted at a level where between-group difference is greatest, nine habitat types are recognised as a basis for

Table 3. Representation by points

Number of points of each habitat type in each zone or category divided by the total number of points of each habitat, expressed as percentages. IUCN categories corresponding to each zone are given in parentheses below the zone name. A subtotal of IUCN Category IV zones is provided to allow comparison between the categories

Habitat group	Zone and IUCN category					
	General use (VI)	Habitat (IV)	Conservation (IV)	Buffer (IV)	Subtotal IV	Protection (II)
A Bioturbated mud	100					
B Sparse on rubble and sand	100					
C Seagrass dominated	20		80		80	
D Inshore algae and sponge	70	30			30	
E Diverse sandy	100					
F Depauperate sandy	50	50			50	
G Offshore sparse but diverse	18	82			82	
H Bioturbated sparse	100					
I Reefal		67	33		100	
Overall	63	30	7	0	37	0

Table 4. Representation by polygon area

Area of each habitat type within each zone or category, divided by total area of each habitat type, expressed as %. IUCN categories corresponding to each zone are given in parentheses below the zone name. A subtotal of IUCN Category IV zones is provided to allow comparison between the categories

Habitat group	Zone and IUCN category					
	General use (VI)	Habitat (IV)	Conservation (IV)	Buffer (IV)	Subtotal IV	Protection (II)
A Bioturbated mud	98.29	1.31	0.40		1.71	
B Sparse on rubble and sand	86.59	12.42	0.99		13.41	
C Seagrass dominated	17.04	1.01	81.95		82.96	
D Inshore algae and sponge	39.16	39.93	18.24		58.17	2.67
E Diverse sandy	90.39	9.60	0.01		9.61	
F Depauperate sandy	45.26	46.20	8.32	0.18	54.70	0.04
G Offshore sparse but diverse	34.00	63.94	2.07		66.00	
H Bioturbated sparse	93.70	2.43	3.86		6.30	
I Reefal	49.65	44.37	5.98		50.35	
Overall	58.55	29.50	11.59	0.02	41.11	0.34

assessment of representation. Analyses of representation show that most of the habitat types derived are not included within Protection zones (IUCN Category II). Although about 40% of the existing marine park is not covered by the study, there are no other Protection zones in areas that could be covered by an extension of this survey (Anon 1997), so representation of habitat types in IUCN Category II areas would not be improved by considering the entire marine park. The proportion of each habitat type that should be included in highly protected zones is contingent on the reserve philosophy, the ecology of the benthic assemblages and the degree and likelihood of threat to each habitat type. Nonetheless, any rezoning of the park that included representation as a criterion should include substantially expanded highly protected areas to include samples of each of these habitat types, even at the lowest sampling resolution (5 km).

The use of spatial agglomeration as a mapping tool assumes that an autocorrelative relationship exists between similarity (in this case Bray–Curtis similarity based on relative abundance of epi-benthic taxa) and the distance separating sample sites. To put it another way, we must have confidence that sites randomly selected within a polygon derived from spatial agglomeration will be more similar than those from different polygons. This relationship was tested in the study area by Stevens (2005), who found a strong autocorrelative relationship between similarity and distance at site spacings from 600 m to 50 km. Within that range, sites less than 2.5 km apart were found to be very similar but at distances greater than 10 km, sites were markedly dissimilar.

Within the plethora of planning and summary documents produced in recent years that are relevant to Moreton Bay or south-east Queensland more generally (e.g. Department of

Environment and Conservation 1989; Brisbane River Management Group 1996; Dennison and Abal 1999, to name a few), subtidal habitats other than seagrass beds and coral reefs have received scant attention. Habitat maps in such documents typically illustrate mangroves, salt marshes, seagrass beds and coral reefs and leave the rest blank (e.g. Brisbane River Management Group 1996). Yet the combined area of these high-profile habitats within Moreton Bay Marine Park is less than 10% ($<380\,\text{km}^2$) of the total marine park area (data from Hyland *et al.* 1989; Brisbane River Management Group 1996; Dennison and Abal 1999). The current study has used an inclusive approach, at a management-relevant scale, to 'fill in the blanks'. All the subtidal environments within the study area were classified into habitat types, rather than just highlighting high-profile habitat types. The habitat types were defined on the basis of directly measured biological distributions, rather than physical variables or abiotic surrogates subject to inaccuracies in predicting patterns of biodiversity at this scale (Stevens and Connolly 2004). The habitat types are derived from a quantitative and consistent survey methodology and provide a robust basis for the analysis of representation in the existing MPA, for incorporation of representation in any future revised zoning plan and as a baseline against which to assess any future changes in habitat distribution. This is consistent with contemporary approaches to marine resource management, which make it clear that all habitat types have an intrinsic conservation value and should be represented in reserve systems (Agardy 1995, 2000; Marine Reserves Working Group 2000; Stevens 2002).

This is the most spatially comprehensive survey yet carried out in Moreton Bay. Several studies through the 1970s and 1980s (Hailstone 1976; Poiner 1977; Stephenson and Cook 1977; Stephenson *et al.* 1978; Young and Wadley 1979; Stephenson 1980; Poiner and Kennedy 1984) characterised parts of Moreton Bay, principally Bramble Bay in the west and Middle Banks in the east, on the basis of epifauna and infauna from grab samples. Different benthic communities were apparent with some general east–west trends across the bay (Skilleter 1998). Stephenson *et al.* (1970) defined eight benthic habitat types in the bay on the basis of infauna from 400 dredge samples. However, no previous study has attempted to characterise the greater part of the bay, including the dynamic sand-bank systems in the northern part, and no previous study has examined benthic communities offshore. Other recent surveys in Moreton Bay have focussed on mapping seagrass beds and quantifying changes in their extent over time (Hyland *et al.* 1989; Dennison and Abal 1999).

This survey has brought to light previously unreported aspects of the macrobenthic communities of Moreton Bay and associated offshore areas. Of particular interest is the dominance of anemones *Cerianthus* sp. in the northern part of bay, at maximum densities in a single frame of over 100 individuals per m^2. Given the nature of the local environment, with mobile sand substrates in high to moderate current flows, the diversity of this habitat group is surprising. The dynamic sand bank systems of the northern bay (e.g. Pattiaratchi and Harris 2002) have long been assumed, in the absence of quantitative information (e.g. Dennison and Abal 1999), to be quite depauperate. This study shows that this is not the case. Eighteen macrobenthic taxa (with eight contributing more than 1% to total-group similarity) were recorded from the area including the high densities of cerianthid anemones previously mentioned, but also seagrasses and mobile taxa, particularly echinoderms. Seagrasses have also been noted in previously unmapped locations, particularly on the sand banks outside the northern entrance and sparsely offshore to about 25-m depth.

The inclusive approach to habitat survey and mapping used in this study has also located examples of deep-water algal reefs (site 31) and soft coral reefs (site 54) not previously recorded in this area. The scale of the survey programme, dictated by the target scale of the classification, did not permit finer scale investigation to determine the boundaries of these habitat types. Subsequent surveys using a stratified sampling arrangement would probably locate further examples and perhaps smaller-scale habitat features not found in this study.

This study permits no analysis of temporal stability in the composition or distribution of the derived habitat types. The observed patterns may change seasonally or as a result of pulse recruitment, although the data transformation used is designed to ameliorate the influence of numerically dominant taxa. Further studies are planned to investigate patterns in temporal distribution of habitat types.

All landscapes sit within a nested hierarchy of scales (Ray and McCormick-Ray 1995) and it is not possible to survey across all scales from continental to the microscopic. The selection of the range of scales examined is therefore driven by the needs of the analysis, in this case a map of habitats at the scale at which MPAs are drawn. Moreover, if surveys over relatively large areas are desired, there is an inevitable tradeoff between spatial resolution and the total area characterised by the sampling (Armonies 2000). This is partly offset by use of video surveys in this study, which allow far greater areas to be sampled than 'traditional' survey tools such as box cores, grabs or dredge samples. However, it is acknowledged that this involves a sacrifice in taxonomic resolution because organisms are not retrieved for taxonomic verification. Previous studies on the impact of using taxonomic levels higher than species to characterise habitats (e.g. Williams and Gaston 1994) or detect impacts of pollution (e.g. Thompson *et al.* 2003) have shown conflicting results, linked, in some cases, to the spatial scale of the analyses (Vanderklift *et al.* 1998). In the area of the current study, Stevens (2003) has shown that habitat groups defined on the basis of morphospecies (as used in this study) were highly correlated with those derived from a lifeform classification (roughly equivalent to family level).

Studies seeking to characterise benthic habitats at scales similar to the current study have generally used grab samples, dredges, corers and trawls, individually or in combination (e.g. Tselepides *et al.* 2000), often as an adjunct to acoustic characterisation (e.g. Brown *et al.* 2002). Video sampling has been used as an adjunct to grab or trawl sampling (Cailliet *et al.* 1999), acoustic characterisation (Bax *et al.* 1999), radio-acoustic positioning telemetry (Parsons *et al.* 2004) or laser swath mapping (Carey *et al.* 2003) but has seldom been used as the primary or exclusive device for habitat classification.

Video-based surveys clearly sample different components of biodiversity than grab samples, box corers or trawls, and should therefore not be seen as a replacement for such methods. For rapid, broad-scale survey, it has advantages over all these methods in terms of its low environmental impact, ease of use, rapid acquisition of quantitative data and the provision of *in situ* information. Cailliet *et al.* (1999) compared quantitative sampling from trawl, video sled and submersible and reported that video sampling gear was less subject to bias from gear avoidance and provided consistently higher 'and perhaps better' (*ibid* p. 579) estimates of density. The 'flying' video arrays used in this study and others (Barker *et al.* 1999) have the additional advantage of being usable on virtually any substrate. However, there is a clear trade-off between the area sampled and taxonomic resolution of the samples. In this study, taxa observed were classified to morphospecies, although some higher taxonomic categories were necessary and samples were not retrieved for verification. In this application, the information lost compared to diver, grab or dredged samples is offset by the ability to sample extensively in a cost-effective manner. The ability to deploy the compact lightweight sampling array used in this study from a small vessel dramatically reduces field costs and the capital cost of the equipment is low. Estimated costs, based on equipment and vessel costs and person days in the field and in the laboratory are an order of magnitude less than comparable diver-based (Cohen *et al.* 2000), video-sled (CSIRO 1994) or ROV-based methods (Parry *et al.* 2003).

The use of MPAs as a management tool is increasing around the world, and with it the need for robust and objective methods of characterising the habitats encompassed. The method used for this study is characterised by: (*i*) an inclusive approach to habitat characterization; (*ii*) the use of biological information rather than abiotic surrogates; and (*iii*) a cost-effective and quantitative survey technique. It therefore has potentially broad application for the design of MPAs both in south-east Queensland and in other parts of the world.

This study has provided a major increase in the information available on the distribution of habitat types on a bay-wide scale. The fact that this study has located examples of habitat types not previously described in Moreton Bay, a relatively well known and intensively studied system (e.g. Crimp 1992; Tibbetts *et al.* 1998), adds urgency to the need to carry out habitat mapping at this scale more generally, before we are reduced, as Stachowitsch (2003) suggests, to studying only impacted marine environments. There is clearly a risk that we may lose habitats before we even realise they are there.

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Appendix 1. List of taxa encountered during the surveys

Primary source for field identification was Davie (1998) and the table arrangement follows the order used in that reference

Species or taxon designator	Common name or description
Macroalgae	
Asparagopsis taxiformis	Iodine weed
Caulerpa taxifolia	Sea fern
Chlorodesmis major	Turtle weed
Cystoseira trinodis	Chain float
Delisea pulchra	Red Bushy Algae
Ecklonia sp.	Kelp
Hypnea pannosa	Crisp tangled algae clump
Padina australis	Brown fan algae
Sargassum crassifolium	Sargassum
Ulva sp.	Sea lettuce
Encrusting alga	Encrusting green sheet
Chlorophtya sp. 1	Single lobed green algae
Phaeophyta sp. 1	Tangled brown algae
Phaeophyta sp. 2	Filamentous macroalgae
Rhodophyta sp. 1	Red alga with tufted branches
Rhodophyta sp. 2	Fine branched red algae
Macroalgae unidentified	Other macroalgae spp.
Algal mat	Fine filamentous algal mat over sediment
Seagrass	
Halophila ovalis	Dugong grass
Halophila spinulosa	Spiny dugong grass
Zostera capricorni	Eelgrass
Seagrass rhizome mat	Seagrass rhizome mat
Sponges	
Callyspongia manus	Blue ridge sponge
Dysidea sp.	Pink sandy sponge
Iotrochota coccinea	Black slimy sponge
Niphates sp.	Furry vase sponge
Clathria craspedia	Orange bulbous sponge
Clathria kylista	Orange tube sponge
Spirastrella montiformis	Mountainous pillow sponge
Psammocinia sp.	Grey massive sponge
Sponge cf. *Callyspongia* sp.	White ridge sponge
Sponge sp. 1	Grey-brown finger sponge
Sponge sp. 2	White lumpy sponge
Sponge sp. 3	Brown bladder sponge
Sponge sp. 4	Brown vase sponge
Sponge sp. 5	Grey-purple bowl-forming sponge
Sponge sp. 6	Encrusting sponge
Sponge sp. 7	Grey cavernous sponge
Sponge unidentified	Other sponge spp.
Anthozoans	
Cavernularia obesa	Obese sea pen
Cerianthus sp.	Tube anemone
Macrodactyla doreensis	Purple-tipped Bay anemone
Sphenopus marsupialis	Solitary zooanthid
Virgularia gustaviana	Short-quill seapen
Virgularia rumphi	Long-quill seapen
Anemone sp. 1	Fan-foming sand anemone
Anemone sp. 2	Giant sand anemone
Anemone sp. 3	Rubber disc anemone
Anemone sp. 5	Small blue anenome
Anemone sp. 4	Sand anemone
Anemone unidentified	Other anemone spp.
Hydroid spp.	Hydroid spp.
Seapen unidentified	Other seapen spp.
Soft corals	
Carijoa sp.	Fouling soft coral
Echinogorgia sp.	Elongate sea fan
Guaiagorgia sp.	Seawhip soft coral
Melithaea sp.	Gorgonian fan
Mopsella sp.	Orange sea fan
Digitate soft coral	Digitate soft coral spp.
Fan-forming soft coral	Fan-forming soft coral spp.
Lobate soft coral	Lobate soft coral spp.
Seawhip sp. 1	Deep-water spiral seawhip
Hard corals	
Acropora spp.	Branching coral
Digitate non-Acropora coral	Digitate non-Acropora coral
Encrusting non-Acropora coral	Encrusting non-Acropora coral
Massive non-Acropora coral	Massive non-Acropora coral
Annelids	
Balanoglossus carnosus	Acorn worm
Chaetoperus variopedatus	Parchment tube worm
Sabellid sp. 1	Flexible parchment tubes on surface
Annelid sp. 1	Tubeworm 2–3 stiff tentacles
Worm tube aggregation	Worm tube aggregation
Worm tube solitary	Worm tube solitary
Bivalves	
Malleus albus	White hammer oyster
Pinna bicolor	Razor clam
Trichomya hirsuta	Hairy mussel
Bivalve sp. 1	Large pale bivalve
Bivalve sp. 2	Orange/white bivalve
Bivalve unidentified	Other bivalve spp.
Crustaceans	
Portunus pelagicus	Sand crab
Scylla serrata	Mud crab
Grapsid sp. 1	White clawed grapsid
Echinoderms	
Asterina cepheus	Burton’s seastar
Astropecten vappa	Spoilt seastar
Comanthina sp.	Yellow crinoid
Comasterid sp.	Comasterid crinoid
Echinocardium cordatum	White heart urchin
Holothuria atra	Blackfish
Holothuria scabra	Sandfish
Himerometra sp.	Large dark himerometrid crinoid
Lovenia elongata	Brown Heart urchin
Luidia australiae	Fragile seastar
Gomophia mamillifera	Ornamented seastar
Pentaceraster regulus	Spotted seastar
Pentagonaster dubeni	Vermillion seastar
Stichopus horrens	Flemfish
Stichopus naso	Warty seacucumber
Zygometra microdiscus	White-tipped featherstar
Asteroid unidentified	Other asteroid spp.
Brittlestar unidentified	Other ophuroid spp.
Crinoid sp. 1	Small white crinoid
Crinoid unidentified	Other crinoid spp.
Echinoid sp. 1	Sand dollar

(*continued next page*)

Appendix 1. (*continued*)

Species or taxon designator	Common name or description
Echinoid sp. 2	Large dark urchin with thick stubby spines
Echinoid sp. 3	Large pale regular urchin with short spines
Echinoid unidentified	Other echinoid spp.
Holothurian unidentified	Other holothurian spp.
Ascideans	
Cnemidocarpa stolonifera	Soft sediment ascidian
Eudistoma elongata	White ascidian 'rope' colony
Phallusia obesus	Fat brown ascidian
Polycarpa papilata	White and red ascidian
Pyura rosbusta	Robust ascidian
Ascidean sp. 1	Small translucent solitary ascidian
Solitary ascidean unidentified	Other solitary ascidian spp.
Colonial ascidean unidentified	Other colonial ascidian spp.
Bioturbation indicators	
Biogenically worked sediment surface	Evidence of tracks, mounds or sediment displacement
Small burrows	Burrows <3 cm
Medium burrows	Burrows 3–10 cm
Large burrows	Burrows >10 cm