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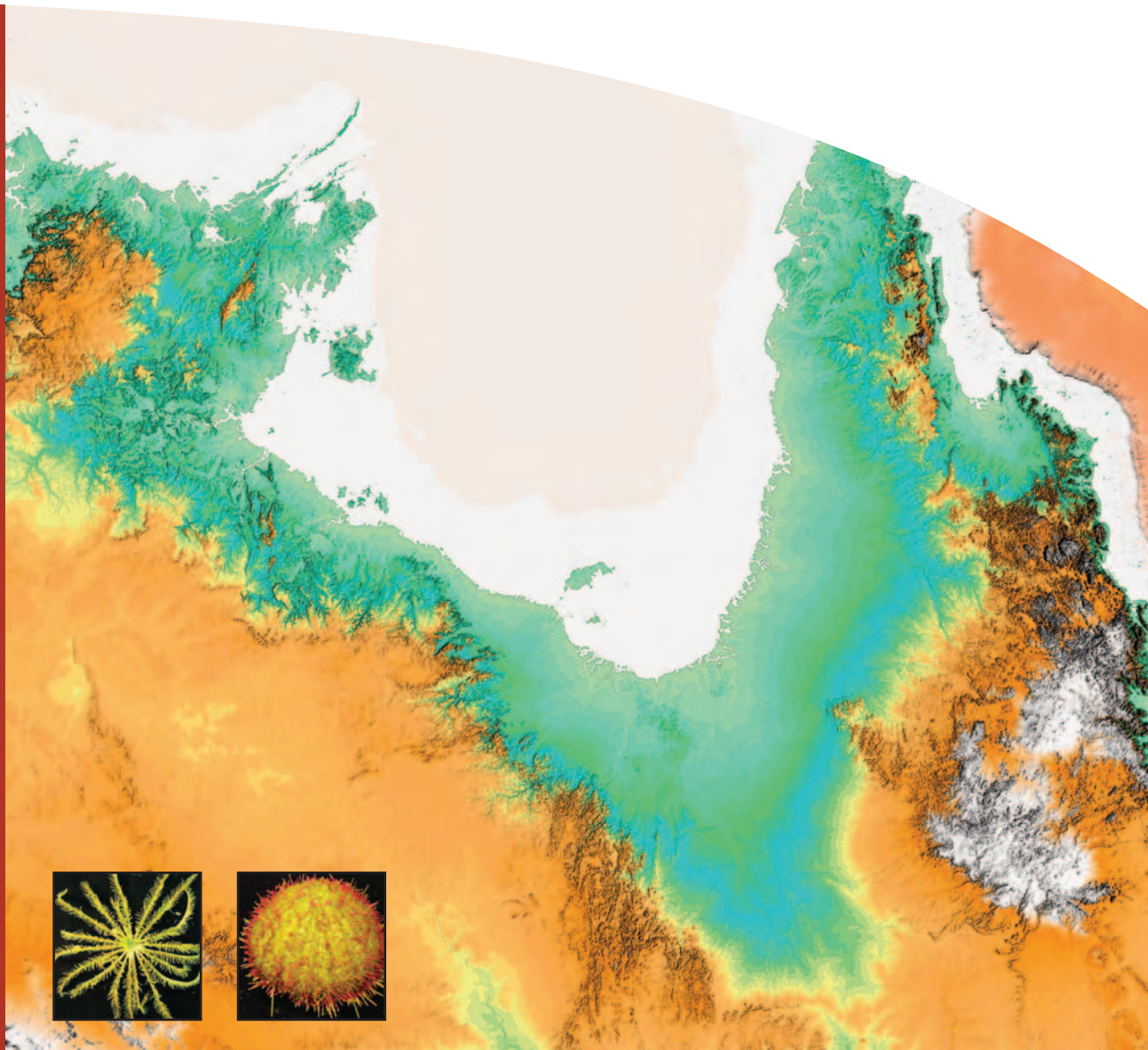
# Physical surrogates for benthic organisms in the southern Gulf of Carpentaria, Australia:

Testing and application to the Northern Planning Area

*Alexandra L. Post*

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2006/09



# **Physical surrogates for benthic organisms in the southern Gulf of Carpentaria, Australia: Testing and application to the Northern Planning Area**

GEOSCIENCE AUSTRALIA  
RECORD 2006/09

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## **Executive summary**

The characterisation of benthic habitats based on their abiotic (physical and chemical) attributes remains poorly defined in the marine environment, but is becoming increasingly central in the development of marine management plans in Australia and elsewhere in the world. In this report, the link between physical and biological datasets is tested for the southern Gulf of Carpentaria, Australia, and the results applied to the whole of the Northern Planning Area (NPA). The results presented are based on a range of physical factors, including the sediment composition (grain size and carbonate content), sediment mobility, water depth and organic carbon flux. The relationship of these physical parameters is tested against the distribution and diversity of benthic macrofauna. The results reveal the importance of process-based indices, such as sediment mobility, in addition to factors such as the percent mud and gravel, the seabed morphology and water depth in explaining the distribution of benthic macrofauna. Species-environment relationships observed at the small scale of this study are consistent with broader associations observed for other organisms within the Gulf of Carpentaria, allowing extrapolation to the wider NPA. Uncertainties in the extrapolation of the physical relationships across broader gradients than those tested need to be recognised in the application of these results to marine planning. In this report I seek to address the uncertainties associated with both the spatial prediction of habitats and the classification of seabed habitats through statistical procedures such as cluster analysis.

## 1. Introduction

Australia's Oceans Policy, which was introduced in December 1998, together with the *Environment Protection and Biodiversity Conservation Act 1999*, ensure the maintenance of Australia's marine biodiversity. Since the inception of Australia's Oceans Policy, Geoscience Australia has provided data and knowledge in support of oceans policy, and has developed a research program to investigate the way in which physical datasets may be used to describe benthic habitats. Some of the key questions in undertaking this research have been to determine whether there are meaningful relationships between physical datasets and the distribution of benthic organisms, what physical datasets can best be used to describe benthic habitats and, how we can apply these relationships for marine planning purposes. These are the key issues which are covered in this report, with a focus on the Northern Planning Area.

Physical datasets have been shown to be significant in describing the distribution of benthic biota in a range of settings and scales, however, the environmental associations derived do vary between studies (e.g. Thouzeau et al, 1991; Kostylev et al., 2001; Ramey and Snelgrove, 2003). It is for this reason that Geoscience Australia has been pursuing research to test and determine physical surrogates for biological distributions in a range of different settings around the Australian margin, including Bass Strait (Passlow et al., 2005a); south-eastern Australia (Beaman et al., 2005); the Recherche Archipelago (Ryan et al., submitted); Torres Strait and the northern Great Barrier Reef (Beaman and Harris, in press; Post et al., in press a); and the Gulf of Carpentaria (Post et al., in press b). By conducting this research, the use of physical datasets can be applied much more rigorously in the determination of a National Representative System of Marine Protected Areas (NRSMPAs).



The NRSMPA has been established to ensure the sustainable management of Australia's marine ecosystems, and the protection of representative biological communities within Australia's entire marine jurisdiction. The representative protection of Australia's marine biota would ideally be based upon extensive knowledge of the distribution of biota and ecosystem components. Such knowledge is largely unattainable given present timeframes and funding available for biological research. Even within existing MPAs, our knowledge of the distribution, abundance and diversity of marine organisms remains sparse (e.g. in the southeast region; Harris, in press). The lack of biological information reflects the great time and expense required to collect and identify biological specimens. Due to this impediment, an alternative to the species-focussed approach to conservation has been proposed, focussing on the conservation of habitats based on physical characteristics (e.g. Zacharias and Roff, 2000). Physical parameters such as water depth, slope and sediment properties, can be measured relatively easily across wide areas. Use of these physical parameters for community composition may therefore provide a rapid assessment of marine ecosystems, which can contribute increasingly to the selection and ongoing monitoring of MPAs.

The data for this report focuses on the Gulf of Carpentaria, as this is part of the Northern Planning Area which is the current focus for regional marine planning in Australia. There are several competing values in the Gulf of Carpentaria, with a multi-million dollar prawn industry, the most valuable prawn industry managed by the Australian Government (McLoughlin, 2004); onshore mining for bauxite, zinc, lead, silver, aluminium and manganese with associated shipping (National Oceans Office, 2003); unique ecosystems including submerged reefs which support diverse coral communities (Harris et al., 2004); large populations of dugongs (Saalfeld, 2000); and nesting and foraging sites for marine turtles (Limpus and Chatto, 2004). Understanding the

diversity and sensitivity of habitats in the Gulf to these various pressures is therefore important for the sustainable management of this region.

The data presented in this report draws largely on datasets collected on the Southern Surveyor in 2003 during survey SS04/2003 by Geoscience Australia and CSIRO Marine and Atmospheric Research (CMAR) in the Gulf of Carpentaria. The region sampled incorporates a range of habitat types, including reefs, plateaus, valleys and shelf environments. The shallow water depths and sheltered nature of this region means that factors such as temperature and nutrients remain fairly constant, allowing detailed testing of the relationship between other physical variables, such as the substrate type, and the distribution of biological communities. This report begins with a review of some of the key associations that have been determined between the distribution of benthic organisms and physical parameters, and then summarises the approach to obtaining representative biological and physical datasets. I then present an analysis of physical and biological relationships for the southern Gulf of Carpentaria to determine a subset of physical parameters which best explain variability in the benthic biota. The relationships determined at a relatively small-scale, are discussed in terms of how they may be used to inform our understanding of benthic habitat variability within the entire Northern Planning Area (NPA). This work is distinct from the 'seascape' approach (e.g. Harris, in press) in that it seeks to extrapolate known relationships from a small part of the Gulf, to a much broader area. The consistency of these small-scale relationships at the larger scale is unknown, so this report also presents some of the uncertainties associated with this extrapolation.

## **2. Background to species-environment relationships**

One of the fundamental controls on the composition of seabed communities is the nature of the seafloor substrate (e.g. Greene, 1995; Auster and Langton, 1999; Kostylev et al., 2001; Beaman et al., 2005). In general terms, the life habitat modes of organisms (sessile or attaching) limits their distribution to soft versus hard substrates respectively, since the attaching forms need something solid to cling to, while the sessile forms tend to burrow in the sediment and forage within it for food. These associations are not exclusive, since attaching forms may attach to scattered cobbles or larger shells within the sediment (Auster and Langton, 1999), however, the abundance of attaching faunas tends to be much greater on harder, more stable substrates. Habitats can therefore be differentiated at a broad level based on a knowledge of the substrate properties.

### **2.1. Geomorphology**

At a broader spatial scale, the seafloor structure, or geomorphology, can also help to define important seabed habitats (e.g. Greene et al., 1995). Geomorphic features such as seamounts have been shown to be important habitats for a diversity of fish and sessile organisms, with high endemism (de Forges et al., 2000). Submarine canyons are also important habitats, generally associated with high organic matter content and a variety of physical habitats due to the dramatic canyon topography. The La Jolla Canyon offshore California has been shown to have much higher biomass (up to 50 times more) than adjacent areas, as well as high diversity (Vetter and Dayton, 1998), most likely due to the input of nutrients via upwelling and the variety of substrates provided on the canyon walls. Even minor variations in elevation have been associated with the distribution of suspension feeders (Beaman et al., 2005). Changes in slope are also shown to be significant in describing the broad distributions of

the benthic fauna in the northern Great Barrier Reef/Torres Strait region (Beaman and Harris, in press). Identifying variations in the seafloor morphology is therefore important in any classification of seabed habitats.

## 2.2. Grainsize

Many studies invoke a relationship between grain size properties and species distributions (e.g. Thouzeau et al., 1991; Long and Poiner, 1994; Somers, 1994; Greene et al., 1995; Auster and Langton, 1999; Kostylev et al., 2001; Beaman and Harris, in press; Post et al., in press b), reflecting the importance of sedimentary features for species refuges and habitat. Crevices or interstices between cobbles and boulders may provide shelter, hard surfaces allow a substrate on which epibenthic organisms can grow, and boulders and sand waves can provide protection from currents (Auster and Langton, 1999). Biogenic sediments of mixed size classes have also been shown to provide a diversity of habitats and support a diversity of organisms (e.g. Webb et al., 1976; Thouzeau et al., 1991; Kostylev et al., 2001). For example, the mixture of sand, gravel, cobble and bryozoan fragments on eastern Georges Bank provides a heterogeneous habitat and refuge for a high diversity of invertebrate species (Kostylev et al., 2001). In some regions the organic carbon content is correlated to grain size, with a higher proportion of organic carbon in the mud-sized fraction (Mayer, 1989). The correlation between grain size and organic carbon content may explain the association of some organisms with grain size.

Feeding modes have also been widely linked to sediment types (e.g. Long and Poiner, 1994; Long et al., 1995; Kostylev et al., 2001; Denisenko et al., 2003), particularly for deposit feeders. Deposit feeders ingest large volumes of sediment, bacteria, bacterial products, living microscopic plants and animal

matter (living or dead) (Jumars, 1993), so would be expected to have highest abundances in soft sediments. Blurring of the association between feeding modes and sediment properties may occur due to the fact that the grouping of organisms as suspension or deposit feeders is not clear. Some studies have found that a number of deposit-feeders living in muddy sediments will suspension-feed in response to suspended sediment flux (Taghon et al., 1980; Levinton, 1991). Additionally, some species once thought to be suspension-feeders actually utilise deposited sediment as well (Mills, 1967; Tenore et al., 1968; Hughes, 1969).

### 2.3. Dependence on scale

Relationships between organisms and environmental parameters are also dependent on scale. In a study of macrofaunal distribution, Ramey and Snelgrove (2003) found that grain size had an important influence on community composition. On a broader scale, however, community composition was most strongly (negatively) associated with the sedimentary organic carbon content. In other large scale studies a positive relationship has been shown between surface production and benthic biomass and/or abundance (e.g. Grebmeier et al., 1988; Ambrose and Renaud, 1995), indicating that species-environment relationships vary between regions. In the Gulf of Carpentaria, Burford et al. (1994) found that organic carbon was of only secondary importance to sediment type in describing the distribution of macrobenthos. Variations between regions are further highlighted by a recent study by Beaman and Harris (in press) in the northern Great Barrier Reef / distal Fly Delta. Communities in front of the Fly Delta were most strongly correlated (spearman rank correlation ( $\rho$ ) = 0.75) with a combination of slope, gravel and percent  $\text{CaCO}_3$  in the sand fraction, while community type at sites

in the northern Great Barrier Reef most strongly correlated ( $\rho = 0.6$ ) to a combination of slope, gravel and turbidity.

## 2.4. Physical processes

Tides, waves and bottom currents can play an important role in defining sediment grain size (e.g. Jumars, 1993; Wildish and Kristmanson, 1997), and also control the distribution of larvae (Snelgrove and Butman, 1994), food availability, and pore water flow (Newell et al., 1998). The stability of the seabed environment has important implications for the habitat conditions. For instance, recently deposited muddy sediments tend to have high water content, and organisms are predominantly deposit feeders and burrows are unstable (Newell et al., 1998). Older deposits of muddy sediments are harder, by contrast, and organisms are thus predominantly suspension feeders and there are many permanent burrows. The incorporation of sediment movement and stability models into the analysis of benthic habitats can provide an insight into these dynamics of the sea floor environment (e.g. Porter-Smith et al., 2004, Hemer, in press).

### **3. Survey to the south-eastern Gulf of Carpentaria**

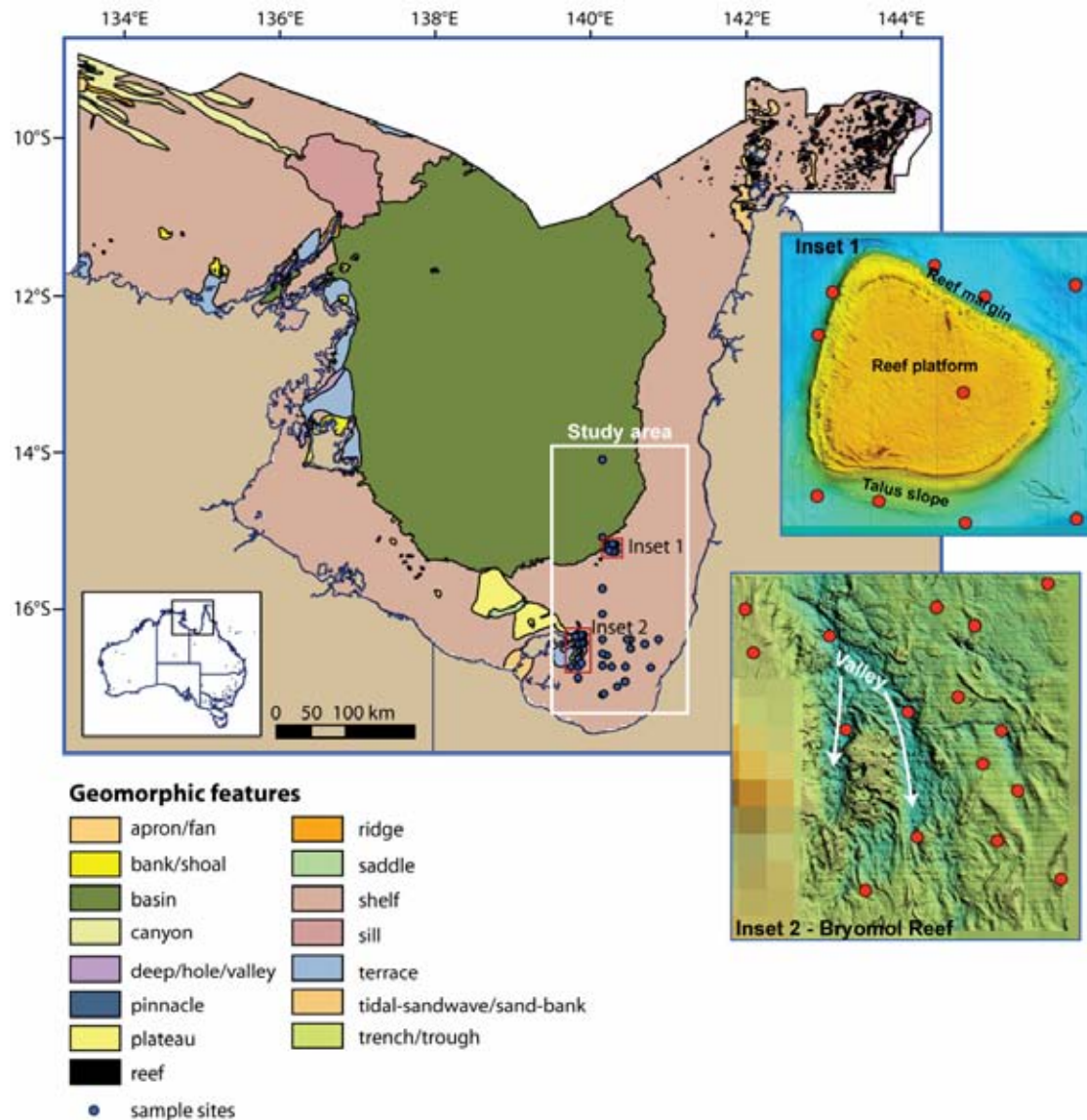
This report draws together physical and biological datasets collected largely during Southern Surveyor Survey SS04/2003. From these datasets, a detailed analysis of species-environment relationships has been established for the south-eastern corner of the Gulf (Post et al., in press b). The physical surrogates determined from this regional scale study are extrapolated in this report to the whole of the NPA based on historic datasets and derived products held at Geoscience Australia, such as the Marine Samples database (MARS; [www.ga.gov.au/oracle/mars](http://www.ga.gov.au/oracle/mars)), bathymetry data, interpreted geomorphic features (Harris et al., 2005), and sediment mobility parameters, including the seabed exposure (Hemer, in press).

#### **3.1. Survey design**

Knowledge of the way in which the distributions of benthic organisms vary in relation to environmental factors, has significant implications for the planning of research surveys. Traditionally, geological and biological sampling has been undertaken with little prior knowledge of the areas being surveyed, limiting the capacity to sample areas in a truly representative way. Today, with sophisticated mapping techniques such as multibeam sonar systems, which give high-resolution bathymetry and seabed images, samples can be targeted within distinct seafloor environments, thereby capturing a diverse range of seabed habitats, in a way which is representative of the area as a whole.

During Southern Surveyor Survey SS04/2003 to the south-eastern Gulf of Carpentaria, the seabed morphology was characterised on the basis of high resolution bathymetry obtained from multibeam sonar. This seafloor bathymetry allowed detailed mapping of seven distinct seabed morphologies across the region: 1) shelf environments; 2) a bryomol (bryozoan / mollusc)

reef; 3) a valley; 4) talus slopes adjacent to living reefs; 5) reef platforms; 6) the reef margin; and 7) basin environments (Figure 1) (Heap et al., 2004). Samples were targeted within each of these zones to obtain measures of the seabed properties and the biological communities within them.



**Figure 1:** Geomorphic features across the Northern Planning Region, and within the study area, with sample areas shown by the blue dots. The insets show multibeam bathymetry images and detailed geomorphic features intersected by the sample sites.



Sample collection needs to be undertaken in a way that is appropriate for the datasets which are required. In this study, a benthic sled was used to sample the macrofauna. Sleds are effective for collecting a range of benthic organisms in soft sediments, but they retrieve only a fraction of the fauna lying on the surface of the seabed and very few of the burrowing animals (Eleftheriou and Holme, 1984). The size range of the organisms is also limited by the mesh size of the net, in this case 13 mm. Grabs and cores can be used to collect slow-moving and sedentary organisms living within or on the sediment surface, and organisms that may be smaller than the mesh size of the nets on the sleds and trawls. The drawback of using grabs and cores is that there is poor penetration in gravely and coarse sand sediments, limiting comparisons between sediment types unless the sediments can be partitioned to a consistent depth, as in a box core (Gray et al., 1992). The surface sediments and organisms may also be disturbed by down-wash as the gear approaches the sediment surface, limiting the collection of smaller organisms from the surface. For collection of very small organisms, a multi-corer provides the best results. Analyses of the benthic fauna from grab and core samples were not available for this study, so the density of organisms should be considered as a minimum estimate, with very low representation of the infauna.

Sleds are also not able to adequately sample hard or rocky substrates as the net is easily damaged. On these hard-grounds, a rock dredge fitted with a polypropylene liner may be used to sample the benthic biota. Video footage can also be used for a more general classification of the biota, providing information about the classes and types of organisms present. For comparison between sites, video footage needs to be collected in a systematic way, so that the duration and direction of towing are consistent. Limitations of underwater video are that the benthic infauna can only be assessed in an indicative way, in terms of the number of burrow holes or mounds, and it is rarely possible to

identify organisms to species level, which limits the power of any relationships derived (e.g. Pitcher et al., 2002). In this study, video footage is used only in the characterisation of the sedimentary features.

Sampling techniques such as cores, grabs, box cores and even benthic sleds sample a very small area of the seabed, and thus provide a restricted picture of environments and biota. It is important to determine the heterogeneity of sediments and habitats away from these points so that sampling can be conducted at an appropriate spacing. If sites are too close to each other the sampling will be inefficient, while sampling sites which are too far apart will provide inadequate information on the seabed features. Reconnaissance mapping using broad scale techniques such as multibeam sonar, as well as video analysis can help to constrain relevant sampling scales. In this study, habitats were targeted for more detailed sampling based on the habitat features revealed by the physical datasets.

### **3.2. Data collection**

At each station a suite of sampling devices was used to collect biological and sedimentary material. Seabed samples were collected using a Smith-McIntyre grab, and this material was later analysed for grain size by sieving and laser diffraction and carbonate content. Video footage (minimum 10 minutes) of the seabed was collected to aid the characterisation of sedimentary features and general biological composition. A benthic sled was also used to collect samples of benthic organisms on the seabed in soft sediments, with one reef top sample also obtained. The benthic organisms collected in the net of the sled were sorted by hand on board and frozen for later description and analysis. The samples were then identified to species or putative taxon, counted and weighed to the nearest 1 g by taxonomists of the Queensland Museum,

Australia where the samples were lodged. The species were also placed into feeding guilds of deposit feeders, scavengers or carnivores and suspension feeders according to Fauchauld and Jumars (1979) for polychaetes, Short and Potter (1987) for molluscs and Barnes (1974) for the remaining phyla.

Estimated values for sediment movement due to tidal currents and surface swell waves were also incorporated into our analysis as a measure of seabed stability. These data were derived from Geoscience Australia's GEOMAT (Geological and Oceanographic Models for Australia's ocean Territory) program (Porter-Smith et al., 2004) and the revised version, GEOMACS (Geological and Oceanographic Model of Australia's Continental Shelf) (Hemer, in press). The wave- and tide-induced sediment threshold exceedance values provide an estimate of the percentage time that sediments on the seabed may be mobilised by surface waves and tidal currents (for further details see Porter-Smith et al., 2004). The total bed shear stress energy and a measure of seabed exposure to energy were also incorporated into our analyses from the GEOMACS output. The total bed shear stress measures the combined energy due to waves and tides over all frequency ranges (semi-diurnal through to annual time scales), and the seabed exposure is a measure of the probability that different magnitude events will occur (Hemer, in press). The seabed exposure index seeks to account for the relationship between the structure of seabed communities and the intensity and recurrence of seabed disturbance events (e.g. Connell, 1978).

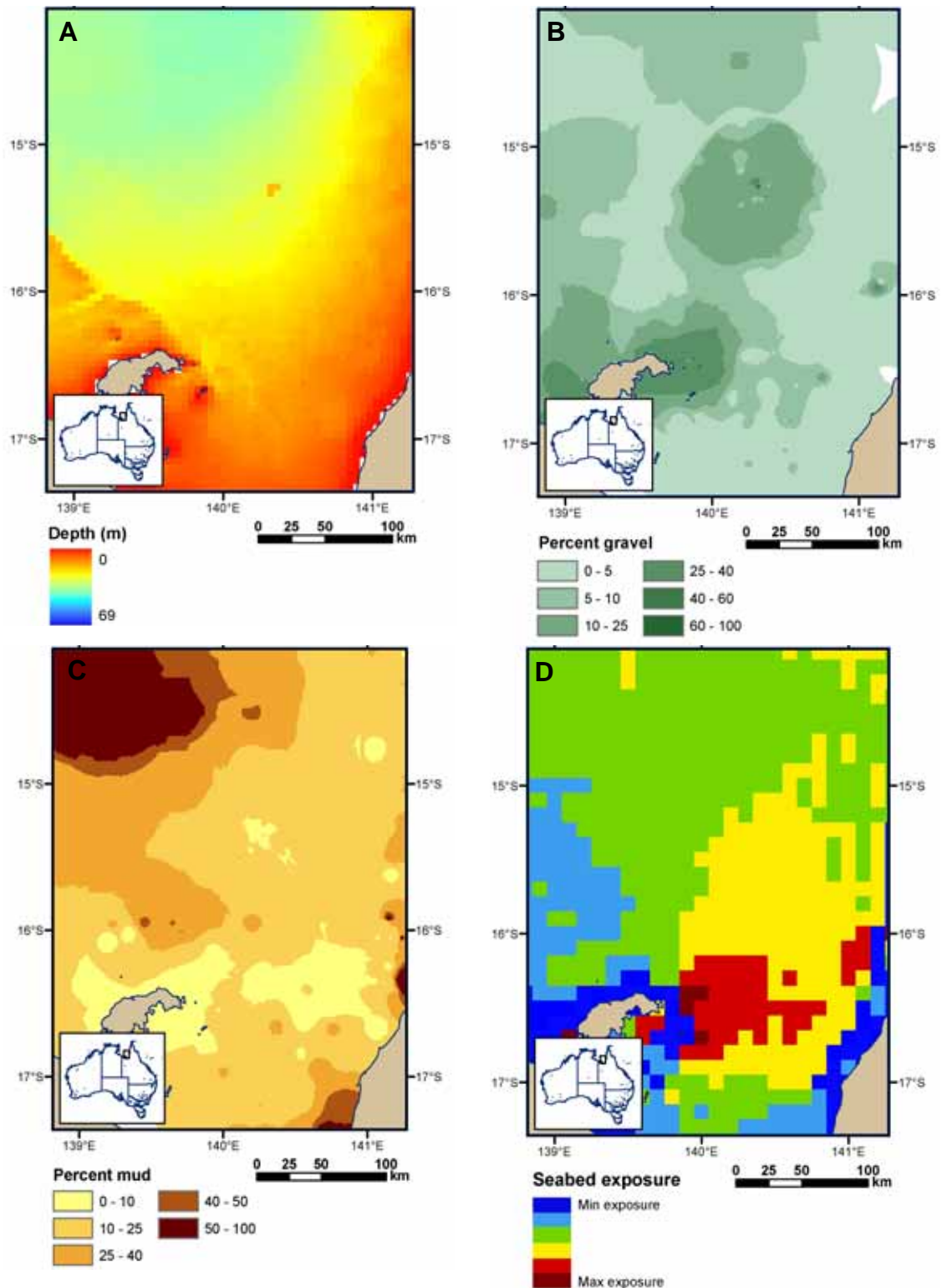
Gridded values for a subset of key attributes were combined for the whole NPA. These variables were used in a cluster analysis, to show the main variability in the substrate properties which best describe the benthic habitats. Cluster analysis rarely produces discrete, independent classes. To indicate the degree of uncertainty associated with the classification a grid was derived

using a maximum likelihood classification. This classification calculates the probability of each cell belonging to its assigned class, or in other words, the level of certainty in the classification of each cell. Extrapolation of the relationships between the physical and biological components to the broader scale of the NPA encompasses larger gradients in the physical parameters than those analysed in the south-eastern Gulf dataset. To indicate the uncertainty associated with this extrapolation, a grid was also generated which indicates the areas where the parameters exceed either the minimum or maximum values by more than 10 percent. A value of 10 percent was chosen as a convenient way of expressing the degree of uncertainty for values outside the tested range.

## **4. Results**

### **4.1. Distribution of key environmental variables**

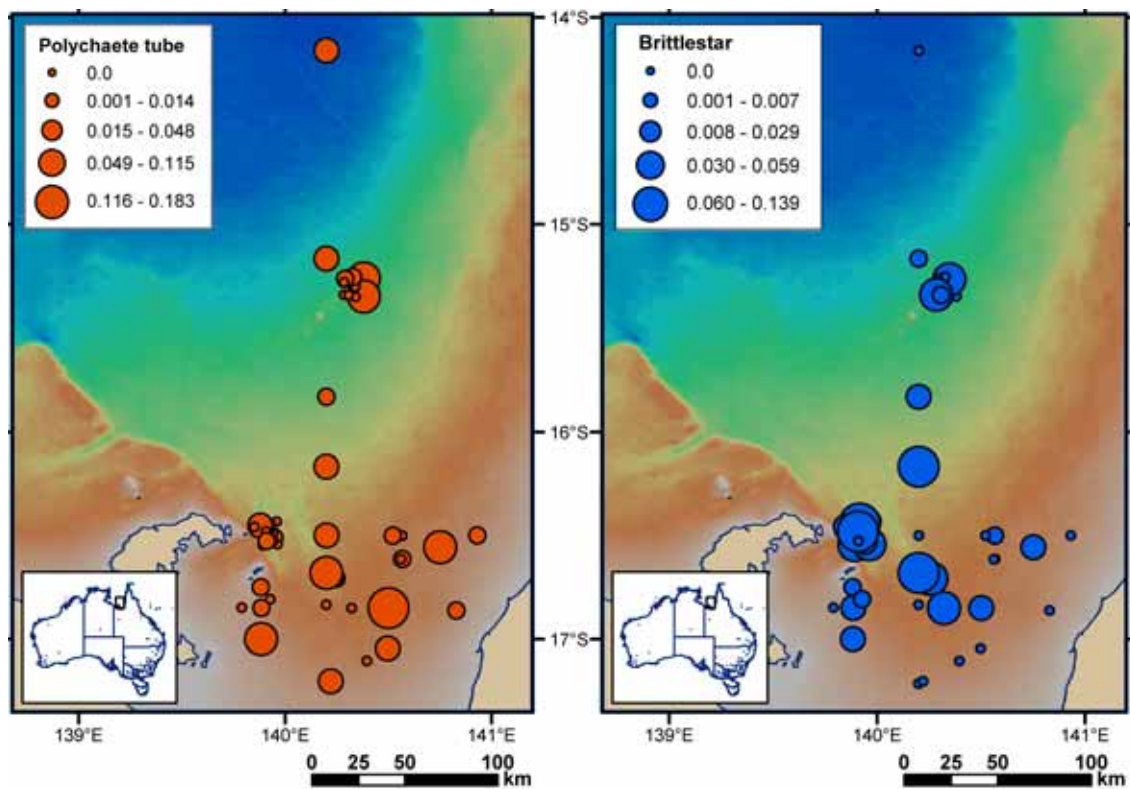
Water depth across the south-eastern part of the Gulf ranges from 14 to 65 m, with increasing depth with distance offshore ([Figure 2a](#)). Changes in the sediment composition partly reflects these changes in water depth. The gravel content is highest across the bryozoan / mollusc reef build up (bryomol reef) and valley areas (up to 43%), although across the other sites values are generally low ([Figure 2b](#)). Mud content is also low, with higher values (>50%) restricted to the deeper basin areas ([Figure 2c](#)). The seabed exposure has moderate to high values across the sites, with highest values across the relict reef and valley sites, and lowest values across the deep basin sites, partly reflecting the changes in water depth with lower exposure in deeper areas ([Figure 2d](#)).



**Figure 2:** A) Water depth; B) percent gravel content; C) percent mud content; and D) seabed exposure across the study area. The extent is as shown by the white rectangle in Figure 1.

## 4.2. Distribution of macrofauna

The abundance and distribution of the benthic macrofauna is extremely variable across the sample sites. The six taxa with the highest abundance across the study area are: polychaete tubes, brittlestars, the bryozoan *Cigclisula* sp., a species of hydroid, crinoids and a heart urchin *Metalia* sp. (Figure 3). The *Metalia* sp., has the highest total abundance, while the *Cigclisula* sp. and hydroid sp. have the broadest distribution. The brittlestar has a very similar distribution to the *Cigclisula* sp., with both relatively abundant across the Mornington sites and deeper parts of the Southern area, but absent from the shallower areas and sites on the reef. Crinoids are particularly abundant in the channels within the bryomol reef and at some of the deeper water sites in the shallow shelf area and adjacent to the reef, but were not found in waters deeper than 48 m. The species of hydroid is most abundant in the shallow shelf sites, and is present across sites with a mean water depth of 27 m. The *Metalia* sp. is also most abundant across the shallower parts of the Southern shelf area, across a depth range of 14 - 33 m, and is associated with low gravel content (<15%). The polychaete tubes show a wide but variable distribution, present across the full range of water depths.



**Figure 3:** Distribution and abundance of the most abundant macrofaunal taxa across the study area. Note that *Cigclisula* sp is a bryozoan and *Metalia* sp is a heart urchin. Measurements are as number of individuals / m<sup>2</sup>.



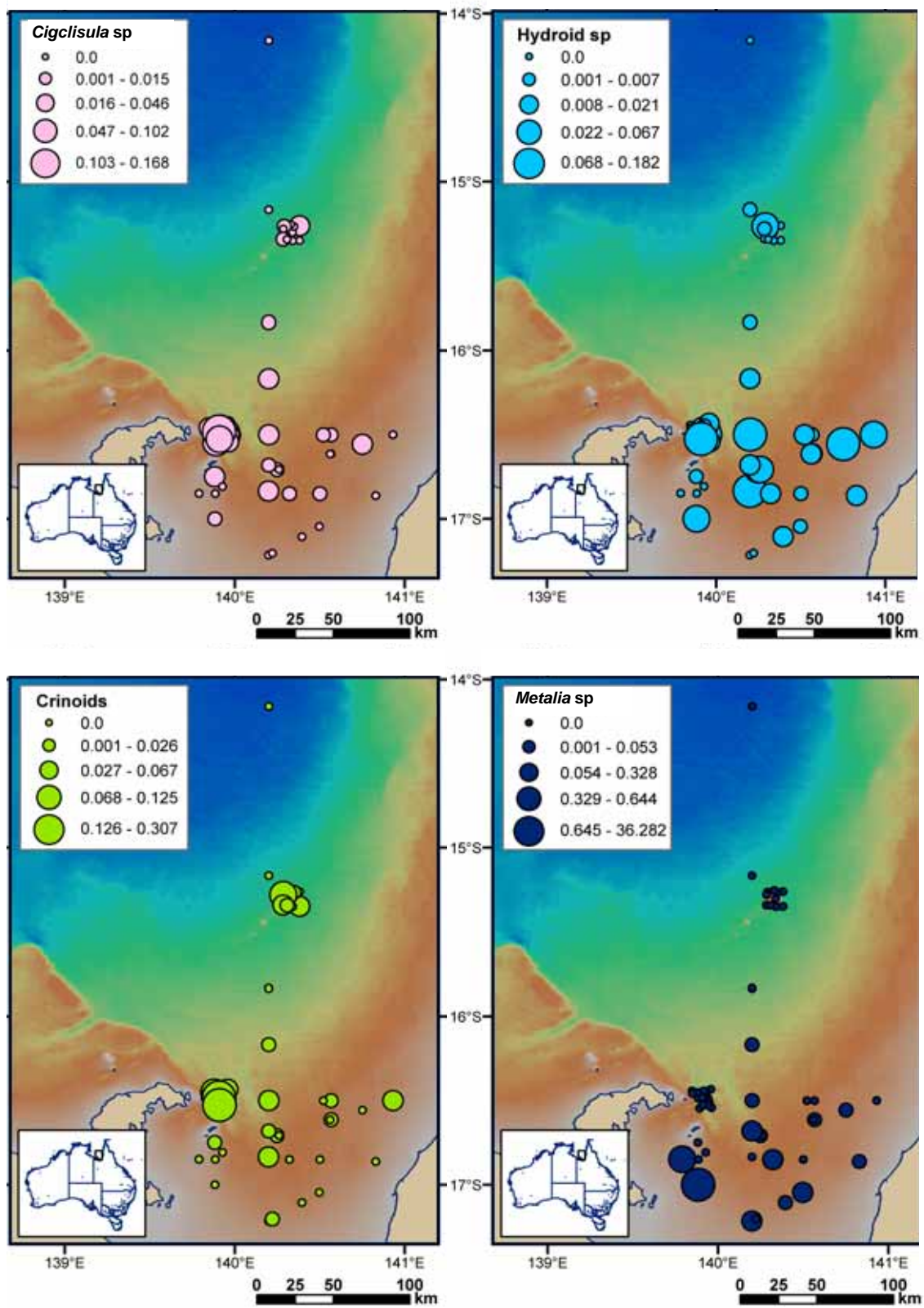
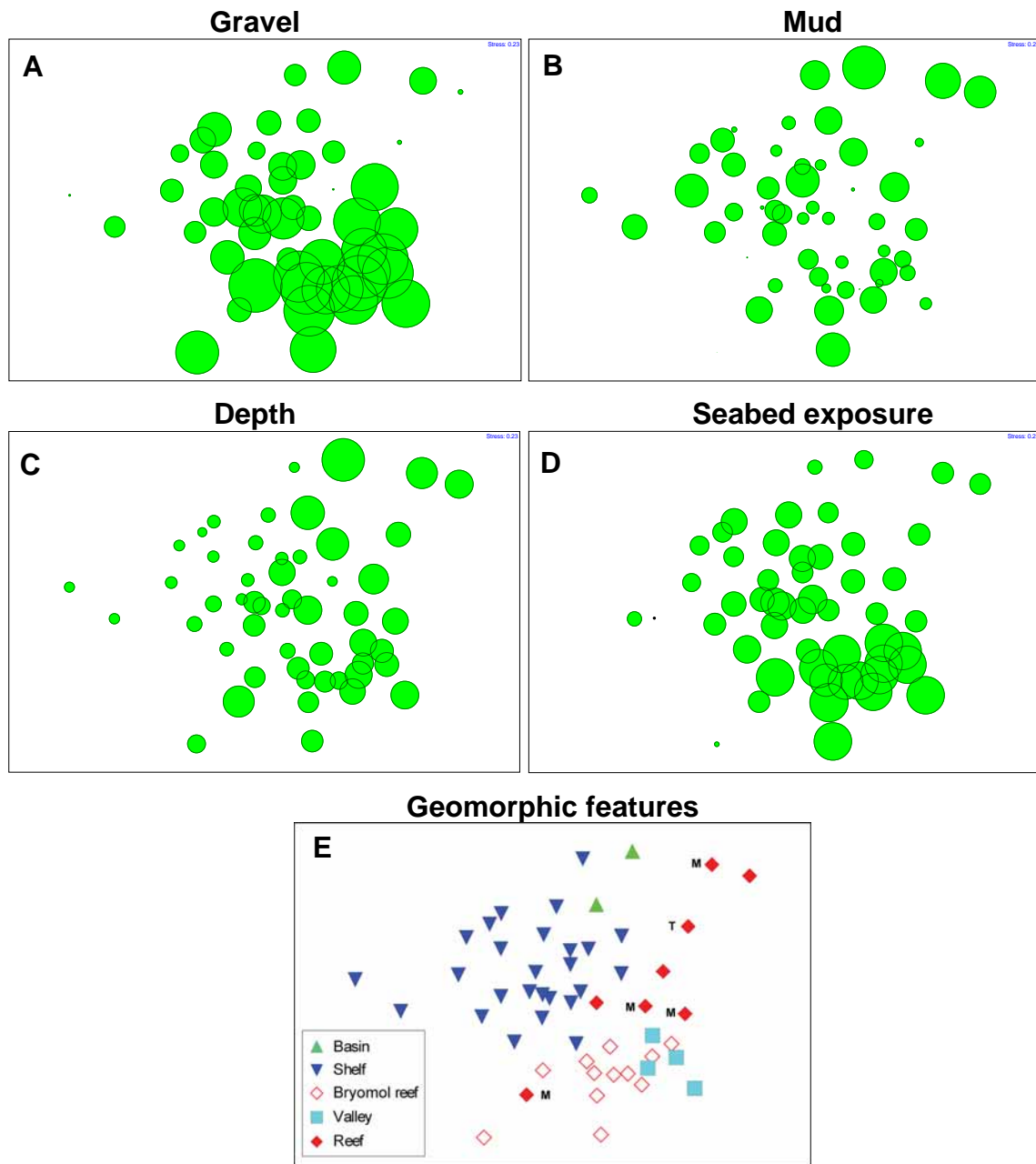


Figure 3 cont.

### 4.3. Relationship between taxa and environmental variables

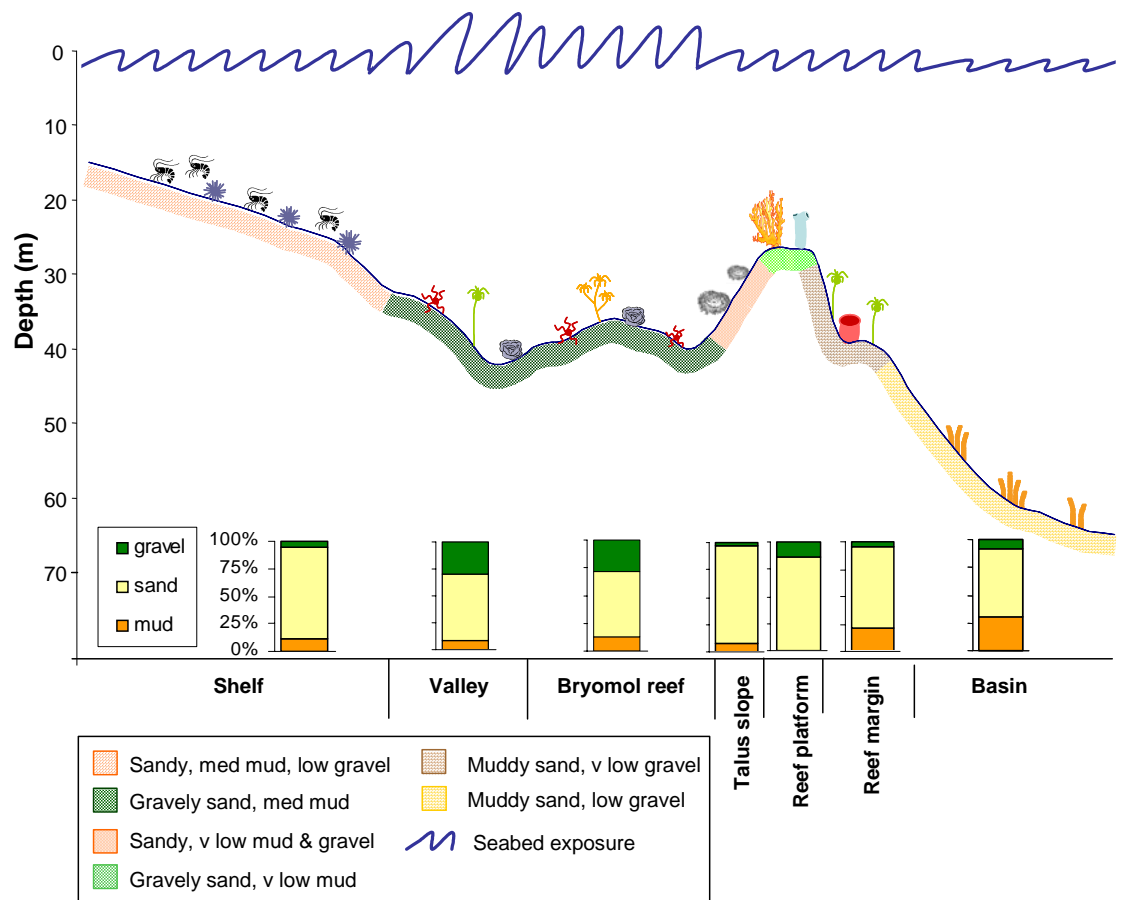
Relationships between taxa and the environmental variables were tested for the south-eastern Gulf using physical datasets available for the entire NPA. Carbonate content was therefore excluded from the analysis because data for this parameter is incomplete in the western and central parts of the Gulf (Passlow et al., 2005b). Input for this analysis included grain size properties (percent mud, sand and gravel), water depth, geomorphic features, modelled wave and tide exceedance, total seabed energy, and an index of seabed exposure. Measurements of mean primary productivity, temperature, salinity, oxygen, chlorophyll and phosphorus were also available, but were not included since their range across the Gulf is too narrow to produce a meaningful relationship to the distribution of the macrofauna.

Taken individually, each environmental variable exhibits only a weak correlation against the distribution of the taxa. Much stronger correlations, however, are achieved from the combination of environmental variables. The strongest correlation ( $\rho = 0.60$ ) results from the combination of percent mud, percent gravel (log transformed), water depth and the seabed exposure (Figure 4). There is low correlation between these parameters, with the strongest correlation for gravel content and the seabed exposure ( $R^2 = 0.38$ ). In addition, there is a strong correspondence between the distribution of the biota and the seven geomorphic features identified across the sample sites (Figure 4E). The correlation between the biota and the geomorphic features is much clearer when the classes identified from the multibeam data are used, rather than the less detailed classification based on the pre-existing bathymetry data (Harris et al., 2005).



**Figure 4:** MDS plots with the distribution of sites based on the similarity of taxa. A) percent gravel; B) percent mud; C) water depth; D) the seabed exposure; and E) geomorphic features. For the bubbles in Figures A-D, larger bubbles reflect higher values for the variable shown, e.g. for water depth, there is a trend of increasing depth towards the right hand side of the faunal distribution. The distribution of the geomorphic features is also distinct across the species distributions. For the reef areas, the talus slope site (T) and reef margin sites (M) are also shown.

Based on the correlation between the benthic biota and the physical properties, a conceptual model can be used to describe the distribution of the benthic macrofauna within the south-eastern Gulf of Carpentaria ([Figure 5](#); [Table 1](#)). The model is divided into the seven geomorphic zones: 1) shelf; 2) bryomol reef; 3) valley; 4) talus slope; 5) reef platform; 6) reef margin; and 7) basin. The shelf zone within the south-eastern part of the Gulf is characterised by shallow depths (15-30 m) with moderate seabed exposure and sandy low carbonate sediments ([Table 1](#), [Figure 5](#)). The fauna in this shelf zone are dominated by mobile organisms with relatively low diversity, with prawns and sea urchins reaching highest abundances. The Basin environment is also dominated by mobile fauna (predominantly polychaetes) with medium diversity, and due to the deeper water has low to moderate seabed exposure with muddy sand sediments. The bryomol reef and valley environments lie at depths intermediate between the shelf and basin zones (25-39 m and 37-42 m respectively), with very high seabed exposure (maximum values), particularly across the valley area, and a gravelly sand substrate. The faunas associated with these two zones are composed of equal abundances of attaching and mobile faunas, with the bryomol reef dominated by brittlestars, hydrozoans and bryozoans, and the valley faunas by bryozoans, crinoids and brittlestars.



**Figure 5:** Conceptual model of the relationship between physical properties and benthic biota in the southern Gulf of Carpentaria. For a full description of the key benthic biota refer to [Table 2](#). Variability in the species composition within each unit can be assessed from [Figure 4E](#).

**Table 1:** Characteristics of different benthic habitats and associated faunas.

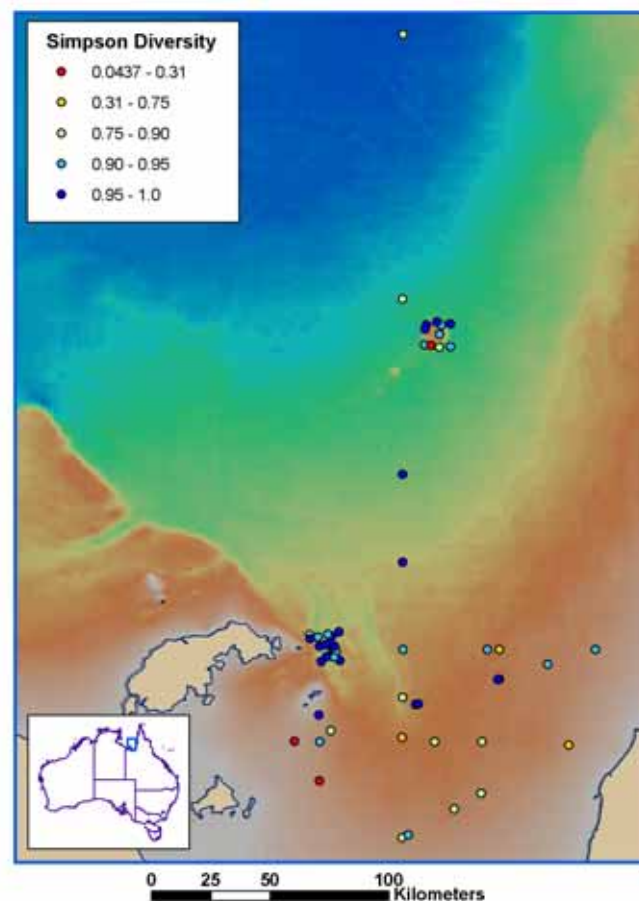
<b>Morphology</b>	<b>Average depth (m)</b>	<b>Seabed exposure</b>	<b>Grain size</b>	<b>Dominant Fauna</b>
<b>Shelf</b>	14 - 35	Mod	Sandy	Prawns Sea Urchins
<b>Valley</b>	37 - 43	Max	Sandy gravel	Bryozoans Crinoids
<b>Bryomol reef</b>	27 - 36	Max	Sandy gravel (lithified)	Brittlestars Hydrozoans Bryozoans
<b>Talus slope</b>	38 - 43	Mod-High	Sandy	Anemones
<b>Reef platform</b>	27	Mod-High	Sandy gravel	Ascidians Octocorals
<b>Reef margin</b>	48 - 49	Mod-High	Sandy mud	Crinoids Sponges
<b>Basin</b>	51 - 65	Low-Mod	Sandy mud	Polychaetes

The modern reef environment is divided into 3 distinct zones, each with a moderate to high seabed exposure (Table 1; [Figure 5](#)). The talus slope is sandy with high carbonate content, and the presence of ripples indicates strong bottom currents. These characteristics are associated with low faunal diversity dominated by solitary anemones. The reef margin, by contrast, is composed of muddy sand sediments, reflecting the lower energy of this area. These features have produced high faunal diversity with crinoids and sponges dominating the community. The reef platform is distinct from these other two zones in the higher energy and harder substrates, with relatively high gravel content. Faunas on the reef platform show high diversity, with an abundance of ascidians and octocorals.

#### 4.4. Macrofaunal diversity and distribution

The benthic diversity was measured using the Simpson diversity index. The diversity of the macrofauna exhibits a distinct north-south gradient across the southern shelf and bryomol reef areas ([Figure 6](#)). The lowest diversity occurs

in the most southerly part of the Southern area, with values of 0.04 and 0.18 at two sites. The northern part of the Southern region has moderate to high diversity with values ranging from 0.57 to 0.96. Diversity in the bryomol reef area is typically high, with all but one site having values  $> 0.90$ . The mid-depth basin areas also exhibit high diversity, while the deeper parts of the basin show decreasing diversity (to 0.85). The reef area typically has high diversity ( $> 0.93$ ), apart from a site situated on the talus slope which has low diversity (0.3).



**Figure 6:** Simpson diversity based on macrofaunal abundance at each site. Highest diversity occurs over the bryomol and other reef areas, and deeper water parts of the shelf environment. The deepest and shallowest water areas have low to moderate diversity, possibly associated with the low seabed exposure at these sites.



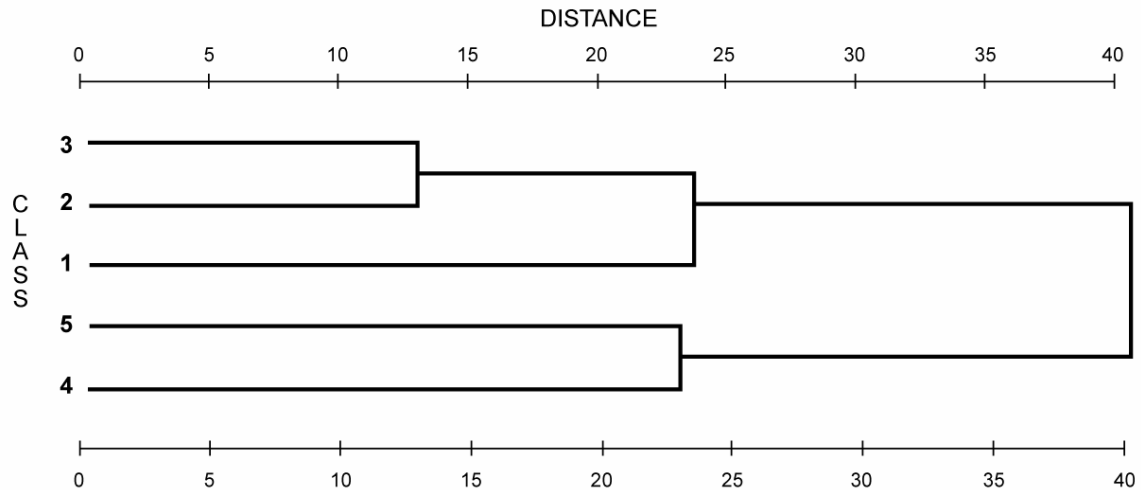
Univariate relationships between environmental variables and the Simpson diversity provide no strong correlations. Correlations derived from multiple regression are also relatively weak, with an  $R^2$  value of 0.51 from the combination of total energy, percent fine sand and mud, organic carbon flux and skewness in the grain size distribution. The low correlation between the diversity of the benthic fauna and the physical properties is not surprising since the diversity data lacks the structure of the species level data. Sites with similar diversity may have very different species compositions, and hence a very different association to the environmental variables. Additional low diversity sites are required to further define these relationships since few sites with low diversity were sampled, and this may reveal non-linear effects in the relationship between species diversity and the environmental parameters.

#### 4.5. Analysis of datasets across the Northern Planning Area

Cluster analysis was performed for the key physical datasets across the whole NPA using those datasets with the highest correlation to the species data: the percent gravel and mud, the water depth and the seabed exposure. The geomorphic units were not included in the clustering process because these categories cannot be made into meaningful quantitative values, but they are included at a later stage of the analysis. The unsupervised classification reveals 5 distinct clusters based on these variables. The dendrogram ([Figure 7](#)) indicates that clusters 2 and 3 have the closest similarity (a distance of less than 13), followed by clusters 4 and 5 (a distance of 23). There is a low similarity (distance of 41) between clusters 1, 2 and 3 and clusters 4 and 5. Means for each of the physical parameters in these classes are shown in [Table 2](#), with mud content showing the strongest distinction between clusters. The spatial distribution of the clusters indicates a change in the seabed habitats from the eastern to the western part of the Gulf ([Figure 8](#)). Clusters 1, 2 and 3



are distributed in the eastern and southern part of the Gulf and Torres Strait, with a narrow distribution also in the eastern Arafura Sea. Clusters 4 and 5 are located in the central to western parts of the Gulf, and in the western Arafura Sea.

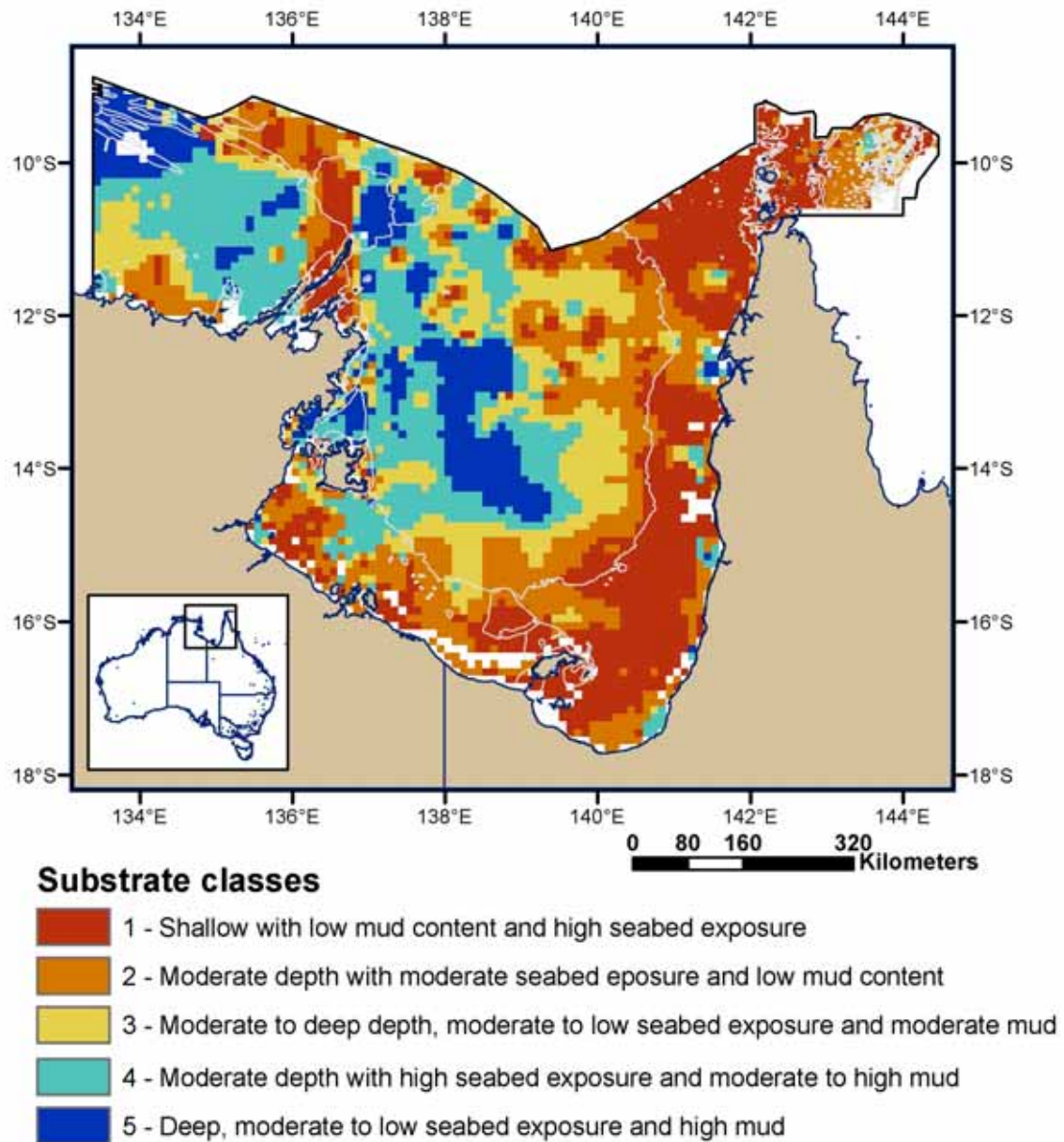


**Figure 7:** Cluster analysis based on the percent gravel and mud, the water depth and the seabed exposure for the entire NPA. Five distinct clusters are recognised from this analysis.

**Table 2:** Mean values for the four substrate properties for each cluster.

	Water depth (m)	Exposure index	Gravel (%)	Mud (%)
<b>Cluster 1</b>	30.8±19.2	-2.20±1.39	9.5±7.7	13.9±7.8
<b>Cluster 2</b>	42.7±21.6	-2.88±2.50	7.8±4.6	28.3±7.6
<b>Cluster 3</b>	56.2±13.9	-2.25±0.41	6.1±2.9	42.9±7.3
<b>Cluster 4</b>	50.4±15.5	-2.30±1.07	4.1±2.7	58.9±7.9
<b>Cluster 5</b>	65.6±29.5	-2.23±0.33	1.7±2.0	75.5±9.2

The 15 geomorphic features are overlain on the substrate clusters ([Figure 8](#)), to reveal the distinction in habitat characteristics within clusters. Cluster 5, for instance, occurs within basin, shelf, canyon, sill, terrace and ridge environments, creating unique seabed habitats within this cluster. The substrate clusters should be used in combination with the geomorphic features in assessing the potential distribution of benthic habitats.



**Figure 8:** Distribution of 5 clusters derived from the percent gravel and mud, the water depth and the seabed exposure for the entire NPA, with geomorphic units shown by the grey outlines. The south-eastern and eastern parts of the Gulf and Torres Strait are characterised as clusters 1, 2 and 3, while the central and western Gulf and the western Arafura Sea are characterised by clusters 4 and 5. Substrate clusters occur within different geomorphic features, illustrating the importance of combining these datasets.

## **5. Discussion**

### **5.1. Biological and physical associations**

This study highlights the importance of substrate properties (particularly the percent mud and gravel), the seabed disturbance, water depth and morphology in describing the distribution of benthic biota in the southern Gulf of Carpentaria. The mechanisms by which these factors may be associated with the types of organisms present are varied. The substrate properties are clearly associated with the habitat modes of the organisms present. The areas with sandy substrates, such as the shelf and basin areas, are dominated by mobile deposit feeders and infauna since these organisms require soft substrates in which they can burrow and forage for food (Jumars, 1993). Gravelly areas, such as on the reef and bryomol reef areas, contain high proportions of suspension feeders, which attach to the strong anchor points available in these environments.

The seabed exposure describes the stability of the seabed environment. In areas with a low frequency and magnitude of disturbance, competition between organisms is enhanced, which tends to suppress diversity (Connell, 1978). The relatively low seabed exposure of the shelf and basin environments (low to moderate) in this study is most likely associated with the lower overall diversity in these environments. In areas of very high frequency and magnitude of disturbance, diversity is also suppressed due to the high variability of the environment which reduces reproductive success and the ability of the community to mature or be recolonised prior to the next disturbance event (Connell, 1978). An area of very high disturbance in this study occurs on the talus slope adjacent to the main patch reef, which is characterised by active sedimentation. Video footage reveals modern ripple bedforms along this slope, while dates derived from sediment cores imply that the sedimentation rate on the talus slope is 2 to 4 times that of other sites near

the reef (Heap et al., in press; Post et al., in press b). The diversity of faunas collected from the talus slope is much lower (0.3) than that at the surrounding reef sites (0.8 to 1.0) where sediment input is much lower. This comparison suggests that areas of lower sediment input and lower disturbance adjacent to the reef support a large variety of faunas relative to the highly variable talus slope where species diversity is suppressed. The intermediate disturbance of the reef top sites not only allows a balance between competition and maturity in the biological community, but also ensures a consistent food supply is brought in via moderate strength currents, in an environment where suspension feeders are favoured due to the hard substrate.

In summary, this study reveals an association between the sediment composition and the types of macro-organisms present, and particularly their habitat modes. Mobile and infaunal species are more prevalent on softer substrates, while suspension feeders dominate areas with higher gravel content and harder substrates. The seabed exposure may reflect the supply of food via currents to suspension feeders in areas of intermediate disturbance, while low exposure leads to reduced diversity, which may be due to higher levels of competition. The high seabed exposure on the sandy substrate of the talus slope is also associated with a low diversity of mobile organisms, reflecting the stress to organisms in high energy environments where anchor points are not available (e.g. Connell, 1978). The water depth primarily reflects changes in light intensity, temperature, oxygen, salinity and energy (Murray, 1991), and is associated with the distinct communities that occur between the shelf and basin environments in this study.

## 5.2. Application of physical surrogates to the Northern Planning Area

The development of meaningful surrogates that can be used to predict the diversity and distribution of marine benthic organisms has become central to the success of marine planning. In this report, a range of physical variables have been assessed as surrogates for species distributions and diversity in a relatively small (50,000 km<sup>2</sup>) part of the Gulf of Carpentaria. Representative management of the marine environment requires the application of bio-physical relationships across much broader scales. The scale across which these relationships can be applied is largely unknown. In the Great Barrier Reef, Pitcher et al. (2002) determined that due to the complexities of the environmental gradients across the region, bio-physical relationships could only be confidently extrapolated to a maximum of 10 km away from the areas sampled. The reliability of any extrapolation can only be assessed by well-targeted biological sampling. In the Gulf of Carpentaria, the seabed environments have low heterogeneity compared to the Great Barrier Reef, suggesting that extrapolations may be appropriate across much larger scales. Additional sampling recently completed by Geoscience Australia and CMAR in the southern and western parts of the Gulf will allow further validation of the results of this study. In addition, analysis of historic datasets can provide insight into the broader scale patterns in species distributions across the Gulf (e.g. Blaber et al., 1994; Long and Poiner, 1994; Rothlisberg et al., 1994; Long et al., 1995).

Sampling of infauna at sites broadly distributed across the Gulf indicates that the composition of the community changes laterally (Long and Poiner, 1994). The benthos, which were sampled by beam trawl, also change laterally in their composition, with the presence of just 2 distinct communities, one in the eastern and south-eastern area coinciding with this study area, and the other

in the central-western Gulf (Long et al., 1995). These two distinct zones of the Gulf also define communities of phytoplankton (Rothlisberg et al., 1994) and demersal fish (Blaber et al., 1994). The spatial changes in community composition within the south-eastern Gulf observed for the infauna, benthos, phytoplankton and demersal fish are consistent with the changes observed in this study for the benthic macrofauna. No distinct grouping of sites is observed in terms of either the species composition or the environmental variables.

The distinction in the community structure observed for the benthos (Long et al., 1995), phytoplankton (Rothlisberg et al., 1994) and demersal fish (Blaber et al., 1994) between the south-eastern and central-western parts of the Gulf have been related to the differences in the physical properties between these regions. The central-western zone has relatively higher mud content and deeper waters compared to the eastern and south-eastern Gulf (Long et al., 1995; Heap et al., 2004). The two zones are also distinct in terms of wave and tidal power. Sediment mobility in the south-eastern region is influenced only by waves, whereas the west is mostly tide-dominated and a large area in the central and south-western region shows no sediment mobility from either tides or waves (Heap et al., 2004). The seabed exposure also contrasts between these two areas, with the south-eastern part of the Gulf subject to moderate to maximum exposure, while the south-western and central areas have minimum to moderate values of exposure. The southeast also experiences a higher frequency of cyclones (Lourensz, 1981), and this may act to homogenise the fauna throughout this region by dispersing juveniles and subadults (Levin et al., 2001). While detailed analysis of species associations between organisms and geomorphic features is not available from these historic datasets, the importance of the seabed morphology is highlighted in the restricted distributions of reef-associated fish (Blaber et al., 1994).

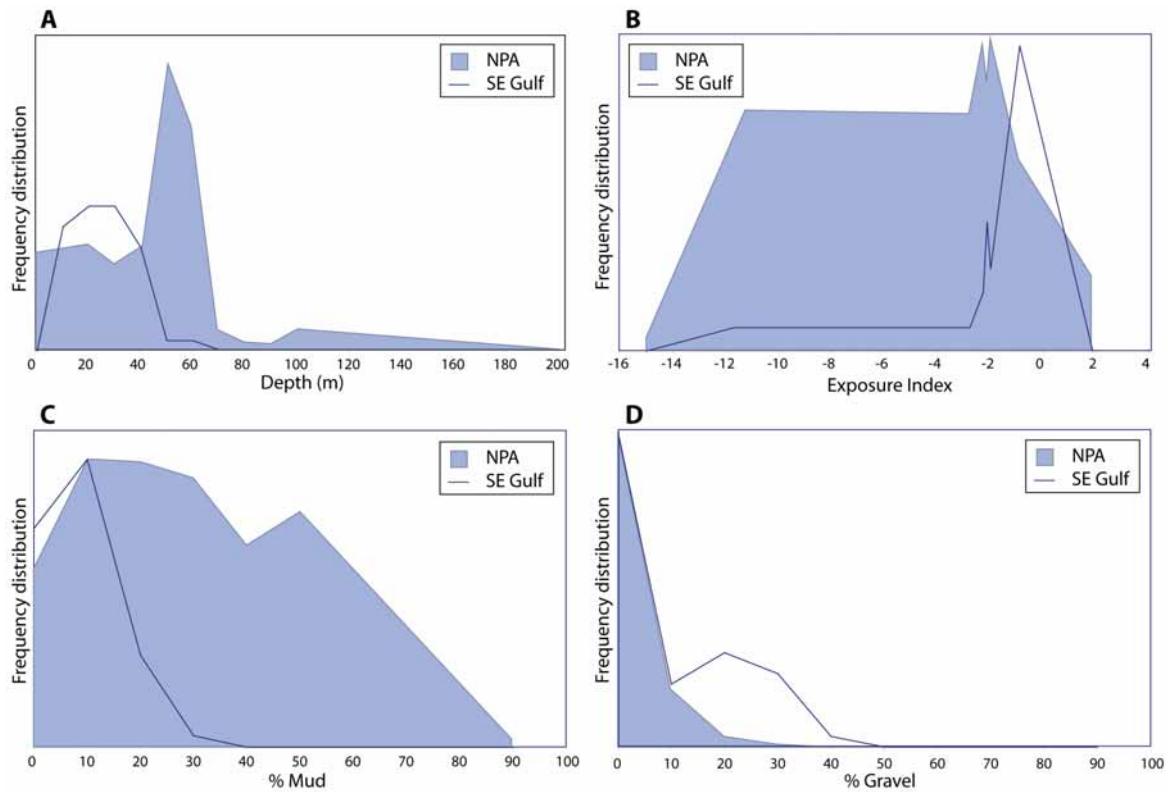
The broad scale distribution of biological and physical attributes suggests that sediment type, water depth, sediment mobility and seabed morphology can be used to define distinct biological communities across the Gulf of Carpentaria. These factors are consistent with the patterns observed at the smaller scale of this study. The consistency between the broad and small-scale bio-physical patterns suggests that the relationships derived from this study may apply more broadly to the NPA, allowing characterisation of habitats throughout this area. The cluster analysis of the substrate properties indicates the occurrence of 5 classes across the NPA, which are distributed within 15 geomorphic features. For representative management of the NPA, a broad range of ecosystem components needs to be included. The geomorphic features can provide a broad indication of the seabed habitat types, in combination with the relevant substrate properties. However, the results from this study also indicate that the correlation with geomorphic features is much stronger when detailed bathymetry data, such as from multibeam surveys, is available, so the available datasets should be interpreted as indicative of the broad habitat types. The substrate properties vary within each geomorphic features, as well as between them. In targeting representative areas for marine protection, the full range of variability within and between the geomorphic features should be included.

### **5.3. Validation of the application of physical surrogates in the NPA**

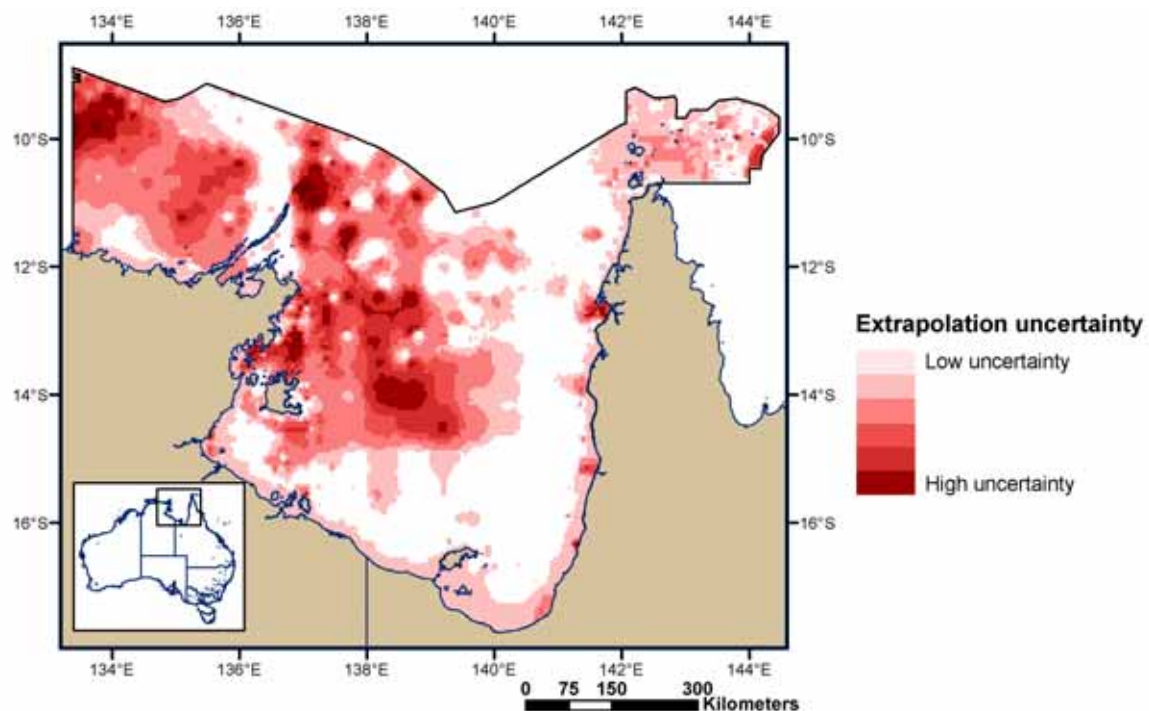
The application of the physical surrogates derived at the small scale of the present study to the whole of the NPA is associated with a degree of uncertainty. The two main sources of uncertainty are due to the relatively narrow range in the physical gradients across the study sites and uncertainty associated with the cluster analysis. The physical gradients encountered across

the study sites are narrower than those which occur across the entire NPA, particularly for the percent mud and water depth, and to a lesser extent for the seabed exposure (Figure 9). Uncertainties were mapped for each parameter by selecting cell values that exceed the maximum and minimum values across the study sites by more than 10%, with increasing uncertainty occurring as the range in values increases. The combined grid shows the uncertainty values for all four physical parameters (Figure 10). High uncertainty is associated with relatively deep water depths (up to 211 and 434 m) in the north-western Arafura Sea and eastern Torres Strait, and the relatively high mud content in the central Gulf and western Gulf and the Arafura Sea. Low uncertainty along the coast is associated with shallow water depths (<10 m). The Torres Strait area also has slightly higher seabed exposure than encountered in the south-eastern Gulf, resulting in low to moderate uncertainty in this area. Extrapolation of the results from this study across these larger gradients may introduce some uncertainty into the characterisation of the seabed habitats, however, previous studies at broad scales across the Gulf do support the importance of the physical relationships derived at the smaller scale of this study.





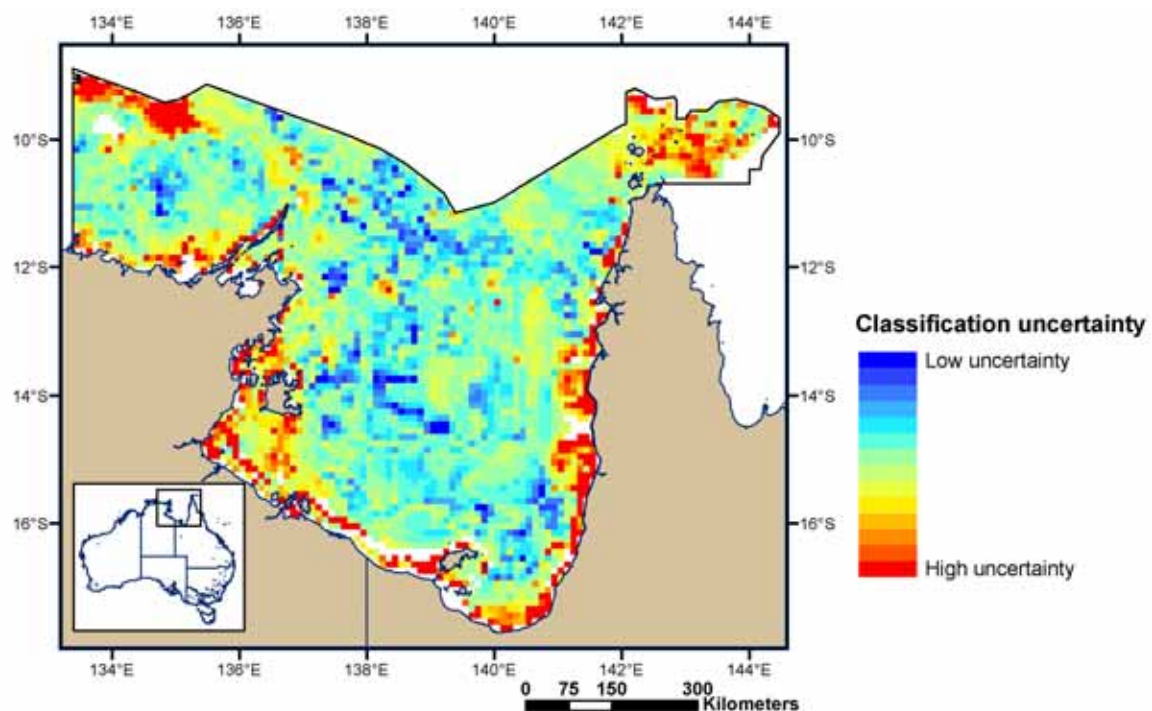
**Figure 9:** Frequency distribution of values sampled within the study area (southeast Gulf) and in the whole of the Northern Planning Area (NPA) for A) depth, B) Seabed exposure, C) percent mud and D) percent gravel. Shallow areas (less than 10 m) and deeper waters (>100m) were not sampled in the study area, leading to higher uncertainty in extrapolation across these values within the NPA. Seabed exposure values between 0 and 2 were not sampled, while they are represented within the NPA, and mud content greater than 30% is not represented within the study area, but has high representation within the rest of the NPA. Gravel content sampled in the south-eastern Gulf is representative of values within the NPA.



**Figure 10:** The uncertainty associated with extrapolating the results from the south-eastern Gulf to the entire NPA, due to the larger gradients in the environmental parameters encountered. Highest uncertainty occurs in parts of the central Gulf and the far western and eastern Arafura Sea.

There is also a degree of uncertainty associated with the cluster analysis process. This is due firstly to the nature of cluster analysis in forcing boundaries to be drawn where in reality changes in the environmental properties and the faunal distributions are more likely to occur gradationally (eg. Orpin et al., 2005). The boundaries between clusters should therefore be interpreted as part of a gradient, rather than as a barrier between species and environmental properties. The other uncertainty associated with cluster analysis is that cells are forced into clusters, when they may in fact not conform to the mean values of the cluster for one or more of the parameters. The variability in parameters away from the mean values for cells within each cluster can be determined using a maximum likelihood classification. This function determines the level of uncertainty associated with the classification of cells in each cluster (Figure 11). For definition of seabed habitats, greatest

distinction in physical features between clusters will occur where there is low uncertainty. Highest uncertainty in the classification of the cells occurs towards the edges of the data distribution due to boundary effects, so less confidence should be placed in the definition of these habitat features. Across most of the NPA, there is low uncertainty in the cell classifications, providing a high degree of confidence that the cluster analysis is a good representation of the physical variation in the benthic substrates.



**Figure 11:** Uncertainty associated with the cluster analysis occurs due to offsets from mean values for one or more of the environmental variables within the 5 clusters identified. Highest uncertainty in the classification occurs towards the edges of the data distribution due to boundary effects.

The physical surrogates determined in this study assume that communities will be similar in areas where physical properties are also similar. However, the distribution of biota also depends on factors such as competition, predation and dispersal of larvae (Jumars, 1993). Selection of replicate areas for inclusion in marine protected areas may better ensure the adequate

protection of species as well as of the seabed habitats (for further discussion see Ponder et al., 2002).

#### **5.4. Recommendations for future NPA surveys and survey design**

The map of uncertainty that has been derived in this study can provide guidance for future surveys within the NPA. Biological data is required for those areas where the environmental gradients are larger than those encountered in the south-eastern region of the Gulf to test the consistency of the species-environment relationships. Detailed analyses of the benthic biota is only available for the south-eastern Gulf, with new datasets currently being analysed for surveys SS03/2005 and SS04/2005 for the southern Gulf (north and west of Mornington Island, and north east of the Vanderlin Islands) and the western Gulf (to the north of Groote Island). These datasets will provide additional information in areas which have low to high uncertainty in the current analysis. Survey SS05/2005 in the northern Arafura Sea will also provide additional biological data across the areas of low to high uncertainty in this part of the NPA. The remaining areas of high uncertainty are in the central Gulf, the southern Arafura Sea and the area north east of Cape Wessel. These areas should be a priority for future surveys.

This study shows the relationship between the substrate morphology and the species distributions, especially for those features that are revealed by mapping with high resolution multibeam data. Reconnaissance mapping is an important part of any survey, with detailed bathymetry and backscatter data allowing better targeting of samples within a broad range of habitat types. High resolution mapping of the seabed, combined with biological sampling, will also allow further testing of the relationship between substrate type and the distribution of the benthic biota.

The limitations of the sampling equipment needs to be recognised in the analysis of the data. Benthic sleds provide an effective means of collecting a range of benthic organisms, but they do not collect representative samples of the infauna. Combination of benthic sled data with analysis of infauna from sediment cores would provide a more comprehensive view of the benthic community. In the analysis of the biological data, this study indicates that species level data provides a much stronger relationship to the physical parameters than measures of diversity. The identification of organisms to at least putative taxon level is therefore crucial for the development of meaningful physical surrogates.

## **6. Summary and Conclusions**

The seabed environments across the Northern Planning Area can best be defined by the seabed morphology, grain size, water depth and sediment mobility properties. These factors are shown to be important at both a local and a broad scale across the Gulf of Carpentaria. Five classes broadly define the substrate properties, with a distinct zoning of classes from west to east across the region. Combination of these classes with the seabed morphology illustrates the variety of potential seabed habitats within the NPA nested within geomorphic features. For comprehensive and representative selection of Marine Protected Areas, the full range of geomorphic and substrate classes need to be included. Uncertainties in the extrapolation of the surrogates derived for the south-eastern part of the Gulf across the whole NPA also need to be recognised to ensure accurate selection of MPAs and to guide future surveys in the area. Uncertainties may be introduced where the real gradients in the physical parameters exceed that measured, and also where there are outliers in the classification. Areas of greatest uncertainty in the physical gradients should be targeted in future surveys in the NPA to test the consistency of bio-physical relationships.

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