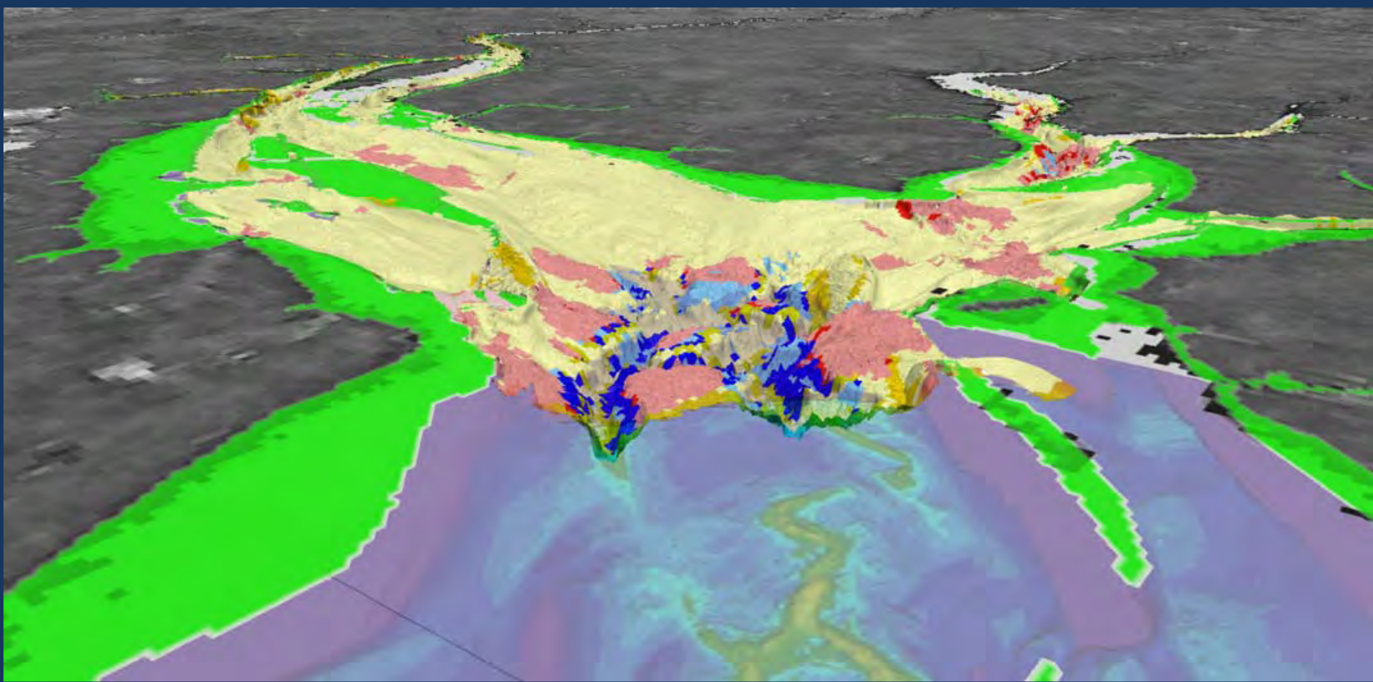
Northern Territory Government

DEPARTMENT OF LAND RESOURCE MANAGEMENT

Assessment of marine biodiversity and habitat mapping in the Weddell region, Darwin Harbour



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2012

www.nt.gov.au/lrm

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PO Box 496
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ISBN: 978-1-74350-009-5

Report prepared for the Northern Territory Department of Lands, Planning and Environment.

This Report should be cited as:

Smit, N., Penny, S.S. and Griffiths, A.D. 2012. *Assessment of marine biodiversity and habitat mapping in the Weddell region, Darwin Harbour.* Report to the Department of Lands, Planning and Environment. Department of Land Resource Management, Palmerston.

Executive summary

The Territory Government is currently planning for Weddell, the next major urban development in the Top End. The new urban centre will be approximately 15 km from Palmerston and 30 km from Darwin CBD. Weddell is located within the Darwin Harbour catchment covering up to 3000 ha and with proposed housing for up to 50,000. The Darwin Harbour catchment plays a central role in the economy of the Northern Territory and the lifestyle and character of the Top End. It is the Territory's most densely populated area with the highest concentration of commerce and industry.

This report was commissioned to improve our knowledge and understanding of the marine environment in the areas adjacent to Weddell, specifically the upper reaches of East and Middle Arms, to assist planning and sustainable development for the new township. The report provides an assessment of the diversity, distribution and conservation values of benthic fauna (invertebrates), fish and marine megafauna (marine turtles, dugong and coastal dolphins) using historical and recent survey data. It also describes and maps the benthic habitats in the upper reaches of the harbour using remote-sensed and survey data.

Ninety-four sites were sampled across the Elizabeth and Blackmore River. Sampling from beam trawls and benthic grabs identified 256 different marine invertebrate species. In general, species present in East and Middle Arms are found throughout North West Australia and the wider Indo-West Pacific. Although the diversity of marine invertebrates is high, species richness curves failed to reach asymptote indicating sampling effort (including historic data) was insufficient to fully characterise the invertebrate fauna. No marine invertebrate species identified in this report are listed as threatened or significant under Australian or Northern Territory legislation. Many of the invertebrates collected were juveniles indicating that the area is important nursery habitat. Crustaceans dominated samples in regards to species richness (43%) and abundance (92.5%) across both regions, however these data are skewed by a few swarming species of shrimps. The survey has provided improved knowledge of crustacean taxonomy and distribution: a new genus (Alpheida: gen. nov.), three new species (Alpheida, Amphipod: *Grandidierella* sp. nov.; Decapod: Brachyura: Majidae: *Oncinopus* sp. nov. (Davie 2012)); Decapod: Brachyura: *Takedellus* sp. nov.), three new Australian records (*Grandidierella* cf japonica, *Utica boreenensis, Alpheopsis equalis and* two new records for the NT *(Grandidierella gilesi, Neorhynchoplax minimal).* No collected species are endemic to Australia (except for the proposed new genus and species). The remaining invertebrate fauna are predominantly polychaetes (57 species, 30% of total number of species) and molluscs (42 species, 22%). It is likely that these fauna were under sampled due to the use of 1.0 mm minimum sieve mesh size, which has been shown to retain a small percentage of benthos living within sediments. Many of the species identified in this survey prefer fine-grained sediments, although at least two, *Nephtys mesobranchia* and *Inermonephtys* sp. are usually associated with sands.

Sixty-three species of fish were collected, which represents 15% of species known to occur in Darwin Harbour (415 species). Twenty-two species were collected during the hook and line surveys; and an additional 61 species were collected from beam trawl surveys. Gobies (family Gobiidae) were the most numerous in terms of number of species (n = 15) and number of fish collected (40% of all fish specimens collected), followed by six species of gudgeons (family Eliotridae, 19% of captures) and Cardinal fishes (family Apogonidae, 7.5%). No new species were recorded for Darwin Harbour during these surveys. Significantly, two species of Syngnatids, Girdled pipefish (*Festucalex cinctus*) and Straight Stick Pipefish (*Trachyrhamphus longirostris*) were sampled during benthic trawl and grab surveys. These two species and an additional two species of Pipefish (Girdled pipefish, *Festucalex cinctus* and Straight Stick Pipefish, *Trachyrhamphus longirostris*) also recorded from Darwin Harbour are listed under “Listed Marine Species” in the *Environmental Protection and Biodiversity Conservation* Act. The majority of fish collected were species know to be associated with benthos and were predominantly at juvenile life stages, followed by adult, post-larval and larval stages. The estuarine parts of East Arm and Middle Arm make a significant contribution to the fish biodiversity of Darwin Harbour and are important as a nursery habitat for many species of fish.

No new surveys were conducted for marine megafauna but the report presents a desktop review of existing data. Marine mega-fauna known to occur in the project area include three species of coastal dolphins, dugong, four species of marine turtles, marine snakes and saltwater crocodiles. East and Middle Arms of Darwin Harbour are important foraging areas for the Indo-Pacific humpback in particular, and to a lesser extent both the Indo-Pacific bottlenose and Australian snubfin. Current data and unpublished observations have recorded three marine turtle species - green, flatback and hawksbill - on the reefs and around the islands in the Elizabeth River (East Arm Wharf area). The green turtle is most often seen further upstream in East and Middle Arms because of its ability to also feed on mangroves. There no known nesting habitats for marine turtles within the Weddell region. Thirteen species of marine snake have been recorded in and around Darwin Harbour including 2 species of File snakes (Family Acrochordidae), two species of Mud snakes (Family Colubridae: subfamily Homalopsinae), and nine species of True sea snakes (Family Hydrophiidae). True sea snakes are Listed Marine Species under the *Environmental Protection and Biodiversity Conservation Act*, 1999. Saltwater crocodiles occur throughout Darwin Harbour, although there are limited nesting sites available inside the harbour. The Weddell region is considered suitable habitat for crocodile foraging due to the mangrove forests and tidal mud flats.

Substrate in Middle Arm and Elizabeth River is dominated by mobile sediments (4265 ha, 87.1%) with the remaining substrates being rock (630 ha, 12.9%). Weddell sediments are in general poor to very poorly sorted with mixed sediments being the most dominant sediment class (3688 ha, 75.3%). Hard substrates are found throughout Middle Arm and Elizabeth River and occur in varying environmental conditions. Spatial analysis of bathymetric data successfully grouped zones of similar seascapes. The analysis shows that both Middle Arm and Elizabeth River are complex systems with intertwining channels, ridges, reef edges, large extents of flats and many sand banks. Many of these attributes also occur at varying spatial scales (e.g. local high points within broad scale depressions such as Pioneer Creek, northern part of Elizabeth River).

Twelve benthic communities were identified, dominated by bare sand/mud and bare sand. Most diverse was the epibenthic community associated with reefs. The Middle Arm / Elizabeth River region is less diverse than the outer-harbour environments. In Middle Arm / Elizabeth River, only two epibenthic community classes were encountered (filter-feeders (1.5% of available substrate) and mixed epibenthic communities (10.3%); whereas in the outer Darwin Harbour four community classes have been identified: hard coral (1%), macro-algae (1%), filter-feeder dominated (6%) and mixed communities (2%). This is most likely a reflection of differences in environmental and water quality parameters for both areas. Habitat mapping identified three important “hot spots” within the study area: 1) in the ‘mouth’ of Middle Arm, 2) the depressions in Pioneer Creek, and 3) northern part of Elizabeth River.

In conclusion, the areas adjacent to Weddell are a complex marine environment consisting of intertwining channels, ridges, rocky reefs, reef edges, large extents of flats and many sand banks that support a diverse range of fauna. The principal conservation values of this area are as foraging and nursery habitats for many marine species. Some further work is required to fully characterise the structure of marine fauna and flora communities of the region and to determine the environmental factors that underpin macro invertebrate and flora distribution. An understanding of the natural variability in these factors is important for future monitoring of the health of the Weddell estuarine ecosystem.

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List of Abbreviations

ABT	Aggregated Boosted Tree analysis
BPI	Benthic Position Index
BRT	Boosted Regression Trees analysis
BRUVS	Baited remote underwater video system
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CBD	Central business district
D50	median grain size
DHAC	Darwin Harbour Advisory Committee
DLP	Department Lands and Planning
DPI	Department of Planning and Infrastructure
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999*
EUNIS	European nature information system
IUCN	International Union for the Conservation of Nature
LAT	Lowest Astronomic Tide
MAGNT	Museums and Art Galleries of the Northern Territory
MBG	Marine Biodiversity Group
MBES	Multibeam echosounder
MDS	Multidimensional scaling
MSL	Mean Sea Level
NRETAS	Department of Natural Resources, Environment, the Arts and Sport
NTG	Northern Territory Government
SSS	side scan sonar
TPWC Act	*Territory Parks and Wildlife Conservation Act 2010*

Acknowledgements

The project was funded through NT Department of Lands and Planning and we thank Steve Gilmour for his support. Marine invertebrates were identified by the following people: Chris Glasby (MAGNT), Charlotte Watson (MAGNT), Erica Keppel (MAGNT Visiting Research Associate), Richard Willan (MAGNT), Barry Russell (Curator Emeritus, MAGNT), Helen Larsen (Curator Emeritus, MAGNT), Rex Williams (MAGNT), Jim Lowry (Australian Museum), Peter Davie (Queensland Museum). Ray Chatto and Megan Fleming provided valuable support on the water.

1 Introduction

Shane Penny, Neil Smit

The Territory Government is currently planning for Weddell, the next major urban development in the Top End. The new urban centre will be approximately 15 km from Palmerston and around 30 km from Darwin CBD. Weddell covers approximately 3000 ha of land within the Darwin Harbour catchment is planned to support housing for up to 50,000 people. The Darwin Harbour catchment plays a central role in the economy of the Northern Territory and the lifestyle and character of the Top End. It is the Territory's most densely populated area with the highest concentration of commerce and industry.

To guide sustainable development in the region, the Territory Government has adopted the Darwin Harbour Strategy, which was developed by Darwin Harbour Advisory Committee (DHAC 2010). The Strategy's purpose is to provide policy and decision makers within government, industry, commerce and the community, with guidance for the integrated management of Darwin Harbour. The Strategy advocates a consistent, coordinated approach to decision making and resource use for the region, and it encourages stakeholders to work together and adapt their practices to ensure that values of the region are recognised and conserved for current and future generations.

Darwin Harbour is an extensive estuary with over 286 km^2 of open water (depending seaward boundary) and 38 km^2 of intertidal flats (OZCoasts 2011) with three major arms fringed by some of the largest and floristically diverse mangrove communities (Wightman 2006). The harbour is a poorly flushed, semi-diurnal and macro-tidal system with a maximum spring tidal range of 7.8 m (Wang et al. 2011) Tropical monsoons provide seasonal freshwater inflows and increased sediment loads. Darwin Harbour is situated within a region recognised for its relative pristine condition, a direct consequence of low industrialisation, few commercial fisheries and a relatively low and dispersed coastal population (Halpern et al. 2008).

This report was commissioned to improve our knowledge and understanding of the estuarine environment in the areas adjacent to Weddell, specifically the upper reaches of East Arm (Elizabeth River) and Middle Arm (Blackmore River and Pioneer Creek), to assist planning and future development. The report provides an assessment of the diversity, distribution and conservation values for benthic fauna (Chapter 2. Invertebrates), marine megafauna (Chapter 3 Marine Vertebrates) and fish (Chapter 4 Fish) using historical and recent survey data. Benthic habitats were described and mapped using remote-sensing and survey data (Chapter 5 Benthic Communities and Habitat Mapping)

1.1 Aims

This project aims to improve the knowledge and understanding of the marine environment in the areas adjacent to the Weddell project, specifically:

1. Describe the diversity, distribution and conservation values of marine invertebrate fauna;
2. Describe the diversity, distribution and conservation values of marine vertebrate fauna (fish, marine reptiles, marine mammals);
3. Identify abiotic factors (i.e. physical characteristics) that influence the distribution of benthic fauna;
4. Describe and map the distribution of the benthic communities.

Figure 1.1. Locality map for Darwin Harbour and the proposed Weddell development area (shown in yellow).

2 Invertebrates

Shane Penny, Neil Smit, Chris Glasby, Peter Davie

2

2.1 Introduction

In general the marine biodiversity and coastal hydrography across the Northern Territory is poorly documented or understood, although Darwin Harbour has received considerably more, episodic, research into its marine fauna and flora. Contemporary collection efforts can be traced back as far as September 1839 when Lieutenant John Stokes sailed on the HMS Beagle into Darwin Harbour. Many biological surveys have been conducted since: Miers on HMS Erebus and HMS Terror (1874); TJ Sturt (1875 – 1877); and Riddley on HMS Alert (1884). More recently, Pope (1967) surveyed intertidal communities of fringing reefs in the Darwin region in the early 60s, and staff from the Museum and Art Gallery of the Northern Territory (MAGNT) have conducted both targeted and opportunistic surveys since the museum was established in 1981. Examples include the mangrove benthic fauna surveys of the Darwin South region (Hanley 1993), the Wet and Dry Season subtidal surveys in 1993/4 of Darwin Harbour of which only the polychaetes have been analysed (Keppel & Glasby, in prep.); the Beagle Gulf Benthic Survey (BGBS) (Smit et al 2000) and the Baseline Survey of Darwin Harbour for introduced marine species (Russell and Hewitt 2000).

The Museum and Art Gallery of the Northern Territory (MAGNT) has over 24,000 vouchered specimens collected from within Darwin Harbour, of which only 1.4% are located from within the marine environment adjacent to the proposed Weddell development. This indicates that the diversity and abundance of marine fauna is poorly understood within the estuarine areas adjacent to the Weddell region. The only comprehensive effort to describe benthos in the Weddell area was undertaken by consultants BTM WBM in 2010, where they used underwater video to describe the benthos in the Elizabeth River and Middle Arm (including Blackmore River and Pioneer Creek) (BMT WBM 2010). Abundance of benthic fauna was determined by counting individuals or colonies for each underwater video transect. Taxa were identified to the lowest practical taxon: hard corals were identified to genus, while soft corals, sponges and hydroids were identified to genus or morphotype (often to family or higher). Consequently, no biological samples were kept for identification.

2.1.1 General overview of the major taxonomic groups in Darwin Harbour

The total number of macro-invertebrate species in Darwin Harbour will exceed 3,000 (Russell and Hewitt, 2000); there are 1100 species of molluscs alone (R Willan pers comm.). A summary of estimated number of species per taxa in the Darwin Harbour region can be found in Table 2.1. A description of the major groups is provided below.

Sponges. In terms of sponge fauna, the Northern Territory, northwest Western Australian and adjacent Commonwealth marine waters are one of the most species rich areas in Australia (Hooper et al 1997). More than 800 species have been collected from North West Australia of which approximately 300 have been described in the literature, with a high degree of endemism – up to 70%, for some families (Hooper and Levi 1994). The sponge fauna of the Darwin Harbour region is a subset of the North West Australian fauna. Ninety-one species from the Beagle Gulf and 56 species from Darwin Harbour have been described. A recent revision of the Order Halichondrida added another 6 new species, 22 new descriptions and 3 new records for the region (Alvarez and Hooper 2009, 2010 and 2011). Significantly, Darwin Harbour is the type locality for 22 species of sponge. Nevertheless, the described fauna probably represents less than 10% of the known sponges of the region (Hooper et al 1997).

Sponge fauna is most prolific on hard substrates and transition areas between a reef and subtidal mud flats. However, sponges are also found in and on soft-bottom substrates. Substrates dominated by gravel and/or shell grit and sand-silt are the most conducive for larval settlement. Hooper and Ward (unpublished data (cited in Hooper 1988)) suggest that coarse sand (mean sediment grain size of 0.8 phi) provides the optimal substrate for sponges. Those species of sponges that prefer soft substrates are often submersed within the sediment. Sponges play a role in the productivity and trophic processes of the ecosystem and provide refuge for many species of small fish and invertebrates (e.g. crabs, shrimps, brittle stars and polychaetes).

Gorgonians and soft corals . Darwin Harbour has a relatively low diversity of soft corals and sea whips, with 20-25 species (11 genera) and 30-40 species (18 genera). Their poor representation has been attributed to the high turbidity of water in the harbour, one of a range of parameters (e.g. sedimentation, light availability, wave and flow exposure and steepness of a reef) that control the abundance of soft corals (Fabricius and Alderslade 2001). Generally, gorgonians are restricted to current-exposed but wave-protected environments. Most species require hard substrate for larvae to settle. However, some species have colonised soft-bottom substrates with root-like structures by either aggregating gravel to form a suitable substrate to attach to or by digging into the sediment (e.g. sea pens).

Hard coral s. One hundred and twenty-three species are recorded in Darwin Harbour (Wolstenhome et al 1997), a surprisingly high number given local environmental conditions. In the Darwin Harbour region, the distribution of coral reefs is restricted to hard substrates with strong currents. Exposure rate during extreme low spring tides and poor light availability restricts their depth distribution (Hooper 1988), which is generally between mean sea-level and 10 m deep within the Darwin Harbour. Further offshore, where the waters are less turbid, coral reefs are found at greater depths.

Hydroids. Recent work by Watson (Watson 1999, 2000) has contributed enormously towards taxonomy of hydroids for the Darwin Harbour region. In total 72 species of hydroids have been identified, of which seven species are only found in this region. Watson reported that there are no common environmental parameters that could be used as a surrogate indicator for species richness. Hydroids do need a substrate for attachment, even if this is a small pebble or shell grit. Interestingly, Watson (2000) reports that many species were associated with the tubes of the marine polychaete worm *Eunice tubifex*. These tubes stand erect (up to 30 cm) above the seabed and provide a sediment-free substrate.

Marine worms. As polychaete worms are often used as indicator species for ecosystem health, their diversity is well described in sites with regular monitoring. However, the literature on polychaete worms from Darwin Harbour is sparse. Straughan (1967), Hanley (1984, 1985), Hutchings and Glasby (1987), Consulting Environmental Engineers (1983, 1986) and Hutchings (1997) have described the polychaete fauna in the Darwin Harbour region, however, their taxonomy is still intractable. For example, the Beagle Gulf Benthic Survey (BGBS) (Smit et al. 2000) collected 100 morphospecies of marine worms of which only one specimen could be identified to species. Hanley (1988) estimates that there are probably 600 species of polychaetes in Darwin Harbour, with their distribution belonging to the Indo-West Pacific region. The greatest diversity is found on subtidal reefs followed by subtidal mud flats and intertidal mud flats. Polychaetes are also found living in encrusting algae and in or on other sessile invertebrates such as sponges; other species are reef- or at least habitat-forming, such as the encrusting intertidal serpulids and the long, leathery tubes of *Eunice tubifex*. Smit et al. (2000) reported that polychaetes are found over a wide variety of habitats, with preference for fine grained, sandy and unsorted sediments. Eunicids, terebellids and sabellids prefer fine-grained sediments (sandy mud), whereas the capellids favoured sandy to unsorted sediments. Phyllodocids were found in all sediments. Polychaetes are also similar in diversity to molluscs (about 90 species each) in intertidal mangrove habitats of Darwin Harbour (Glasby, pers. com.; Metcalfe & Glasby 2008).

Echinoderms. This group includes sea urchins, holothurians, seastar, feather stars, brittle stars and crinoids. Clark (1938, 1946) has described the echinoderm fauna for Darwin Harbour, and during the BGBS 117 species were collected (Smit et al 2000), of which 22% are endemic to northern Australia. The coastal Darwin region can be considered species-rich (Smit et al 2000). Interestingly, Marsh (1984) noted that a large proportion of the species collected during the BGBS were juveniles. This suggests that the fauna may be unstable, either due to natural perturbations such as redistribution of sediment during the wet season, river silt or from anthropogenic impacts.

Molluscs. Darwin Harbour is the best-collected locality for marine molluscs in northern Australia. Laseron (1957, 1958, 1959), Blackburn (1977) and LeProvst (1982) have all described mollusc fauna. Further, MAGNT has compiled a mollusc list for Darwin Harbour which has a total of 924 species, including 75 mangrove species (Willan pers comm.). Species diversity is considered to be impoverished when compared with other nearby regions (Willan, pers. comm.). Molluscs are found in wide range of habitats with many species occupying a specific niche. In terms of species richness, molluscs are one of the most dominant taxa in Darwin Harbour region.

Crustaceans. The crustacean fauna of Darwin Harbour region is typical of northern Australian waters and is dominated by Indo-West Pacific species (Morgan 1992). The total number of crustacean species is estimated to be about 1,000 (Hanley 1988). Decapods, (e.g. crabs, prawns, shrimps and lobsters) have been the focus of most crustacean research (e.g. Miers 1884, Banner and Banner 1973, 1975, 1981, Bruce 1987a, b, 1988, 1997). Thirty-two species of decapod crustaceans are described from mangrove environments (LeProvost et al. 1982). It is estimated that there are probably 40-60 species of crabs associated with mangroves in Darwin Harbour (Hanley 1988). Fiddler crabs and hermit crabs have been described by George and Jones (1982) and Morgan (1987) respectively.

There is little known of other crustacean taxa, such as copepods, amphipods, isopods, cirripedes (barnacles), mysids and tanaids. Keable (1997) reported 24 cirolanid isopods from Darwin Harbour and Edgar (1997) described a new genus and three new species of tanadacean crustaceans.

Crustaceans are a diverse group and many species have found their own niche within the broad range of marine environments. Consequently, it is difficult to determine which habitats have higher species diversity. In general terms, thalassinids, leucosiids, cumacs, portunids, penaeids are abundant on muddy and sandy substrates; calappids are found on sandy-gravelly/shelly substrates; xanthids and diogenids prefer coral and rocky reefs; and xanthids, cariids, stenopodids and paguriids prefer hard substrates (Morgan 1992, Pointer and Long 1994, Southcott 1974). Metclafe (2007) has described crustacean fauna (60 species) in Darwin Harbour mangrove communities.

Crustaceans play an import role in the trophic structure in marine ecosystems. Many decapods graze on the substrate for algae and detritus; copepods are an important component of the marine plankton and provide a major food source for many small and juvenile fish; shrimps, prawns and crabs are an important food source for many species of fish; isopods feed in great numbers on dead fish. Consequently, any changes in the marine environment which impact on crustacean abundance will affect those species that use crustaceans as a food source. Conversely, if the fish composition is modified this may have an impact on decapod fauna with a cascading effect on habitat structure and ecosystem function.

2.1.2 Aims

This study aims to collect invertebrate data where data gaps exist and provide an overall assessment of diversity, distribution and conservation values of benthic fauna (invertebrates).

This chapter describes methods and results from invertebrate surveys undertaken in between 26 March and 13 April 2011. This chapter describes the methods used and the benthos sampled. An assessment is made of the conservation significance of the biodiversity of the benthos, and information gaps are identified that may be applicable to the development of Weddell.

Table 2.1. Species diversity: number of species per taxa in the Darwin Harbour region (Smit 2003 updated for Polychaetes and Molluscs 2012 (Glasby and Willan, pers Comm.)).

Taxa	no. of species	Author	Comments
Sponges	62	Hooper *et al* 1987	only aprox. 10% of the sponge fauna has been described (56 species) Sponge fauna in NW west Australia, including Darwin Harbour, is unique for Australia
Cnidarians	20-25	Russell and Hewitt 2000	low diversity, poorly represented
	30-40	Russell and Hewitt 2000	low diversity (possibly due to turbidity)
	123	Wolstenholme *et al.* 1997	surprisingly rich considering the high turbidity and little substrate available to colonise Diversity is lower than E and W coasts of Australia. Data from surveys from Anson Bay to Vernon Islands, thus there may be fewer species in Darwin Harbour.
	63	Watson 1999, 2000	lack of taxonomic attention
Nematodes	?	Hodda and Nichols 1987	22 genera collected from East Arm
Polychaetes	600	Hanley 1988	estimates that there are probably 600 species of polychaetes with the greatest diversity on subtidal reefs
	1,000	C Glasby (pers Comm.)	recent studies indicate the number will be closer to 1000 species;
Crustaceans	1,000	Hanley 1988	estimated number of species
	121	Bruce and Coombes, 1997	shrimps: 121 species
	184	Smit *et al.* 2000	decapod species were collected during the Beagle Gulf Benthic Survey
	40 - 60	Russell and Hewitt 2000	decapod species from mangroves
	60	Metcalfe	invertebrate fauna Darwin Harbour Mangroves
	24	Keable 1997	isopods
Molluscs	1100	Willan (pers Comm)	diversity is considered low when compared with other areas e.g. Port Essington, Cobourg Peninsula
Echinoderms	60	Hanley1988	echinoderm fauna is poor with the exception of Brittlestars which are associated with muddy habitats
	117	Smit *et al 2000*	soft substrates, considered species rich

2.2 Methods

Sampling was undertaken between 26th March and 13th April 2011. Sampling sites were kept as close as practical to the BTM WBM sampling locations, to ensure that comparable habitats were sampled and collected data could be pooled for analysis. Forty-four sites were sampled using beam trawl and benthic grabs. An additional six sites were sampled just using benthic grabs (Figure 2.3).

In this report, East Arm includes estuarine waters between East Arm Wharf and Wickham Point and includes Elizabeth River and associated creeks; Elizabeth River, is considered to be defined by the line between mouths of Slack and Tricky creeks; Middle Arm is defined by the line between Wickham Point and Stokes Point and includes Blackmore River, Pioneer Creek and Little West Arm and associated creeks; Blackmore River is delineated by the north bound line from Colvin Point and includes Haycock Reach and associated creeks.

Sediment sampling and associated benthic infauna was collected using a Petersen benthic grab (area 0.0039 m^2) deployed by hand across a range of depths and soft bottoms. The depth, and hence volume, of grab sample varied according to the sediment hardness. Sediment composition was classified down to level 2 classifiers [see 5.2.2 Sediment classification. Figure 5.8], and grab samples were then washed and sieved through 5 mm, 2 mm and 1 mm sieves to sort by grain size and trap infauna. A 2 x 1 m beam trawl with 6.5 mm mesh size and 1.4 mm cod end was trawled at between 2 to 4 knots for 10 minutes at each sample site to collect mobile epibenthic organisms. All specimens were sorted into phyla and fixed immediately in either 80% ethanol or 10% formalin. Post-survey sorting of samples into finer taxonomic groups was completed and specimens forwarded to MAGNT for identification.

For sites sampled using grabs and trawls, we conducted an assessment of the relative species diversity and richness for each Elizabeth and Blackmore rivers by sampling technique (beam trawl and sediment grab). Predictive curves for overall richness and diversity were created using the *BiodiversityR* (1.6) package in R version 2.14.0 (R Development Core Team 2011).

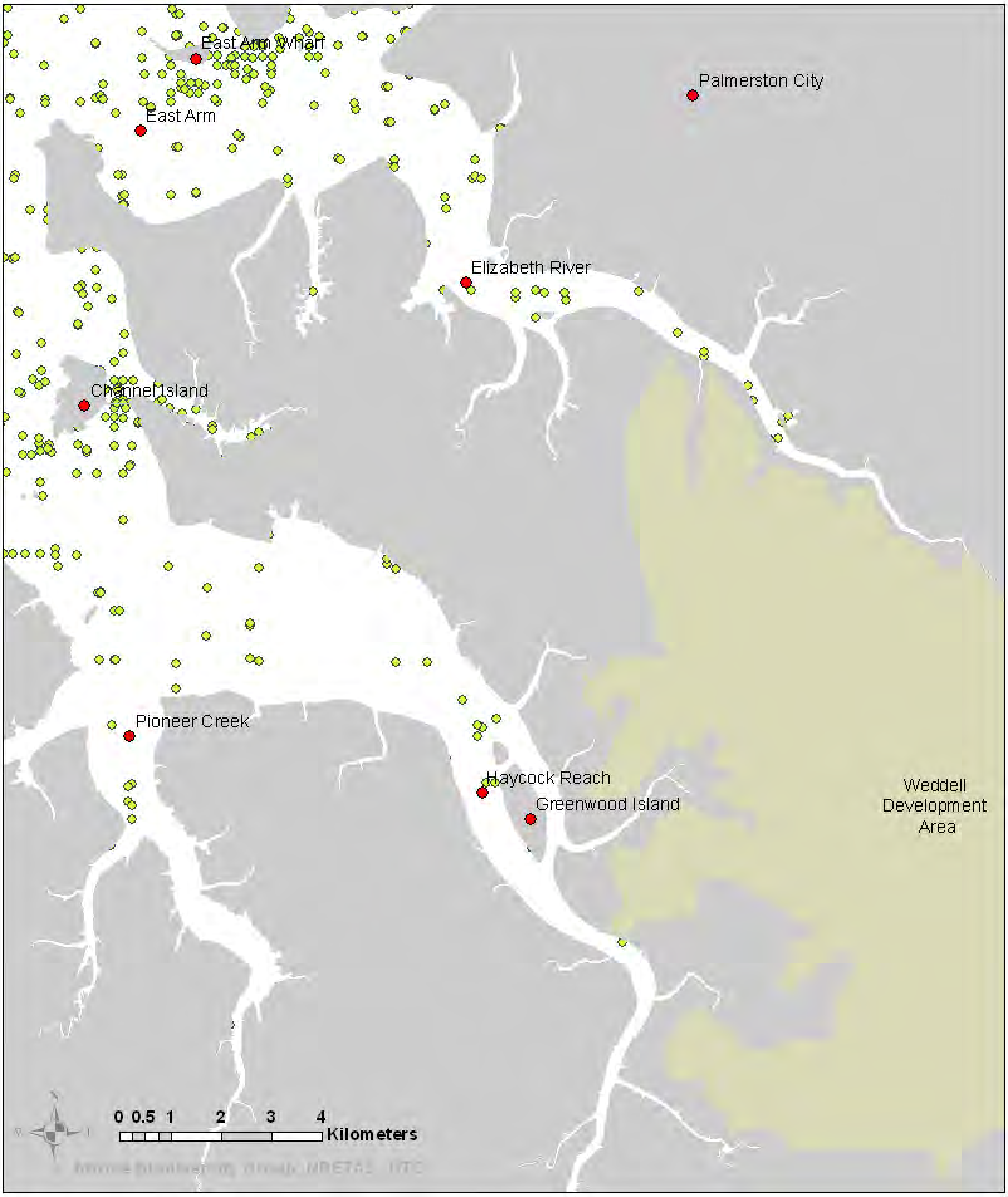

Figure 2.1. Museum and Art Gallery of the Northern Territory (MAGNT) database records for East Arm, Elizabeth River, Middle Arm and south-east Port of Darwin. Data supplied by MAGNT (2011). **Green dots**, sample sites; **red dots**, locality names.

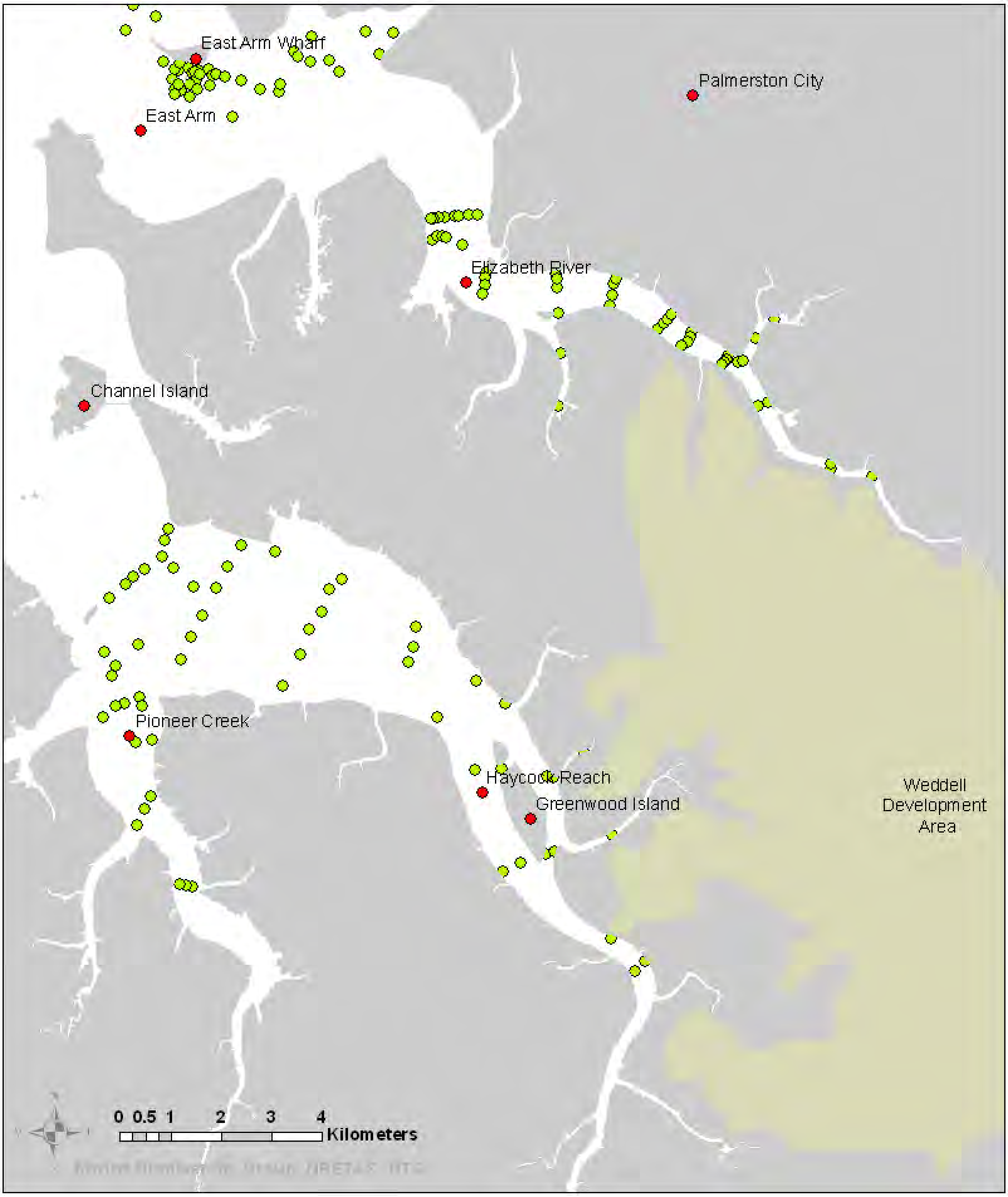

Figure 2.2. BMT WBM survey records for East Arm, Elizabeth River and Middle Arm. Data supplied by BMT WBM / IX Survey 2011. **Green dots**, sample sites; **red dots**, locality names.

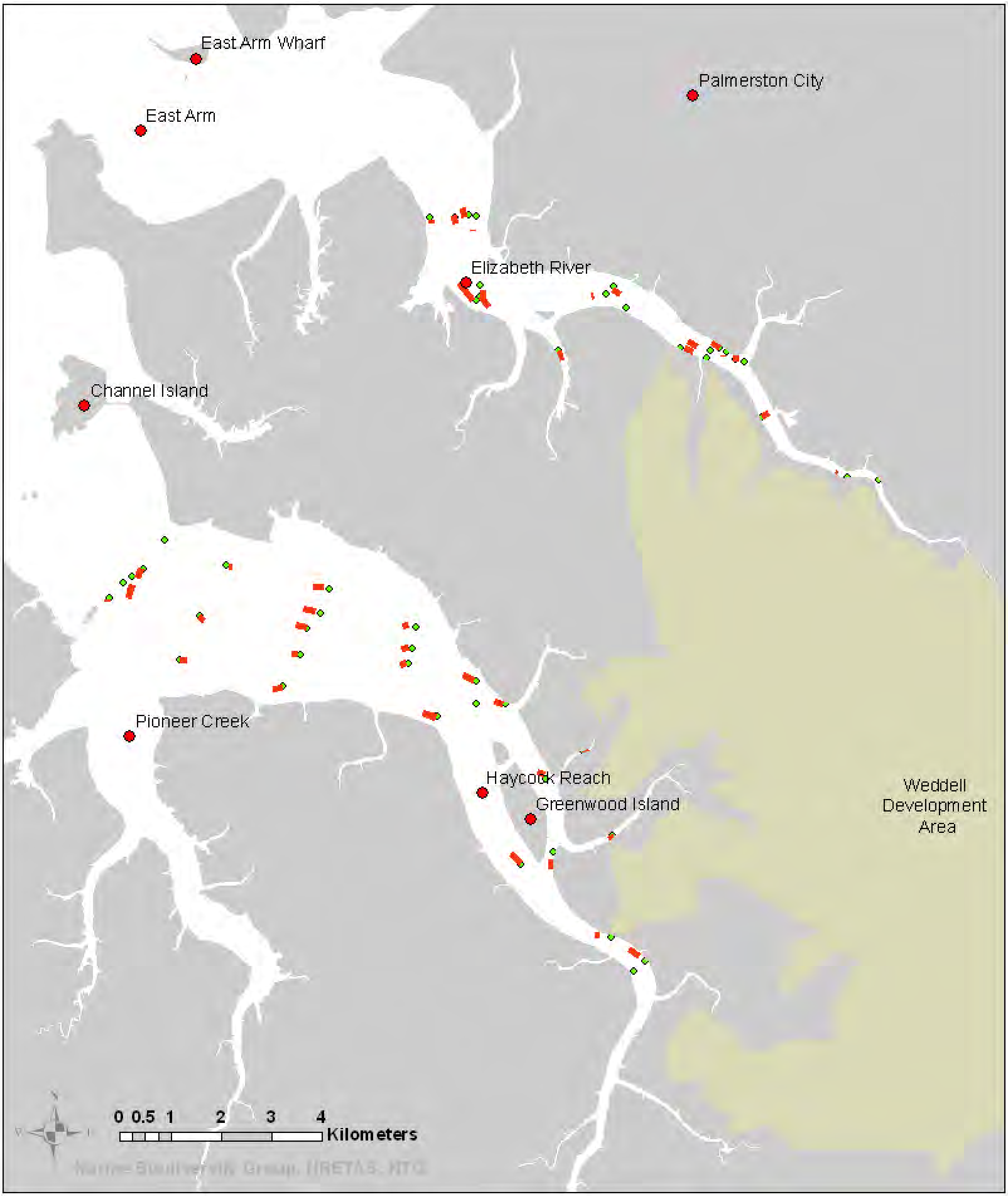

Figure 2.3. Extent of MBG sampling across the Elizabeth River and Middle Arm (Blackmore River). **green circle**, benthic grab; **red line**, beam trawl track; **red dots**, locality names.

2.3 Results

Sampling from beam trawls and benthic grabs identified 256 different species from 4,982 individuals. Crustaceans dominated numerically for both species and individuals across all regions and in particular in beam trawl samples (Table 2.2, Figure 2.4). There was little difference in numbers of individuals and species between Elizabeth River and Middle Arm / Blackmore River, but benthic grabs sampled fewer individuals and were biased towards polychaetes (Figure 2.4).

In general, benthic trawls sampled more species for all but polychaetes (Figure 2.5). Elizabeth River contained greater species richness for molluscs and fish than Middle Arm / Blackmore River. No species richness curve attained convergence to an asymptote (Figure 2.5); suggesting sampling effort was too low to comprehensively survey the different taxonomic groups.

Table 2.2. Summary of major invertebrate taxa identified from beam trawls and benthic grabs. Full species list see Appendix 1.

	n	% n of Total	Species	% species of Total
Crustacea	4296	92.51	82	43.16
Amphipods	102	2.2	11	5.79
Decapods	4022	86.61	56	29.47
Anomura	20	0.43	6	3.16
Brachyura	494	10.64	16	8.42
Caridea	798	17.18	17	8.95
Penaeoidea	2710	58.35	17	8.95
Other	172	3.7	15	7.89
Anthuridea	1	0.02	1	0.53
Cirrepedia	3	0.06	2	1.05
Isopoda	13	0.28	4	2.11
Mysidacea	127	2.73	2	1.05
Ostracod	1	0.02	1	0.53
Phyllocarida	2	0.04	1	0.53
Pycnogonid	1	0.02	1	0.53
Stomatopoda	13	0.28	1	0.53
Tanaidacea	11	0.24	2	1.05
Echinodermata	2	0.04	2	1.05
Echinodermata	1	0.02	1	0.53
Holothuria	1	0.02	1	0.53
Mollusca	155	3.34	42	22.11
Bivalvia	57	1.23	19	10
Gastropoda	92	1.98	18	9.47
Polyplacophora	1	0.02	1	0.53
Cephalopoda	4	0.09	3	1.58
unknown	1	0.02	1	0.53
Polychaeta	163	3.51	57	30
Oligochaeta	2	0.04	1	0.53
Polychaeta	161	3.47	56	29.47
Other	28	0.6	7	3.68
Brachiopoda	1	0.02	1	0.53
Hydrozoa	2	0.04	1	0.53
Nemertea	4	0.09	1	0.53
Porifera	1	0.02	1	0.53
Rotifer	14	0.3	1	0.53
Sipuncula	3	0.06	1	0.53
indet	3	0.06	1	0.53
Totals	**4 644**	**100**	**190**	**100**

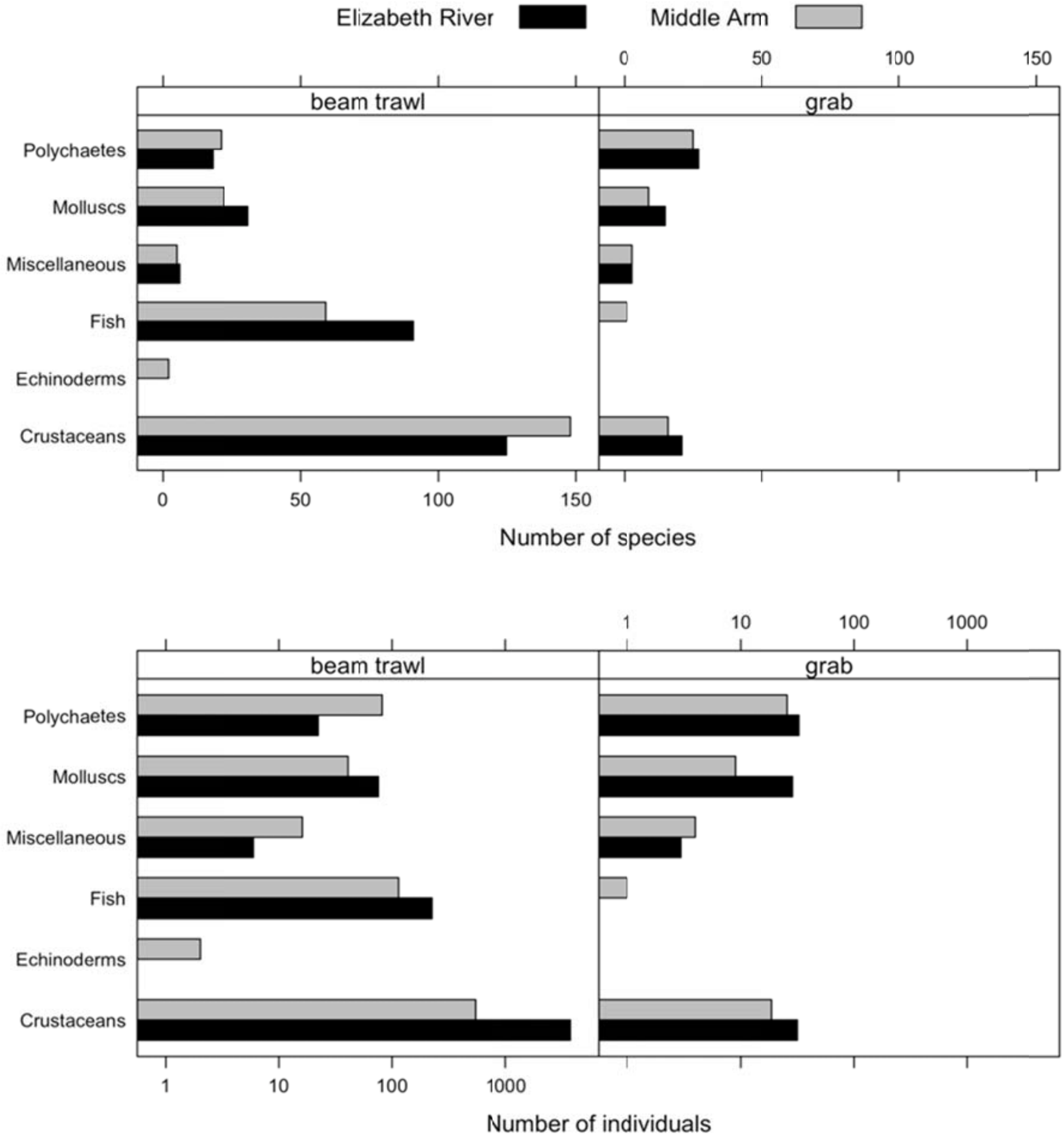

Figure 2.4. Top, number of species by major taxa for region and method; **Bottom**, number of individuals by major taxa for region and method.

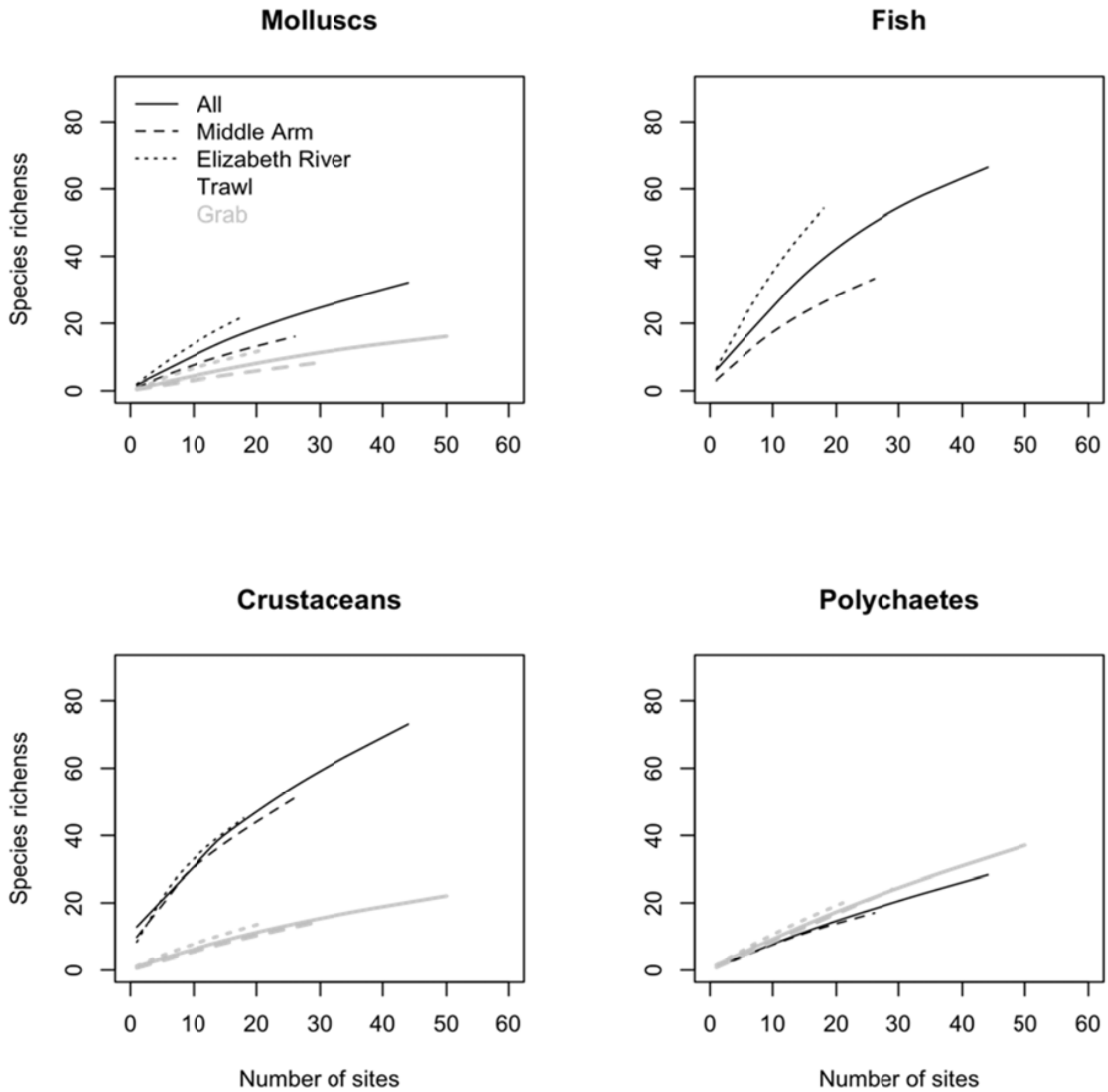

Figure 2.5. Species accumulation curves (richness) by major taxa, region, and method.

2.4 Discussion

Number of species collected is low in comparison with species estimates for Darwin Harbour (Table 2.2). This is in large part due to two factors. Samples were sorted using a 1.0 mm minimum mesh size, which has been shown to retain only 8% of all estuarine macrofauna (Schlacher & Wooldridge 1996). Further, not all available habitats were sampled that were later identified in the spatial analysis of environmental characteristics (see chapter 5 Benthic Communities and Habitat Mapping). Nevertheless, given the constraints of the infauna survey (sampling effort and method), the diversity is still notable. For example, just under half of the crustacean species collected during the 1993 Darwin Harbour wide survey were also present in this survey.

2.4.1 Polychaetes

About half of the species that were identified in this study were also present in the samples of the 1993-4 subtidal Darwin Harbour study (Keppel and Glasby, in prep). The different species composition between the surveys may be due in part to the different seasons sampled in the two studies (Dry in the early study, Wet in the Weddell study). Almost all of the polychaetes present in the Weddell Survey are species that are found throughout NW Australia and the wider Indo-west Pacific. However, many species in this survey were not able to be fully identified as the polychaete fauna of northern Australia is still relatively poorly known. This survey did not collect any new records at the species/genus level. However, a recent Weddell mangrove survey collected specimens of the nereidid, *Rullierinereis* sp. which is a new generic record for Australia[1], highlighting gaps in the existing data for polychaete assemblages. No polychaete species recorded are listed as threatened by IUCN.

Polychaetes were once thought to be habitat generalists; occurring on both soft or hard substrates. However, recent studies suggests that they exhibit considerable habitat preference, responding to grain size, organic load and other pollutants, vegetated vs unvegetated sites, and to the type of hard substrate (wood vs rock vs calcareous). Many of the species identified in this survey prefer fine-grained sediments, although at least two, *Nephtys mesobranchia* and *Inermonephtys* sp. are usually associated with sands. The *Capitella capitata* species-complex is a group of worms classically associated with organically polluted sediments. Populations of this species would likely respond positively to increases in organic load associated with sewage discharge. Further analysis of species habitat preferences will be possible when their distribution within Darwin Harbour is better known as a result of proposed surveys and analysis of the historical data at MAGNT.

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[1] see http://www.environment.gov.au/biodiversity/abrs/online-resources/fauna/afd/home.

2.4.2 Crustaceans

Crustaceans were the most abundant (92.5% of the total number recorded) and species-rich group in this study, comprising 43% of all species recorded. The richest sites had up to 24 species (Appendix 1).

Total crustacean abundance is dominated by two species - *Acetes sibogae*, and an unidentified species of *Caridea* (sp. 2). Both species are small and form large swarms in shallow estuarine waters. The density and distribution of *Acetes sibogae* is highly variable (Omundsen et al 2000).

Over three-quarters of the crustacean individuals sampled were identified to at least genus level (Appendix 1), with the majority of non-decapod species only being identified to Order or Family. This largely reflects the status of our local taxonomic knowledge. A significant number of decapod specimens are juvenile or subadult, and this can make positive identification even more difficult as adult morphological characters upon which most keys rely are not developed.

Only 6% of known NT crustacean species was collected, and only 34% of species recorded during the 1993 Darwin Harbour baseline survey. These figures, together with the fact that the species accumulation curve for crustaceans does not converge to an asymptote (Figure 2.5) suggest that sampling effort was too low to adequately assess crustacean fauna within the study area. However, due to the limited range of habitats and depths available within the Weddell region, it is not expected that crustacean diversity would be as high as recorded for Darwin Harbour more broadly.

Table 2.3. Comparison of number of crustacean species between Darwin Harbour survey (Hanley et al 1993), Weddell survey (this survey) and NT wide (MAGNT 2012 data).

Taxonomic Group	1993	2011	NT
Amphipoda	9	11	76
Decapoda total	161	56	876
Brachyura	92	16	363
Caridea	42	17	349
Paneoidea	9	17	65
Anomura	18	6	99
Anthuridea		1	1
Cirripedia	1	2	54
Isopoda	1	4	178
Mysidacea	1	2	43
Ostracoda	1	1	1
Phyllocarida		1	3
Pycnogonid		1	1
Stomatopoda	8	1	50
Tanaidacea	4	2	11
Total	**186**	**82**	**1293**

In general most species recorded are widespread in the Indo-West Pacific. Even with low sampling effort the survey has provided improved knowledge of crustacean taxonomy. Three new species were found: 1) an amphipod *Grandidierella* sp. nov.; 2) a new spider crab *Oncinopus kathae* Davie, 2012 (Decapoda: Brachyura: Majidae); and 3) a new low-intertidal shore crab, *Takedellus* sp. nov. (Decapoda: Brachyura: Camptandriidae). There were also two new Australian records (*Grandidierella* cf *japonica*, *Utica boreenensis* - previously known from Japan to West Irian, Indonesia)*,* and two additional records new to the Northern Territory: *Neorhynchoplax minima* (Decapoda: Brachyura: Hymenosomatidae) and *Alpheopsis equalis* (Decapoda: Caridea: Alpheidae), both previously recorded from the Australian east coast.

A large number of collected specimens were larval or juvenile (e.g. all mantis shrimps (Stomatopoda); the swimming crab *Charybdis* sp. (Portunidae), and many of the penaeid prawns), suggesting that the study area is, as for fish, an important juvenile habitat. Given the importance of Darwin Harbour estuarine habitats for larval and juvenile fauna, dedicated zooplankton survey and monitoring programs would greatly assist the understanding of ecological processes in the Harbour, provide important information for testing hypotheses on interactions between water quality and living resources, and help develop indicators for the health of Darwin Harbour'. Such monitoring would also allow testing for the presence of introduced pests such as zebra mussels.

The only commercial species collected were the Banana prawn (*Penaeus merguiensis*), which was collected at 14 sites; and the Mud crab (*Scylla serrata*) which was found at a single site (41) (Appendix 1). However, most samples were juvenile, and no commercial fishing occurs within Darwin Harbour itself.

2.5 Conservation significance

No marine invertebrate species identified in this study are listed as threatened or otherwise of conservation significance under relevant legislation or international treaties. From the data available, the conservation status of individual species recorded cannot be adequately assessed. However, the data does suggest that the study area contains important nursery habitats invertebrate species, consistent with results for vertebrate marine fauna.

2.6 Information gaps

The results of this survey demonstrated that some important gaps remain in our knowledge of the marine invertebrate fauna in this area. Further sampling using a broader range of methods is required to provide a comprehensive account of the invertebrate diversity. It is recommended that the stratification of any further sampling is based on the identified seascapes (see 5.3.4) to ensure that all marine habitats are adequately sampled, and that sampling incorporates seasonal variability.

The surveys reported here provide some baseline for the development of monitoring programs to track the health of invertebrate communities. However, the design and interpretation of such monitoring requires an improved understanding of the natural temporal variability in invertebrate communities, and the relationship to environmental factors including water quality parameters, light availability at the seafloor and chemical-physical characteristics of sediments in which benthos is found. Further research on ecological and hydrodynamic processes in Darwin Harbour should help inform the development of appropriate indicators for Harbour health, with those relating to larval and juvenile fauna likely to be particularly relevant for the Weddell region.

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3 Marine Vertebrates

Carol Palmer

3.1 Introduction

Darwin Harbour provides significant habitats for a range of marine mega-fauna and protected marine species including dolphins, dugongs, marine turtles, marine snakes and saltwater crocodiles. Three species of coastal dolphin as well as dugong are resident within the harbour and an off-shore dolphin is an irregular visitor. Four species of marine turtle are recorded in the harbour, with one species, the flatback turtle, regularly nesting on beaches adjacent to suburban Darwin.

In response to the Weddell Region habitat mapping program and to provide a broader biodiversity context for Darwin Harbour, the collation of location records for marine mega-fauna and marine snakes was undertaken. Marine vertebrate records for dolphins, dugongs, marine turtles, marine snakes and crocodiles for Darwin Harbour were collated from a range of databases including the Northern Territory Government Fauna Atlas, the Museum and Art Gallery of the Northern Territory (MAGNT) and various publications (Chatto 2000, Whiting 2003, Palmer et al. 2011; 2009a, b; Frere et al 2011, Palmer 2010).

3.2 Dolphins

In Australia, populations of the Australian snubfin *Orcaella heinsohni*, Indo-Pacific humpback *Sousa chinensis* and Indo-Pacific bottlenose *Tursiops aduncus* are found in coastal waters of Queensland, Northern Territory and Western Australia and are the only truly coastal dolphins found in northern Australia. All three species are regularly recorded in Darwin Harbour.

In addition, an ocean-going dolphin, the false killer whale *Pseudorca crassidens* is an irregular visitor to Darwin Harbour and sightings suggest a previously unexpected abundance and reliance on estuarine habitats in north Australian coastal waters (Palmer et al 2009).

The Australian snubfin is a recently described Australian endemic dolphin (Beasley et al 2005, Palmer et al 2011). Australian snubfin inhabit shallow, coastal waters and are regularly recorded in estuaries and tidal rivers. To varying degrees they are sympatric with the Indo-Pacific humpback and Indo-Pacific bottlenose dolphins. In Queensland the species is generally found in waters less than 15 m deep (Parra et al 2006) and in the Northern Territory the species has been recorded in depths ranging from 3.3 to 20 m (Palmer 2010). Australian snubfin dolphins forage on a wide variety of fishes (including anchovies, sardines, eels, halibut, breams, grunters, and other estuarine species), cephalopods (squid, cuttlefish, and octopus) and crustaceans (Reeves et al 2008a).

Similar to the recently described Australian snubfin, genetic evidence suggests that the Indo-Pacific humpback dolphin is also likely to be a new Australian endemic species (Frere et al 2011). Humpback dolphins occur in tropical to warm temperate coastal waters, including open coasts and bays, rocky and/or coral reefs, and estuarine areas (Reeves et al 2008b), They are rarely encountered more than a few kilometres from shore (Reeves et al 2008b), though in the NT, there is a skeletal record of an Indo-Pacific humpback dolphin (caught in the Taiwanese gill net fishery) 160 km from the nearest coastline (Parra et al., 2004, Palmer, In Prep.). Indo-Pacific humpback dolphins appear to be opportunistic feeders, eating a wide variety of nearshore, estuarine, and reef fishes and cephalopods (Reeves et al 2008b). In the NT the species has been observed eating barramundi, threadfin salmon and a number of mullet species (Palmer unpublished data).

Indo-Pacific bottlenose dolphins generally occur over shallow coastal waters on the continental shelf or around oceanic islands. They feed on a wide variety of schooling, demersal and reef fishes, as well as cephalopods (Hammond et al. 2008). In the NT they have been observed eating mackerel, longtail tuna, queenfish, garfish and a number of mullet species (Palmer unpublished data).

The false killer whale is one of the larger members of the dolphin family. Despite its distribution throughout the global tropics and subtropics it is one of the least known of the large tropical oceanic dolphins (Odell and McClune 1999), and appears to be relatively uncommon throughout their range (Wade and Gerrodette 1993). In most parts of their distribution, false killer whales are usually far from shore, though there have been occasional exceptions, and individuals have been recorded on the west coast of Vancouver Island in Barley Sound, Canada (Stacey and Baird 1991). Apart from the Northern Territory, the only other areas where false killer whales are frequently seen close to the shore are near tropical oceanic islands including Hawaii (Acevedo-Guitierrez et al. 1997; Baird et al. 2008).

Coastal dolphins are difficult animals to study because they are hard to see, can move in and out of areas regularly and research is usually time consuming and expensive. Furthermore, snubfin and humpback dolphins are wary of vessels and typically their surfacing patterns are unpredictable. Individuals tend to maintain a low profile upon surfacing and inhabit turbid in-shore waters (Dhandapani 1992, Parra et al. 2001, 2002, Kreb 2004, Palmer et al 2011).

Based on results from a three year research program on coastal dolphins in Darwin Harbour:

- The most commonly sighted dolphin was the Indo-Pacific humpback, followed by the Indo-Pacific bottlenose and then the Australian Snubfin;
- Average school sizes for the humpback and snubfin was three and for the bottlenose six;
- Depths where the species were recorded ranged from 0.7 m to 25 m;
- Populations of humpback and bottlenose dolphins appear resident (Australian snubfin numbers were low);
- All three species use the area for breeding and there appears to be a wet season peak in calves;
- There is some degree of spatial preference within the Harbour, and this varies between the species. Bottlenose dolphins are rarely recorded on the western side of the harbour or in more turbid and muddy waters, nevertheless most areas of the harbour are used by coastal dolphins

The East and Middle Arms of Darwin Harbour are important foraging areas for the Indo-Pacific humpback in particular, and to a lesser extent both the Indo-Pacific bottlenose and Australian snubfin (Figure 3.1). There are no specific location records for coastal dolphins in the upstream arms immediately adjacent to Weddell region but it is possible that the Australian snubfin and the Indo-Pacific humpback use these waters Other coastal dolphin studies (Palmer 2009) have recorded the Australian snubfin and Indo-Pacific humpback dolphins 20 to 50 km upstream in the macro-tidal East, South and West Alligator Rivers of Kakadu National Park and the Australian snubfin 20 km upstream the Roper River, in the Gulf of Carpentaria.

3.3 Dugong

The dugong *Dugong dugon* is a large herbivorous mammal that is recorded in shallow bays around the northern and north-eastern coastline of Australia. Dugong populations are reliant on seagrass communities for foraging, and the species is known to decline when seagrass health is affected by sedimentation and epiphyte growth after substantial flooding (Dostine and Townsend 2012).

In Darwin Harbour, dugongs are mainly recorded in association with seagrass meadows in Fannie Bay, Talc Head, and the outer fringes of the Old Man Rock (near Casuarina beach) and on the rocky reef at Channel Island in Middle Arm (Whiting 2003) (Figure 3.1).

Table 3.1. Marine mammals recorded in Darwin Harbour and their conservation status (**DD** = Data Deficient; **LC** = Least Concern; **NE** = Not Evaluated; **NT** = Near-Threatened; **VU** = Vulnerable; **M** = Migratory Species; **Ma** = Marine Listed Species).

Marine mammals	Common name	TPWC Act	EPBC List	IUCN
Dugong dugon	Dugong	NT	M/Ma	VU
Tursiops aduncus	Indo-Pacific bottlenose dolphin	NE	M/Ma	DD
Pseudorca crassidens	False killer whale	LC	M/Ma	DD
Sousa chinensis	Indo-Pacific humpback Dolphin	DD	M/Ma	NT
Orcaella heinsohni	Australian snubfin dolphin	DD	M/Ma	NT

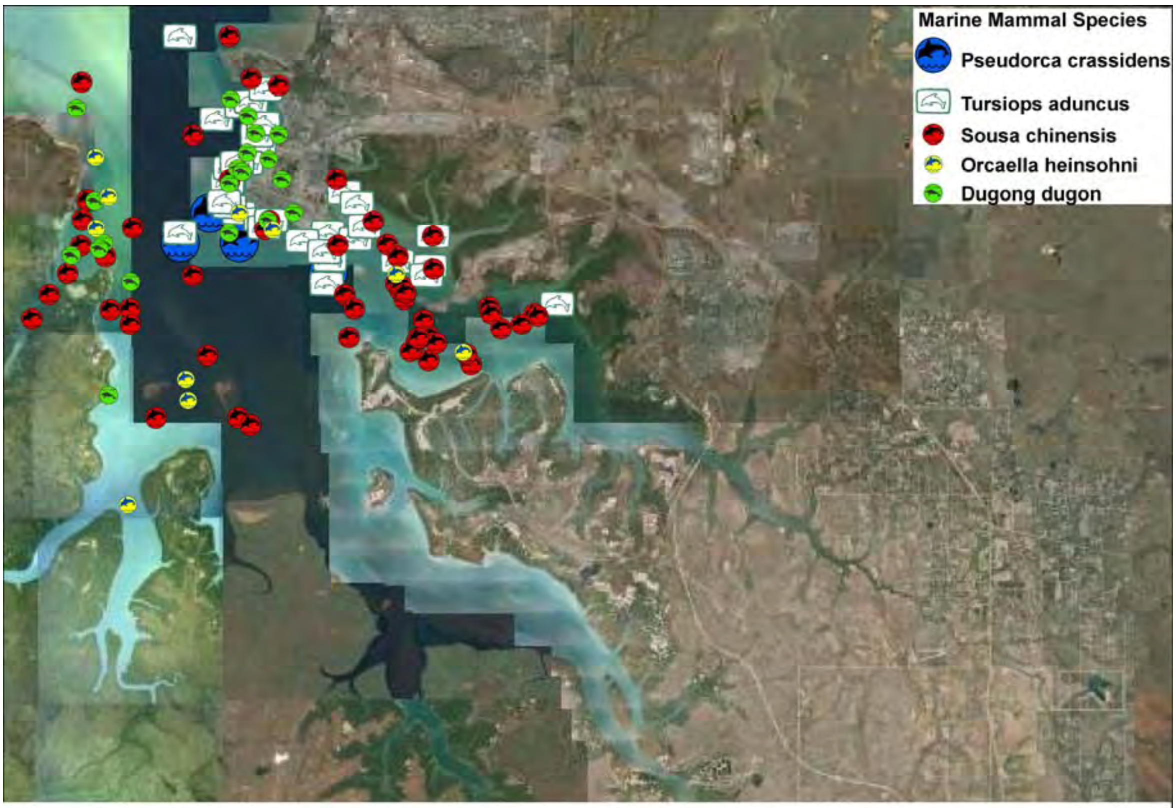

Figure 3.1. Marine mammal location records from Darwin Harbour.

3.4 Marine turtles

In Australia, marine turtles are largely found in the tropical and subtropical waters of Western Australia, Northern Territory and Queensland. There appears to distinct sub-populations of most marine turtles and genetic analysis suggests that these populations are distinct geographic units, and should be managed on that basis (Moritz et.al. 1998a & b). The breeding behaviour of female marine turtles dictates that they return to their natal beach or nearby to lay their eggs, and if a sub-population should become extinct over time it is unlikely that female marine turtles would use those nesting beaches in the future. Green turtles *Chelonia mydas* are predominantly vegetarians and are known to feed on seagrasses and algae. Olive ridley *Lepidochelys olivacea*, flatback *Natator depressus* and hawksbill *Eretmochelys imbricata* turtles are omnivores (although in some areas hawksbill are reported to be sponge specialists). In particular, olive ridley turtles are difficult to observe as they are known from mainly turbid waters.

In Darwin Harbour, four species of adult marine turtle are recorded: green, hawksbill, flatback and olive ridley (Whiting 2003, Chatto 2008). Juvenile and subadult green and hawksbill turtles have also been recorded in Darwin Harbour. There have been around 150 turtle nesting sites recorded in or near Mandorah on the western side of the harbour, with 97% of records flatback, 3% olive ridley, and a single green turtle recorded nesting in 1997 (approximately) (Ray Chatto pers. comm.). Populations of olive ridley could already have declined in the harbour as large numbers were killed by set nets in the Darwin Region during the 1990's (Guinea and Chatto 1992), and this species is regarded as the most threatened of the four species (Table 3.2).

In relation to the Weddell region, current data and unpublished observations (Chatto pers. comm.) have recorded three species- green, flatback and hawksbill - on the reefs and around the islands in the Elizabeth River (East Arm Wharf area). Of these species the one most often seen further upstream in East and Middle Arms is the green turtle, presumably because of its ability to also feed on mangroves. There is no turtle nesting reported in this area.

Table 3.2. Marine reptiles occurring in Darwin Harbour and their conservation status. (**DD** = Data Deficient; **LC** = Least Concern; **NE** = Not Evaluated; **NT** = Near-Threatened; **VU** = Vulnerable; **M** = Migratory Species; **Ma** = Marine Listed Species).

Marine reptiles	Common name	TPWC Act	EPBC List	IUCN
Crocodile				
Crocodilus porosus	Saltwater crocodile	LC	M, Ma	LC
Marine turtles				
Chelonia mydas	Green turtle	LC	VU,M,Ma	EN
Eretmochelys imbricata	Hawksbill turtle	DD	VU, M,Ma	CR
Natator depressus	Flatback turtle	DD	VU, M,Ma	DD
Lepidochelys olivacea	Olive ridley turtle	VU	EN, M,Ma	VU
Marine snakes				
Family Acrochordidae				
Acrochordus granulatus	Little file snake	NE	?	NL
Acrochordus arafurae	Arafura file snake	?	?	?
Family Colubridae	Subfamily Homalopsinae			
Fordonia leucobalia	White-bellied mangrove snake	NE	-	NL
Myron richardsonii	Richardson's mangrove snake	LC	-	NL
Family Hydrophiidae				
Astrotia stokesii	Stokes' sea snake	LC	Ma	NL
Acalyptophis peronii	Horned sea snake	LC	-	NL
Disteira major	Olive-headed sea snake	LC	Ma	NL
Hydrelaps darwiniensis	Black-ringed mud snake	LC	Ma	NL
Hydrophis elegans	Bar-bellied sea snake	LC	Ma	NL
Hydrophis mcdowelli	Small-headed sea snake	LC	Ma	NL
Lapemis curtus	Short sea snake	LC	Ma	NL
Parahydrophis mertoni	Northern mangrove sea Snake	LC	Ma	NL
Pelamis platurus	Yellow-bellied sea snake	LC	Ma	NL

3.5 Marine snakes

Thirteen species of marine snake have been recorded in and around Darwin Harbour and comprise three different lineages. The file snakes, Family Acrochordidae, are a group of primitive aquatic snakes found in Australia and Indonesia with three species recognised. All are entirely aquatic and they lack broad belly-scales and possess dorsally located eyes. Adults grow to between 60 cm and 2.43 m in length. The little file snake (*Acrochordus granulatus*) is the only marine representative of the non-venomous acrochordids that specialise in capturing fish. Two species are recorded in and around the harbour (Table 3.2).

The mud snakes, Family Colubridae (subfamily Homalopsinae), as the name suggests live in muddy habitats and include 10 genera and approximately 48 species. They are typically stoutbodied water snakes, and all are mildly venomous. Two species have been recorded in the harbour (Table 3.2).

The true sea snakes (Family Hydrophiidae) are a group of venomous elapid snakes that inhabit marine environments for most or all of their lives. They are found in warm coastal waters from the Indian Ocean to the Pacific. All have paddle-like tails and many have laterally compressed bodies that give them an eel-like appearance. Unlike fish, they do not have gills and need to surface regularly to breathe. Among this group are species with some of the most potent venoms of all snakes. Currently, 17 genera are described comprising 62 species. Nine species have been recorded in the harbour and are Listed Marine Species under the Environmental Protection and Biodiversity Conservation Act, 1999 (Table 3.2) (Whiting 2003).

Research on marine snakes in Darwin Harbour has been opportunistic and ad hoc (Whiting 2003). They are difficult animals to study because of their predominantly aquatic habits and the turbid waters of Darwin Harbour. However, at least 13 species of marine snakes are known to occur in the Harbour. There are a few marine snake records in the Elizabeth River (Figure 3.2) and there is suitable habitat in the Weddell vicinity for a number of species recorded elsewhere in the Harbour.

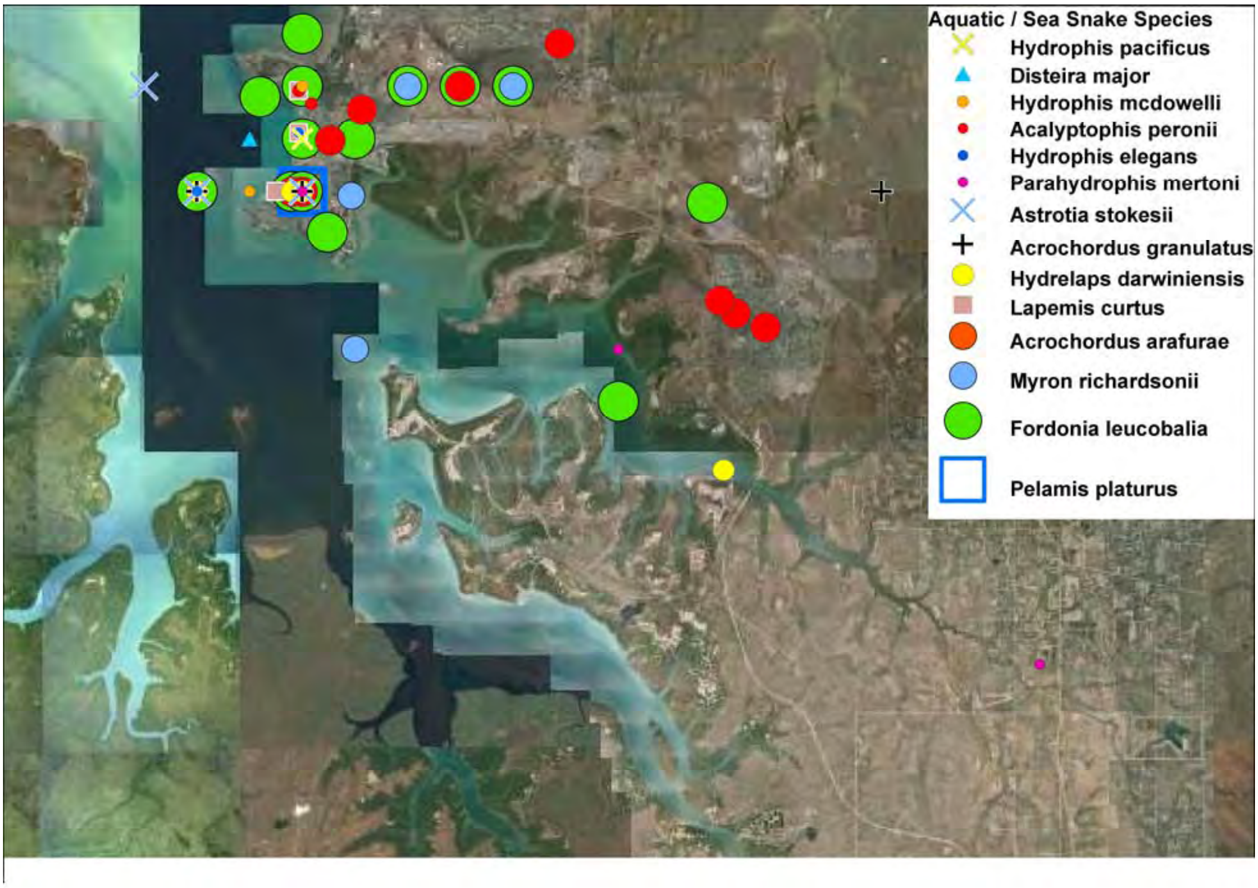

Figure 3.2. Marine snake records from in and around Darwin Harbour

3.6 Saltwater crocodiles

Saltwater crocodiles (*Crocodilus porosus*) inhabit mangroves, coastal marshes, and tidal rivers around the north of Western Australia, the Northern Territory and Queensland. They are known to travel long distances upstream during the wet season to access areas which may be inaccessible in the Dry season. Saltwater crocodiles also live in the open ocean for periods of time and will cross large expanses of water to reach new areas.

Saltwater crocodiles occur in Darwin Harbour, although there are limited nesting sites available inside the harbour and it is not considered critical habitat for crocodiles in the Northern Territory (Dostine and Townsend 2012). Large numbers of saltwater crocodiles are removed from traps set in the waterways of the Darwin Harbour each year. There are approximately 14 trap sites in the estuarine portions of Darwin Harbour. Captures at these sites accounted for approximately 70% of the total number of crocodile captures in the Top End in the previous 3 years (Dostine and Townsend 2012). The Weddell region is considered good habitat for foraging crocodiles due to the mangrove forests and tidal mud flats.

3.7 Discussion

This report provides a collation of marine megafauna location records and also documents the broad habitat requirements for these species. Coastal and river dolphins are among the world's most threatened mammals, mainly because populations are small and localised and they often occupy habitats which are directly impacted by human activities. Dugong and green turtle populations are also susceptible to habitat loss associated with coastal development as they are dependent on seagrass meadows for food. A good understanding of the spatial distribution and key habitats of the marine megafauna using Darwin Harbour is important to mitigate potential impacts of development on these species.

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4 Fish

Victor Gomelyuk

4.1 Introduction

Because of rich and diverse fish fauna and proximity to major population centre, Darwin Harbour is undoubtedly the most important location for recreational fishing in the Northern Territory and more than 30% of all recreational fishing in the Territory takes place here (Coleman 2003). Darwin Harbour is the most comprehensively studied water body in the Northern Territory. However, there is still a relatively limited understanding of the composition and distribution of fish fauna in Darwin Harbour. There is very little or no data on fish abundance, trophic and functional group composition, or seasonal and annual dynamics of fish assemblages.

4.1.1 Review of historical data

The first scientific collection of fishes from Darwin Harbour was made by HMS Beagle crew in September, 1839. Lt James Emery have collected and made drawings of the first six species from Talc Head (Larson and Williams 1993). The first summary of Darwin Harbour fishes was made by Macleay (1878) who reported 114 species from the Harbour, 21 which were new. Klunzinger (1979) recorded 46 species from the Harbour, eight of which he described as new. Paradice and Whitley (1927) recorded 34 species and described one new species from the harbour. Taylor (1964) recorded 12 species from Darwin Harbour in his Fishes from Arnhem Land and described a new species based on the Harbour material (Larson & Williams 1993). Helen Larson (1988) recorded 408 nominal fish species from the harbour (Larson & Williams 1993). The last extensive fish fauna survey of 40 stations within Darwin Harbour was made as part of the Sixth International Marine Biological Workshop (Darwin, 5–23 July, 1993). The survey, limited to beam trawling, collected 75 species and three new records for the Northern Territory. An annotated list of Darwin Harbour fishes summarising all previous survey results contains 415 fish species known for the Harbour and includes 31 new records for the Northern Territory.

Of the 415 species recorded from Darwin Harbour (Larson and Williams 1997), the mangal fish study done by Martin (2005) documented 63 species from three habitats within the fringing mangrove forests. The study has been the first to document the relative abundance, distribution and trophic ecology of the fish inhabiting mangrove forests habitats in Darwin Harbour. The most abundant species were from four families: Clupeidae, Engraulidae, Ariidae and Mugilidae. All species were coastal, estuarine or mangrove associates. The most abundant species, gizzard-shad *Anodontostoma chacunda*, was represented entirely by juveniles. In addition, some of the most commonly harvested species in the recreational fishery in Darwin Harbour were found as juveniles in the mangroves. The most numerous of these were species from the families Carangidae, Polynemidae and Mugilidae and the barramundi, *Lates calcarifer* (Martin 2005). A wide size range of fish was sampled, with individuals greater than 100 mm in length making up 60% of the catch (Martin 2005).

Table 4.1. The list of fish species collected in East Arm and Middle Arm of Darwin Harbour by Australian Museum Mainly Zoological collections from 'Atlas of Living Australia'.

Family	Common Name	Scientific Name
Ambassidae	Vachell's Glassfish	*Ambassis vachellii* (Richardson, 1846)
Apogonidae	Mouth Almighty	*Glossamia aprion* (Richardson, 1842)
Atherinidae	Endracht Hardyhead	*Atherinomorus endrachtensis* (Quoy & Gaimard, 1825)
Batrachoididae	Threespine Frogfish	*Batrachomoeus trispinosus* (Günther, 1861)
Callionymidae	Dragonet	*Callionymus sublaevis*
Carangidae	Bluespotted Trevally	*Caranx bucculentus* (Alleyne & Macleay, 1877)
Eleotridae	Crimsontip Gudgeon	*Butis butis* (Hamilton-Buchanan, 1822)
Gobidae	Bluemarked Drombus	*Drombus ocyurus*
	Mangrove Flathead Goby	*Glossogobius circumspectus* (Macleay, 1883)
	Bluespotted Mangrovegoby	*Amoya gracilis* (Bleeker, 1875)
	Lidwill's Dwarfgoby	*Pandaka lidwilli* (McCulloch, 1917)
	Giant Mudskipper	*Periophthalmodon freycineti* (Valenciennes, 1824)
Haemulidae	Silver Javelin	*Pomadasys argenteus* (Forsskål, 1775)
Leiognathidae	Ponyfish	*Leiognathus sp.*
Monocanthidae	Pigface Leatherjacket	*Paramonacanthus choirocephalus* (Bleeker, 1852)
Serranidae	Sixbar Grouper	*Epinephelus sexfasciatus* (Valenciennes, 1828)
Soleidae	Tufted Sole	*Brachirus muelleri* (Steindachner, 1879)
Syngnathidae	Straightstick Pipefish	*Trachyrhamphus longirostris* (Kaup, 1856)
	Northern Spiny Seahorse	*Hippocampus multispinus* (Kuiter, 2001)
Tetraodontidae	Rusty-spotted Toadfish	*Torquigener pallimaculatus* (Hardy, 1983)
	Starry Puffer	*Arothron stellatus* (Bloch & Schneider, 1801)

Data sourced from: http://spatial.ala.org.au/?q= species_group:Fish state:"Northern Territory"&qc=

Table 4.2. Bottom habitat, date, time and GPS locations for the sites of hook and line survey in Elizabeth River in 2011.

Site	Bottom habitat	Date	Time in - time out
1	Bare sand-mud	23/08/2011	10:10-11:03
2	Bare sand-mud	13/09/2011	9:50-10:25
3	Bare sand-mud	13/09/2011	10:30-11 :00
4	Bare sand-mud	13/09/2011	11 : 1 0-11 :40
5	Bare sand-mud	13/09/2011	11 :50-12:00
7	Bare mud	13/09/2011	14: 15-14:50
8	Mixed community, Corals, Algae, Sponges, Soft corals	13/09/2011	12:50-13:12
9	Mixed community, Corals, Algae, Sponges, Soft corals	23/08/2011	14:15-15:10
10	Bare sand-mud	*2/09/2011*	12:00-12:30
11	High density mixed community, Corals, Algae, Sponges, Soft corals	*12/09/2011*	1215-12:40

Habitat data derived from results from Chapter 5 Benthic Communities and Habitat Mapping.

Figure 4.1. Hook and line fish survey sites in Elizabeth River in August-September 2011.

4.2 Methods

4.2.1 Hook and Line Surveys

Due to the very poor water clarity in East Arm and Middle Arm of Darwin Harbour it was impossible to use non-extractive and efficient baited remote underwater video station method (Cappo et al. 2007, Gomelyuk 2009). Data on fish collected by the hook and line method in August-September 2011 in estuarine part of East Arm was provided by Department of Resources – Fisheries. It was the first systematic fish collection done in this part of the Harbour.

4.2.2 Beam trawl samples

A 2 x 1 m beam trawl with 6.5 mm mesh size and 1.4 mm cod end was trawled at 2 – 4 knots for 10 minutes at each sample site to collect mobile epibenthic organisms and fish (see section 2.2. Methods). All specimens were sorted into phyla and fixed in either 80% ethanol or 10% formalin immediately while in the field. Post survey sorting of samples into finer taxonomic groups was completed in the lab and forwarded to MAGNT for identification.

4.3 Results

4.3.1 Hook and line surveys

A total of 145 individuals of 22 fish species was collected during this survey (Table 4.3). The sample was dominated by Snapper *Lutjanus russellii*, Seabream *Acanthopagrus berda*, Snapper *Lutjanus johnii,* Spotted Javelinfish *Pomadadys kaakan* and Grass Emperor *Lethrinus laticaudis* (72% of the total catch, Figure 4.2). Ten fish species in the catch were represented by singe individuals. A size-frequency analysis was employed for some more numerous species in the collection. A description of samples of more common commercially or recreationally significant fish species is given below.

Table 4.3. Fish collected during Fisheries hook and line surveys in Elizabeth River in August - September 2011

Family	Common Name	Scientific Name	Number collected, N
Apogonidae	Western Gobbleguts	*Apogon rueppellii*	1
Ariidae	Catfish	*Neoarius sp.*	1
Carangidae	Giant Trevally	*Caranx ignobilis*	4
	Fringefin Trevally	*Pantolabus radiatus*	2
Carcharhinidae	Milk Shark	*Rhizoprionodon acutus*	1
Ephippidae	Shortfin Batfish	*Zabidius novemaculeatus*	5
Ginglymostomatidae	Tawny Shark	*Nebrius ferrugineus*	1
Haemulidae	Painted Sweetlips	*Diagramma labiosum*	1
	Barred Javelin	*Pomadasys kaakan*	12
Labridae	Blackspot Tuskfish	*Choerodon schoenleinii*	3
Lethrinidae	Grass Emperor	*Lethrinus laticaudis*	11
	Redspot Emperor	*Lethrinus lentjan*	7
Lutjanidae	Stripey Snapper	*Lutjanus carponotatus*	1
	Golden Snapper	*Lutjanus johnii*	17
	Moses' Snapper	*Lutjanus russelli*	46
	Brownstripe Snapper	*Lutjanus vitta*	1
Scatophagidae	Striped Scat	*Selenotoca multifasciata*	1
Sciaenidae	Black Jewfish	*Protonibea diacanthus*	1
Serranidae	Goldspotted Rockcod	*Epinephelus coioides*	6
Sparidae	Pikey Bream	*Acanthopagrus berda*	18
Tetraodontidae	Darwin Toadfish	*Marilyna darwinii*	2
Uranoscopidae	Stargazer	*Uranoscopus sp.*	1

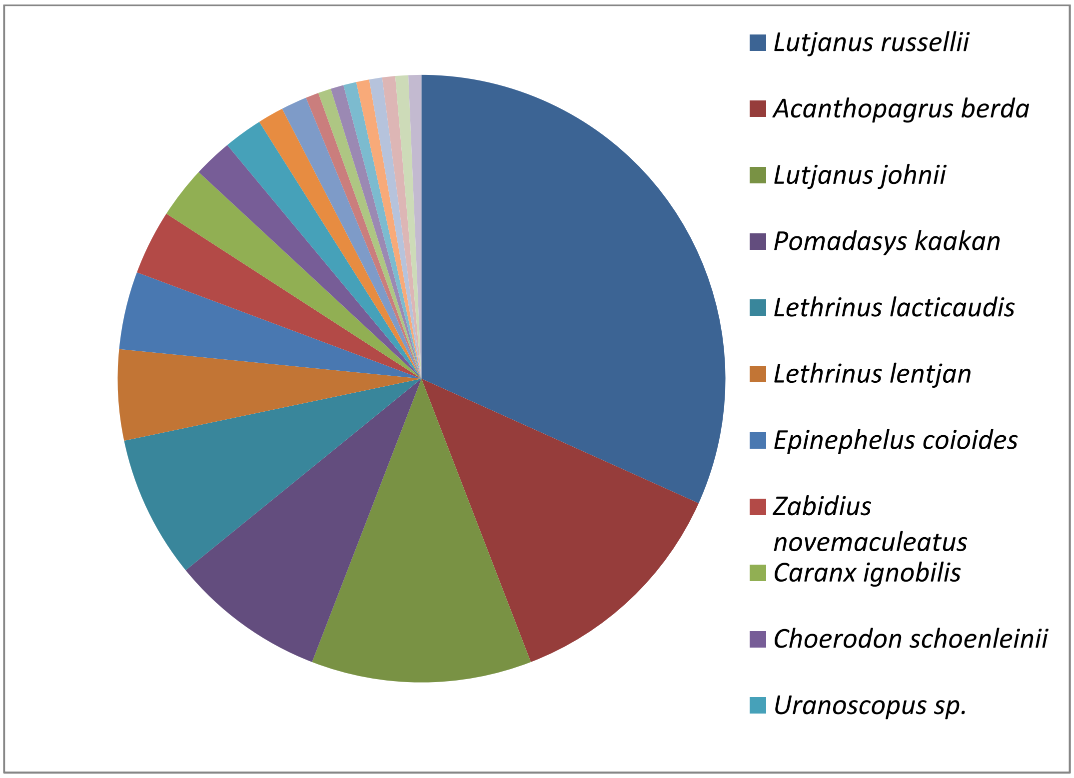

Figure 4.2. Fish species composition and abundance (in percentage of total number of fish caught) in hook and line survey in Elizabeth River in August-September 2011.

Moses' Snapper, *Lutjanus russellii.*

This species dominated in the catch and was present at all nine sampling sites (Figure 4.1 and Figure 4.3). Size-frequency distribution of this fish indicates that smaller size individuals (<210 mm) dominated the sample (Figure 4.4). Mean fish total length (TL) was 177.5 mm, SE=3.7. All fish were young, immature individuals (Allen 1985).

Figure 4.3. Moses' Snapper samples sites during fish survey in Elizabeth River in August-September 2011.

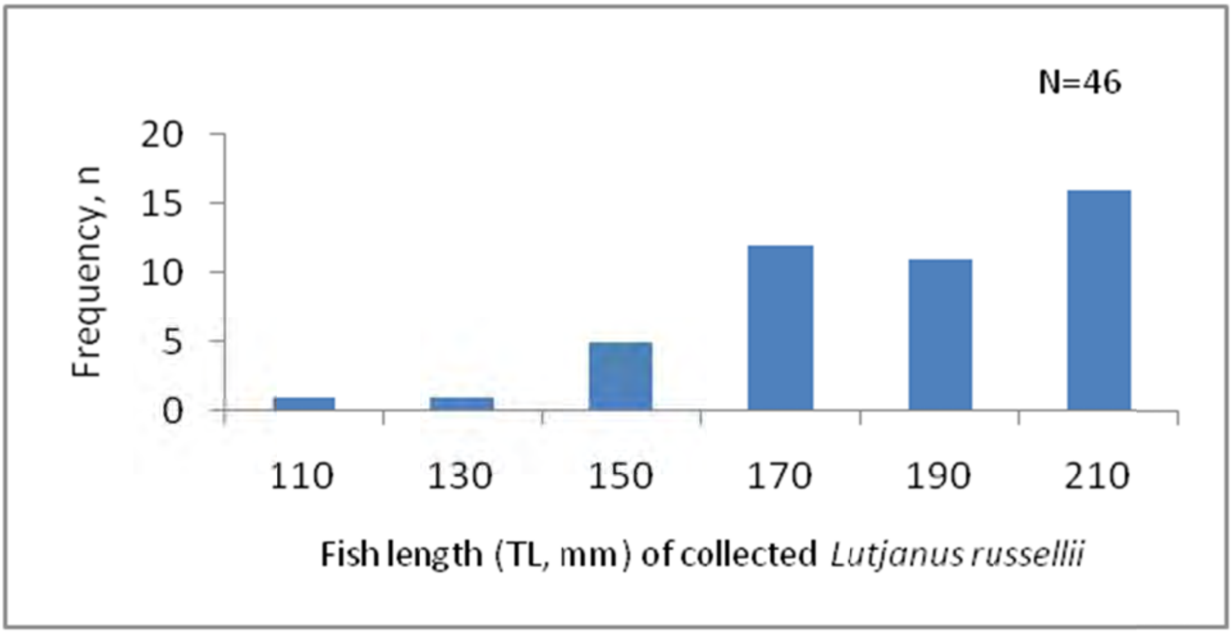

Figure 4.4. Size-frequency distribution of Moses' Snapper collected in Elizabeth River in August-September 2011.

Pikey Bream, *Acanthopagrus berda.*

Size-frequency distribution of sampled fish is represented in Figure 4.6. This fish was the second most abundant in the catch (Figure 4.2). Mean fish total length in the sample was 234.2 mm, SE=9.2. This species reaches maturity stage at the length range of 200-220 mm (Bouhlel 1988; James et al. 2003). According to the size of this protandrous hermaphrodite species, the majority of sampled fish were young, yet already mature individuals.

Figure 4.5. Pikey Bream samples sites during fish survey in Elizabeth River in August-September 2011.

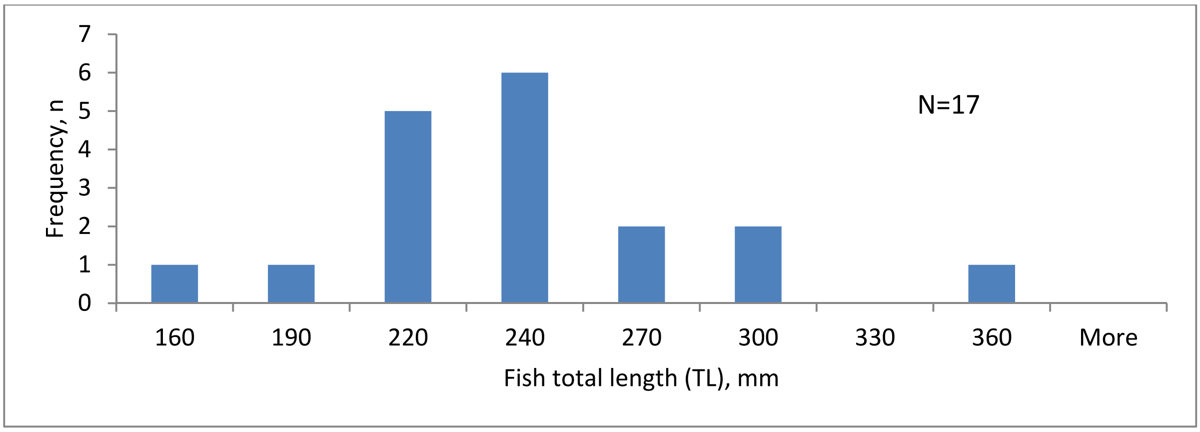

Figure 4.6. Size-frequency distribution of Pikey Bream collected in Elizabeth River in August-September 2011.

Golden Snapper, *Lutjanus johnii*.

Sites where this fish was collected and the size-frequency distribution in the sample are presented in Figure 4.7 and Figure 4.8. The mean total length of collected fish was 216.0 mm, SE=8.4. In the Northern Territory waters 50% of females of this species of the length of 630 mm are mature, while 50% males are mature at the length of 470 mm (Hay et al. 2005). Therefore, it is more likely that the sample contains young, immature individuals.

Figure 4.7. Golden Snapper samples sites during fish survey in Elizabeth River in August-September 2011.

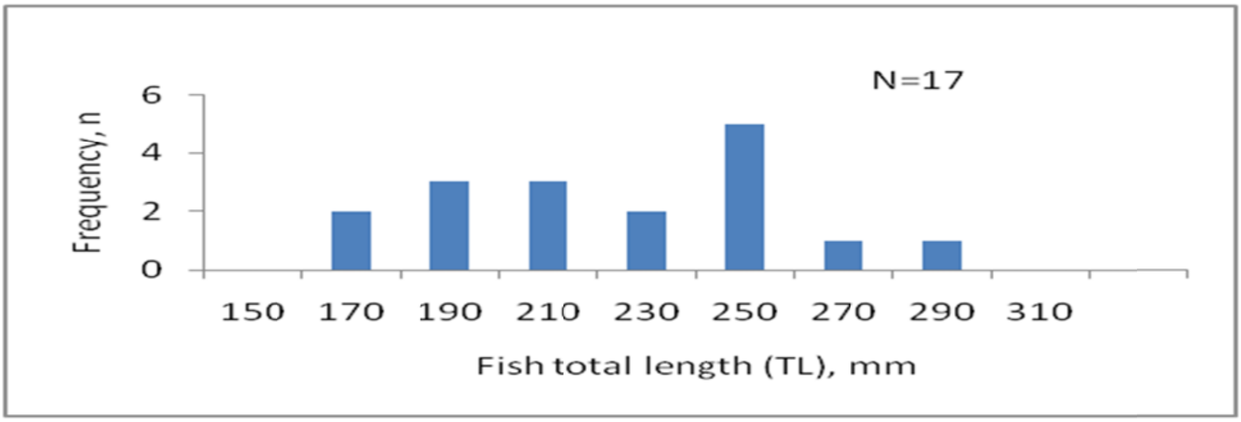

Figure 4.8. Size-frequency distribution of Golden Snapper collected in Elizabeth River in August-September 2011,

Grass emperor, *Lethrinus laticaudis*.

Figure 4.9 shows stations where individuals of this species were collected suggesting this species has a very local distribution over the study area. Mean fish TL in the sample was 208.2 mm, SE=7.5 (Figure 4.10). Grass Emperor is sequential protogynous hermaphrodite, that is, fish mature as females and later change to males. Study carried out in Northern Territory waters showed that all individuals under 320 mm were female with progressively more males occurring at larger sizes (Knuckey et al. 2005). Size-distribution (Figure 4.10) indicates that all fish in the sample are young, immature females.

Figure 4.9. Grass Emperor sample sites (emerald circles) and Red Spot Emperor (**white circles** with X on a left) during fish survey in Elizabeth River in August-September 2011.

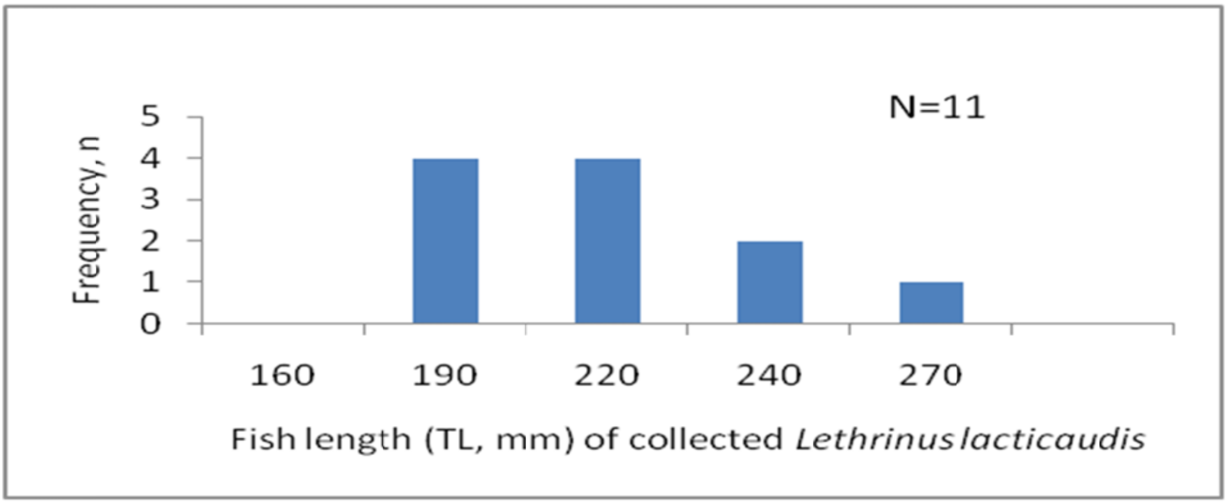

Figure 4.10. Size-frequency distribution of Grass Emperor collected in Elizabeth River in August-September 2011.

Barred Javelin, *Pomadasys kaakan*.

Distribution of catches of Barred Javelin over the study area and size-frequency distribution in the sample are presented in Figure 4.11 and Figure 4.12. This fish is long-living (up to 36 years), reaching more than 70 cm in length. In Kuwait waters (Red Sea) it starts maturing only at the lengths of 26–30 cm TL (age 1.5–2 years) (Al-Husaini et al. 2001). Therefore, it is safe to presume that the fish sample collected in Elizabeth River contains young individuals and that immature fishes dominated the sample (Figure 4.12).

Figure 4.11. Barred Javelin sample sites during fish survey in Elizabeth River in August-September 2011.

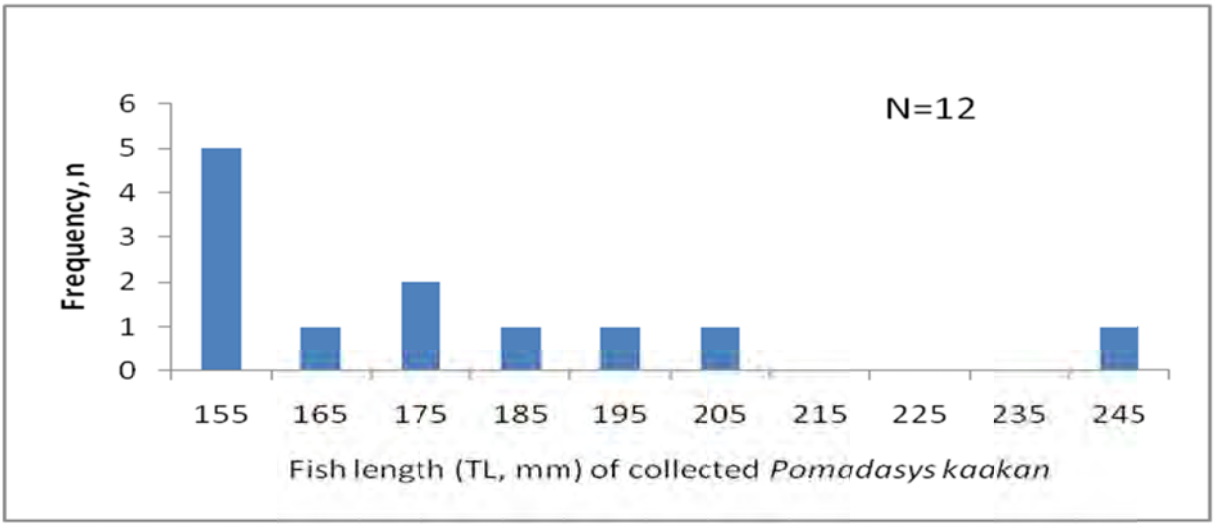

Figure 4.12. Size-frequency distribution of Barred Javelin collected in Elizabeth River in August-September 2011.

Red Spot Emperor, *Lethrinus lentjan*

All seven individuals of Red Spot Emperor were caught at one site (Figure 4.9). Due to the small number of fish in a sample no graph of size frequency distribution was drawn. Mean total length of fish in the sample was 180 mm, SE=4.75. In the Red Sea the assessed age of individuals of this species of similar total length was 1.5-2 year (Wassef 1991). This fish is protogynous hermaphrodite (Young and Martin 1982) and can live up to seven years reaching 400 mm in total length (Wassef 1991). Therefore, we suggest that fish sampled in Elizabeth River are young individuals at female stage of their development.

Goldspotted Rockcod, *Epinephelus coioides.*

Five of six Goldspotted Rockckod collected in this study were small, juvenile fish, mean total length 212 mm, SE=20.2 (Figure 4.13). The largest fish had a total length of 330 mm. Heemstra and Randall (1993) in their study of this species in Persian Gulf, Red Sea reported that females of *E. coioides* are mature at 25–30 cm total length (2–3 years old), and that sexual transition in this protoginous sequential hermaphrodite species occurs at a length of 55-75 cm.

Figure 4.13. Goldspotted Rockcod sample sites during fish survey in Elizabeth River in August-September 2011.

Giant Trevally, Caranx ignobilis.

This is the largest species in the family, reaching 1.7 m in length and a weight of over 60 kg (Kuiter and Tonozuka 2001). Reproduction in Giant Trevally begans at fish length ~600 mm when they are ~3.5 years old, Sudekum et al. (1991). Mean total length of *C. ignobilis* in the sample was 278.7mm, SE=60.5, with the smallest fish 155 mm, and the largest 390 mm. So, we can conclude with a high confidence that all collected fish were immature juveniles.

All other fish species commercially important or important to amateur recreational fishing were represented by single individuals (Table 4.1). Catch rates (the number caught per minute, CPM) varied slightly among sites; the highest rate recorded at the small island at the entrance of Elizabeth River (Figure 4.14). The number of fish species caught at this site was also highest (Figure 4.15). There was a positive correlation between the catch rates and the number of fish species caught (r= 0.838, N=10, p<0.01).

Figure 4.14. Catch rates (number of fish*-1 min) at different sites in Elizabeth River in August-September 2011.

Figure 4.15. Biodiversity (the number of fish species caught) at different sites in Elizabeth River in August-September 2011.

4.3.2 Beam trawl survey

Fishes collected during grab and beam trawl samples represented 25 families and 61 species. Due to the gear employed during sampling the majority of collected fishes were relatively small bottom species, larvae and juveniles. The only exception was large adult Shortfin Batfish *Zabidius novemaculatus* caught in beam trawl (Table 4.4). Gudgeon *Butis koilomatodon*, Gobies *Drombus globiceps*, *Redigobius nanus Gobiopterus* sp, unidentified goby and Cardinalfish *Apogon unitaeniatus* were the most common species collected, comprising 48.6% of the whole catch (Table 4.4).

Fifteen species of Gobies (family Gobiidae) were the most numerous in the sample (40% of all fish number collected), followed by six species of gudgeons (family Eliotridae, 19%) and Cardinalfishes (family Apogonidae, 7.5%). Families above dominated in the samples comprising 66% of all sampled fishes. The following families were represented by single specimens: Anchovy (family Engraulidae), Pipefishes (family Syngnathidae), Grunters (family Terapontidae), Cardinalfishes (family Apogonidae), Northern Whitting (family Sillaginidae), Snappers species (family Lutjanidae), Batfishes (family Ephippidae), Leatherjackets (family Monacanthidae) and Frogfishes (family Batrachoididae) (Table 4.4).

The majority of fish collected were at juvenile life stages, followed by adult, post-larval and larval stages (Table 4.4). Sampling gear employed in this survey was adequate for sampling benthic epifauna and in-fauna. Grab and beam trawl of this size most likely bias the results, over representing smaller, less mobile species and under representing large, more mobile forms.

No fish species previously unrecorded for Darwin Harbour were found during the grab and beam trawl sample survey.

Table 4.4. List of fishes collected 23 March–13 April 2011 during grab and beam trawl samplings in upper estuarine areas of Darwin Harbour.

				LIFE STAGE			
FAMILY	**SPECIES**	**Adult**	**Juvenile/Sub-adult**	**Juvenile**	**Larva**	**Post-larva**	**Total**
Clupeidae	*Herklotsichthys gotoi*	7		1			8
Clupeidae	*Nematalosa come*			2			2
Engraulidae	*Papuengraulis micropinna*					1	1
Engraulidae	*Stolepherus sp*			2	3	2	7
Engraulidae	*Thryssa sp*					3	3
Batrachoididae	*Batrachomoeus trispinosus*			1			1
Syngnathidae	*Festucalex cinctus*	1					1
Syngnathidae	*Trachyrhamphus longirostris*	1					1
Tetrarogidae	*Paracentropogon longipinnis*	3					3
Aploactinidae	*Bathyaploactis curtisensis*	2					2
Aploactinidae	*Bathyaploactis ornatissima*	6		2			8
Platycephalidae	*Cymbacephalus staigeri*			5			5
Platycephalidae	*Inegocia japonica*			2			2
Terapontidae	*Terapon puta*			1			1
Apogonidae	*Apogon melanopus*	1					1
Apogonidae	*Apogon poecilopterus*	1					1
Apogonidae	*Apogon rueppellii*		3				3
Apogonidae	*Apogon unitaeniatus*	15					15
Apogonidae	*Siphamia roseigaster*	3					3
Apogonidae	*Siphamia spp*				2		2
Sillaginidae	*Sillago sp*			1			1
Leiognathidae	*Leiognathus blochii*			7			7
Leiognathidae	*Leiognathus sp*			5	3		8
Leiognathidae	*Secutor sp*					2	2
Leiognathidae	*spp*				1	3	4
Lutjanidae	*Lutjanus johnii*			1			1
Lutjanidae	*Lutjanus malabaricus*			3			3
Haemulidae	*Pomadasys kaakan*					3	3
Haemulidae	*Pomadasys maculatus*			2		5	7
Sciaenidae	*spp*				1	2	3
Scatophagidae	*Drepane punctata*					4	4

'spp' represents unidentified species.

Table 4.4 (continued). List of fishes collected 23 March -13 April 2011 during grab and beam trawl samplings in upper estuarine areas of Darwin Harbour.

				LIFE STAGE			
FAMILY	**SPECIES**	**Adult**	**Juvenile/Sub-adult**	**Juvenile**	**Larva**	**Post-larva**	**Total**
Ephippidae	*Zabidius novemaculatus*	1					1
Pholidichthyidae	Pholidichthys anguis			2			2
Callionymidae	Repomucenus russelli	3		1			4
Gobiidae	*Caragobius rubristriatus*	2		1			3
Gobiidae	*Drombus globiceps*	13	19				32
Gobiidae	*Drombus ocyurus*	5					5
Gobiidae	*Drombus triangularis*			2			2
Gobiidae	*Drombus triangularis?*			7			7
Gobiidae	*Favonigobius melanobranchus*		4	4			8
Gobiidae	*Favonigobius reichei*					1	1
Gobiidae	*Favonigobius sp*			1			1
Gobiidae	*Favonigobius spp*			1			1
Gobiidae	*Gobiopterus sp*	1		12		10	23
Gobiidae	*Gobiopterus sp A*	3					3
Gobiidae	*Pandaka rouxi*	1					1
Gobiidae	*Psammogobius biocellatus*			1			1
Gobiidae	*Redigobius nanus*	12		1			13
Gobiidae	*spp*				3	28	31
Eleotridae	*Butis butis*			2			2
Eleotridae	*Butis koilomatodon*			47			47
Eleotridae	*Butis sp*			3			3
Eleotridae	*Butis? spp*					1	1
Eleotridae	*Prionobutis microps*	2					2
Eleotridae	*spp*					7	7
Bothidae	*Arnoglossus sp*			2			2
Paralichthyidae	*Pseudorhombus arsius*	1		1			2
Cynoglossidae	*Cynoglossus maculipinnis*			8			8
Triacanthidae	*Trixiphichthys weberi*			2			2
Monacanthidae	*Anacanthus barbatus*			1			1
Monacanthidae	*Paramonacanthus choirocephalus*			2			2
Unidentified fish	*spp*				5	1	6
Grand Total		**84**	**26**	**136**	**15**	**73**	**337**

'spp' represents unidentified species.

4.4 Conservation significance

Two recorded species from the Family Syngnatidae are "Listed Marine Species" under the EPBC Act: Girdled pipefish, *Festucalex cinctus* and Straight Stick Pipefish, *Trachyrhamphus longirostris.* Both species were sampled during benthic trawl and grab surveys. Northern Spiny Seahorse *Hippocampus multispinus* (Kuiter, 2001) and Straightstick Pipefish *Trachyrhamphus longirostris* (Kaup, 1856) had been previously recorded in the study area (Table 4.2).

The results presented here demonstrate that fish samples taken using hook and line method from Elizabeth River mainly contained smaller size fish, generally mature individuals using the area at early life stages. The role of estuaries as the nursery for many species of marine fish has been shown in many studies. As Boesh and Turner (1984) have pointed out, it is well established that coastal wetlands, such as mangrove forests, are important nursery sites for juvenile fish and crustaceans. For instance, Moses' Snapper - an important commercial and recreational fish - spend their early life stages in estuarine waters. Adults are solitary in deeper waters, while juvenile and small adults are found in estuaries, over sea grass beds and in mangroves swamps (Randall & Ben-Tuvia 1983, Allen 1985, Allen & Talbot 1985, Randall 1987, Randall et al. 1990; Newman and Williams 1996).

Sheaves (1995) concluded that estuaries of north-eastern Australia are important juvenile development grounds for lutjanids (*Lutjanus argentimaculatus* and *L. russellii*) and serranids (*Epinephelus coioides* and E. *malabaricus*). This conclusion was based on comparisons of the size, age and reproductive maturity of fishes from estuaries to fishes of the same species from offshore area. All fish from the estuaries possessed immature gonads, and for both serranids (protogynous hermaphrodites) all were females. Furthermore, all fish from the estuaries were much smaller and younger than the largest fish of the same species from offshore (Sheaves, 1995). It was found in a study carried out in Alligator Creek, Queensland, that post-larval, juvenile and small adult fish were significantly more abundant (4 to 10 times) in the mangrove habitat throughout the 13 months of sampling (Robertson and Duke 1987). In several studies it was pointed out that mangrove estuaries of the Indo-Pacific have a characteristic fish fauna, comprising both permanent and temporary residents (Gundermann and Popper 1984). The temporary residents use the estuaries mainly as nursery grounds for juveniles or as feeding grounds for adults (Hutchings and Saenger 1987; Blaber & Milton 1990). The role of the estuaries as nursery grounds for coral reef fish species was assessed and found to be insignificant, but they are used as feeding grounds by mobile piscivorous species that inhabit marine environments as adults and are often referred to as "reef fishes". Some juvenile jacks occupy estuaries opportunistically before moving to nearshore marine habitat (Smith and Parrish 2002).

Virtually all habitats, including shallow intertidal areas play an important role in the ecological functioning of the Harbour. At high tide all habitats in all locations became available for fish and appeared to be important feeding areas for them. All abundant species are important prey species for recreationally harvested species. Depending on their location in the Harbour, different habitats appear to be important for different species and groups of fish. For instance, observation of mangrove creeks during low tide suggests that even the sinuous narrow gutters are important feeding habitats for fish (Martin 2005).

More than 200 hours of baited remote underwater video survey at 30 sites in non-estuarine, outer part of Darwin Harbour in May-September 2001 revealed that some commercially and recreationally important fish species that are common and abundant in Elizabeth River such as Barred Javelin, *Pomadasys kaakan* and Pikey Bream *Acanthopagrus berda* were absent outside of the estuarine part of Darwin Harbour. Other species targeted by amateur fishers such as Moses' snapper and golden snapper (Coleman 1998, 2004) have been represented in the outer harbour only by larger individuals and were relatively rare (Victor Gomelyuk, unpublished data).

In conclusion, the conservation role of estuarine parts of East Arm and Middle Arm of Darwin Harbour in supporting fish biodiversity of the Harbour can be considered high, as:

- some fish that are important components of communities in estuarine areas of the Harbour are not found or are rare in other parts of the Harbour. (Barred Javelin, *Pomadasys kaakan,* Pikey Bream *Acanthopagrus berda).*

- for other fishes estuarine areas are an important nursery (Giant Trevally**,** *Caranx ignobilis,* some species of emperor and snappers*).*

- some fish species can be found in different areas of the Harbour, but they are particularly abundant in estuarine zone (species from families: Clupeidae, Engraulidae, Ariidae and Mugilidae, Martin 2005)

4.5 Information gaps

The line and hook fish sampling presented here was the first systematic study of fish in the estuarine zone (outside of mangroves forests) for Darwin Harbour. This highlights a significant gap exists in our knowledge of fish communities, their composition and structure of this area of Darwin Harbour. This relatively limited study suggests that these fish communities differ from both mangal fish communities and communities of the main body of the Harbour.

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Benthic Communities and Habitat Mapping

5

Neil Smit and Shane Penny

5.1 Introduction

Darwin Harbour is situated within a region recognised for its relative pristine condition, a direct consequence of low industrialisation, few commercial fisheries and a relatively low and dispersed coastal population (Halpern et al. 2008). However, Darwin Harbour is the focal point for future economic and population growth. To allow for sustainable coastal development there is a need for adequate ecological information in order to assess and manage the pressures and impacts that such development may have on the environment.

Marine flora and fauna surveys in Darwin Harbour have previously focussed on *in situ* sampling (e.g. dredges, grabs and trawls), without or with very little prior knowledge of the environment in which biota are found. Examples of such surveys date back to as early as 1839 when HMS Beagle sailed into Darwin Harbour. However, more recently marine benthos have been described for Channel Island (Cadwell and Connell 1983), East Arm and south Shell Island (Acer Vaughan 1993), Wickham Point (LeProvost Dames and Moore 1997), and a single Darwin Harbour-wide survey conducted by MAGNT in 1995 (Hanley et al 1997). These surveys have allowed characterisation of benthic communities at selected sites, compilation of species lists, biodiversity assessments and biogeography of species (see Chapter 2). However, these data have limited value for the production of habitat and community maps as the sampling effort is usually insufficient due to highly variable and patchy nature of marine benthos.

Recently, marine remotely-sensed methods have been used to describe seascape characteristics with local site characteristics and species composition in Darwin Harbour. For example, underwater video techniques have been used to describe marine benthos along the path of a proposed gas pipeline and at East Point (Dames and Moore 1997, GHD 2007, 2009). Side scan sonar (SSS) and swath multibeam technologies (MBES) have been used to collect bathymetric data at high spatial resolution (0.25 m), thus allowing landscape analysis to be coupled with site specific data. Smit (2009) used side scan sonar to map habitats and characterised benthos at East Arm sand banks.

More recent benthic mapping for Darwin Harbour have described ‘habitats’ in a variety of ways (URS (2011 (supplement)), BMT WBM (2010) and Geo Oceans (2010, 2011)) using underwater video and remotely-sensed bathymetry data. This has resulted in products that are broadly based on substrate type (i.e. rocky and sediment grainsize classes) and show either where ‘important’ communities (i.e. coral and seagrass) occur or provide a more detailed assessment of the distribution of community classes, (e.g. sponge, coral, seagrass or algae dominated). Based on the most recent benthic mapping for the harbour, the following conclusions can be made:

A: there are differences in benthos between the “outer” Darwin Harbour (north of the line between Mandorah and Emery Point (Cullen Bay) and the “inner” Darwin Harbour, which includes the Port of Darwin, Elizabeth River and Middle Arm (BMT WBM 2010, GHD 2007, 2009). These differences can be summarised as:

- Outer harbour:
  - extensive seagrass communities occur in shallow waters
  - corals and algae dominate on hard substrates in shallow waters.
  - deeper waters are characterised by filter feeder communities (e.g. sponges)
- Inner harbour
  - hard substrates in shallow *and* deeper waters consist of mixed communities or are dominated by sponge communities
  - no seagrass communities are present

B: Overall Darwin Harbour sediments are considered bare (i.e. low to no epibenthic communities, (BMT WBM 2010)) and little effort has been placed on describing the infauna of mobile substrates. However, Smit (2009) reports that sand wave systems in East Arm have large numbers of tube worms on the lee-side of the sand waves.

This chapter describes work aiming to map the extent of marine benthos habitats within the waters surrounding the Weddell development area. This chapter first describes the methods used, followed by a description of the derived habitat and community maps. The chapter concludes by making an assessment of the conservation significance and threats and impacts on identified community classes that may be applicable to the development of Weddell and identifies information gaps and suggested future works.

Figure 5.1. Locality map for Darwin Harbour and the proposed Weddell development area (shown in yellow).

5.2 Methods

Overview. The mapping method used primary (e.g. sediment type, depth) and secondary data sets (derived from bathymetry) that describe seascape complexity and characteristics of the seabed. Boosted Regression Tree Models were used to model species relationships with physical environmental and seascape characteristics and GIS interpolation tools were used to create habitat maps for the estuarine environment surrounding the Weddell development.

5.2.1 Existing data sets

To assist in acquiring baseline information for proposed developments at East Arm Wharf and Weddell, the Department of Lands and Planning (DLP) contracted iX Survey to acoustically survey four areas in Darwin Harbour: East Arm Harbour, Elizabeth River, Middle Arm and Blackmore River (Figure 5.1). The survey took place between 17 October and 7 November 2010 and used a Kongsberg Multi-Beam Echo-Sounder (MBES) to record the bathymetry and backscatter at 0.15 m and 0.3 m vertical and horizontal accuracy respectively. The acoustic data (soundings and backscatter) were processed to produce mosaics with 2.0 and 0.5 m resolution respectively (iX Survey 2010) (Figure 5.2 and 3.3).

Within this program, BMT WBM was subcontracted to describe (1) spatial patterns of sediment classes and (2) to undertake a broad-scale assessment of epibenthic communities within the four areas in Darwin Harbour. Seas Offshore was tasked to undertake subsurface sediment sampling and analysis. The BMT WBM survey used underwater video transects to describe epibenthic communities (BMT WBM 2010). Where conditions were unsuitable for video, then benthic trawls were deployed. In total 142 video transects and 10 benthic trawls were sampled (Figure 5.5). Taxa were identified to lowest practicable taxon (genus or higher and morphotype). A grab was used to sample surface sediments along video/trawl transects. The grab samples were use to confirm sediment type and provide a visual inspection of representative epibenthic specimens. No infauna or epibenthic specimens were kept. BMT WBM used non-metric multidimensional scaling (nMDS) to describe patterns of similarity and variability in the epibenthic community classes. In total nine classes were identified (Scleractinian reefs, Moderate-high density sponge and soft corals, Low-moderate density sponge bed, Rocks with ascidians, Low density sponge bed, Sand with *Macrohynchia* and soft coral, Sand with occasional encrusting sponge, Sand with low densities of Other taxa and Bare substrate) (Table 5.1). Following from these surveys, the Marine Biodiversity Group (MBG) further enhanced the biological sampling by undertaking beam trawls and infaunal sampling at most sample BMT WBM sites. Results from these surveys are presented in Chapter 2.

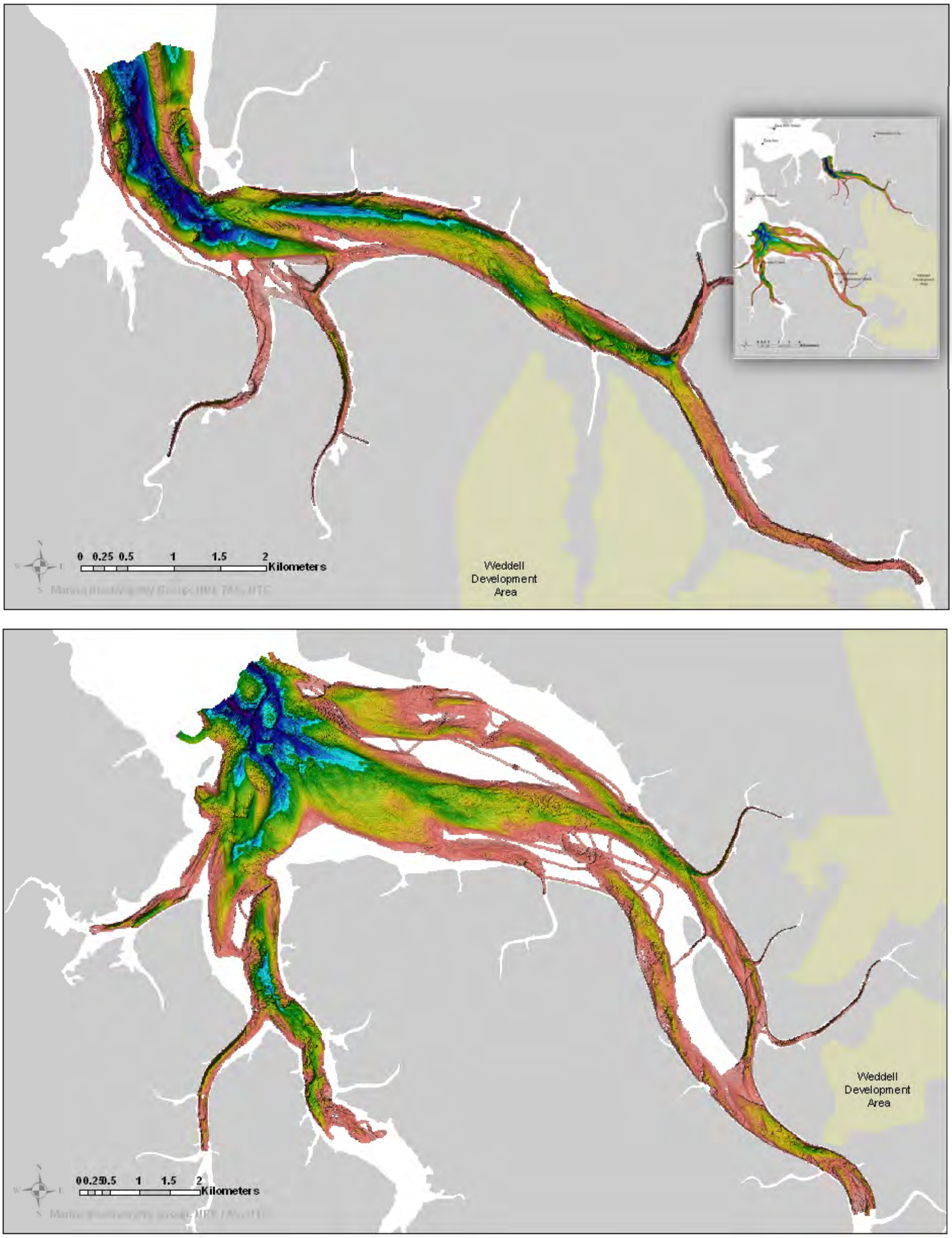


Figure 5.2. Top, Bathymetry for Elizabeth River and Bottom, Middle Arm / Blackmore River. Data supplied by iX Survey 2010.

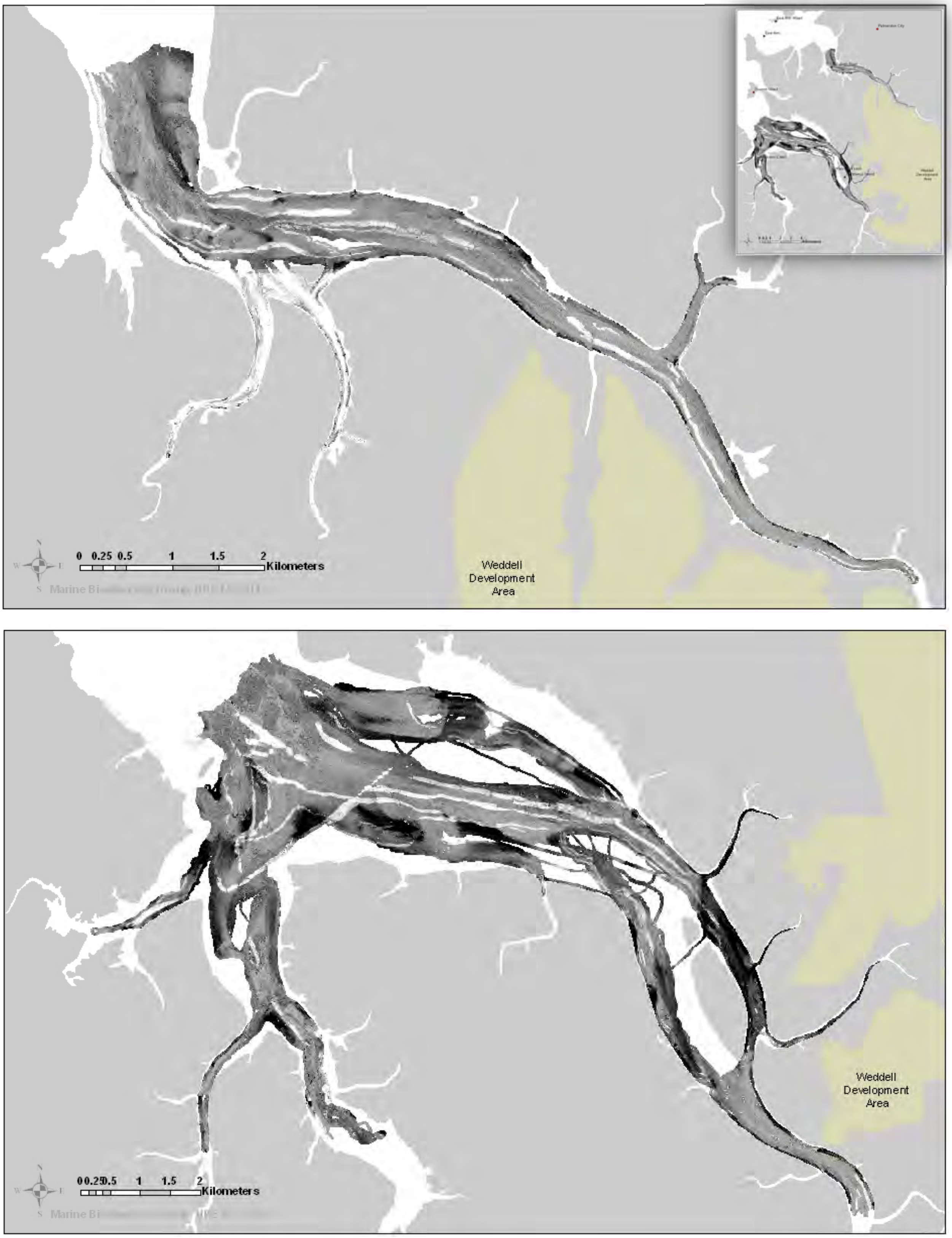


Figure 5.3. Top, Backscatter data for Elizabeth River; Bottom, Middle Arm / Blackmore River. Data supplied by iX Survey 2010.

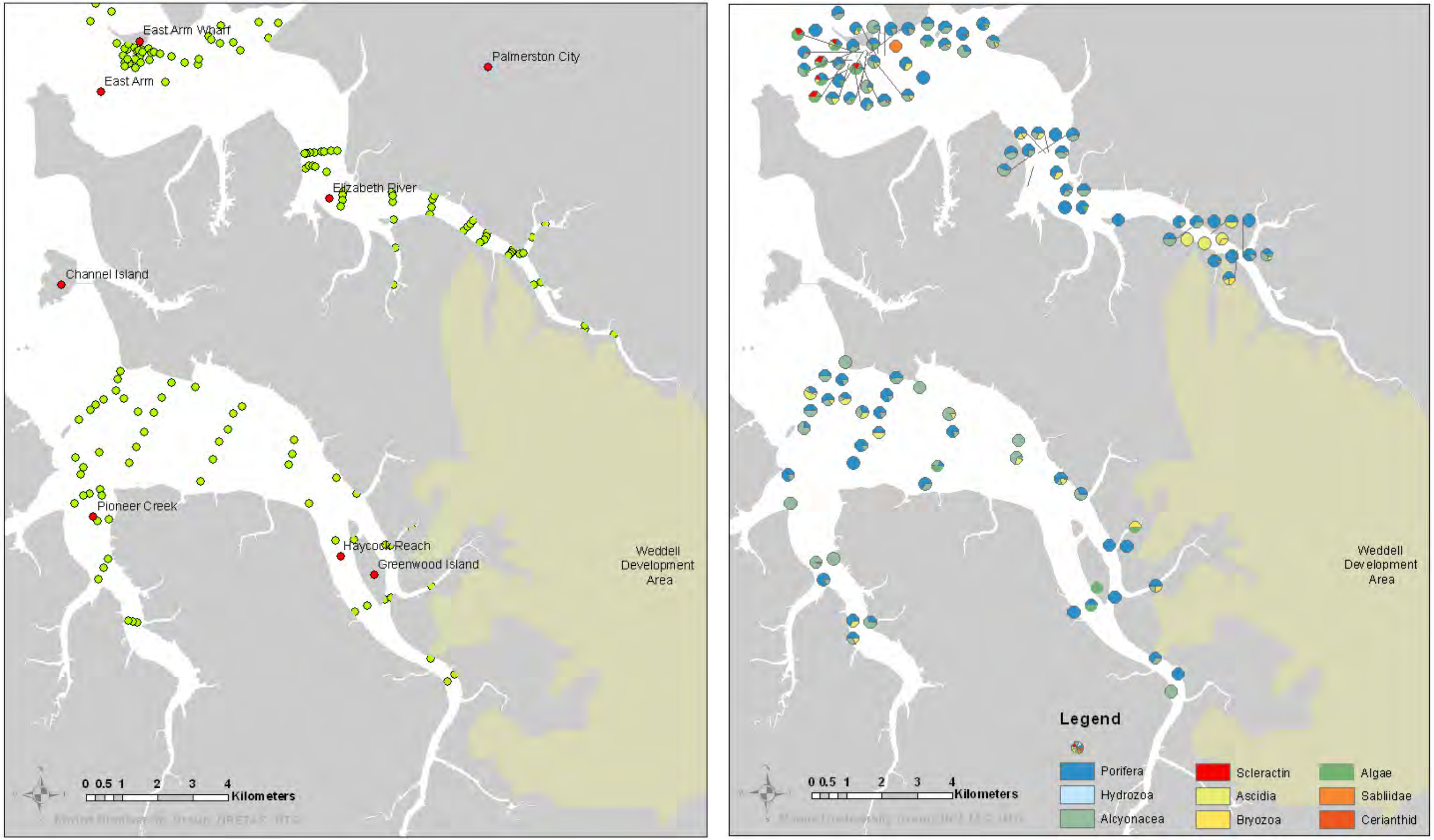


Figure 5.4. Left, BMT WBM video and grab survey sites; **Right**, BMT WBM benthos composition as a percentage of total numbers recorded.

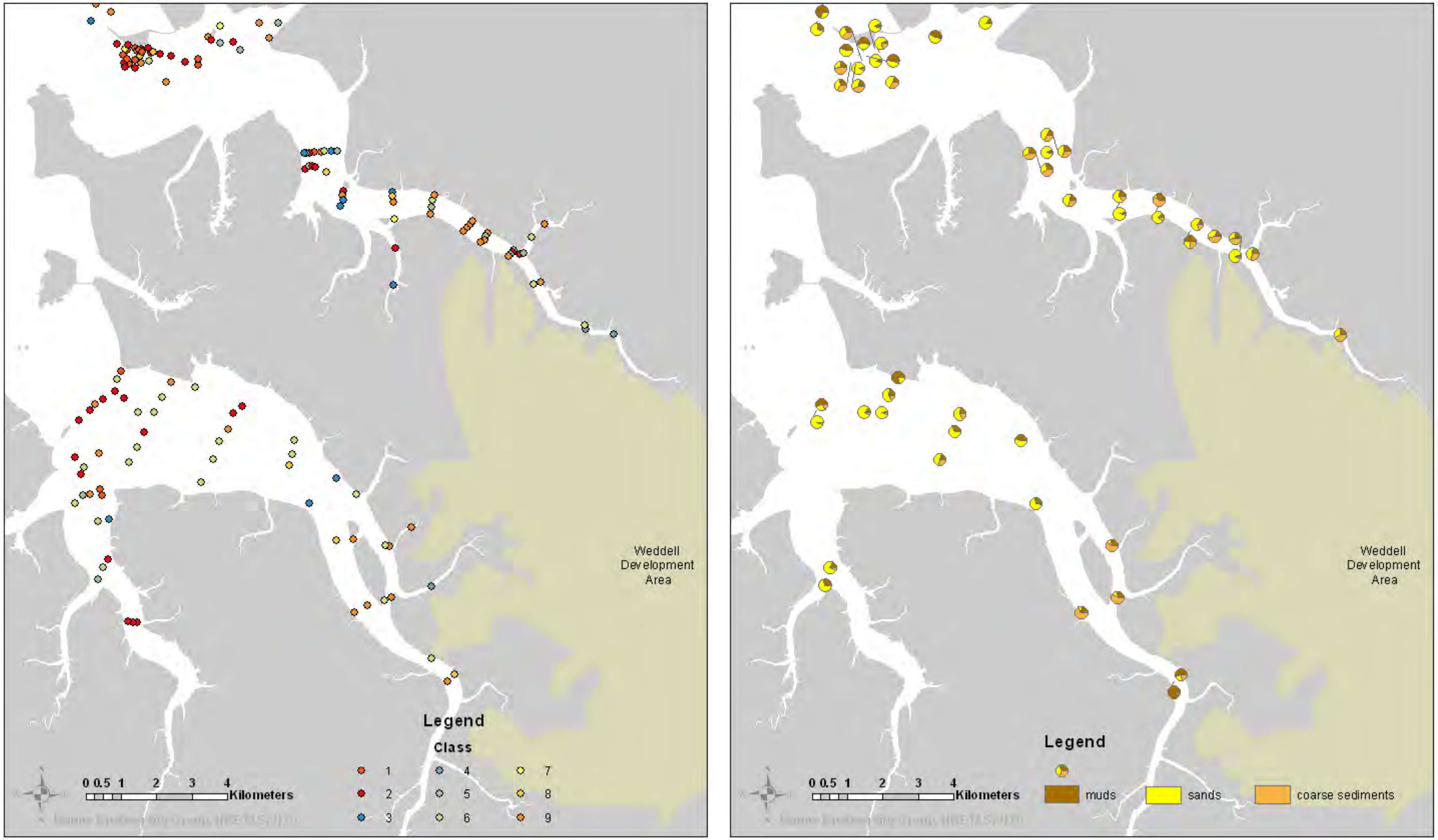


Figure 5.5. Left, Epibenthic classes (see Table 5.1 for description of epibenthic classes); **Right**, Percentage of muds, sands and coarse sediments. Data supplied by BMT WBM 2010.

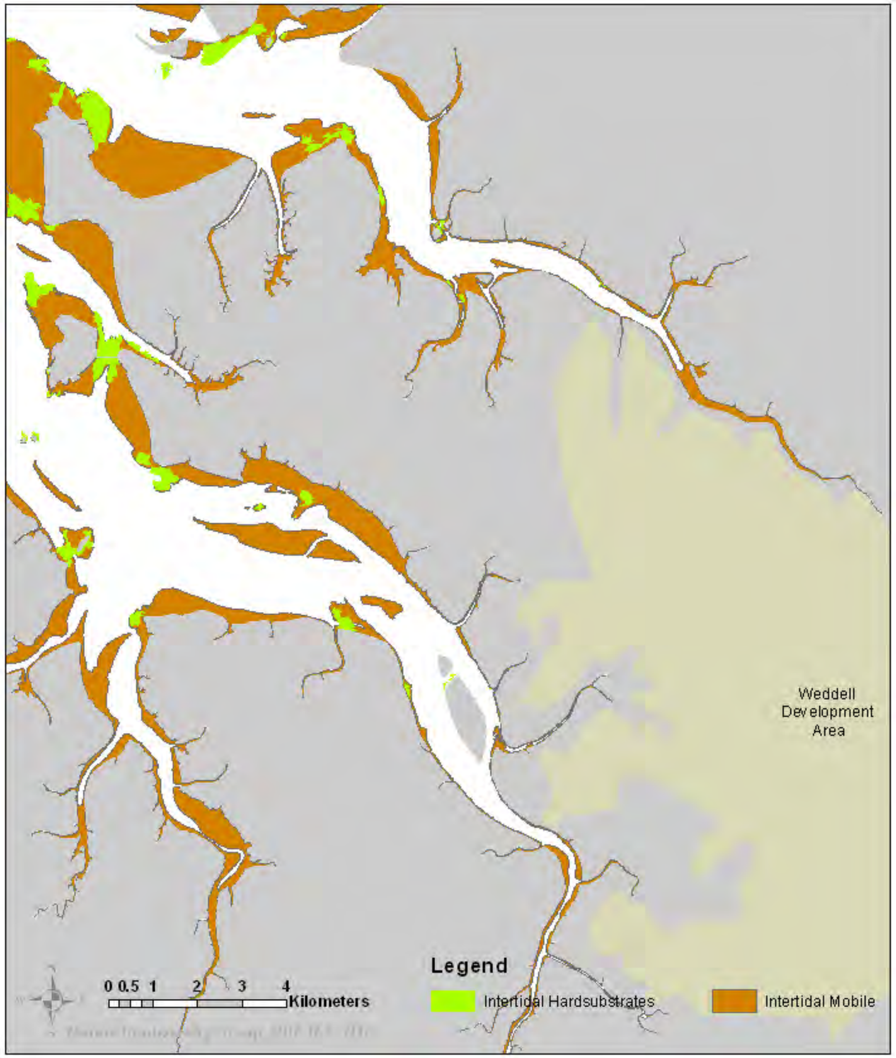


Figure 5.6. Intertidal substrates (Level 1: rock (**green**) mobile substrates (**brown**)). Digitised from low tide aerial photography. Data supplied by MBG

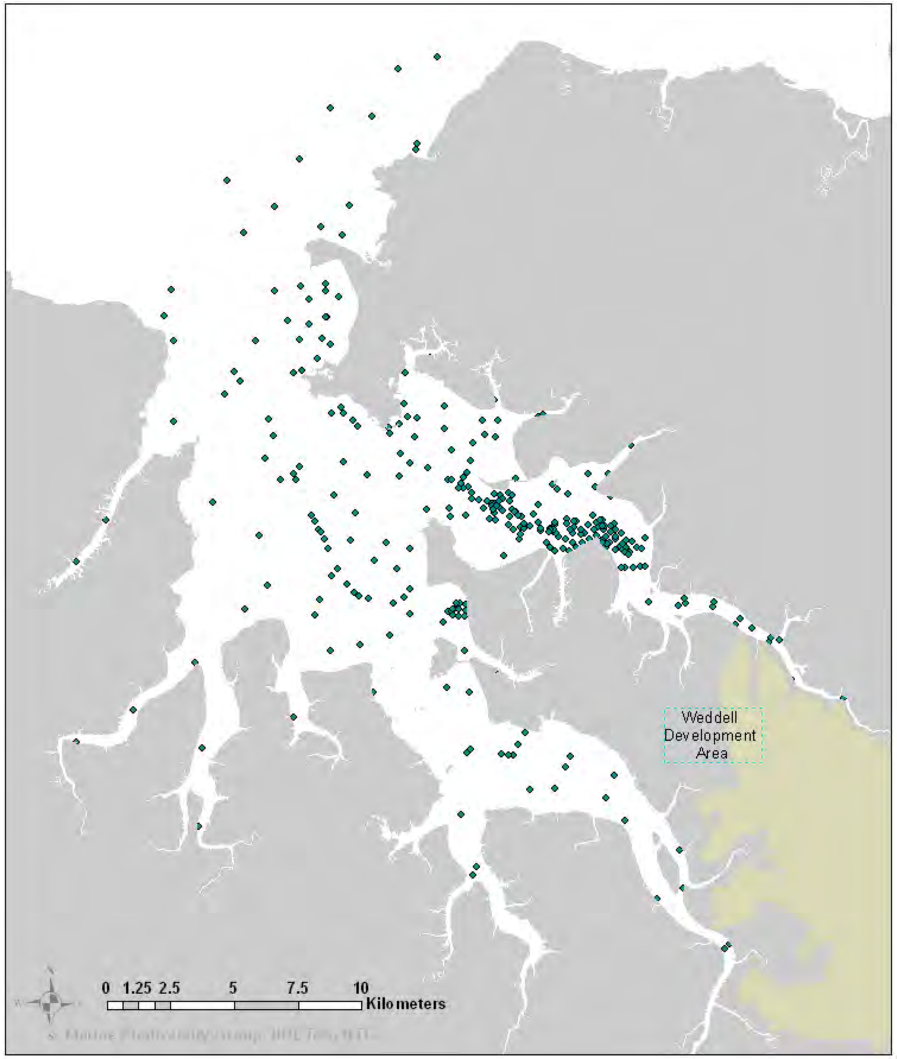


Figure 5.7. Sediment sample sites used for surface sediment modelling. Data combined from multiple sources (see Table 5.2).

Table 5.1. Epibenthic community classes derived based on patterns of similarity and variability from non-metric multidimensional scaling (nMDS) analysis of predominantly underwater video data. Spatial distribution of these habitats are shown in Figure 5.5. Data supplied by BMT WBM, 2010.

	BMT WBM Epibenthic community classes	Class description	Substrate	Location	Characteristics
1	Scleractinian reefs	scleractinian corals (mostly Goniopora spp.), hydrozoans Lytocarpus sp. soft corals, particularly alcyoniinds; algae including Halimeda spp., Caulerpa spp. and Botrycladida leptopoda, Sponges (branching, lobate, massive, basket forming, and encrusting)	Hard substrate; Interstitial material was composed of sand and shell grit.	Between the intertidal zone and the upper subtidal zone	High diversity (93 taxa) and high abundance
2	Moderate-high density sponge and soft corals	encrusting and branching sponges (eg white Calyspongia and raspalids), calcaxonid soft corals (eg Viminella, Junceella, and Dichotella), hydrozoans (eg Lytocarpus and Agalophenia)	Varied, hard and soft sediments,	Often adjacent to Class 1, subtidal only	High diversity (100 taxa) High abundance
3	Low-moderate density sponge bed	hydrozoans (Lytocarpus sp., Sertularidae); sponges (white Calyspongia, Ciocalypta spp. raspalid sponges); Ascidians, sea penns, and; no encrusting sponges) and contained very few soft corals (no calcaxonids or holaxonid soft corals)	patches of hard substrate with sandy to silty substrates	Subtidal; in the deeper channels and scour points	Moderate diversity (25 taxa) low to moderate cover
4	Rocks with ascidians	Abundant Ascidians with few Bryozoans and ceriantheid anemones	Rocks amongst patches of mud or steep-sided mud channels	Subtidal, upper reaches of Blackmore River and the Elizabeth River	least diverse class apart from bare substrate
5	Low density sponge bed	low cover of sponges (Ciocalypta spp. Calyspongia) with occasional holaxonid soft corals and hydrozoans (c.f. Macrorhynchia)	sandy to silty substrates.	Subtidal channels or sediment banks	Low diversity 17 taxa Low abundance
6	Sand with *Macrohynchia* and soft coral	Occasional colonies Hydrozoa (c.f. Macrorhynchia), sponges (Cioclaypta), ascidians, and holaxonid soft corals (cf Echinomuracea indomollucensis, Plexauridae Junceella, Viminella, and Rumphella)	sandy substrates with occasional small patches of coarser material	Subtidal sand flats surrounding East Arm, throughout Middle Arm and Elizabeth River.	Moderately diverse (25 taxa) Low abundance
7	Sand with occasional encrusting sponge	open substrates with small patches of encrusting sponge (eg *Oceanapia* sp. 4) and the soft coral genus Nephthya	Soft substrate		Low diversity (4 taxa) Low abundance
8	Sand with low densities of Other taxa	occasional inconsistent taxa	Sandy substrates		Low diversity (12 taxa) Low abundance
9	Bare substrate	Bare with mangrove debris	Sandy or muddy substrates		

Fifty-two grab samples were kept for grain size analysis (Symbio Alliance Laboratories 2010) which were grouped into five sediment classes: Silt, fine-med sand; medium sand, coarse sand and fine gravel (Figure 5.5). Additional data sets were reviewed (Table 5.2) and added to the Symbio Alliance Laboratories sediment data set where appropriate. Figure 5.7 shows the data points that were used for sediment modelling. Further, the MBG's intertidal mobile/non-mobile substrate map (Figure 5.6) was used to complement the predominantly subtidal iX Survey and BMT WBM data sets. The intertidal hard versus soft substrate map was digitised from low-tide aerial photography.

5.2.2 Sediment classification.

Sediment data were classified based on a hierarchical classification scheme (Figure 5.8). This consisted of a distinction between consolidated (ie hard substrates) and mobile substrates (Level 0). Mobile substrates were then classified according to the EUNIS sediment classification scheme (Level 1) (Long 2006). This classification scheme is based on the Folk classification scheme (Folk 1954) with the difference that some classes of grainsize have been merged and matches better with the types of substrate classes that can be distinguished from video or in situ descriptive techniques that were used for this project. In some cases it may be possible to further classify substrata into the original Folk classes (Level 2). Where appropriate, modifiers were attached to the Level 1 or 2 classification classes. Only existing grainsize data sets were used (Table 5.2) and grouped according the classification scheme used. Mapping products (percent muds, ~sands and ~gravel; Level 2&3 substrate classes; and Median Grainsize (D50)) are based on kriged Darwin Harbour-wide data sets.

5.2.3 Datasets derived from bathymetry.

Bathymetric xyz ascii files were converted to grid files in ESRI ArcGis 10. Raster resolution for data analysis was set at 2 m horizontal resolution. Secondary datasets derived from bathymetric data are listed in Table 5.4 and include seascape characteristics such as slope, aspect, curvature, range, the standard deviation of depth, rugosity and benthic position index.

***Depth Range and Standard Deviation*.** Focal statistics were calculated in ESRI ArcGIS 10 using Spatial Analysis tools for depth range and standard deviation of depth, based on cell radius of 3, 5, 10, 25 and 50 (cell size being 2 x 2 m).

Slope. Slope was calculated using the Spatial Analyst extension in ESRI ArcGIS 10. Slope was calculated by taking the steepest slope between each raster cell and its 8 nearest neighbours.

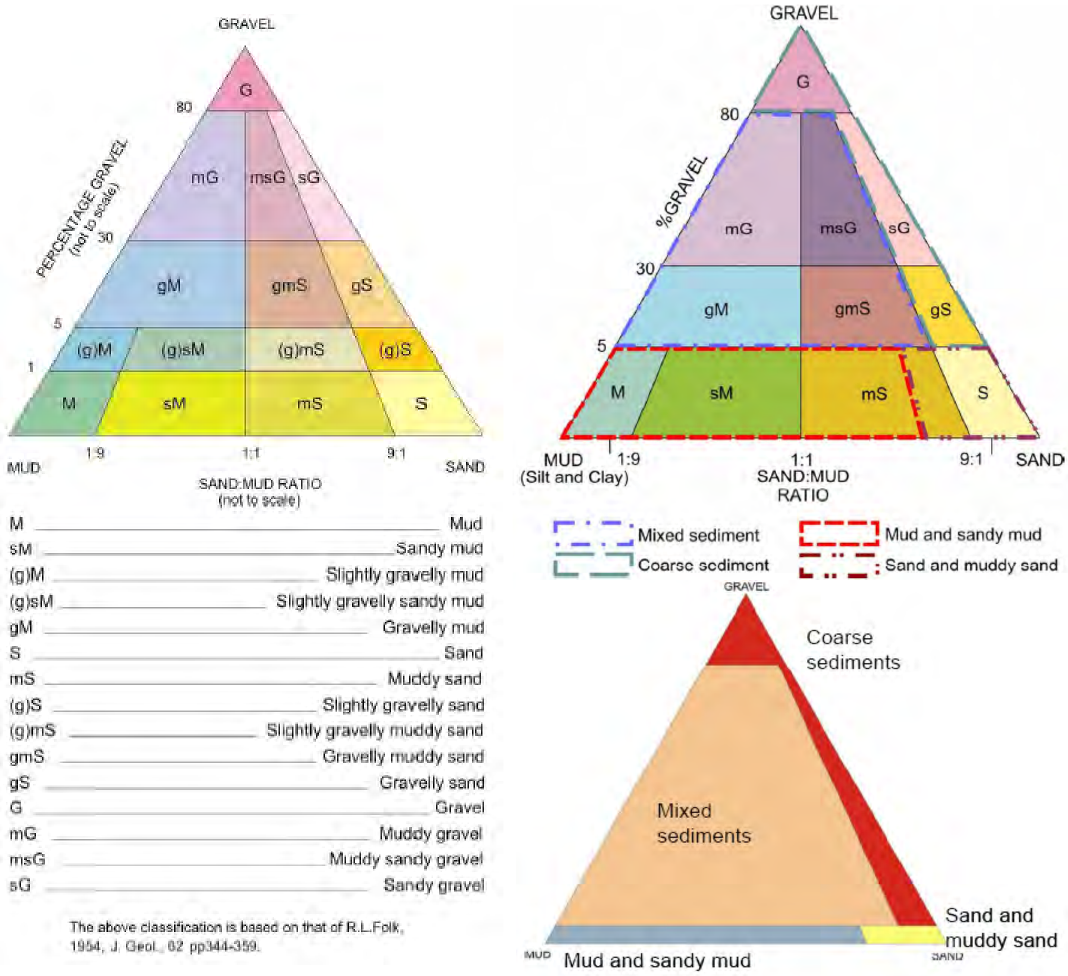


Figure 5.8. Sediment classification for mobile sediments. **Top left**, original Folk's classification scheme. **Top right**, Level 3 sediment classes including decision rules for simplification. **Bottom right**, Level 2 mobile sediment classes (simplified EUNIS sediment classification triangle, images sourced from Long 2006).

Table 5.2. Sources used for Sediment data sets

Survey id	Survey description	Date
2	Darwin Harbour Sediment Study sampled in Dry Season	6/07/1993
9	INPEX Sediment survey East Arm	7/03/2008
10	INPEX Sediment survey Pipeline	8/03/2008
11	INPEX Sediment survey Shore crossing	8/03/2008
13	BTM WBM SymbioAlliance Sediment report	22/11/2010
14	VibrCore SEAS	22/11/2010

***Rugosity*.** Rugosity was calculated in ESRI ArcGIS 9.3 using the *Surface Area and Ratios tool* created by Jenness Enterprises (Jenness 2010). Rugosity measures the ratio of surface area to planar area, which creates an estimate of the roughness of the seafloor. The higher the rugosity value, the rougher the seafloor.

Aspect. Aspect was calculated using the Spatial Analyst extension in ESRI ArcGIS 10. Aspect is calculated by taking the steepest slope between each raster cell and its 8 nearest neighbours.

***Curvature*.** The primary output is the curvature of the surface on a cell-by-cell basis, as fitted through that cell and its eight surrounding neighbours. Curvature is the second derivative of the surface, or the slope-of-the-slope. ESRI ArcGIS 10 allows for two optional output curvature types are possible: the profile curvature is in the direction of the maximum slope, and the plan curvature is perpendicular to the direction of the maximum slope. Curvature is used in determining relief characteristics and seascape characteristics. A positive curvature indicates the surface is upwardly convex at that cell. A negative curvature indicates the surface is upwardly concave at that cell. A value of 0 indicates the surface is flat. The larger the value the more extreme the relief.

***Benthic position index*.** Benthic position index was calculated in ESRI ArcGIS 10 using spatial analyst tools and raster calculation tools (Lundblad et al 2006, Erdey-Heydorn 2008). Focal means were calculated for each grid cell from the bathymetric grid data to generate average mean depth values for a given neighbourhood size. Focal means were then subtracted from the depth of the cell to create an index of relative elevation.

BPI [scale factor] = int [(bathymetry-focalmean(bathymetry, annulus, irad, orad)) + 0.5]

The index values were then standardised by subtracting the mean index value for the whole grid from the original cell index value, which was then divided by the standard deviation of the index values for the whole grid (Jenness 2010).

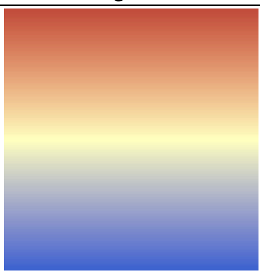
BPI standardised = (BPI cell – BPI $Grid_{mean}$) / BPI $Grid_{Std}$

Focal means were calculated for neighbourhood sizes of 5 (10), 10 (20), 15 (30), 25 (50), 35 (70), 50 (100), 75 (150), 100 (200) and 125 (250m) cells (m).

Standardised BPI values were used in preliminary analysis. BPI values provide a visual representation of regional highs, lows, slopes and flat areas for a given neighbourhood size (Table 5.3).

The modelling tool in ArcGIS 10 was then used to derive BPI seascape classes. The model first reclassified the fine scale and broad scale BPI zones, using the standard deviation as units; followed by reclassifying the slope data into two groups: flat - less than four degrees; and sloped - greater than four degrees. The three grid layers were then combined into a single grid layer and reclassified into BPI Seascape classes (Lundblad *et al* 2005, Table 5.3).

Table 5.3. A description of the resulting benthic position index (BPI) values derived from bathymetric data (Weiss 2001, Iampietro *et al* 2005, Lundblad *et al* 2005), resulting in 12 BPI classification groups (BPI Seascape classes).

Colour range	BPI value	Geomorphic feature/position
	High(positive)	Hill top, ridge top
		Upper slope
		Gentle lateral ridges
	zero	Flats, constant sloped areas, saddles
		Gentle lateral valleys
		Lower slopes
		Cliff base
	Low (negative)	Depression, valley bottom

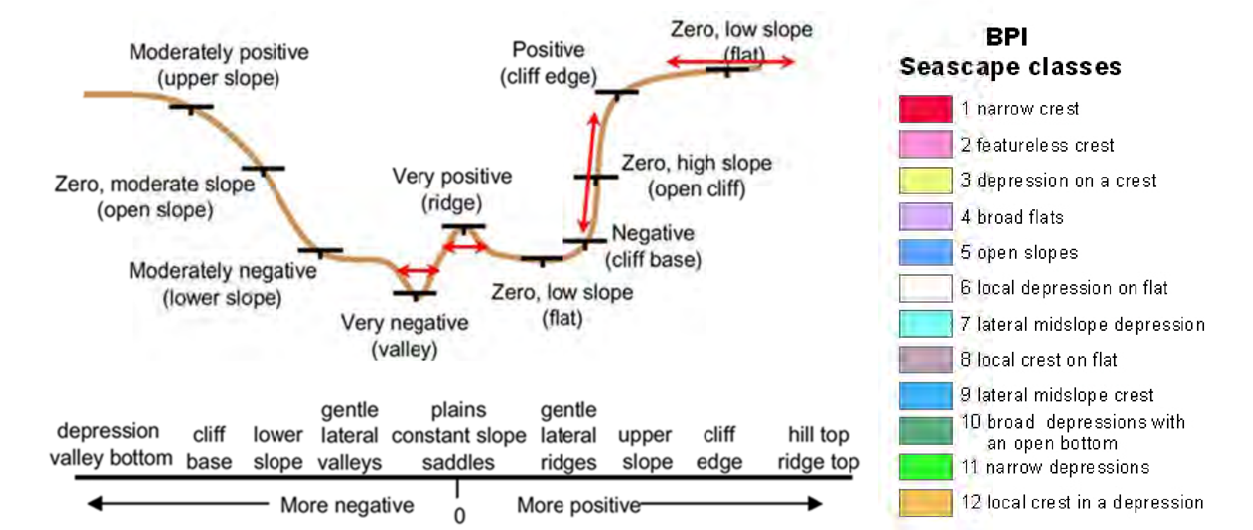


Table 5.4. Description of datasets included in the modelling process as predictors of seafloor substrate and biota.

Dataset	Variable	data type	Source or algorithm	Use
Bathymetry	depth in meters, relative to AHD	Primary, xyz ascii, converted to grid	IX Survey (IXSurvey 2010)	Used as environmental parameter & to derive secondary datasets
Backscatter	Intensity of return signal (dB)	Primary, xyz ascii, converted to grid	IX Survey (IXSurvey 2010)	Assist interpolation of substrate types
Aspect	Degrees of compass rose	Derived, slope direction	ESRI ArcGis 10, Spatial analysis tool	Only used in ABT / BRT analyses
Slope	Degrees,	Derived, change in depth over distance (from neighbouring cells)	ESRI ArcGis 10, Spatial analysis tool	Assist identification of channels and reef edges
Curvature	Degrees	Derived, combined index of profile and plan curvature	ESRI ArcGis 10, Spatial analysis tool	Parameter needed for topographic position
Plan curvature	Degrees	Second Derivative of depth, curvature perpendicular to slope	ESRI ArcGis 10, Spatial analysis tool	Parameter needed for topographic position
Profile curvature	Degrees	Second Derivative of depth, curvature parallel to slope	ESRI ArcGis 10, Spatial analysis tool	Parameter needed for topographic position
Range	Depth range (m)	Derived, local neighbourhood analysis,	ESRI ArcGis 10, Spatial analysis tool	Surrogate for rugosity
Standard deviation	Standard Deviation of depth	Derived, local neighbourhood analysis,	ESRI ArcGis 10, Spatial analysis tool	Surrogate for rugosity
Rugosity	Surface area normalised	Derived, local neighbourhood analysis,	Jenness, ESRI ArcGIS 9.3 add-in tool	Indicator for benthic complexity
Benthic position index	Standard Landform slope classification	Derived, local neighbourhood analysis,	ESRI ArcGis 10, Raster calculation	Seascape analysis at varying scales
Photic zone	Depth in meters relative to AHD	Derived from bathymetry, cut-off zone from ABT / BRT analysis & literature	ESRI ArcGis 10, Raster calculation	Key driver for establishing dominance by algae/corals vs filter feeder benthos

5.2.4 Environmental correlates

A preliminary assessment of the relative contribution of physical (derived and observed) parameters to predict biotic variables was undertaken using aggregated boosted tree (ABT) analysis. This was followed by analysis of key parameters and taxa using boosted regression trees (BRT) to create probability density maps for taxa abundance and distribution. BRT is a machine learning technique that combines regression and classification methods to quantify and visualize results (Elith et al 2008). ABT is a modified version of BRT that further reduces predictive error (De'ath 2007). For regression tree analysis we used the abt (2.2), and dismo (0.7-13) packages, and created raster maps with the raster (1.9-52) package in R version 2.14.0 (R Development Core Team 2011).

5.2.5 Mapping of habitats and sediments

Habitats were classified according to Table 5.5 and Table 5.6. This hierarchical classification scheme is adapted from the National habitat classification scheme (Mount et al 2007). Community maps are presented are a combination of level 3 physical characteristic classes and level 2 benthos classes.

To create maps of areas of similar environmental characteristics (i.e. habitat maps), ArcGIS Spatial Analyst toolbox (ArcGIS 10, ESRI) was used to reclassify and merge primary and secondary raster data layers. Besides raster analysis, rippled sandy substrates (rippled sand and sand waves/dunes) were digitised by hand and were used to provide a roughness index for mobile sediments. The key criteria used were the depth, substrate type (level 2), slope/roughness and topographic position. The final maps represent classes with cell clusters larger than 2500 cells, classes with less than 2500 cells were amalgamated into their parent hierarchic level.

Final community maps were created by using habitat maps as a basis over which the modelled species maps and BTM WBT and MBG benthos data layers were laid. Expert knowledge was used to create the final benthos community maps. All maps were full coverage to the spatial resolution of 5 by 5 m resolution.

Table 5.5. Hierarchical classification of physical characteristics for Darwin Harbour benthic environment (see Figure 5.8 for substrate classification). Light grey cells indicate level used for mapping habitats.

Level 0	Level 1: Depth zoning	Level 1a	Level 2: light zone	Level 3: Substrate	Level 3a: Level 2/3 sediment class	Modifier: Profile
			Dominance by photo ~ vs heterotrophs	Reef vs sediment	Rock, Mixed, coarse, sand & muddy sands; mud & sandy muds Or Grainsize based	
Marine	Subtidal		A-photrophic zone	Mobile (Sediment)		Flat, small \ medium \ large ripples; waves; dunes
				Non-mobile (Rock)		Rough, smooth
			Phototrophic zone	mobile		
				Non-mobile		
	Intertidal	High Intertidal	Phototrophic zone	mobile		
				Non-mobile		
		Low Intertidal	Phototrophic zone	mobile		
				Non-mobile		

Table 5.6. Hierarchical classification of benthos characteristics for benthic habitats in Darwin Harbour. Light grey cells indicate level used for mapping habitats.

Level 0	Level 2	Level 2	Level 3	Modifiers
Epibenthos Present	Phototroph	Algal	Brown, green, red algae, mixed;	Turfing, dominant species
		Seagrass	Dominant species	Meadow type
		Mangroves	Dominant Mangrove species	
		Saltflats	Dominant Saltflat species	
	Heterotroph	Coral		Life forms, species
		Filter feeders	Sponge, soft coral, gorgonians, Hydroid, ascidian	Life forms / species
		Mixed		
Epibenthos absent	Infauna present	Bioturbation present	species	High, medium, low
		Bioturbation absent	species	
	Infauna absent		Bare	

Table 5.7. Sorting properties for Darwin Harbour and Weddell sediments

Region	Number of sites	Sediment sorting properties				
		Moderately Well	Moderately	Poorly	Very Poorly	Extremely Poorly
Darwin Harbour	310	10 3%	9 3%	97 31%	188 61%	6 2%
Weddell	48	0 0%	1 2%	17 35%	24 50%	6 13%

5.3 Results

5.3.1 Substrate

Available substrate consisted of predominantly mobile sediments (4265 ha, 87.1%, Table 5.8) with the remaining being rock (630 ha, 12.9%). Weddell sediments are in general poor to very poorly sorted, with less that 2% being moderate – moderately well sorted. Consequently, mixed sediments (muddy sandy Gravel (44.5%) and gravely muddy Sand (17.3%)) is the most dominant sediment class (3688 ha, 75.3%). Hard substrates are found throughout the Weddell development area (630ha, 12.9%) and in varying environmental conditions.

Interpolation of Darwin Harbour wide sediment data are shown in Figure 5.9. These data were categorised to Level 2 and 3 of the sediment classification scheme (see Figure 5.8) and are shown in Figure 5.10. Hard substrates were derived from analysis of intertidal aerial photography and analysis of acoustic data (bathymetry and backscatter data (Figure 5.2 and Figure 5.3). All Weddell data were combined into a single map layer (Figure 5.11).

Most notable rocky areas are at the ‘mouth’ of Middle Arm (just south of Channel Island); Pioneer Creek and the top end of Elizabeth River (both within depressions of the river channel). Smaller rocky outcrops become more prominent in the upper arms of the Elizabeth and Blackmore rivers.

Table 5.8. Substrate types and area calculations for the estuarine environment within the proposed Weddell Development area.

Substrate type	Level 2	Level 3	Area (ha)	percentage of total available substrate
Rock			630	12.9
Mobile substrates			4265	87.1
	Coarse sediments	gravely Sand	90	1.8
	Mixed sediments		3688	75.3
		muddy Gravel	196	4.0
		muddy sandy Gravel	2178	44.5
		gravelly Mud	496	9.6
		gravelly muddy Sand	846	17.3
	Sand & muddy Sands	Sand	29	0.6
	Mud & sandy Mud		1832	9.4
		Mud	1	0.01
		sandy Mud	82	1.7
		muddy Sand	376	7.7

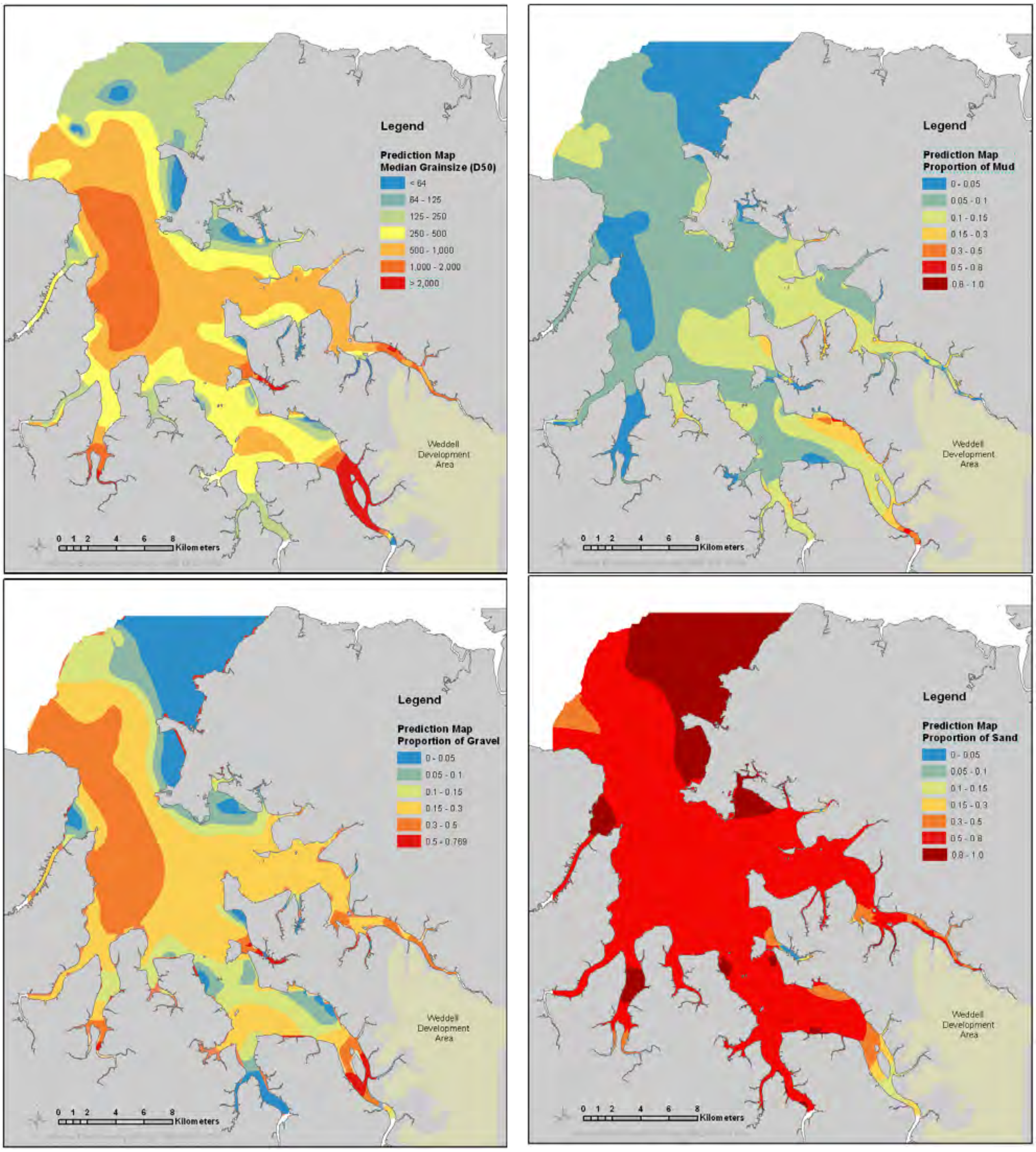


Figure 5.9. Predicted sediment contour maps for Darwin Harbour wide sediment data.
Top left: Median grain size (D50); **Top right**: Proportion of Mud in sediment;
Bottom left: Proportion of Gravel in sediment; **Bottom right**: Proportion of Sand in sediment;
See Table 5.2 for data sources

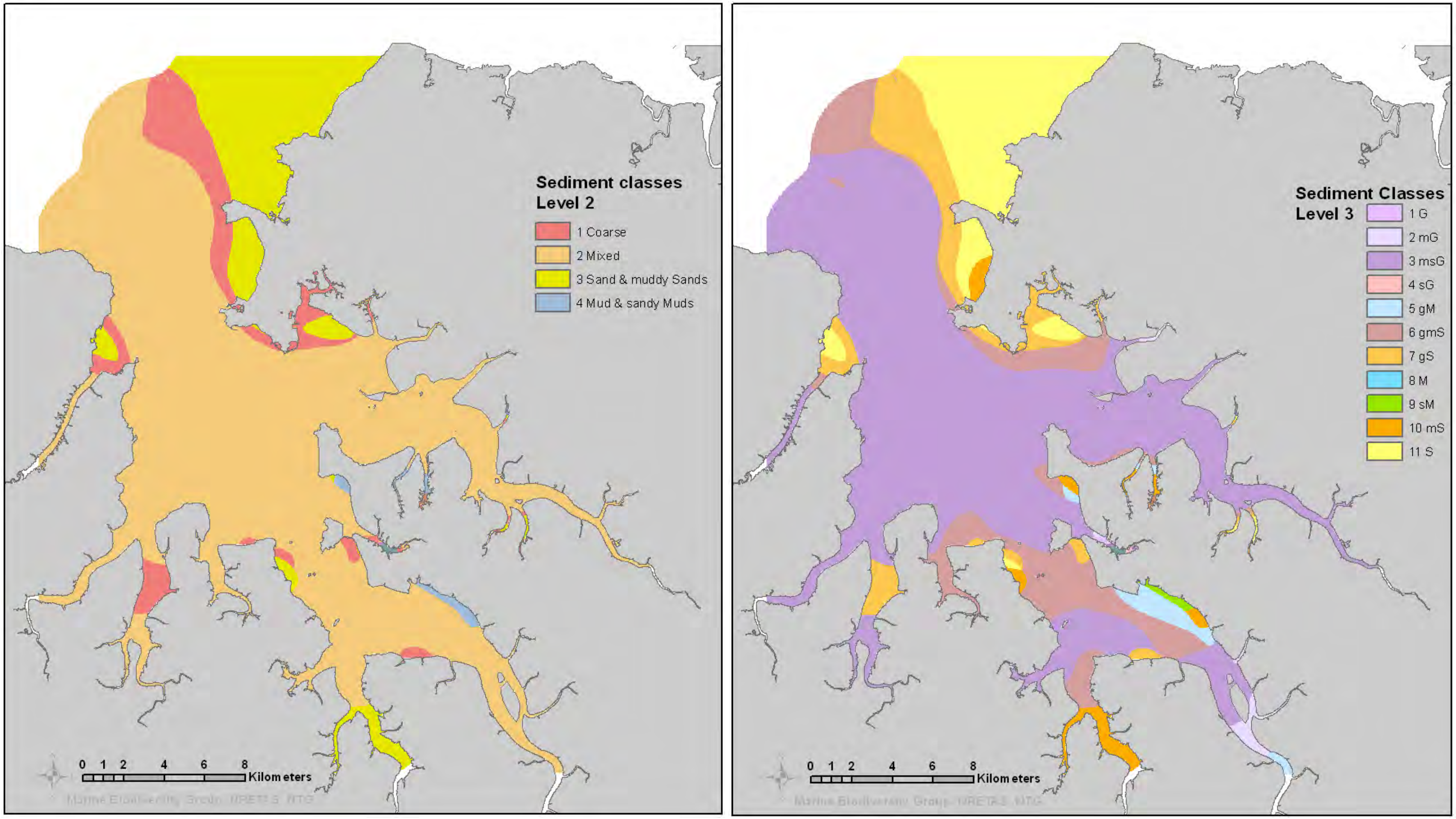


Figure 5.10. Darwin Harbour wide sediment maps classified to Level 2 (**right**) and Level 3 (**left**).

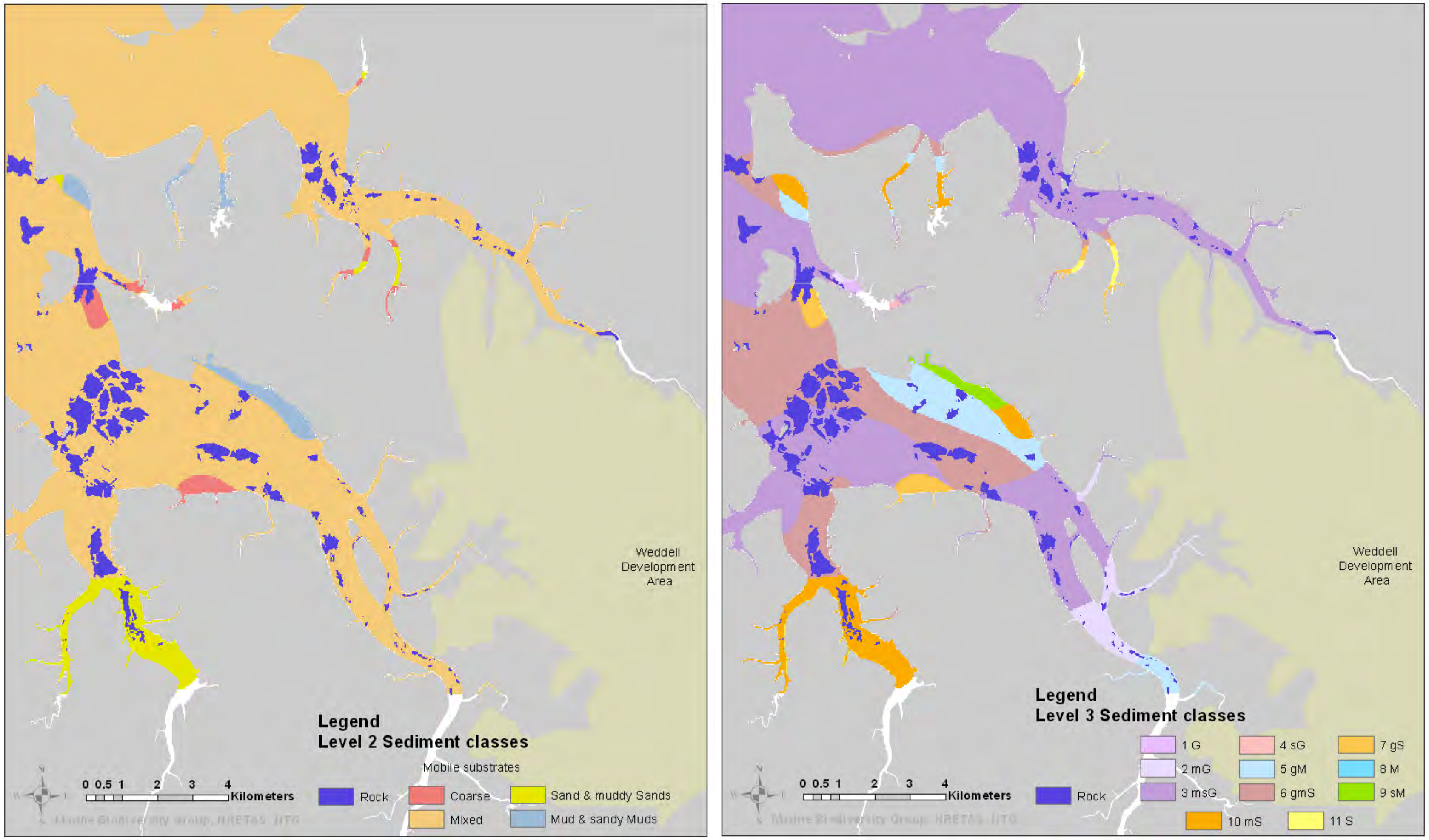


Figure 5.11. Substrate maps for the Weddell development area. Right: Substrate map derived from Level 2 mobile substrate classification with hard substrates derived from analysis of aerial and bathymetric data; Left: Substrate map derived from Level 3 mobile substrate classification with hard substrates. **G**, Gravel; **mG**, muddy Gravel; **msG**, muddy sandy Gravel; **sG**, sand Gravel; **gM**, gravel Mud; **gmS**, gravelly muddy Sand; **gS**, gravelly sand; **M**, Mud; **mS**, muddy Sand; **S**, Sand.

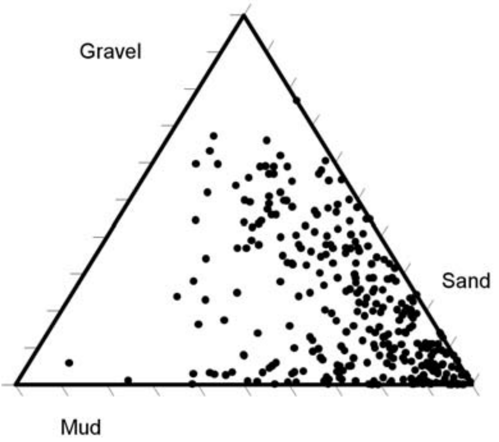


Figure 5.12. Tri-plot of Darwin Harbour wide sediment data. Multiple data sources (Table 5.2).

Table 5.9. Sorting properties for Darwin Harbour and Weddell sediments

Sediment sorting properties	number of sites			
	Darwin Harbour		Weddell	
Moderately Well Sorted	10	3%	0	0%
Moderately Sorted	9	3%	1	2%
Poorly Sorted	97	31%	17	35%
Very Poorly Sorted	188	61%	24	50%
Extremely Poorly Sorted	6	2%	6	13%
Grand Total	**310**		**48**	

5.3.2 Environmental Correlates

Twelve variables were identified as candidate surrogates for biotic abundance and distribution (e.g. Radford et al 2008, SKM 2010). Of these, six variables were identified as the most important environmental factors that contribute towards explaining benthos spatial distribution: latitude, longitude, backscatter, mean depth, planar curvature, and benthic position index (BPI 100 square radius) (Figure 5.13, Appendix 4). These environmental parameters were subsequently used to create predictive maps for the following taxa, or groups: crustaceans (brachyura, mysidacae, caridea, amphipoda, and penaeoidea), gastropods, actinopterygii (fin-rayed fish), polychaetes, hardcorals, macroalgae, and filterfeeders (sponges, polychaetes, and non-photosynthetic soft corals)). Examples are shown in Figure 5.13, with all data presented in Appendix 4).

From the ABT/BRT analysis, backscatter (which can be interpreted as a surrogate for substrate type) is the most important driver for species distribution and richness. Low backscatter values (between -20 and -10) can be equated to hard substrates, where higher values (~ -30's) can resemble mobile substrates. Depth at approximately 10 m below LAT seemed to play a role in the presence/absence of phototrophic species (e.g. corals and algae), whereas filter feeders became gradually more dominant with depth.

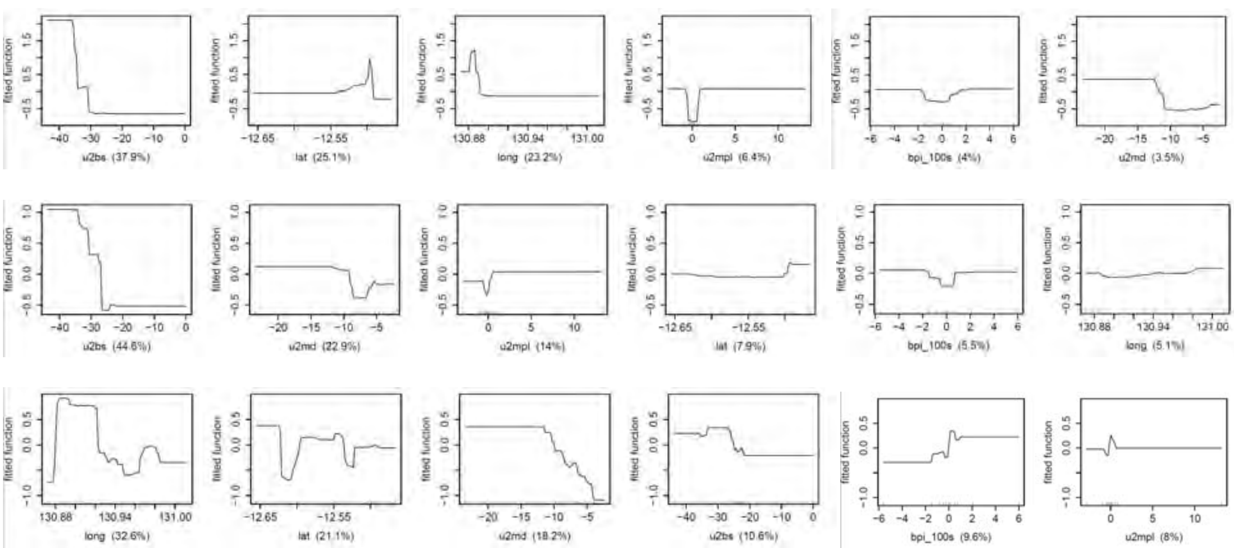


Figure 5.13. Environmental drivers for species richness. **Above**: hard Corals, **Middle**: macro Algae and **Below**, Filter feeders. **Bs**, Backscatter; **Lat**, latitude; **long**, longitude; **mpl**, curvature; **md**, mean depth; **BPI100**, benthic position index (at a 100 cell radius). (see details Appendix 4)

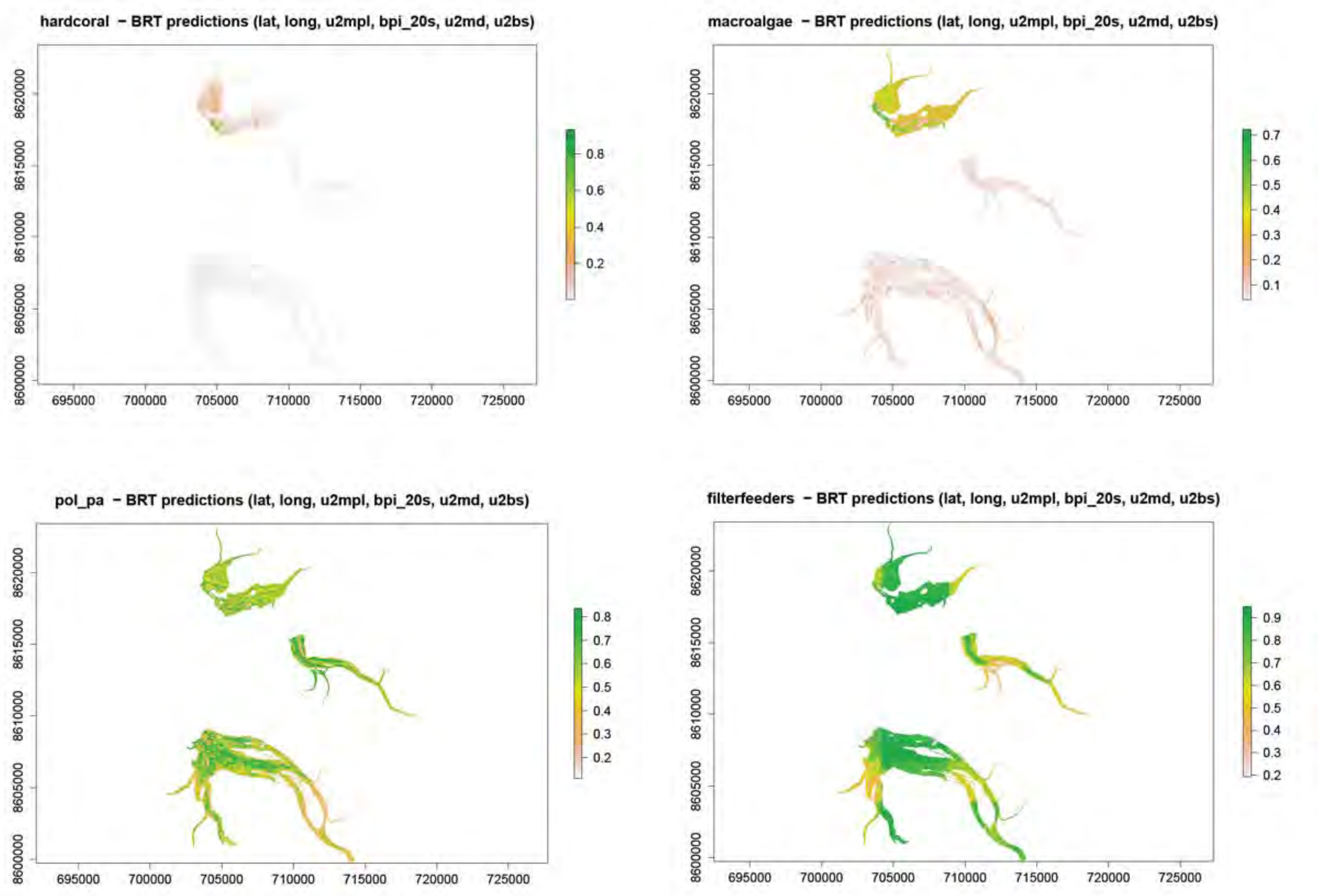


Figure 5.14. BRT predictions for hard corals (**top left**), macro algae (**top right**), polychaete worms (bottom left) and filter feeders (**bottom right**). East Arm wharf area included in the analysis to broaden the range of habitats/ benthos groups.

5.3.3 Primary and secondary derivatives

To characterise the seascapes, results from ABT/BRT analysis provided the key drivers for spatial distribution presence/absence of species and species richness. Besides backscatter, mean depth, curvature, and benthic position index (BPI 100 square radius), which were the most influential drivers, roughness and slope were also used to characterise the estuarine physical environment. Figure 5.16 shows primary data sets (bathymetry and backscatter) used for data analysis. Figure 5.17 and Figure 5.19 show results for roughness, slope, curvature and BPI (100 and 20) which were derived from spatial analysis of bathymetric data.

***Depth*.** Bathymetric data from the multibeam bathymetric survey was provided by iXSurvey (2010) and is shown in Figure 5.16. Depth varied between 3.85 m above LAT and 21.4 m below LAT. The bathymetric maps show data gaps (white) where it was too shallow for the survey vessel. Generally this was near intertidal banks abutting the river banks / mangroves forests and the larger sandbank/waves. The deeper areas are generally found at the “mouth” of Middle Arm, in depressions within Pioneer Creek and Elizabeth River.

To assist seascape modelling, depth was reclassified into four groups, which was based on tidal constants and light availability. Intertidal areas were classified into high intertidal (above mean sea level height (MSL)) and low intertidal (above lowest astronomic tide height (LAT) and below MSL. Subtidal areas were divided into a phototrophic zone and a heterotrophic zone (i.e. a-photic zone). The delineation between the two zones was inferred from the ABT/BRT analysis which showed that at 10 m depth there was a change in the presence/absence of benthos from phototrophic species (e.g. corals and algae) to filter feeders (sponges and soft corals). The results from this classification are shown in Figure 5.23.

***Backscatter*.** Backscatter data from the multibeam bathymetric survey was provided by iXSurvey (2010) and is shown in Figure 5.16. It is clear from the backscatter image that there is a processing issue in areas where the MBES survey lines overlap. Backscatter data was not reanalysed, given that there was no access to dedicated software that is required to process these types of data and therefore no classification of the backscatter data was done. Nevertheless, the backscatter image was used to fine tune the spatial distribution of broad scale physical parameters, such as hard substrates, channel and some extent sand flats, which were incorporated into seascape maps. For example, the backscatter shows clearly reefal areas (e.g. the mouths of Middle Arm and Pioneer Creek) and substrate characteristic change (e.g. channel substrates versus sand banks).

***Slope*.** Slope derived from the bathymetric data produced values from 0º to 64º (Figure 5.17). Overall the substrate is generally flat (0-2º, 73% of the area). High slope areas (>8º accounted only for 1% of the area) and seem to be associated with the slopes of tidal channels (mainly in creeks in the upper reaches of Elizabeth River and Middle Arm), reef edges ("mouth" of Middle Arm), patchy rocky areas (Pioneer Creek and northern part of Elizabeth River, including substrates around Short Islet) or sandbanks/sand waves which can be found scattered throughout the area. Medium sloped areas (2-8º, 26%) are generally found adjacent to high sloped areas in and around Haycock Reach and Blackmore River where they correlate with sand and mudflat banks. In order to use the slope data for habitat / landscape modelling, the grid was divided 4 groups based on standard deviation as a unit for slope classes. Visual inspection of bathymetry the four groups were combined into 2 groups: slopes between 0 – 4º and >4º (4-67º).

***Roughness*.** Roughness follows very similar patterns as that for slope (Figure 5.17), although slightly more restricted in its spatial distribution. Roughness values fall between 1.003 and 1.4 and are considered low in comparison to other studies (e.g. Erdey-Heydorn 2008). From a local perspective, only 3% of the area can be categorised as medium to high rugosity (roughness > 1.011) and is restricted to reefal areas in the "mouth" of Middle Arm, Pioneer Creek and northern parts of Elizabeth River. Roughness was classified using similar technique as for slope. Five groups were identified using standard deviation as a unit.

Given that slope and roughness followed similar spatial patterns, visual inspection the raster layers allowed the two layers to be merged and classified into two groups: flat and smooth, and sloped and rough. These two classes were used for the seascape classification.

***Curvature*.** Curvature is of particular interest in areas where rugosity and slope play a role classifying the seascapes. Although not used perse in BPI analysis, it does assist in validating the interpretation of where a particular site is located within the landscape. As expected areas with high variability in curvature are found in areas where slope is also highly variable. These areas are mainly found in the mouth of Middle Arm, Pioneer Creek and the northern part of Elizabeth River, areas associated with sloped of tidal creeks. Curvature was only used in the ABT/BRT analysis and used as a validation tool for BPI outputs.

5.3.4 Habitat maps

***Geomorphological map*.** The geomorphological map was primarily derived from benthic position index (BPI) data. BPI values provide a visual representation of regional highs, lows, slopes and flat areas for a given neighbourhood size. ABT/BRT identified 100 m neighbourhood size contributed most to explaining spatial distribution presence/absence of species and species richness. Fine scale and broad scale landscape characteristics were better described by using the 10 m and 250 m neighbourhood size windows. Results from BPI_{10}, BPI_{100} and BPI_{250} analyses are shown in Figure 5.18 and Figure 5.19. To assist interpreting the BPI results see Table 5.3 (methods section).

To simplify interpretation of the scale dependent BPI data, BPI data were grouped into 4 broad geomorphological zones (Crests - positive BPI values, Depressions - negative BPI values), Flats - BPI values near zero with slope data included, and Slopes - BPI near zero, but with slope data included (Figure 5.24). This was followed by merging of the BPI raster layers, which then could be grouped into structures, as defined in Table 5.3 (Lundblad *et al* 2005). The result of this analysis is shown in Figure 5.20 to Figure 5.22. Analysis showed clearly that sandbanks/waves are a dominant feature within the Middle Arm and Elizabeth River environment. Consequently these areas were separately mapped when creating the final geomorphological map (Figure 5.24).

Figure 5.19 shows that both Middle Arm and Elizabeth River are complex systems with intertwining channels, ridges, reef edges, large extents of flats and many sand banks. Many of these attributes are also working on varying spatial scales, eg with local high points within broad scale depressions (Pioneer Creek, northern part of Elizabeth River). The “mouth” of the Middle Arm, shows a complex reef that is cut by several deep channels. The reefs slopes are relatively gentle but with numerous slope-crests and slope-depressions, where as the broad scale reef crests are relatively flat with numerous fine scale depressions, which run SW-NE (Figure 5.21). The mouth of Middle Arm gives way to broad open flats and large sand bars/waves.

The mouth of Pioneer Creek shows similar structure as that of Middle Arm, although not as pronounced or extensive in its spatial distribution. Pioneer Creek is characterised by numerous sand waves that intersect the main channel. The channels in these areas are quite well defined; however, they do show quite a bit of variation on a finer scale with local crests (which are believed to rocky outcrops) and depressions. Consequently, the main channel is mapped as several isolated broad scale depressions with local fine scale narrow crests and depressions.

Blackmore River and Haycock Reach is characterised by sandbanks with very poorly defined channels and are mapped as a series of broad scale depressions. The depressions are not as complex as those in Pioneer Creek and have no signs of rocky out crops. The tidal creeks have well defined channels and flanked by steep sloped mud flats.

Elizabeth River mouth is more comparable to Pioneer Creek, in that the main channel is also a series of broad scale depressions intertwined with large sandbanks and intertidal mud/sand flats. The broad depression in front of and north of Short Islet is complex with the bathymetry showing numerous rocky outcrops (ie narrow crests and depressions). These seem to be a continuation of the intertidal reefs surrounding Short Islet (Figure 5.15). The depressions SE of Short Islet (north of Pikey and Slack Creek) are broad depressions with open bottom. Pikey and Slack Creek are a miniature version of Elizabeth River and characterised by broad depressions; sand banks at the mouths; and with steep sloped creek banks. The upper reaches of Elizabeth River are comparable to Blackmore River and Haycock Reach, with broad flats and large broad isolated depressions.

Figure 5.15. Aerial photograph of Short Islet, Elizabeth River. (DLP)

Broad scale habitat map. The broad scale habitat map shown in Figure 5.25 is based on the primary and secondary data layers, including BPI results, which were combined to suit the habitat classification scheme outlined in Figure 5.8 and Table 5.5. Area calculation and percentage of total areas for the habitat classes are presented in Table 5.10.

Within the open water environment (non-mangrove environment), subtidal and intertidal mobile sediments are the dominant habitats (45.3 and 36.5%, respectively). This was also demonstrated in the geomorphological map. Subtidal reefs are four times as more extensive than intertidal reefs (9.6 and 2.4%). However, within non-PS zone, hard substrates occupy over a third of the available substrate (38%).

To calculate the total intertidal area available within the study area, mangrove habitat neighbouring the survey areas was included. Total mangrove area is estimated to be 7750 ha and was considered to be a component of the Intertidal/mobile/PS zone/ smooth habitat class. As a result, the total intertidal area was 9524 ha, which equated to 75.5% of the estuarine environment.

Table 5.10. Area and percentage cover for habitats within the marine environment surrounding the Weddell development.

	Estuarine habitats			Open water		Open water including mangroves	
				ha	%	ha	%
1 Subtidal	non-mobile	below PS zone	rough	30	0.6	30	0.2
2 Subtidal	non-mobile	below PS zone	smooth	42	0.9	42	0.3
3 Subtidal	non-mobile	PS zone	rough	44	0.9	44	0.3
4 Subtidal	non-mobile	PS zone	smooth	400	8.2	400	3.2
5 Low intertidal	non-mobile	PS zone	rough	1	0.0	1	0.0
7 Low intertidal	non-mobile	PS zone	smooth	56	1.2	56	0.4
9 Intertidal	non-mobile			58	1.2	58	0.5
11 Subtidal	mobile	below PS zone	rough	24	0.5	24	0.2
12 Subtidal	mobile	below PS zone	smooth	91	1.9	91	0.7
13 Subtidal	mobile	PS zone	rough	140	2.9	140	1.1
14 Subtidal	mobile	PS zone	smooth	2200	45.3	2200	17.4
15 Intertidal	mobile	PS zone	smooth	1774	36.5	9524	75.5
			Total	**4860**	**100**	**12610**	**100**

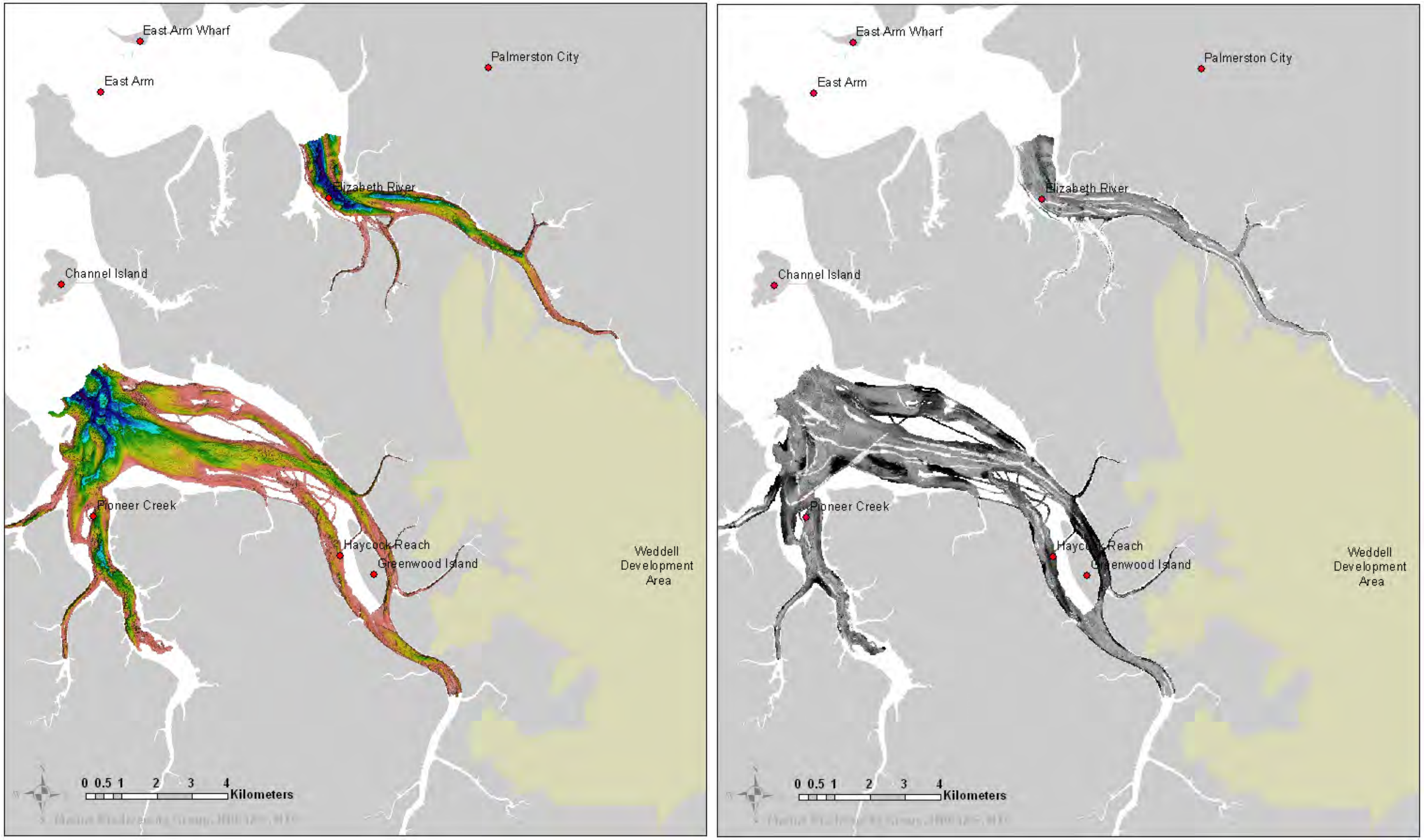


Figure 5.16. Bathymetry (**left**) and backscatter (**right**) data layers used for benthic habitat classification.

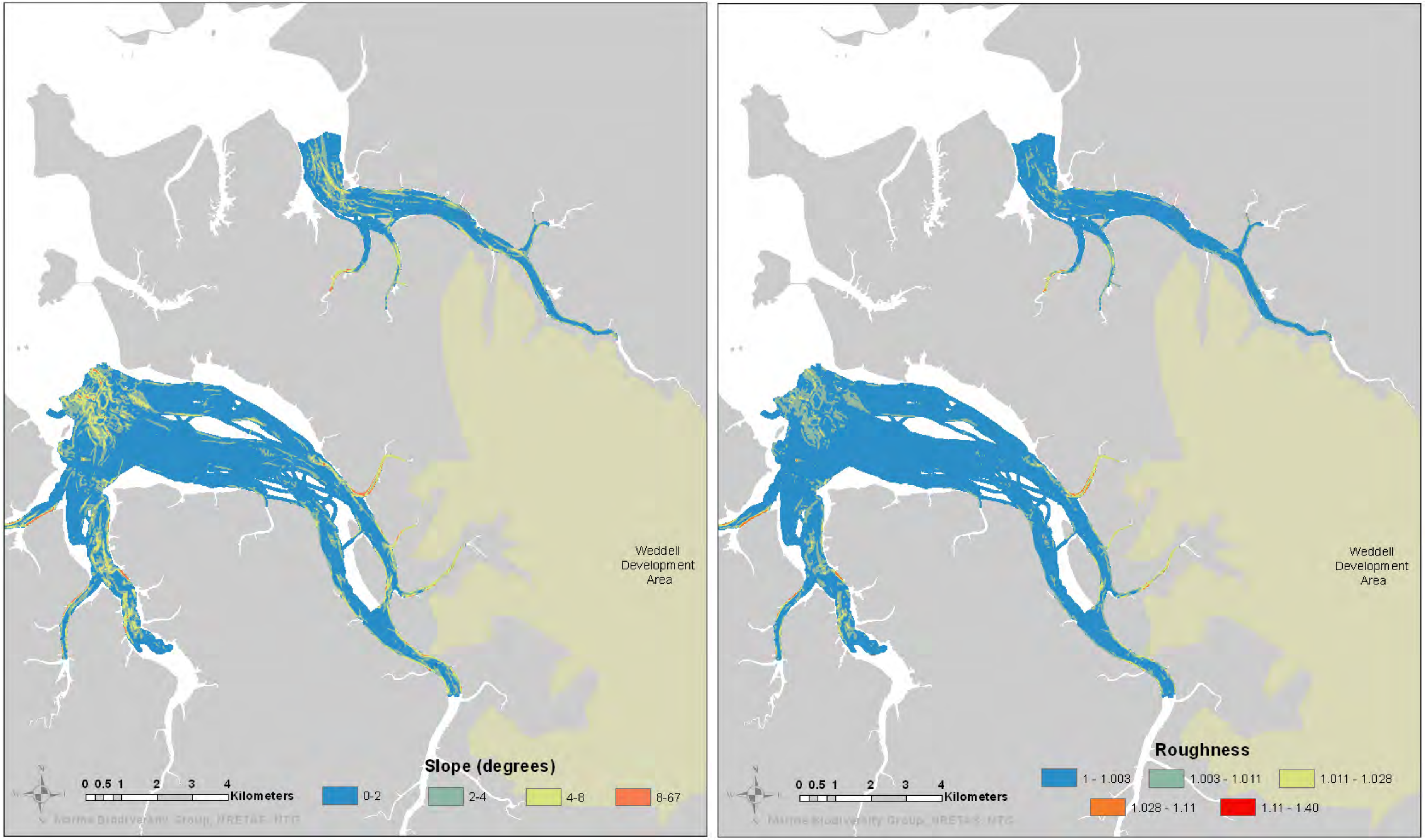


Figure 5.17. Slope (**left**) and Roughness (**right**), derived from bathymetric data.

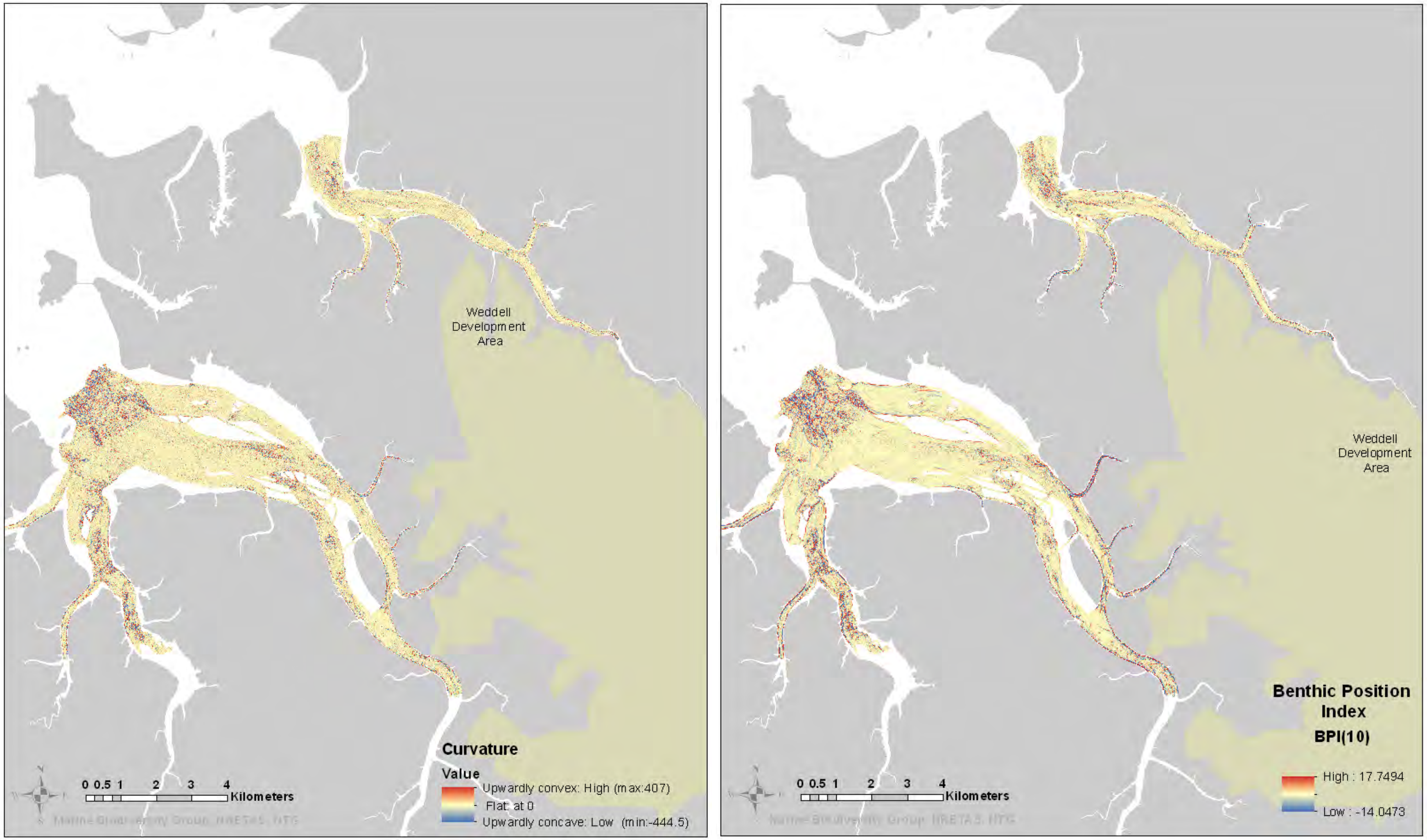


Figure 5.18. Left, Curvature. A positive curvature (**red**) indicates the surface is upwardly convex at that cell. A negative curvature (**blue**) indicates the surface is upwardly concave at that cell. A value of 0 indicates the surface is flat. The larger the value the more extreme the relief is. The ‘busier” the area, the more complex the relief is. **Right**, benthic position index for 10 m neighbourhood size (BPI_{10}).

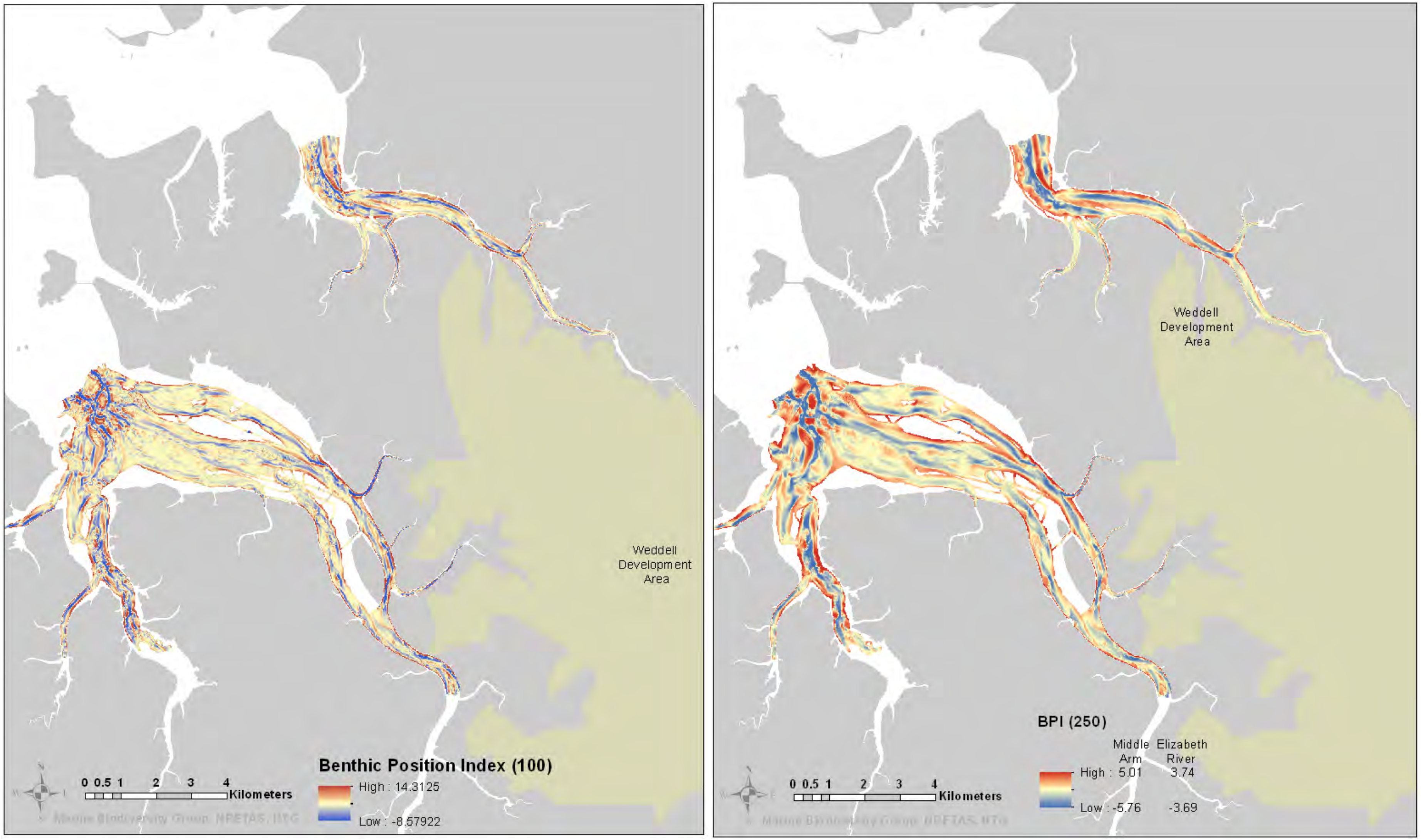


Figure 5.19. Benthic position index: **Left**, $BPI_{100\ m\ radius}$., **Right**, $BPI_{250\ m\ radius}$. Derived from Bathymetric data. BPI values provide a visual representation of regional highs, lows (**blue**), slopes (**red**) and flat areas (**yellow**) for a given neighbourhood size.

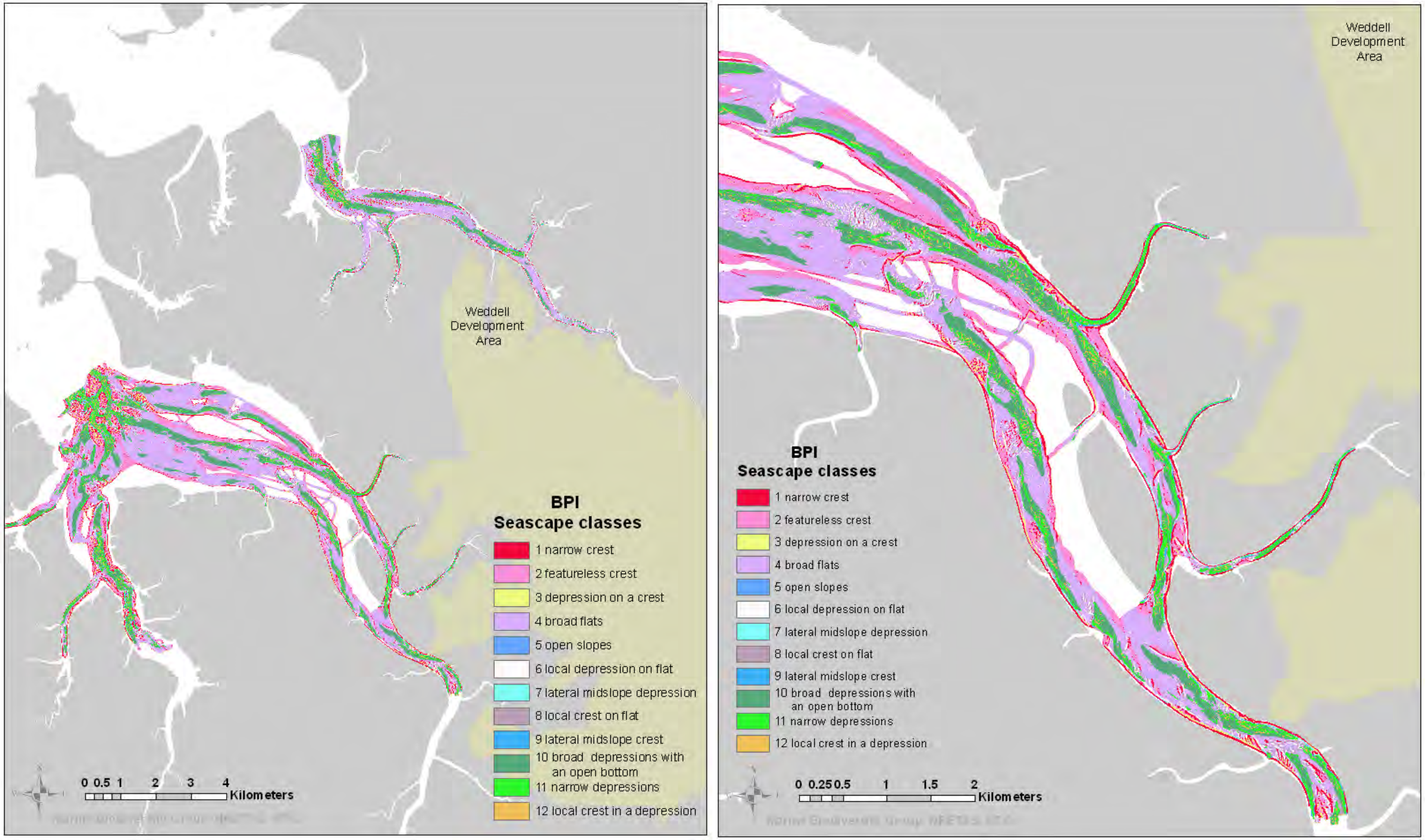


Figure 5.20. Benthic position index classification for study area (**left**) and Middle Arm: Blackmore River and Haycock Reach (**right**)

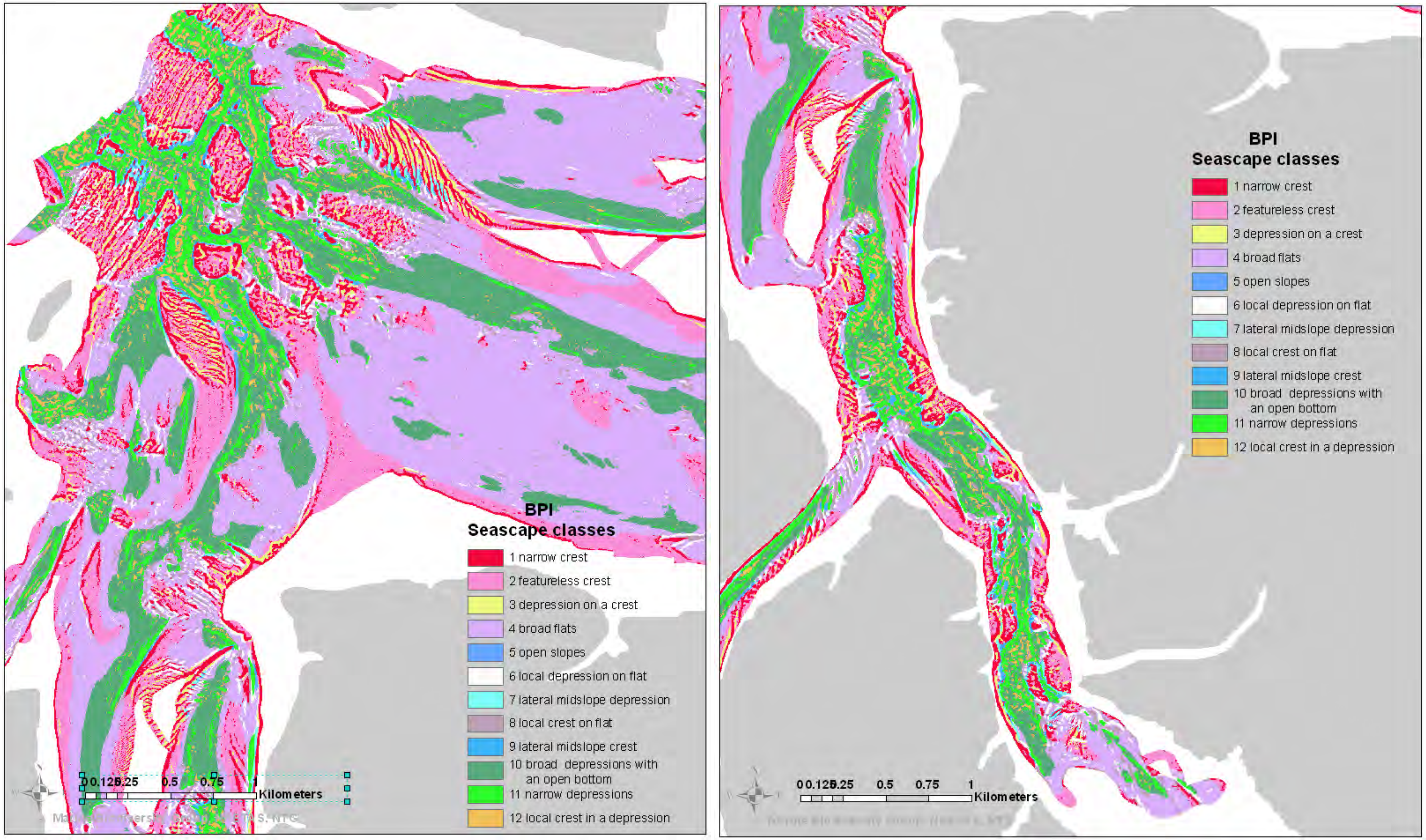


Figure 5.21. Benthic position index classification for Middle Arm. **Left**, “mouth of Middle Arm; **Right**, Pioneer Creek.

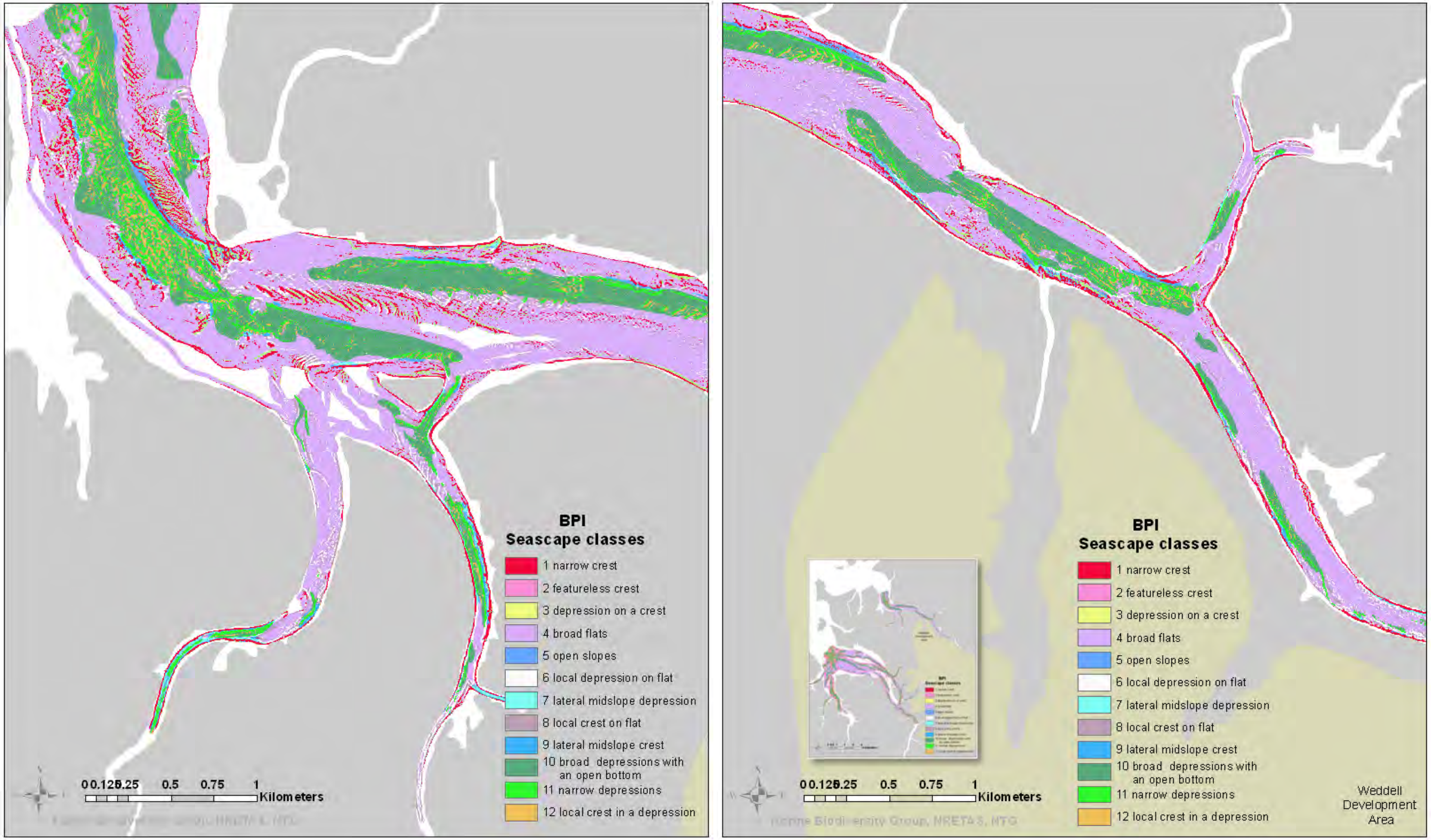


Figure 5.22. Benthic position index classification for Elizabeth River. **Left**, northern part; **Right**, central part.

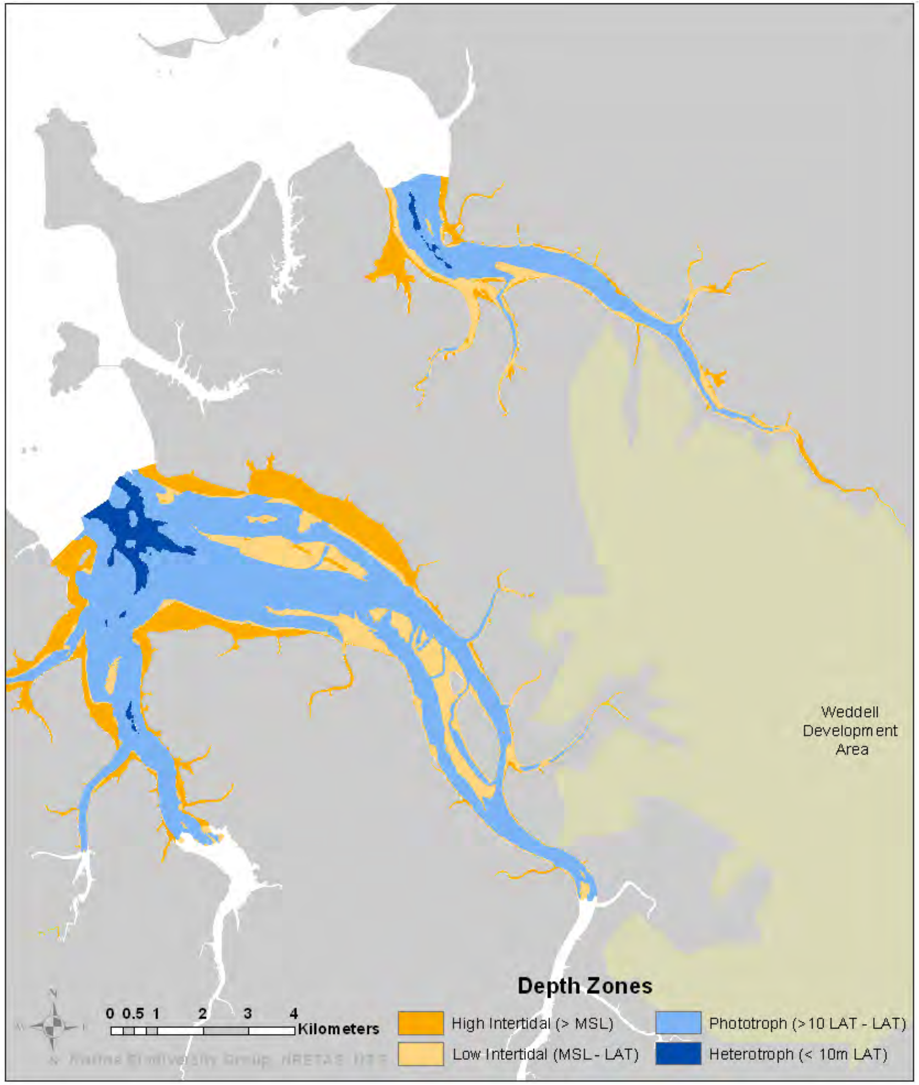


Figure 5.23. Depth classes based on mean sea level height, lowest astronomic tidal height and light availability.

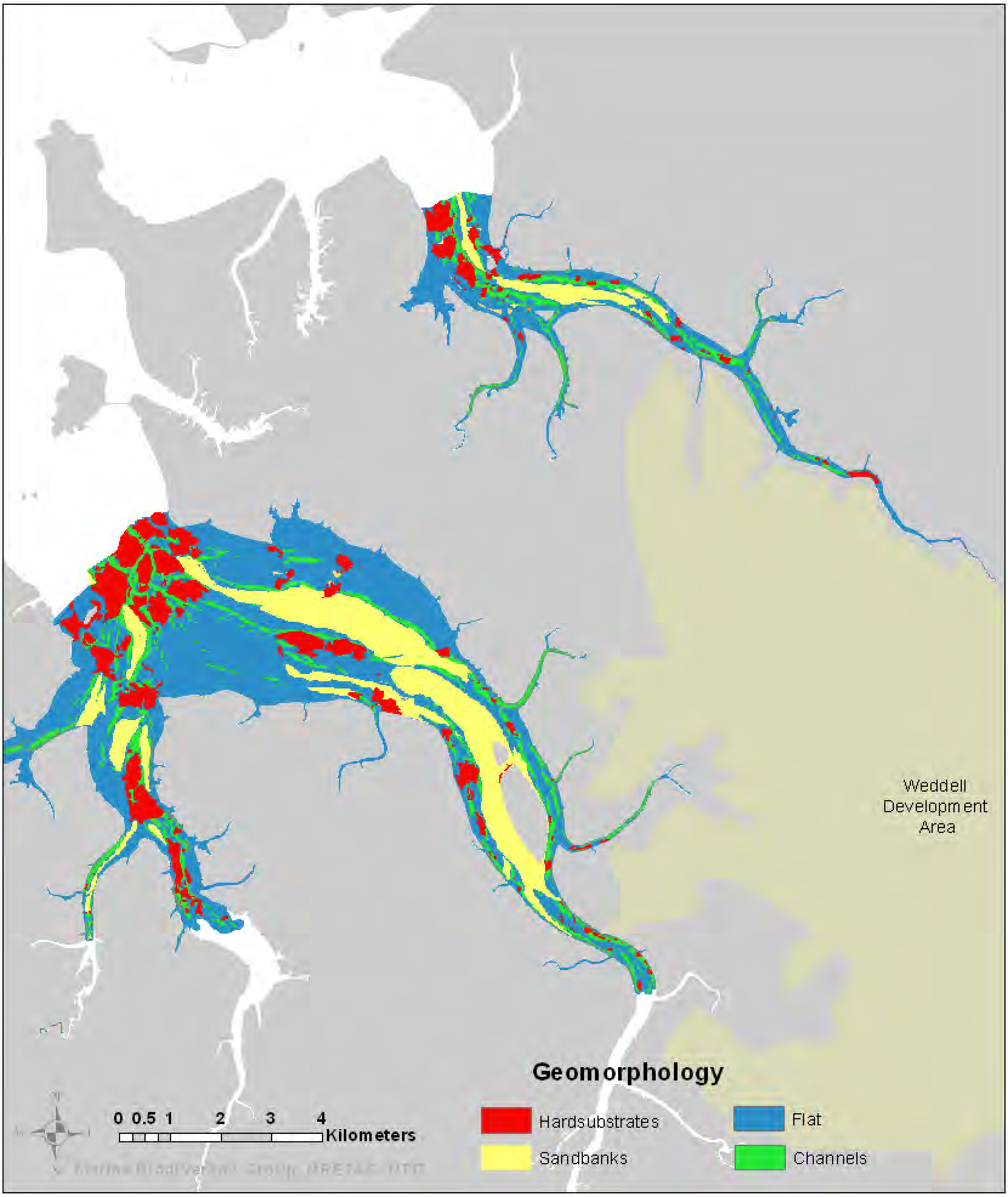


Figure 5.24. Seascape attributes. Data mapped from analysis of Benthic position index (BPI radius 100 m), slope, roughness, backscatter and bathymetric/aerial photography analysis.

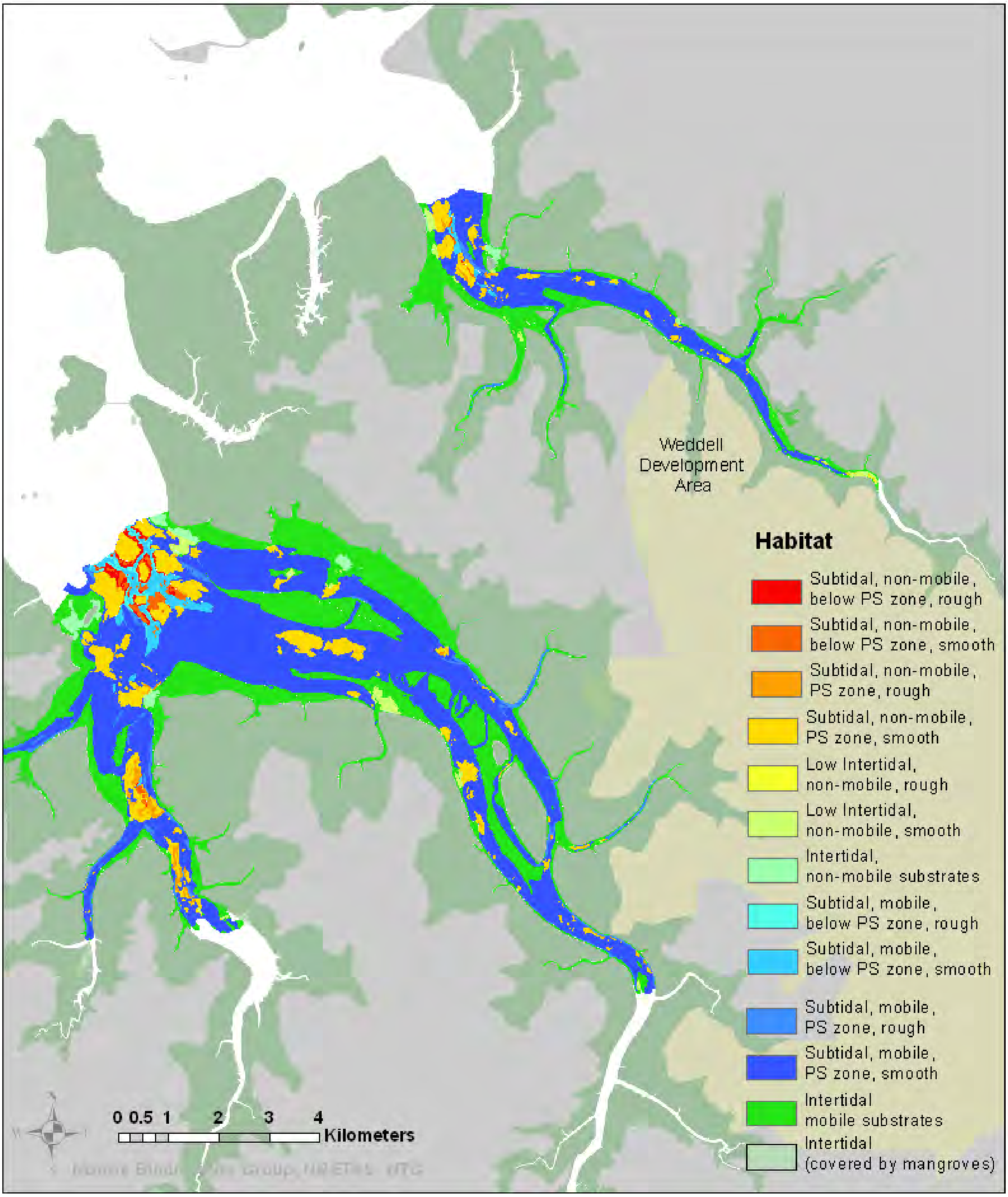


Figure 5.25. Habitat characteristics for estuarine areas neighbouring the proposed Weddell development area. Data combined from substrate, depth, roughness characteristics, Benthic position index. Intertidal area supplement by the area that is covered by mangrove communities (which was not surveyed in this study).

5.3.5 Community Habitat Maps

The community map was based on the habitat map, which was derived from physical environmental data and their derivatives, overlaid with information from iX Survey's underwater video data, MAGNT data and expert knowledge. The map shows Level 2 of the hierarchical classification of benthos characteristics (see Table 5.6, Figure 5.26). Area calculation and percentage of total areas for the community classes are presented in Table 5.11. Communities found in the study area are described in Table 5.12.

The majority of benthic communities consisted of soft-bottom (i.e. mobile sediments) benthos, community habitat classes 7–10. These communities are in general visually bare (no epibenthos) and are best described by substrate characteristics and the benthos living within the sediments (e.g. polychaetes, molluscs and crustaceans). Overall, coarse and soft muddy sediments supported few species and low abundance. However, in the main channels, where currents have removed the fine sediments, larger rocks or rocky outcrops may be dispersed in amongst coarse sediments. The benthos on these rocky substrates mirror that of filter-feeder / mixed community types. Where benthos is present, diversity is variable and abundance is low. Generally, these areas are found at the "mouths" of Middle Arm and Pioneer Creek. Depressions in Pioneer Creek, Elizabeth River and Blackmore River/Haycock Reach are dominated by mobile sediments and may have rocky outcrops. The mobile sediments are highly variable ranging from soft muds to sands. The rocky outcrops can be colonised by filter-feeders or mixed communities. The deeper depressions are characterised by soft sediments and may have large amounts of organic matter. The organic litter provides a niche for mobile organisms, such as the leaf porter crab (*Neodorippe simplex*) and smaller species of fish (e.g. the gobies *Drombus globiceps* and *Gobiopterus* sp).

The majority of benthos was associated with rocky habitat, which accounts for 11.8% of the open-water environment or 4.5% when mangroves included in the area calculations. Within deeper waters (e.g. mouth of Middle Arm), filter-feeders are the dominant trophic group, in which sponges, azooxanthelate gorgonians and soft corals, hydroids and ascidians are the most important fauna that provide structure for the community. They take into account of 1.5% of the open-water environment. However, for the aphotic subtidal zone they occur in 38% of the available area. The division into high, medium and low density communities is based on iX Survey data (numeric data from underwater video) together with the assumption that rugosity is in part a surrogate for biodiversity (Pitcher et al 2007). For example, reefal flats with low rugosity are less complex/diverse than reefal areas with high rugosity; reef slopes with high rugosity also have complex communities.

Hard substrate communities within the phototrophic zone (below mean sea-level height) are best described as mixed communities with varying degrees of cover of corals, alga, sponges, gorgonians, hydroids, with no species group having more than 40% cover. These communities were observed at the mouth of Middle Arm, Pioneer Creek and northern part of Elizabeth River. High intertidal reefal substrates (i.e. above mean sea level height) are generally bare. Benthic communities dominated by macro algae or corals (>50% cover) were not observed.

Table 5.11. Area and percentage cover for community classes within the marine environment surrounding the Weddell development.

Habitat Code / class	Estuarine Communities	Open water		Open water including mangroves	
		ha	%	ha	%
1	High Density Filter Feeders	30	0.6	30	0.2
2	Medium Density Filter Feeders	42	0.9	42	0.3
3	High Density Mixed Epibenthic community	44	0.9	44	0.3
4	Medium Density Mixed Epibenthic community	400	8.2	400	3.2
5	Low-Medium Density Mixed community	57	1.2	57	0.5
6	Bare Rocky Reef	58	1.2	58	0.5
7	Bare coarse sediments	24	0.5	24	0.2
8	Bare Sandy / Mixed sediments	2291	47.1	2291	18.2
9	Bare Coarse sediments - rippled	140	2.9	140	1.1
10	Bare sand / mud	1774	36.5	1774	14.1
20	Mangroves			7750	61.5
	Total	**4860**	**100**	**12609**	**100**

Table 5.12. Benthic community (Benthos) descriptions for estuarine areas neighbouring the proposed Weddell development area.

Habitat Code / class	**High Density Filter Feeders**	
1	Depth zone	Subtidal aphotic zone
	Substrate characteristics	Hard Substrate; high - medium rugosity; flat to steep sloping
	Geology/geomorphology	Reef (reef & reef slopes)
	Epibenthic Community composition	Dominated by a diverse and high abundance of heterotrophic non-photosynthetic fauna; Community composition is dominated by sponges (encrusting and erect), azooxanthellate gorgonians & soft corals, ascidians, hydroids. Lacks macro algae, corals. Is comparable to Class 2 (BMT WBM 2010) and includes taxonomic groups like Calyspongia and raspalids sponges; soft corals (Viminella, Junceella, and Dichotella); hydroids Lytocarpus and Agalophenia).
	Infauna	None
	Mobile fauna	Not sampled in this study
	Example / sites	
Habitat Code / class	**Medium Density Filter Feeders**	
2	Depth zone	Subtidal aphotic zone
	Substrate characteristics	Predominantly Hard Substrate and can have patches of coarse / mixed sediments; medium - low rugosity; flat
	Geology/geomorphology	Reef, Reef flat, tidal channel
	Epibenthic Community composition	Dominated by a moderately diverse and moderate abundance of non-photosynthetic fauna; Community composition is dominated by sponges (encrusting and erect), azooxanthellate gorgonians & soft corals, ascidians, hydroids. Lacks macro algae, corals. Is comparable to Class 2 (BMT WBM 2010) and includes taxonomic groups like Calyspongia and raspalids sponges; soft corals (Viminella, Junceella, and Dichotella); hydroids Lytocarpus and Agalophenia).
	Infauna	Polychaete worms
	Mobile fauna	shrimps
	Example / sites	Single site MBG27 (equivalent to 95 BMT WBM)
Habitat Code / class	**High Density Mixed Epibenthic community**	
3	Depth zone	Subtidal photic zone
	Substrate characteristics	Hard Substrate; high - medium rugosity; flat to steep sloping
	Geology/geomorphology	Reef, reef slope
	Epibenthic Community composition	Dominated by a diverse and high abundance of flora and fauna; Community composition is dominated by varying degrees cover and abundance of corals, macro algae, sponges (encrusting and erect), soft corals, ascidians, hydroids. Is comparable to Class 1, 6 (BMT WBM 2010, includes taxonomic groups like sponges (branching, lobate, massive, basket forming and encrusting (*Dysidea spp*.)) and corals (mostly Goniopora spp.); occasional clumps of the hydrozoans *Lytocarpus* sp. numerous soft corals, particularly alcyoniinds such as *Dendronephthya* spp., algae including *Halimeda* spp., *Caulerpa* spp. and *Botrycladida leptopoda*)
	Infauna	None

	Mobile fauna	Not sampled
	Example / sites	MBG 86 (106 BMT WBM)
Habitat Code / class	**Medium Density Mixed Epibenthic community**	
4	Depth zone	Subtidal photic zone
	Substrate characteristics	Predominantly Hard Substrate and can have patches of coarse / mixed sediments; medium - low rugosity; flat
	Geology/geomorphology	Reef, patchy reef, reef flat, tidal channel
	Epibenthic Community composition	Dominated by a moderate diverse and moderate abundance of flora and fauna; Community composition is dominated by varying degrees cover and abundance of corals, macro algae, sponges (encrusting and erect), soft corals, ascidians, hydroids. Is comparable to Class 1 (BMT WBM 2010).
	Infauna	Polychaetes and Gastropods with Bivalves
	Mobile fauna	Abundant fishes and gastropods with penaeoid crustaceans
	Example / sites	MBG9, MBG26 (BMT WBM96), MBG29 (BMT WBM93), MBG30, MBG33 (BMT WBM96), MBG40 (BMT WBM79), MBG56 (BMT WBM102), MBG69 (BMT WBM48), MBG76 (BMT WBM53), MBG77 (BMT WBM53), MBG79 (BMT WBM52) (MBG89 (BMT WBM105)
Habitat Code / class	**Low-Medium Density Mixed community**	
5	Depth zone	Intertidal below Mean Sea Level
	Substrate characteristics	Predominantly Hard Substrate and can have patches of mobile substrates, varying degrees of rugosity, generally flat or gentle sloping.
	Geology/geomorphology	Reef flat
	Epibenthic Community composition	Dominated by a moderate – low diverse and moderate – low abundance of flora and fauna; Community composition is dominated by varying degrees cover and abundance of corals, macro algae, sponges (encrusting and erect), soft corals, ascidians, hydroids. Upper zone is mainly bare rock dominated by oysters, limpets, barnecles, soft corals (*Singularia* sp., *Sacrophytum* sp., *Lobophytum* sp.) sponges (D*ysidea* sp.) turfing algae and macro algae (P*adina* sp. and *Caulerpa* sp.). The lower zone is comparable to that of Medium Density Mixed Community and Class 1 (BMT WBM 2010).
	Infauna	Polychaetes and Gastropods with Bivalves
	Mobile fauna	Crustaceans (true crabs, amphipods, shrimps and prawns), gastropods and Bivalves,
	Example / sites	MBG14, BMT WBM, MBG74, BMT WBM44, MBG75, BMT WBM44
Habitat Code / class	**Bare Rocky Reef**	
6	Depth zone	Intertidal, above MSL
	Substrate characteristics	Predominantly Hard Substrate and can have patches of mobile substrates, varying degrees of rugosity, generally flat or gentle sloping.
	Geology/geomorphology	Reef, Fringing reef flat, laterite platform
	Epibenthic Community composition	bare
	Infauna	
	Mobile fauna	
	Example / sites	Not sampled

Habitat Code / class	**Bare coarse sediment**	
7	Depth zone	Subtidal, aphotic zone
	Substrate characteristics	Predominantly Mobile sediments (coarse sediments) with large rocks or small rocky outcrops. Rugosity is medium to high and slope is generally flat.
	Geology/geomorphology	Tidal channel, channel side of reef slope
	Epibenthic Community composition	Bare in mobile substrates, however where rocky outcrops exist, benthic fauna will mirror that of filter feeder habitats. Where fauna is present, diversity is variable and abundance is low; the community composition is in part comparable to Class 3 (BMT WBM 2010).
	Infauna	
	Mobile fauna	
	Example / sites	Not sampled
Habitat Code / class	**Bare Sandy / Mixed sediments**	
8	Depth zone	Subtidal, aphotic and photic zones
	Substrate characteristics	Mobile sediment (sand to mixed sediments), Rugosity is low and slope flat to moderate.
	Geology/geomorphology	Sandy flats
	Epibenthic Community composition	Generally bare. Where fauna is present, diversity is variable and abundance is low; The community composition is in part comparable to Class 7, 8 & 9 (BMT WBM 2010). Occasional sponges (eg *Oceanapia*), hydroids, ascidians and soft corals (eg *Nephthya*).
	Infauna	Polychaetes
	Mobile fauna	Fishes, true crabs, Penaeoid prawns
	Example / sites	Numerous sites (total 46 sites); Most diverse: MBG19, 20 & 22; MBG5 (BMT WBM 79), MBG27 (BMT WBM70) Bare sites: MBG7, MBG50 (BMT WBM 99), MBG68 (BMT WBM 48),
Habitat Code / class	**Bare Coarse sediments - rippled**	
9	Depth zone	Subtidal, photic zone
	Substrate characteristics	Sands, rugosity medium and slope is variable
	Geology/geomorphology	Sand flats (rippled), sand waves
	Epibenthic Community composition	Bare The community composition is in part comparable to Class 7, 8 & 9 (BMT WBM 2010).
	Infauna	Very few Polychaetes and Bivalves
	Mobile fauna	Crustaceans (prawns, shrimps and Mysids
	Example / sites	Most diverse: MBG10, Low-bare sites: MBG5, MBG59 (BMT WBM103), MBG66 (BMT WBM111), MBG87 (BMT WBM116)
Habitat Code / class	**Bare sand / mud**	
10	Depth zone	Intertidal
	Substrate characteristics	muds & sands, low rugosity and generally flat or gently sloping.

	Geology/geomorphology	Intertidal Flats
	Epibenthic Community composition	Bare The community composition is in part comparable to Class 7, 8 & 9 (BMT WBM 2010).
	Infauna	Polychaetes, Bivalves and Gastropods
	Mobile fauna	Fishes, gastropods, true crabs, prawns and shrimps,
	Example / sites	Most diverse: MBG11, MBG24 Low-bare sites: MBG6, MBG58 (BMT WBM103), MBG88 (BMT WBM105)
Habitat Code / class	**Mangroves**	
20	Depth zone	Intertidal
	Substrate characteristics	muds & sands, low rugosity and generally flat or gently sloping.
	Geology/geomorphology	Intertidal Flats
	Epibenthic Community composition	Bare (fauna), Flora dominated by mangroves
	Infauna	Polychaetes, Bivalves and Gastropods
	Mobile fauna	Fishes, gastropods, true crabs, prawns and shrimps,
	Example / sites	

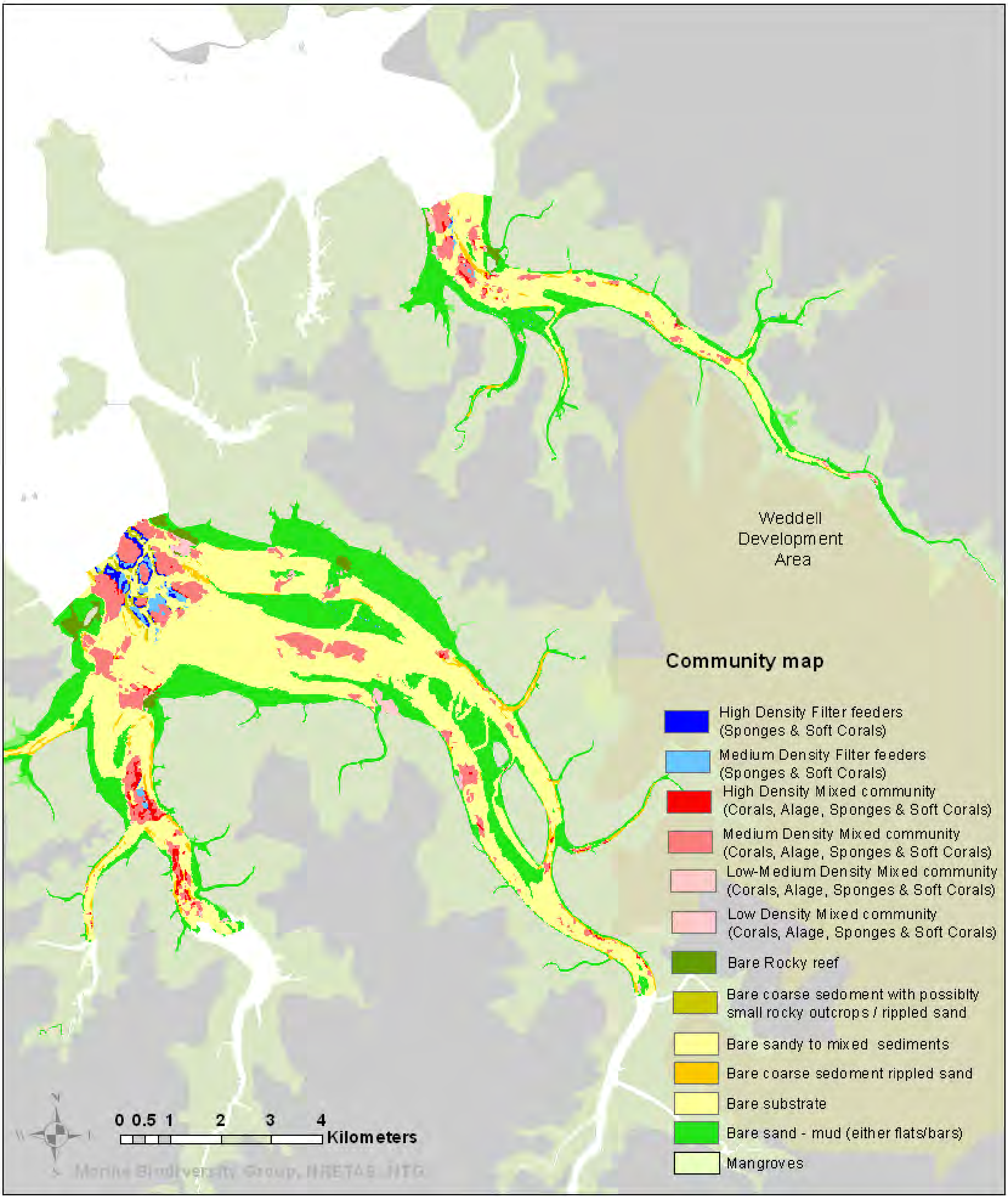


Figure 5.26. Benthic community (Benthos) map for estuarine areas neighbouring the proposed Weddell development. Data combined from substrate, depth, roughness characteristics, benthic position index. Intertidal area supplement by the area that is covered by mangrove communities (which was not surveyed in this study).

5.4 Discussion

This study represents one of the first attempts in the Northern Territory to integrate a wide range of existing and new spatial data sets to describe and map the marine environment. Based on the premise that community types in part can be predicted from physical characteristics of the environment they live in, this study has taken a rigorous and structured approach to describe habitats and biotopes within Elizabeth River and Middle Arm. Individually, physical data may not provide the whole picture, however when combined with other data sets to create habitat maps they can effectively describe the distribution of benthos. Key to the process was the underlying bathymetric and backscatter data collected using full coverage multibeam echosounder system. However, backscatter data was not used to its full potential, for two reasons. Firstly, the backscatter data showed a considerable amount of banding where the bathymetric survey swaths overlapped (Figure 5.3). This is a processing issue and given that there was no access to dedicated software that is required to process these types of data the backscatter data was not reanalysed. Secondly, backscatter data was not calibrated against sediment type (i.e. no sediment samples were taken in order to reliably use backscatter data as a surrogate for sediment type). Consequently backscatter data could not be used to create full coverage map for sediment grainsize. Nevertheless, the backscatter image was used to fine tune the spatial distribution of broad scale physical parameters, such as hard substrates, channel and some extent sand flats, which were incorporated into seascape maps.

As a consequence, the final sediment grainsize maps had to be derived from interpolation of existing grainsize data sets. Although 308 samples across the whole of Darwin Harbour (38 within the study area) were used for spatial interpolation of median grainsize, the results reflect inadequate sampling intensity to properly account for the quite patchy nature of sediments in shallow estuarine waters. Furthermore, the results suffered from the undersampling of intertidal environments. Consequently, sediment grainsize did not assist in defining biotic assemblages, even though it is well established that grainsize is a key environmental factor for understanding benthos composition (Gray and Elliot 2009, Pitcher *et al* 2007).

Under normal circumstances, the BPI zones (i.e. seascapes) and habitat would form the basis for gap analysis and planning for *in situ* sampling of benthos and substrates (*a priori* stratification).

Table 5.13. Number of sites for each seascape class.

Seascape class	1	2	3	4	5	6	7	8	9	10	11	12
Number site	18	7	3	29	2	6	2	3	1	15	10	5

This would then allow benthos to be grouped into community types within the different seascape / habitat classes. However, this study only used existing data and only collected additional data to provide a more comprehensive description of the benthos at existing iXSurvey sites. Consequently, not all BPI zones/structures and habitats were adequately sampled and did not allow a robust statistical analysis of spatial distribution of benthos across all habitat and BPI zones/structures (see Table 5.13). This is, in part, why the boosted regression trees analysis, which would allow prediction of spatial distribution of community types, did not perform as expected. As a result, the final community maps were based on expert knowledge and existing species information (iXSurvey underwater video data and MBG / MAGNT infauna/epifauna data) were used to describe community types that could be expected on the derived habitat classes. It is important that this is kept in mind when using the benthos community map.

5.4.1 Habitats and distribution

Community classes in this study are biased towards benthos living on the seafloor (epibenthos), and is a reflection of the sampling methods used to describe the benthos (predominantly underwater video). Nevertheless, it does provide a good representation of distribution and description of epibenthic benthos within the study area.

Mangrove community is the largest community type in Darwin Harbour and occupies over 60% of the available estuarine environment. Mangrove communities were not assessed in this study but have been described by Brockelhurst et al (2011). Excluding mangrove community, epibenthic communities in open water environments are generally associated with hard substrate environments. These occur mainly in the ”mouths” of Middle Arm and Pioneer Creek and in depressions in Elizabeth River and Pioneer Creek. Available hard substrate is close to 13% of the available substrates and compares reasonably well with what Geo Oceans (2011) found for inshore areas between Gunn Point and Cullen Bay (18%, based only on ‘high confidence habitats’ Geo Oceans 2011). Interestingly, 46% of hard substrate mapped by Geo Oceans was bare, in comparison to only 9% in the Elizabeth River / Middle Arm region. This is largely explained by the majority of hard substrates in the Elizabeth River / Middle Arm region being located in the ‘mouth’ of Middle Arm and are subtidal. Hard substrates surveyed by Geo Oceans had a higher proportion of intertidal reefs (Geo Oceans 2011) which generally have fewer species and lower abundances.

The Middle Arm / Elizabeth River region is less diverse than the outer-harbour environments. In Middle Arm / Elizabeth River, only two epibenthic community classes were encountered: filter-feeders (1.5% of available substrate) and mixed epibenthic communities (10.3%) - defined as ‘varying degrees of contribution by corals, algae and filter-feeders without a single group being dominant' - where as Geo Oceans describe four community classes: hard coral (1%), macro-algae (1%), filter-feeder dominated (6%) and mixed communities (2%). This is most likely reflects differences in environmental / water quality parameters for both areas. The outer-harbour sites are predominantly located in sandy environments (see substrate map, Figure 5.10), with potentially clearer waters and are thus more suitable for phototrophic species like corals and algae. In Middle Arm / Elizabeth River however, mangroves are the dominant feature, resulting in more turbid waters and thus favouring filterfeeders and only those species of corals and alga that can tolerate higher sediment loads and reduced light availability.

Mobile substrates account for 87% of the available substrate. However, community classes used in this study do not adequately describe mobile substrates in Elizabeth River and Middle Arm. The community types in these habitats are better described by their infauna. Although additional grab sampling was done by MBG at sites sampled by iXSurvey, the variability of the species composition within the mobile sediments was not adequately explained by the grainsize, which was used as a surrogate for infauna in this study. Although MAGNT has collected large numbers of infaunal specimens for taxonomic purposes, there has yet been no effort to link species with the environment parameters or describe the fauna as a community. This is largely due to the difficulties in describing mobile sediments whilst recording species presence. For example, underwater video can only record the presence of epibenthos and indicate the presence of infauna through recording the presence/absence of bioturbation at the seafloor/water interface; grab samples can provide information on species presence and abundance and substrate type if sediment samples are retained for analysis. However, to describe the mobile substrates and the fine scale structures within sediments (comparable to BPI structures/zones for epibenthic communities) other physical and chemical data will need to be collected. The rate of sediment chemistry processes (e.g. carbon, nitrogen and sulphur cycles) and fauna and flora composition in and on the sediment are very much linked (Kristensen and Blackburn 1987; Pearson and Rosenberg 1978, Gray and Eliott 2009). However, to what extent differences in sediment biogeochemistry determines which flora and fauna are present and/or what extent does the nature of the fauna and flora control the rates of biogeochemical processes is largely unknown for the Darwin Harbour region. Until the baseline data that underpin these processes have been collected it will not be possible to establish meaningful mobile substrate community classes and develop monitoring programs associated with potential impacts to infaunal communities from the Weddell development.

In summary, the BPI zones, habitats and community maps provide an improved understanding of the spatial variability of benthos across the study area. However, the maps could be further improved by having (and collecting) better defined surrogates for mobile substrates and to appropriate *in situ* sampling design based on physical environmental spatial data sets and its derivative maps.

5.4.2 Habitat Significance

Filter-feeder and mixed communities on subtidal hard substrate habitats are considered to be biodiversity hot spots within the study area and are productive and dynamic ecosystems. Besides providing a structure for a wide range of benthos to attach, reefal communities also form complex trophic structures with multiple pathways and interrelationships between primary producers (e.g. micro and macro algae), herbivores (fishes, crustaceans), detritivores (e.g. fishes, crabs), carnivores (e.g. fishes, worms, molluscs) and decomposers (bacteria). Further, the complex reef structures and large epibenthic fauna provides ample refuge for mobile benthos (e.g. fishes, crustaceans, molluscs).

There are three important “hot spots” within the study area: 1) in the ‘mouth’ of Middle Arm, 2) the depressions in Pioneer Creek, and 3) northern part of Elizabeth River. The ‘mouth’ of Middle Arm is geomorphologically complex (reef flats, rough reef slopes channels with varying substrates types and smaller patchy rocky outcrops); has a wide range of hydrodynamic conditions; and is probably a key refuge area for reefal fauna for Middle Arm. In contrast, the depressions in Pioneer Creek and northern part of Elizabeth River are more protected; have smaller patches of hard substrates amongst larger areas of mobile sediments; more likely to be influenced by fresh water influx during the Wet; and more readily to accumulate organic matter. These depressions are likely to be less diverse and attract different assemblages than the “mouth” of Middle Arm. The benthos in these depressions may also be quite variable between seasons due to the freshwater flow during the Wet.

In contrast to reefal communities, mobile substrates have low diversity and generally low overall abundances; communities are highly variable and patchy in their distribution. The importance of these communities in Darwin Harbour is still poorly understood. In general, mobile substrates ecosystems form a complex trophic structure with a multitude of nutrient pathways and interrelationships. For example, many of the detritus-eating fish, invertebrates and bacteria play an important role in recycling organic matter and detritus and making nutrients available to primary producers (e.g. algae). Conversely these species are also a food resource for the next trophic level and many predatory fish and invertebrates are attracted to soft-substrate habitats to forage. Soft substrates are also connected to other habitats, such as mangroves, subtidal reefs, salt marshes and the open ocean. This connection assists the movement of organisms, in particular when different habitats are used within different stages of their life cycles (e.g. prawns, mud crabs). Besides the ecological importance of mobile substrates, they perform many valuable functions to humans. For example, mobile substrates have the ability of removing contaminants from the water. Plants and bacteria break down many pollutants into less harmful forms. Uptake by sediments and burial in the mobile substrates minimise the toxic effects of pollutants. However, there is a limit to this carrying capacity and excessive input of nutrient and pollutants can overburden the cleansing capabilities of mobile substrates.

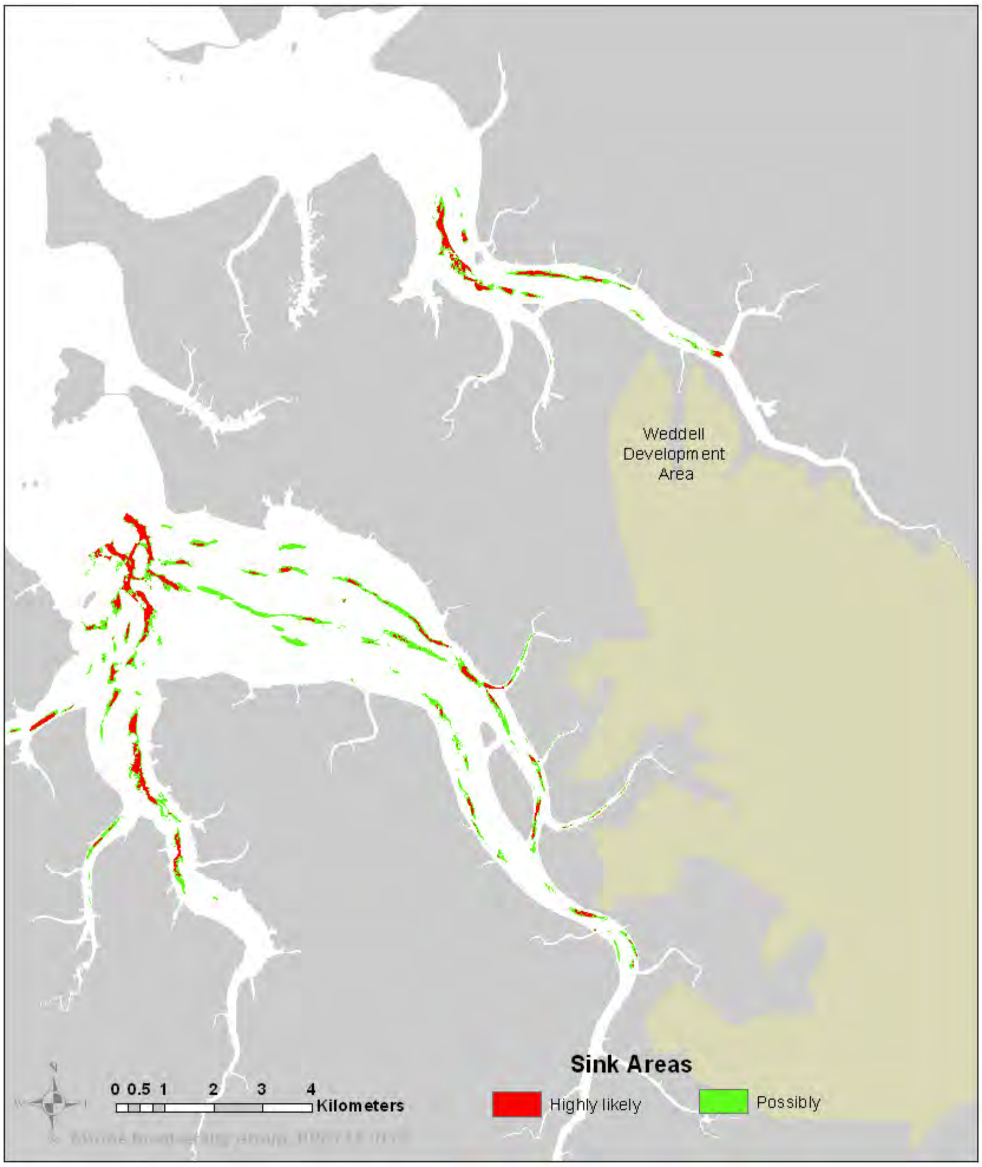


Figure 5.27. Likely deposition/sink areas within Elizabeth River and Blackmore River/Haycock Reach. Derived from BPI indices and river flow analysis (ArcGis 10). Note that sink areas highlighted in the mouth of the Middle Arm are unlikely to occur, as these are channels that lead into Darwin Harbour proper and is a artefact of from only analysing bathymetry up to the mouth of Middle Arm and not taking into account the whole Darwin Harbour bathymetry.

5.4.3 Information gaps

Community classes described in this study (and others in Darwin Harbour) are biased towards benthos living on the seafloor (epibenthos), reflecting the sampling methods used to describe the benthos (predominantly underwater video). However, not all identified seascapes and habitats were adequately sampled to provide a comprehensive description of the benthos in the study area. In particular the complex landscape in the depressions of Elizabeth River and Pioneer Creek and the ‘mouth’ of Middle Arm warrant more detailed description.

Mobile substrates, which occupy over 85% of the available open-water substrate, are relatively poorly described in this report, using sediment grainsize. Beside grainsize, there are a multitude of physical-chemical variables that are important for describing sediments as a habitat for biota, such as current/shear strength at the seafloor/water interface and sediment compactness / hardness (sediment mobility); porosity and permeability (movement of water within sediments); oxygen content and redox potential (chemical processes); light availability (primary production); and organic content (nutrients). Further, an understanding of the biota that inhabits these sediments is also critical, in particular microphytobenthos and bacterial communities, as they play an integral part of ecosystem pathways. Improved data on sediment characteristics (current strength, sediment grainsize with depth, oxygen profile, bacterial composition with depth, microphytobenthos composition, macrobenthos) in the marine area around Weddell is required to more comprehensively map substrate communities and monitor potential impacts.

5.4.4 Future considerations

It is recommended that the following is taken into consideration for future work:

- Undertake a biodiversity assessment of all identified seascapes in the ‘mouth’ of Middle Arm (e.g. to GHD, 2009), to determine the area’s uniqueness and to aid development of appropriate monitoring programs, if required.

- Undertake a biodiversity assessment of all identified seascapes in the depressions in Elizabeth River and Pioneer Creek, to determine the area’s uniqueness and to aid development of appropriate monitoring programs, if required.

- Determine the sediment characteristics (current strength, sediment grainsize with depth, oxygen profile, bacterial composition with depth, microphytobenthos composition, macrobenthos) for mobile substrates in the depressions of Elizabeth River and Pioneer Creek and within the zone of influence from proposed sewage disposal in Blackmore River.

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Appendices

Appendix 1. Museum and Art Gallery Northern Territory identified specimens collected from benthic surveys

Group / Family / Species	Site Number (Number of specimens at site)
Crustaceans (Amphipods)	
Aoridae	
Grandidierella cf japonica	20(23)
Grandidierella gilesi	22(1), 79(9), 203(3)
Grandidierella sp.	74(1)
Caprellidae	
caprellinae sp.	79(1)
Corophiidae	
Paracorophium sp.	2(1)
Maeridae	
?Ceradocus sp.	52(1), 74(1)
Parelasmopus sp. 1	41(1)
Quadrivisio sp. nov.	20(36), 22(9), 23(1), 36(1), 41(4)
Melitidae	
Melita sp.	20(7)
Podoceridae	
Podocerus sp.	41(1)
Unkown	
Unknown	56(1)
Crustaceans (Decapods)	
Alpheidae	
Alpheopsis equalis (?)	35(1)
Alpheus sp. 1	15(1), 19(3), 22(4), 27(1), 35(1), 41(1), 51(2), 64(2), 81(3), 83(2), 203(4)
Alpheus sp.1	20(9), 23(1)
Athanus sp.	35(1)
Genus nov. ? sp.	79(1)
Synalpheus sp. 1	34(1), 35(2)
Unident	34(1)
Camptandriidae	
Takedellus ? sp. nov.	24(1)
Diogenidae	
Clibanarius infraspinatus	83(1)
Diogenes avarus	85(8)
Unident sp.	10(1)
Dorippidae	
Neodorippe ? simplex	3(1), 10(2), 11(77), 12(1), 13(2), 14(2), 15(4), 19(90), 20(47), 22(104), 23(2), 24(2), 35(12), 37(3), 39(1), 41(23), 45(3), 47(2), 48(1), 49(1), 51(6), 57(1), 63(2), 77(4), 81(5), 83(3), 85(2), 203(6)
Hippolytidae	
Latreutes sp. 1	19(1), 20(8), 23(1)
Latreutes sp. 2	20(1), 41(1)
Lysmata vitata	35(1), 73(1)
Hymenosomatidae	
Elamenopsis lineata	2(1)
Neorhynchoplax minima	51(1)
Leuciferidae	
Lucifer sp.	19(1), 20(3), 22(1), 24(42), 41(27), 51(11)
Majidae	
Oncinopus ? sp. nov.	35(1), 37(1)
Phalangipus longipes	35(1)
Matutidae	
Matuta victor	11(3)
Ogyrididae	
Ogyrides myobergi	35(1)
Palaemonidae	
Leandrites celebensis	3(2), 5(2), 14(1), 20(2)
Pontiniinae unident sp 1	41(3)
Unident sp.1	3(2), 10(5), 201(1), 202(73)
Unident sp.2	10(8), 11(5), 19(2), 20(3), 22(6), 39(1), 62(1), 67(1), 81(4), 202(42), 203(572)
Unident sp.3	20(1)
Unident sp.4	25(1), 35(1), 41(2)
Pandalidae	
Chlorotocella gracilis	41(1)
Penaeidae	
Atypopenaeus bicornis	35(2)
Metapenaeopsis ? wellsi	35(3), 41(10)
Metapenaeopsis sp. A	69(1)
Metapenaeus dalli (?)	10(10), 11(72), 19(6), 22(51), 24(11), 35(17), 39(1), 41(1), 43(2), 49(7), 51(3), 57(1), 59(1), 61(4), 65(2), 67(4), 81(6), 83(4), 85(5), 202(2)
Metapenaeus ensis	10(7), 19(2), 24(5), 39(2), 45(2), 55(1), 61(2), 203(217)
Metapenaeus ensis (?)	20(4), 37(2), 41(5), 43(1), 81(1), 83(2), 85(4)
Metapenaeus insolitus	24(1)
Metapenaeus insolitus (?)	20(1)
Metapenaeus sp.	35(1), 37(1), 55(1)
Metapenaeus sp. C	10(4), 15(3), 20(1), 23(2), 24(1), 45(1), 65(1), 81(1), 201(1)
Parapenaeopsis arafurica	10(3), 19(4), 37(2), 45(2), 51(3), 53(1), 55(2), 57(1), 63(9), 81(1), 83(3)
Penaeus merguiensis	10(1), 19(1), 35(1), 37(1), 39(1), 41(3), 43(4), 45(15), 47(2), 49(1), 81(3), 83(1), 85(2), 203(1)
Trachypenaeus fulvus	39(2), 77(1)
Trachypenaeus sp.	19(1), 20(4), 24(18), 47(1), 49(1), 51(1), 61(1), 73(1)
Unident	24(1)
Pilumnidae	
Benthopanope estuarius	19(2), 20(1), 22(1), 61(2), 73(1), 81(1), 203(1)
Porcellanidae	
Polyonyx biunguiculatus	51(6)
Porcellana furcillata	51(1), 73(2)
Portunidae	
Charybdis anisodon	22(1), 24(2), 39(3), 41(4), 49(1)
Charybdis callianassa	35(2), 37(3), 39(5), 45(15), 47(4), 49(1), 51(6), 55(8)
Charybdis cf callianassa	69(1)
Charybdis sp.	18(1)
Portunus armatus	71(1)
Scylla serrata	41(1)
Thalamita spinifera	35(1)
Sergestidae	
Acetes sibogae	3(8), 10(207), 14(1), 19(196), 20(120), 22(1), 24(2), 25(1), 31(32), 32(41), 33(2), 35(22), 37(1), 51(1),

Group / Family / Species	Site Number (Number of specimens at site)
	201(4), 202(1034), 203(349)
Varunidae	
Utica boreenensis	15(1), 19(1), 20(4), 22(1)
Unkown	
Unknown	51(1)
Crustaceans (Other)	
Apseudidae	
? Whiteleggia sp.	4(1), 23(1), 40(1), 44(1)
Cirrolanidae	
	41(1)
Limnoriidae	
	20(2)
Mysidae	
	10(43), 19(22), 20(18), 22(1), 24(5), 31(1), 35(22), 39(1), 41(3), 51(4), 55(1), 203(3)
Paranebaliidae	
Paranebalia sp.	35(2)
Sphaeromatidae	
	41(2), 203(7)
Unkown	
Unknown	35(1), 41(6), 44(3), 56(1), 79(1)
unident.	22(1)
Larva unident.	20(1), 31(1), 32(2), 33(1), 34(1), 51(4), 53(1), 65(2)
Unident	24(2), 51(1)
Unident sp.	20(1)
Echinoderms	
indet	
indet indet	32(1)
Oreasteridae	
Gymnanthenia globigera	35(1)
Fish	
Aploactinidae	
Bathyaploactis curtisensis	71(2)
Bathyaploactis ornatissima	20(2), 22(1), 41(1), 51(2), 81(2)
Apogonidae	
-	24(1), 35(1)
Apogon melanopus	35(1)
Apogon poecilopterus	77(1)
Apogon rueppellii	203(3)
Apogon unitaeniatus	35(3), 39(10), 41(1), 49(1)
Siphamia roseigaster	79(2), 83(1)
Batrachoididae	
Batrachomoeus trispinosus	20(1)
Bothidae	
Arnoglossus sp	35(1), 39(1)
Callionymidae	
Repomucenus russelli	20(1), 24(1), 39(2)
Clupeidae	
Herklotsichthys gotoi	63(1), 203(7)
Nematalosa come	65(2)
Cynoglossidae	
Cynoglossus maculipinnis	37(6), 77(1), 81(1)
Drepaneidae	
Drepane punctata	11(1), 19(1), 20(1), 81(1)
Eleotridae	
-	19(2), 31(3), 41(2)
Butis butis	19(1), 20(1)
Butis koilomatodon	11(3), 19(4), 20(22), 22(5), 34(1), 35(2), 41(1), 63(1), 67(1), 79(4), 81(1)
Butis sp	11(1), 20(2)
Butis?	20(1)
Prionobutis microps	83(1), 203(1)
Engraulidae	
Papuengraulis micropinna	202(1)
Stolepherus sp	202(2), 203(2)
Stolephorus sp	10(3)
Thryssa sp	31(3)
Ephippidae	
Zabidius novemaculatus	77(1)
Gobiidae	
-	11(2), 14(1), 19(4), 20(9), 24(14), 35(1)
Butis koilomatodon	24(1), 203(1)
Caragobius rubristriatus	85(2), 203(1)
Drombus globiceps	3(10), 11(1), 19(1), 22(11), 201(3), 203(6)
Drombus ocyurus	39(1), 67(4)
Drombus triangularis	22(2)
Drombus triangularis?	3(5), 20(2)
Favonigobius	3(1)
Favonigobius melanobranchus	3(4), 22(3), 67(1)
Favonigobius reichei	22(1)
Favonigobius sp	22(1)
Gobiopterus sp	19(2), 20(1), 31(8), 35(12)
Gobiopterus sp A	19(3)
Pandaka rouxi	201(1)
Psammogobius biocellatus	24(1)
Redigobius nanus	11(1), 20(2), 22(1), 79(1), 202(7), 203(1)
Haemulidae	
Pomadasys kaakan	67(1), 203(2)
Pomadasys maculatus	37(1), 57(1), 81(3), 85(2)
Leiognathidae	
-	11(3), 19(1)
Leiognathus blochii	203(7)
Leiognathus sp	24(1), 55(2), 63(2), 67(3)
Secutor sp	11(1), 24(1)
Lutjanidae	
Lutjanus johnii	203(1)

Appendix 1

Group / Family / Species	Site Number (Number of specimens at site)
Lutjanus malabaricus	20(1), 71(2)
Monacanthidae	
Anacanthus barbatus	71(1)
Paramonacanthus choirocephalus	35(1), 45(1)
Paralichthyidae	
Pseudorhombus arsius	11(1), 24(1)
Pholidichthyidae	
Pholidichthys anguis	71(2)
Platycephalidae	
Cymbacephalus staigeri	35(1), 37(1), 39(1), 71(1), 81(1)
Inegocia japonica	37(1), 79(1)
Platycephalus indicus	35(1)
Sciaenidae	
-	47(1), 203(2)
Silliginidae	
Sillago sp	24(1)
Syngnathidae	
Festucalex cinctus	37(1)
Trachyrhamphus longirostris	37(1)
Terapontidae	
Terapon puta	71(1)
Tetrarogidae	
Paracentropogon longipinnis	71(3)
Triacanthidae	
Trixiphichthys weberi	35(1), 37(1)
Unidentified	
	19(1), 35(1)
(blank)	
	3(1), 35(1), 51(2)
Miscellaneous	
?Leptothecatae	
indet indet	20(1), 77(1)
Craniidae	
Discinisca sp. 1	27(1)
indet	
indet indet	8(1), 13(1), 19(1), 22(1), 24(1), 35(8), 40(2), 51(7), 58(1), 63(1), 74(1), 79(1)
Molluscs	
Arcidae	
Barbatia bistrigata	19(1), 41(1), 51(1)
Tegillarca granosa	22(1)
Cerithiidae	
Cerithium coralium	8(2), 24(1), 42(1), 43(1), 49(1), 51(1), 75(6)
Clypeomorus bifasciata	75(2)
Chamidae	
Chama fibula	41(1), 79(1)
Columbellidae	
Mitrella essingtonensis	11(1)
Retizafra intricata	79(1)
Zafra minuscula	79(1)
Corbulidae	
Notocorbula monilis	54(1)
Serracorbula crassa	21(1), 35(1), 78(1)
Idiosepiidae	
Idiosepius pygmaeus	35(1)
Ischnochitonidae	
Ischnochiton sp. 1	75(1)
Laternulidae	
Laternula anatina	24(1)
Limidae	
Limaria orientalis	41(1)
Lucinidae	
Cardiolucina eucosmia	4(3), 13(9), 60(1)
Muricidae	
Rhizophorimurex capucinus	20(1)
Thais dubia	83(5), 85(1), 203(1)
Thais sp. 1	203(2)
Mytilidae	
Modiolus flavidus	52(1)
Modiolus micropterus	41(1)
Nassariidae	
Nassarius dorsatus	1(1), 11(1), 16(2), 85(5), 203(5)
Nassarius fraudator	1(1), 22(1), 203(1)
Naticidae	
Natica fasciata	13(1)
Ostreidae	
Booneostrea cucullina	41(1), 51(7), 75(5)
Potamididae	
Cerithideopsilla cingulata	42(1), 43(3)
Semelidae	
Theora fragilis	4(2)
Sepiolidae	
Euprymna sp. 1	51(1)
Euprymna sp. 2	47(2)
Siliquariidae	
Tenagodus ponderosus	79(20)
Tellinidae	
Tellina cf. vernalis	11(2), 80(1)
Tellina emarginata	18(1)
Tellina iridescens	18(1)
Trochidae	
Calthalotia mundula	11(3), 22(1), 75(1)
Euchelus atratus	71(1), 73(1)
Euchelus horridus	11(2), 19(1), 22(1), 203(7)
Turridae	
Inquisitor sp. 1	18(1)
Turricula nelliae granobalteus	51(1), 85(2)
Veneridae	
Circe australis	8(2), 64(1)
Costellipitar inconstans	11(2), 18(1), 64(1), 258(1)

Group / Family / Species	Site Number (Number of specimens at site)
Dosinia lochi	55(1)
Venerupis irus	41(1)
Polychaetes	
Ampharetidae	
Auchenoplax	16(1), 17(1), 18(2), 21(1), 44(1)
indet	41(1)
indet sp. 1	21(1)
Capitellidae	
Capitella capitata	11(1), 23(1), 41(49)
Heteromastus caudatus?	14(1)
Heteromastus filiformis	14(1)
Leiochrides	18(1)
Mediomastus	56(1)
Notomastus	52(1)
Notomastus torquatus?	13(1)
Scyphoproctus	34(1)
Scyphoproctus (platyproctus??)	25(1)
Chrysopetalidae	
Chrysopetalum sp 12	35(1), 41(2)
Cirratulidae	
Aphelochaeta indet	69(1)
Caulleriella	72(1)
Eunicidae	
Eunice	18(2), 35(1), 41(1)
Euniphysa auriculata??	38(1), 48(1)
Glyceridae	
Glycera macintoshi	21(1), 59(1)
Goniadidae	
Glycinde bonhourei	69(1)
Hesionidae	
indet	4(1)
Syllidia sp_DH	41(10), 79(1)
Lumbrineridae	
Lumbrineris	13(1), 18(1), 23(2), 42(1)
sp1	18(1)
Magelonidae	
Magelona	14(1), 18(1), 201(1)
Maldanidae	
Axiotella	13(2), 18(4), 60(1)
Clymenella	18(1)
Nephtydae	
Inermonephtys sp_DH	25(1)
Nephtys mesobranchia	41(1), 60(1)
Nereididae	
Neanthes cricognatha	41(1)
Nereis hersonnensis	41(1)
Ophelidae	
Armandia	41(1)
Orbiinidae	
Leodamas	44(1), 76(1)
Phyllodocidae	
Hesionura sp	69(1)
Nereiphylla???	41(1)
Pilargidae	
Hermundura gladstonensis	56(2)
Pisionidae	
Pisione sp	69(1)
Polynoidae	
DH_1	31(1)
Sabellariidae	
Sabellaria	35(2)
Scalibregmatidae	
Scalibregma inflatum	72(1)
Spionidae	
Laonice	44(1), 72(1)
Laonice cf lemniscata	25(1)
Laonice indet	34(1)
Paraprionospio	44(1)
Polydora	36(1)
Prinospio	46(1)
Prinospio indet	14(1)
Prionospio	44(1)
Syllidae	
Exogoninae sp1	41(2), 69(1)
Exogoninae sp2	41(1), 69(1)
Opistosyllis	16(1)
Opistosyllis sp	35(1), 41(2), 51(1), 79(3)
Pionosyllis ??? sp.	69(2)
spp	69(3)
Terebellidae	
Amaeana sp_DH	48(1), 78(1)
Trichobranchidae	
Artacamella torulosa	34(1)
Terebellides mundora	36(1)
Trichobranchus bunnabus	27(1), 41(1), 70(1)
(blank)	
	56(1), 69(1)

Appendix 2. Northern Territory Fisheries pot, hook and line sampling.

Family / Species	Common name	Site Number * (Number of specimens at site)
Apogonidae		
Apogon rueppellii	Western Gobbleguts	1(1)
Carangidae		
Caranx ignobilis	Giant Trevally	1(1), 2(1), 3(2)
Pantolabus radiatus	Fringefin Trevally	2(2)
Haemulidae		
Diagramma labiosum	Painted Sweetlip	3(1)
Pomadasys kaakan	Javelin Fish	1(2), 2(10)
Lutjanidae		
Lutjanus carponotatus	Stripey Snapper	3(1)
Lutjanus johnii	Golden Snapper	1(12), 2(5)
Lutjanus russellii	Moses snapper	1(19), 2(12), 3(15)
Lutjanus vitta	Brownstripe snapper	3(1)
Serranidae		
Epinephelus coioides	Gold spot cod	1(6)
Sparidae		
Acanthopagrus berda	Pikey Bream	1(15), 3(3)
Sciaenidae		
Protonibea diacanthus	Jewfish	1(1)
Mullidae		
Selenotoca multifasciata	Striped Scat	1(1)
Monodactylidae		
Monodactylus argenteus	Silver Batfish	1(1)
Tetraodontidae		
Marilyna darwinii	Toadfish	2(2)
Lethrinidae		
Lethrinus lacticaudis	Grass Emperor	3(11)
Lethrinus lentjan	Red Spot Emperor	3(7)
Labridae		
Choeroden schoenleinii	Black spot tuskfish	3(3)
Ariidae		
Neoarius sp.	Fork tail catfish	3(1)
Ephippidae		
Zabidius novemaculeatus	Shortfin Batfish	3(5)
Carcharhinidae		
Rhizoprionodon acutus	Milk Shark	3(1)
Ginglymostomatidae		
Nebrius ferrugineus	Tawny Shark	3(1)
Uranoscopidae		
?	Stargazer	1(1), 2(1), 3(3)
Portunidae		
Portunus pelagicus	Blue Swimmer crab	2(5), 3(5)
Scylla serratta	Mud crab	1(2), 2(1), 3(4)
?		
Myomenippe fornassinii	Mangrove crab	1(2), 3(2)

**** Site number does not correlate with benthic sampling site numbers. Site 1 (S 12 34.044, E 131 00.737), Site 2 (S 12 32.760, E 130 59.254), Site 3 (S 12 32.978, E 130 56.772).***

Appendix 3. Biodiversity Conservation Fauna Atlas records for Elizabeth and East Arm.

Species group	Species Id	Species name	Common name	Number of records	TPWCA 2007	EPBCA 2007	Threatened
Reptiles							
	102	*Crocodylus porosus*	Saltwater Crocodile	6	LC	-	-
	356	*Acrochordus arafurae*	Arafura File Snake	2	LC	-	-
	362	*Fordonia leucobalia*	White-bellied Mangrove Snake	1	LC	-	-
	414	*Hydrelaps darwiniensis*	Black-ringed Mud Snake	1	LC	-	-
	423	*Parahydrophis mertoni*	Northern Mangrove Sea Snake	1	LC	-	-
Birds							
	573	*Pelecanus conspicillatus*	Australian Pelican	16	LC	-	-
	580	*Ardea sumatrana*	Great-billed Heron	6	LC	-	-
	582	*Butorides striata*	Striated Heron	8	LC	-	-
	587	*Egretta sacra*	Eastern Reef Egret	10	LC	-	-
	594	*Pandion cristatus*	Eastern Osprey	10	LC	-	-
	601	*Haliaeetus leucogaster*	White-bellied Sea-eagle	39	LC	-	-
	603	*Haliastur indus*	Brahminy Kite	50	LC	-	-
	622	*Eulabeornis castaneoventris*	Chestnut Rail	20	LC	-	-
	635	*Esacus magnirostris*	Beach Stone-curlew	16	LC	-	-
	636	*Haematopus longirostris*	Australian Pied Oystercatcher	8	LC	-	-
	638	*Himantopus himantopus*	Black-winged Stilt	67	LC	-	-
	639	*Recurvirostra novaehollandiae*	Red-necked Avocet	2	LC	-	-
	641	*Pluvialis fulva*	Pacific Golden Plover	18	LC	-	-
	642	*Pluvialis squatarola*	Grey Plover	24	LC	-	-
	644	*Charadrius dubius*	Little Ringed Plover	1	LC	-	-
	646	*Charadrius ruficapillus*	Red-capped Plover	11	LC	-	-
	647	*Charadrius mongolus*	Lesser Sand Plover	23	LC	-	-
	648	*Charadrius leschenaultii*	Greater Sand Plover	43	LC	-	-
	660	*Gallinago stenura*	Pin-tailed Snipe	1	LC	-	-
	661	*Gallinago megala*	Swinhoe's Snipe	8	LC	-	-
	662	*Limosa limosa*	Black-tailed Godwit	6	LC	-	-
	663	*Limosa lapponica*	Bar-tailed Godwit	9	LC	-	-
	664	*Numenius minutus*	Little Curlew	11	LC	-	-
	665	*Numenius phaeopus*	Whimbrel	87	LC	-	-
	666	*Numenius madagascariensis*	Eastern Curlew	60	LC	-	-
	667	*Xenus cinereus*	Terek Sandpiper	28	LC	-	-
	668	*Actitis hypoleucos*	Common Sandpiper	102	LC	-	-
	670	*Tringa brevipes*	Grey-tailed Tattler	27	LC	-	-
	672	*Tringa nebularia*	Common Greenshank	76	LC	-	-
	673	*Tringa stagnatilis*	Marsh Sandpiper	42	LC	-	-
	674	*Tringa totanus*	Common Redshank	3	LC	-	-
	675	*Tringa glareola*	Wood Sandpiper	3	LC	-	-
	676	*Arenaria interpres*	Ruddy Turnstone	19	LC	-	-
	679	*Calidris canutus*	Red Knot	1	LC	-	-
	681	*Calidris minuta*	Little Stint	3	LC	-	-
	682	*Calidris ruficollis*	Red-necked Stint	33	LC	-	-
	683	*Calidris subminuta*	Long-toed Stint	1	LC	-	-
	684	*Calidris bairdii*	Baird's Sandpiper	1	LC	-	-
	685	*Calidris melanotos*	Pectoral Sandpiper	1	LC	-	-
	686	*Calidris acuminata*	Sharp-tailed Sandpiper	30	LC	-	-
	687	*Calidris ferruginea*	Curlew Sandpiper	9	LC	-	-
	689	*Limicola falcinellus*	Broad-billed Sandpiper	3	LC	-	-
	691	*Phalaropus lobatus*	Red-necked Phalarope	4	LC	-	-
	704	*Onychoprion fuscata*	Sooty Tern	1	LC	-	-
	705	*Sternula albifrons*	Little Tern	7	LC	-	-
	706	*Gelochelidon nilotica*	Gull-billed Tern	22	LC	-	-
	707	*Hydroprogne caspia*	Caspian Tern	3	LC	-	-
	708	*Chlidonias hybrida*	Whiskered Tern	54	LC	-	-
	709	*Chlidonias leucopterus*	White-winged Black Tern	36	LC	-	-
	712	*Sterna hirundo*	Common Tern	3	LC	-	-
	714	*Thalasseus bergii*	Crested Tern	4	LC	-	-
	717	*Chroicocephalus novaehollandiae*	Silver Gull	15	LC	-	-
	762	*Todiramphus chloris*	Collared Kingfisher	37	LC	-	-
	785	*Gerygone levigaster*	Mangrove Gerygone	71	LC	-	-
	846	*Pachycephala melanura*	Mangrove Golden Whistler	6	LC	-	-
	849	*Pachycephala lanioides*	White-breasted Whistler	8	LC	-	-
	870	*Rhipidura phasiana*	Mangrove Grey Fantail	27	LC	-	-
	888	*Peneonanthe pulverulenta*	Mangrove Robin	69	LC	-	-

Appendix 4. Abundance and Biodiversity Analyses of Darwin Harbour Biotic Data

Abundance and Biodiversity Analyses of Darwin Harbour Biotic Data

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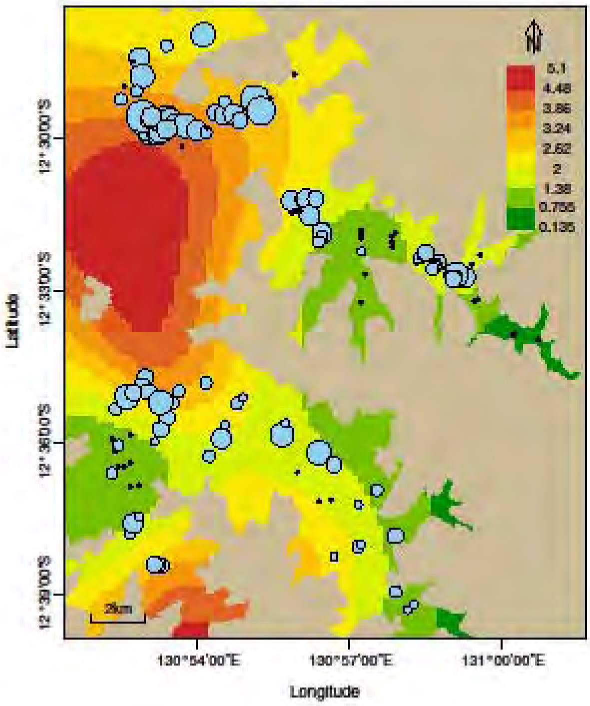
October 10, 2011



Spatial distribution of richness

Summary

This document presents some analyses and interpretations of survey data from Darwin Harbour. It is intended to be a preliminary analysis with the objectives of:

1. Assessing the quality of the data in the sense of strength of spatial pattern and relationships between the biota, environmental predictors and spatial locations.
2. Deterimining the potentials of the species and environmental drivers to be indicators of spatial classification into biotic and/or habitat types.
3. To suggest future options in terms of data analysis and/or addtional surveys.

Less than 46% of sites had two or more observed taxa, and over 23% had no taxa at all. As might be expected, the relationships between the biota and space, and the biota and environmetal measures were all extremely weak. The spatial distributions had also fairly weak patterns. The predictability of the biota in terms of both space and environment were extremely weak, even for the more abundant taxa. Thus any classification of habitat types and/or environments are likely to be extremely uncertian.

Methods

The data were analysed in three ways:

1. The spatial distribution of species richness and each of the biotic seven biotic responses (*Porifera, Hydrozoa, Alcyonacea, Scleractin, Ascidia, Bryozoa, Algae*) were modelled uisng GAMs (Generalized Additive Models). For each of the seven species the spatial distribution of abundance and presence-absence were both modelled. Spatial analyses of richewere based on generalized additive models (GAMs) with smooth terms selected by cross-validation. The results are presented by mapping and quantfying the explained variation. The five taxa comprising *Crinoids, Sabliidae, Cerianthid, Asteriod* were observed on few sites and were not modelled spatially.
2. The relationships of richness and the seven biotic responses (*Porifera, Hydrozoa, Alcyonacea, Scleractin, Ascidia, Bryozoa, Algae*) were then modelled using ABTs (Aggregated Boosted Trees).
3. Spatial coordinates were then included in the ABT analyses to compare the predictive capacity of the spatial and environmental predictors. These included spline terms to smooth effectively independently of teh lat-long coordinate sustem.

The results of all three approaches are presented first for richness and are explained in detail. Results of subsequent analyses and not extensively discussed.

Analyses

Spatial analyses of distribution of richness

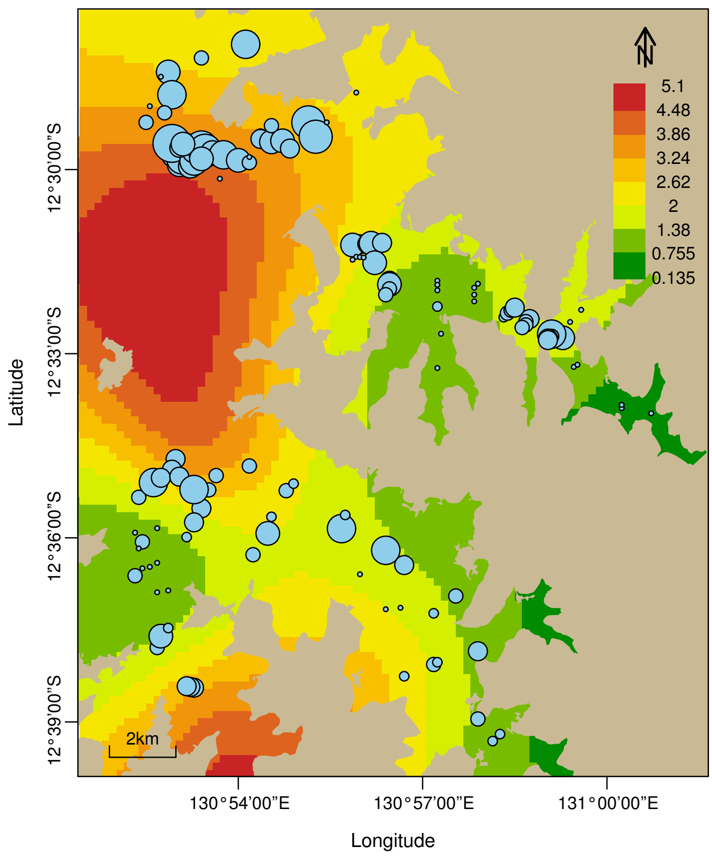


Figure 1: Spatial distribution of richness

```
Approximate significance of smooth terms:
               edf Ref.df     F  p-value
s(long,lat) 10.41  10.93 4.336 1.62e-05
R-sq.(adj) =  0.307   Deviance explained = 30.1%

cor(exp(fit[[1]]$fitted),temp2$Richness) 0.516
mean(exp(fit[[1]]$fitted)) 2.070
mean(temp2$Richness) 2.303
```

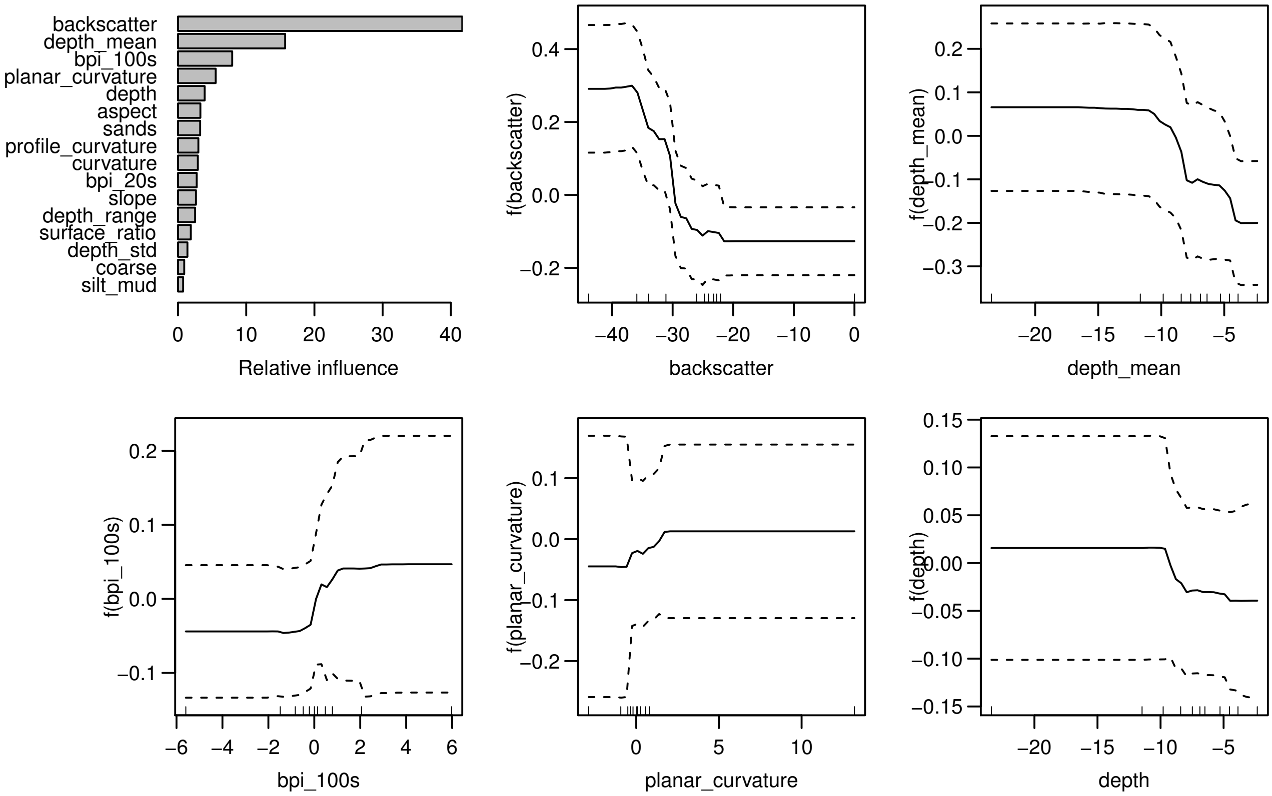


Figure 2: Environmental drivers of richness

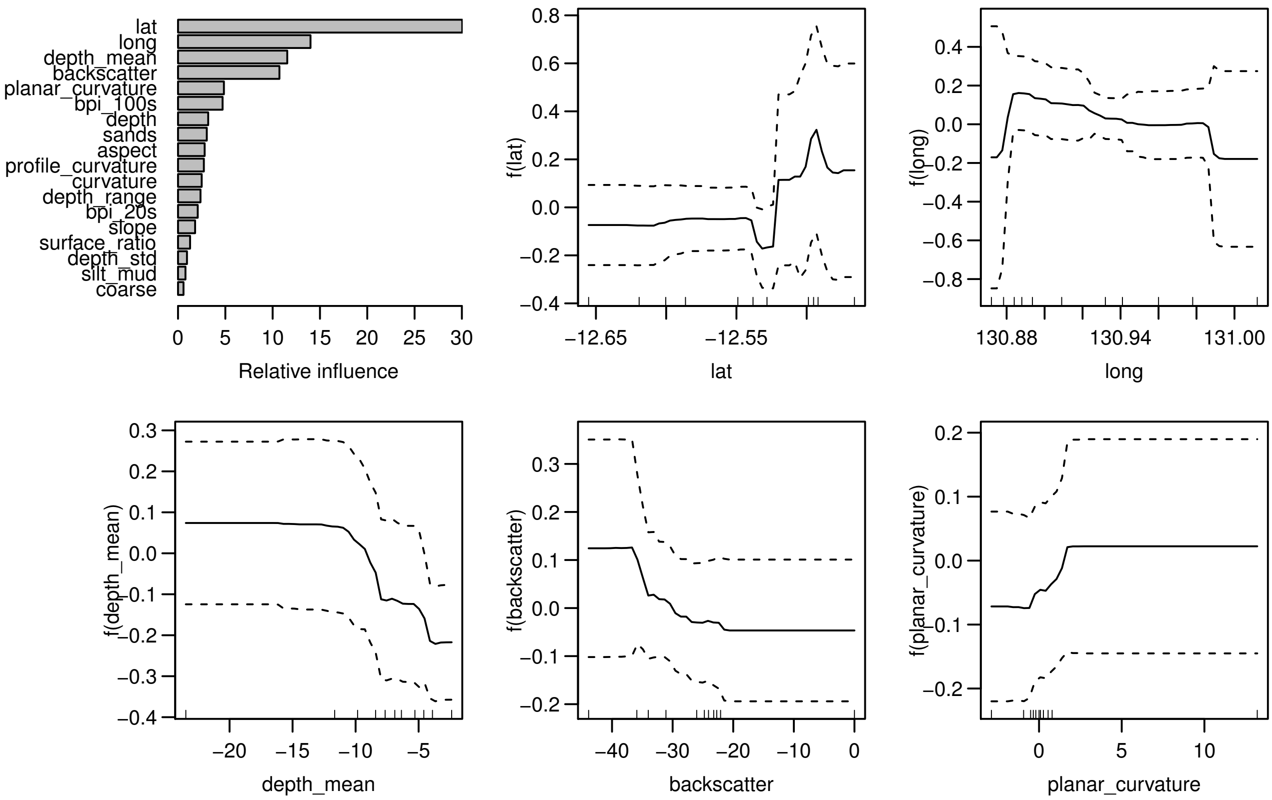


Figure 3: Spatial and environmental drivers of richness

Discussion of methods and results

The difficulty in predicting the biotic values is highlighted in Table 1. The prese-absence

Predicting Biotic Values

Predictors (%)	*Porifera*	*Hydrozoa*	*Alcyonacea*	*Scleractin*	*Ascidia*	*Bryozoa*	*Algae*
Environmental (E)	33.7	39.3	40.6	7.6	27.6	11.0	17.2
Spatial (S)	24.3	35.8	39.3	6.9	28.9	11.0	17.9
S + E	31.0	33.7	39.3	6.9	28.2	11.0	18.6
Majority Vote	35.9	42.8	45.5	7.6	27.6	11.0	17.2

Table 1: Performance of aggregated boosted trees in predicting presence-absence of seven biotic response in terms of environmental and spatial predictors.

Spatial analyses of distribution of *Porifera*

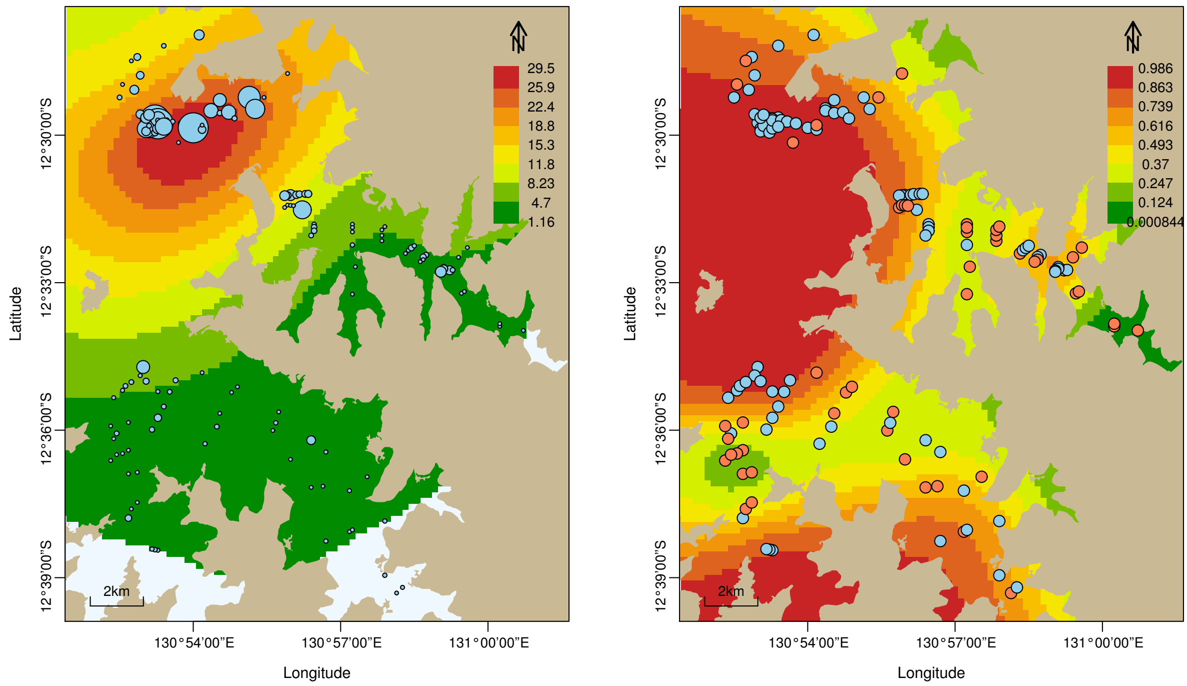


Figure 4: Spatial distribution of abundance (L) and presence-absence (R) of *Porifera*

Abundance:

```
Approximate significance of smooth terms:
              edf Ref.df     F  p-value
s(long,lat) 6.899  8.845 7.466 9.59e-09
R-sq.(adj) =  0.264   Deviance explained = 41.5%
```

Presence-absence:

```
Approximate significance of smooth terms:
            edf Ref.df Chi.sq  p-value
s(long,lat)   2  2.001  16.54 0.000256
R-sq.(adj) =  0.113   Deviance explained = 9.66%
```

Spatial analyses of distribution of ***Hydrozoa***

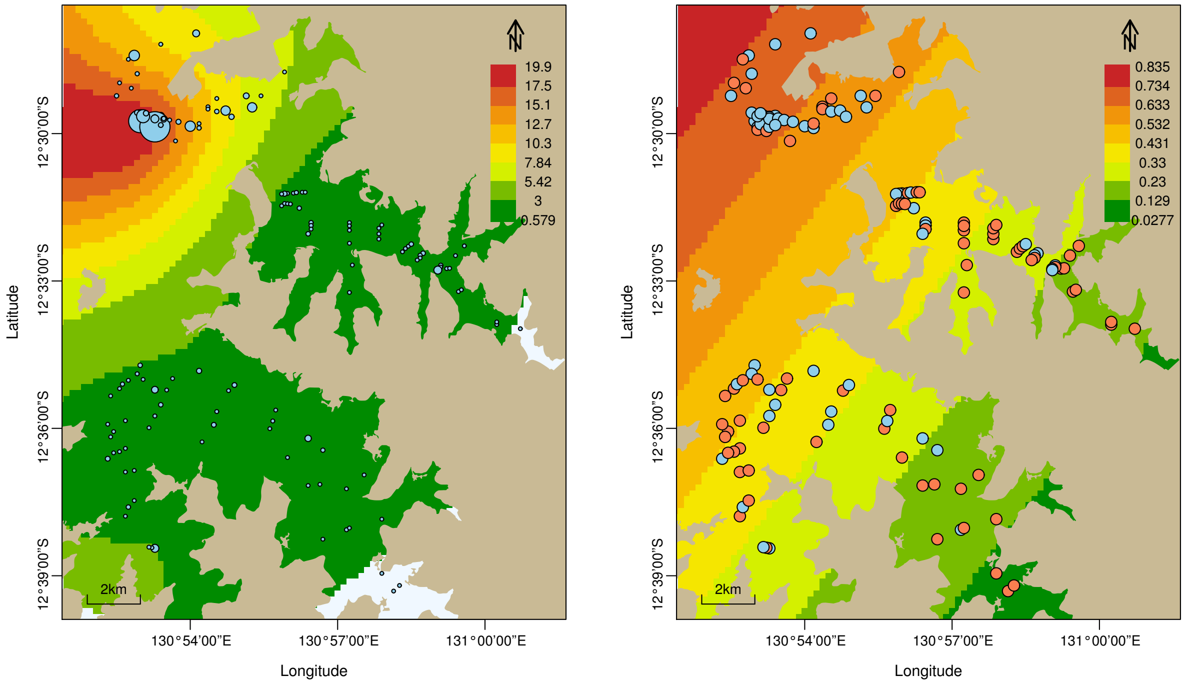


Figure 5: Spatial distribution of abundance (L) and presence-absence (R) of *Hydrozoa*

Abundance:

```
Approximate significance of smooth terms:
               edf Ref.df     F  p-value
s(long,lat) 6.534  8.446 5.201 7.28e-06
R-sq.(adj) =  0.119   Deviance explained = 34.1%
```

Presence-absence:

```
Approximate significance of smooth terms:
             edf Ref.df Chi.sq  p-value
s(long,lat)   2  2.001  16.54 0.000256
R-sq.(adj) =  0.113   Deviance explained = 9.66%
```

Spatial analyses of distribution of *Alcyonea*

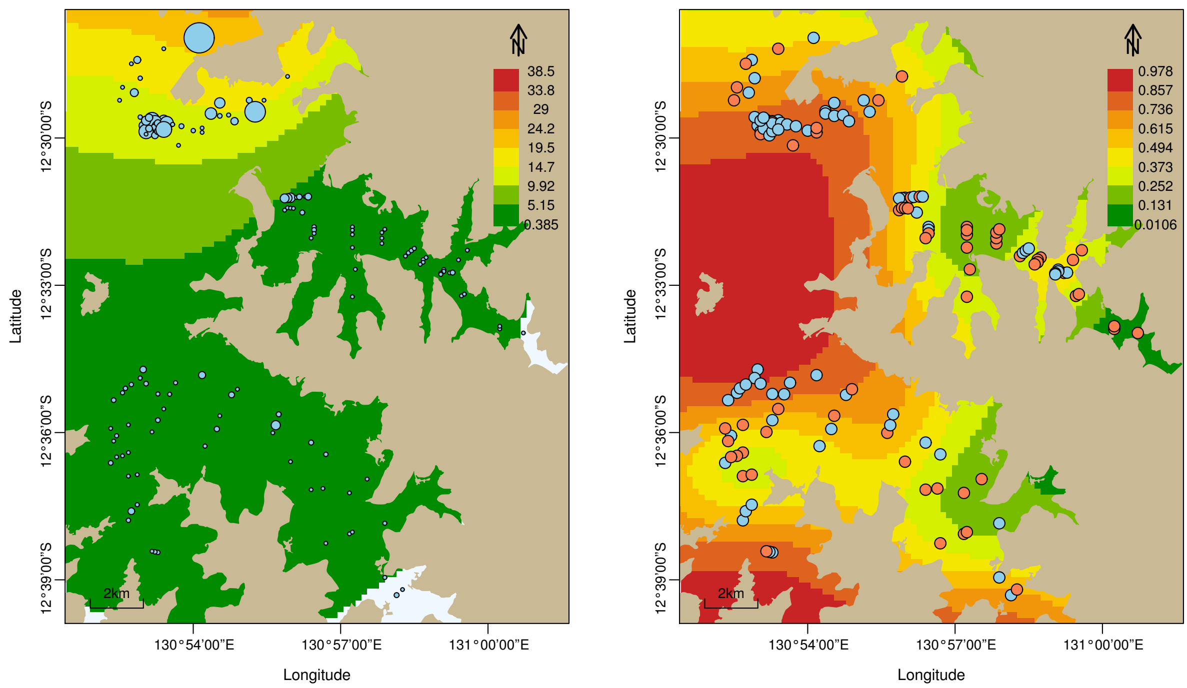


Figure 6: Spatial distribution of abundance (L) and presence-absence (R) of *Alcyonea*

Abundance:

```
Approximate significance of smooth terms:
                edf Ref.df     F  p-value
s(long,lat) 6.238  8.064 7.681 1.62e-08
R-sq.(adj) =  0.229   Deviance explained = 40.8%
```

Presence-absence:

```
Approximate significance of smooth terms:
                edf Ref.df Chi.sq p-value
s(long,lat) 11.85  13.38  28.58 0.00896
R-sq.(adj) =  0.185   Deviance explained = 20.1%
```

Spatial analyses of distribution of *Scleractin*

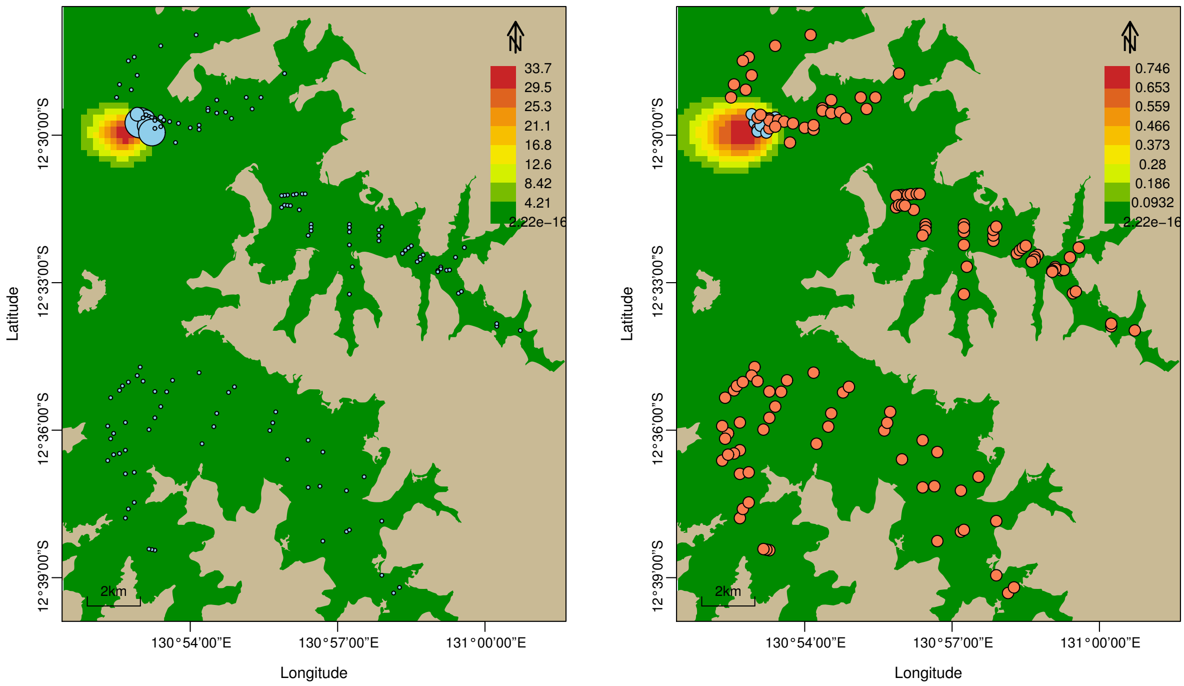


Figure 7: Spatial distribution of abundance (L) and presence-absence (R) of *Scleractin*

Abundance:

```
Approximate significance of smooth terms:
              edf Ref.df    F p-value
s(long,lat) 4.454  5.104 0.29   0.921
R-sq.(adj) =  0.342   Deviance explained = 72.9%
```

Presence-absence:

```
Approximate significance of smooth terms:
              edf Ref.df Chi.sq p-value
s(long,lat) 2.866  3.265  0.195   0.986
R-sq.(adj) =  0.504   Deviance explained = 63.1%
```

Spatial analyses of distribution of *Ascidia*

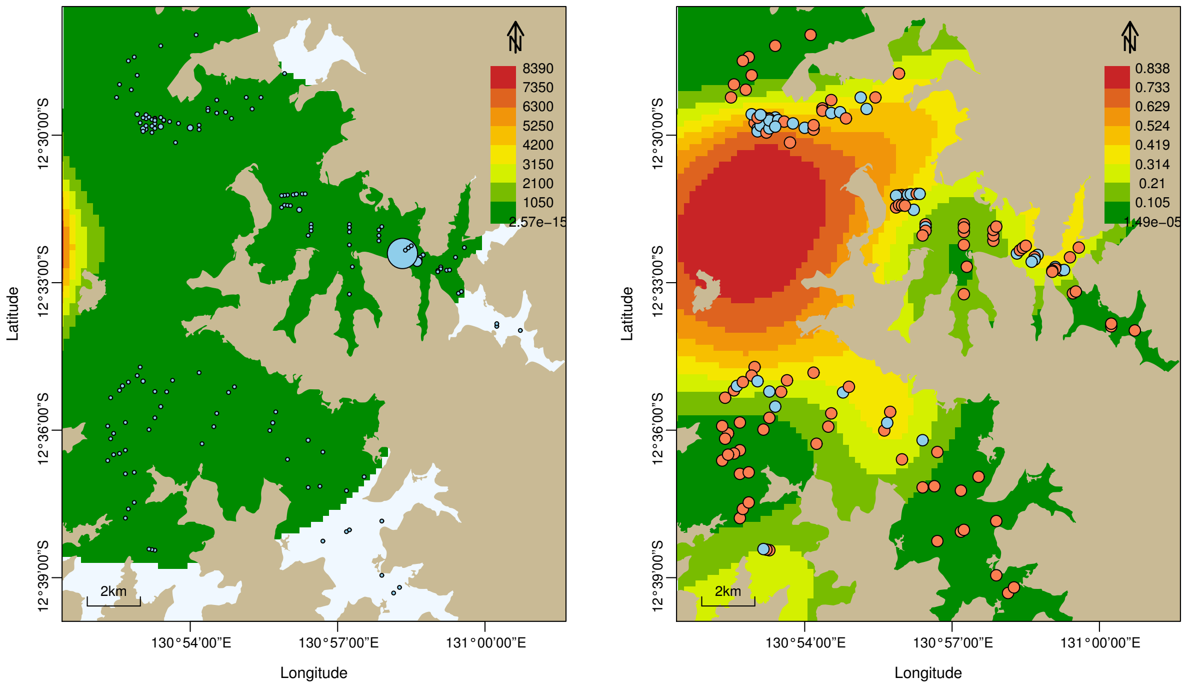


Figure 8: Spatial distribution of abundance (L) and presence-absence (R) of *Ascidia*

Abundance:

```
Approximate significance of smooth terms:
                edf Ref.df     F  p-value
s(long,lat) 13.47  13.87 9.335 6.45e-14
R-sq.(adj) =  0.379   Deviance explained = 61.3%
```

Presence-absence:

```
Approximate significance of smooth terms:
                edf Ref.df Chi.sq p-value
s(long,lat) 11.69  13.08  20.19   0.093
R-sq.(adj) =   0.13   Deviance explained = 20.7%
```

Spatial analyses of distribution of *Bryozoa*

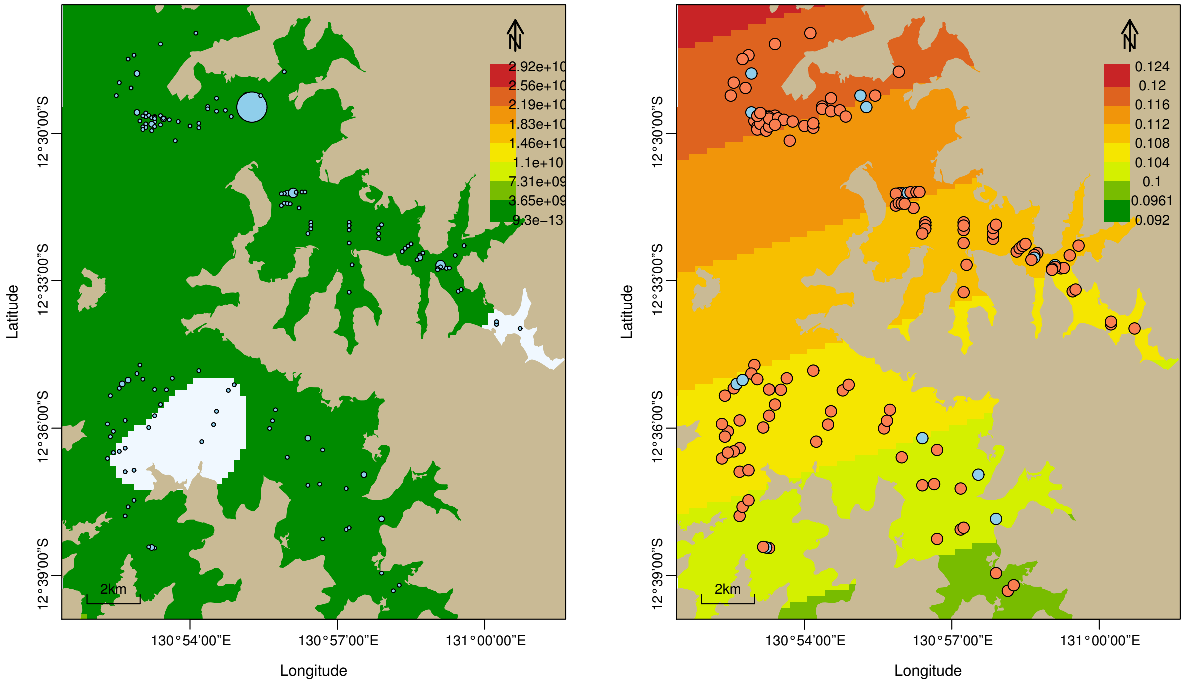


Figure 9: Spatial distribution of abundance (L) and presence-absence (R) of *Bryozoa*

Abundance:

```
Approximate significance of smooth terms:
               edf Ref.df     F  p-value
s(long,lat) 13.89  13.99 4.625 9.14e-07
R-sq.(adj) =  0.259   Deviance explained = 44.8%
```

Presence-absence:

```
Approximate significance of smooth terms:
             edf Ref.df Chi.sq p-value
s(long,lat)   2      2  0.043   0.979
R-sq.(adj) =  -0.0137   Deviance explained = 0.0431%
```

Spatial analyses of distribution of ***Algae***

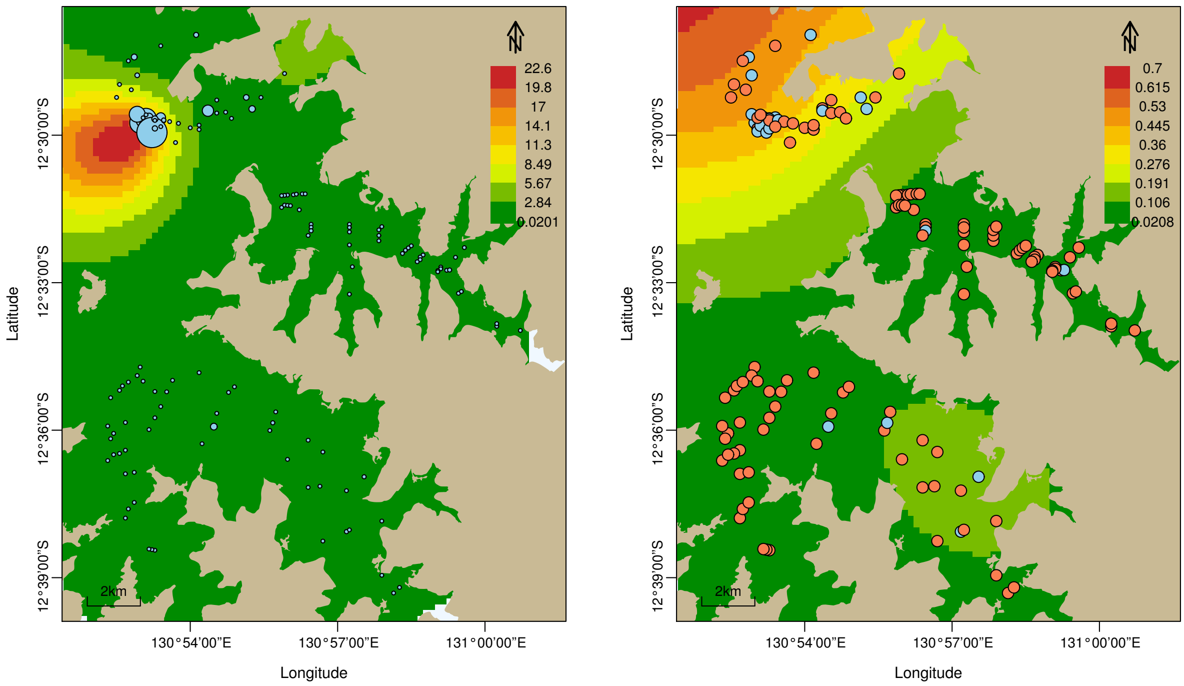


Figure 10: Spatial distribution of abundance (L) and presence-absence (R) of *Algae*

Abundance:

```
Approximate significance of smooth terms:
              edf Ref.df     F p-value
s(long,lat) 8.152  10.01 2.438  0.0105
R-sq.(adj) =  0.234   Deviance explained = 52.7%
```

Presence-absence:

```
Approximate significance of smooth terms:
             edf Ref.df Chi.sq p-value
s(long,lat) 4.69  6.273  22.05 0.00146
R-sq.(adj) =  0.183   Deviance explained = 22.1%
```

Spatial distribution of Silt-Mud and Sands

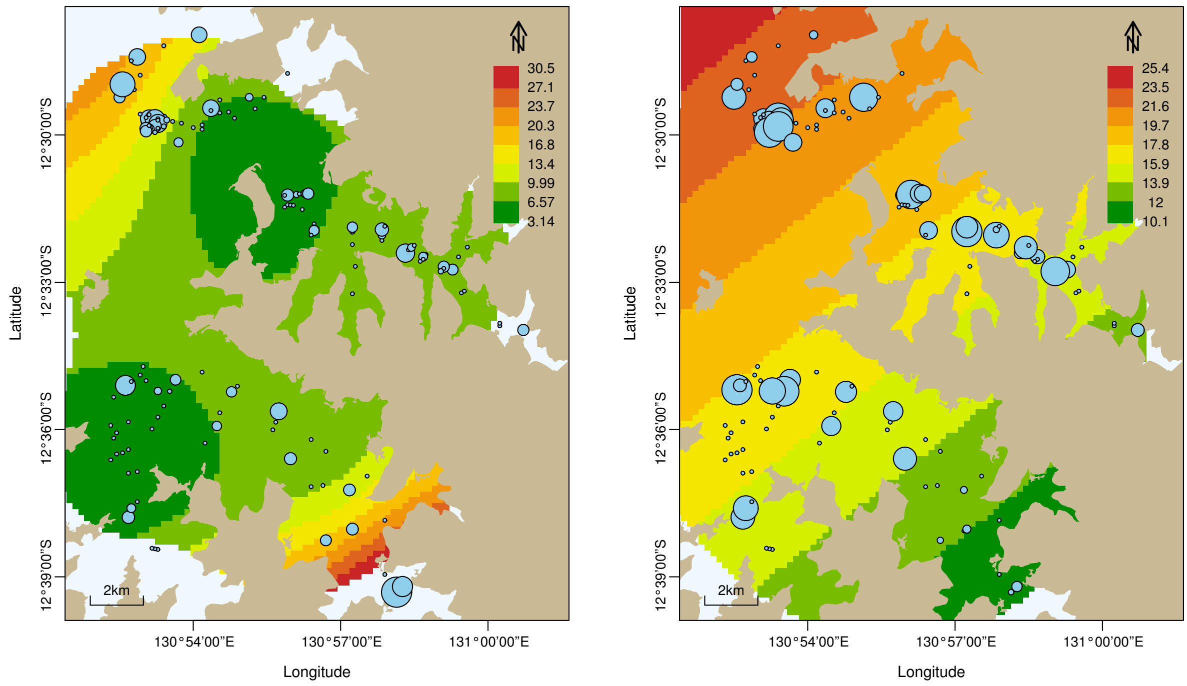


Figure 11: Spatial distribution of Silt-Mud (L) and Sands (R)

Silt-Mud:

```
Approximate significance of smooth terms:
               edf Ref.df     F p-value
s(long,lat) 8.911  11.14 2.14  0.0209
R-sq.(adj) =  0.128   Deviance explained = 18.2%
```

Sands:

```
Approximate significance of smooth terms:
             edf Ref.df      F p-value
s(long,lat)   2      2 0.855   0.428
R-sq.(adj) =  -0.00202   Deviance explained = 1.19%
```

Spatial distribution of Coarse and Backscatter

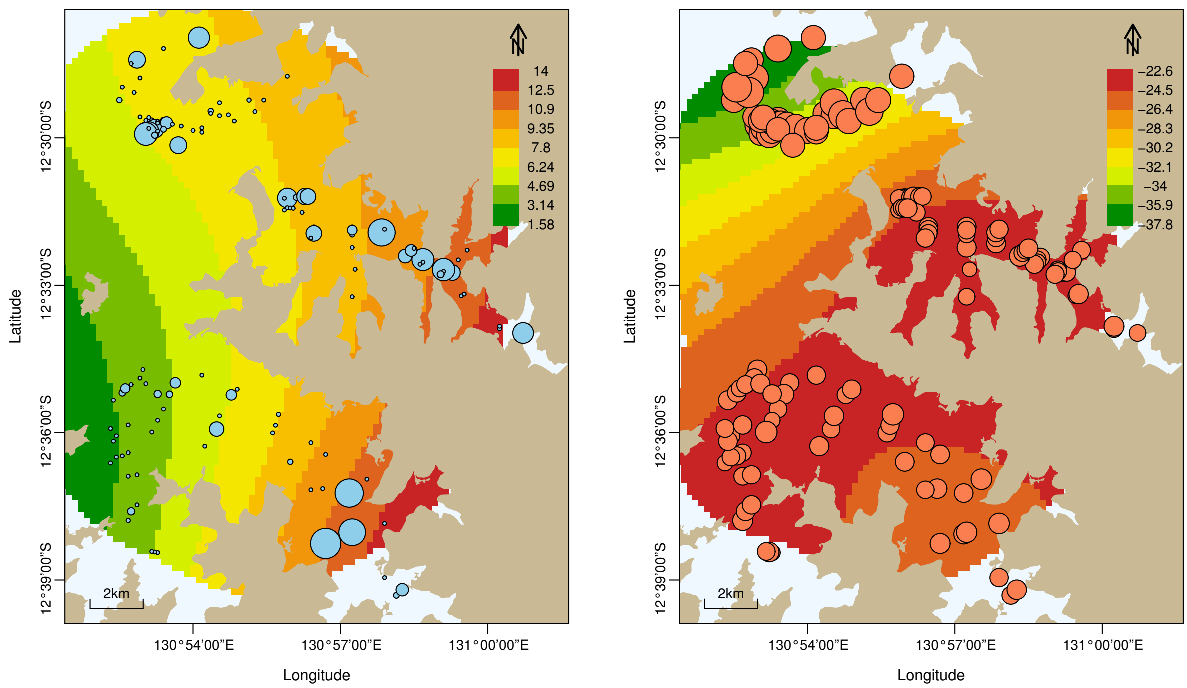


Figure 12: Spatial distribution of Coarse (L) and Backscatter (R)

Coarse:

```
Approximate significance of smooth terms:
                edf Ref.df     F p-value
s(long,lat) 3.118   3.99 1.431   0.227
R-sq.(adj) =  0.028   Deviance explained =  4.9%
```

Backscatter:

```
Approximate significance of smooth terms:
                edf Ref.df     F p-value
s(long,lat) 6.963  9.108 27.31  <2e-16
R-sq.(adj) =  0.637   Deviance explained = 65.4%
```

Spatial distribution of BPI-100s and BPI-20s

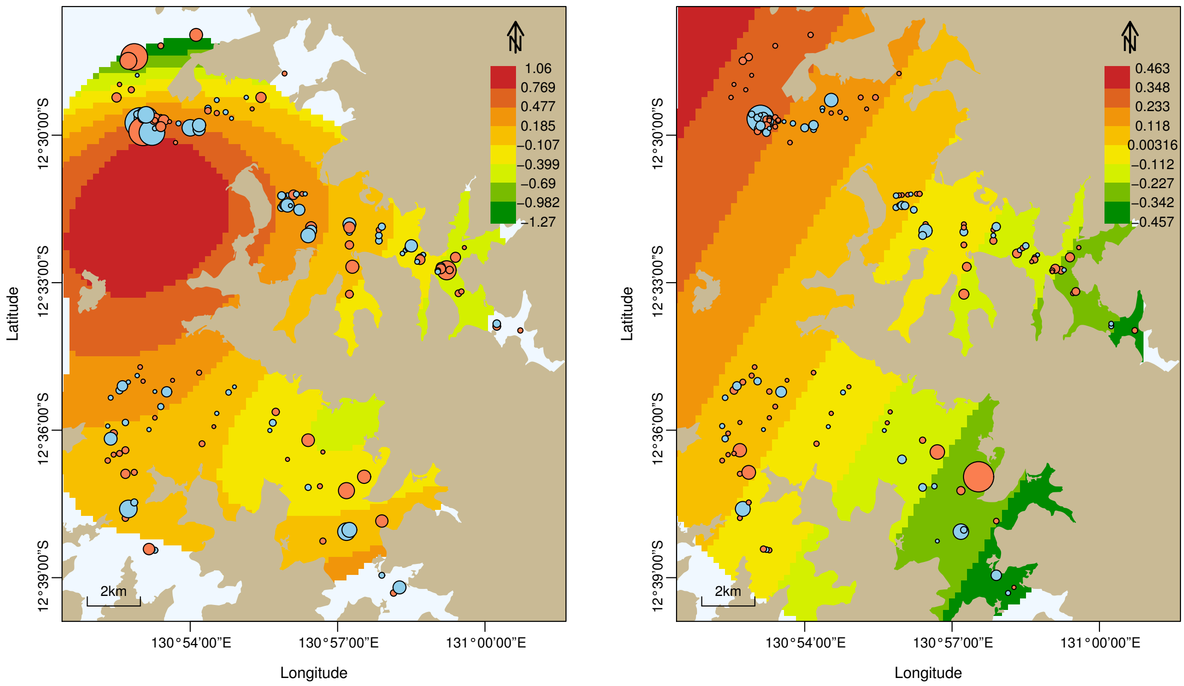


Figure 13: Spatial distribution of BPI-100s (L) and BPI-20s (R)

BPI-100s:

```
Approximate significance of smooth terms:
               edf Ref.df     F p-value
s(long,lat) 8.056  10.29 1.406   0.182
R-sq.(adj) =  0.0775   Deviance explained = 12.9%
```

BPI-20s:

```
Approximate significance of smooth terms:
            edf Ref.df     F p-value
s(long,lat)   2      2 1.974   0.143
R-sq.(adj) =  0.0134   Deviance explained = 2.71%
```

Spatial distribution of Mean Depth and Range of Depth

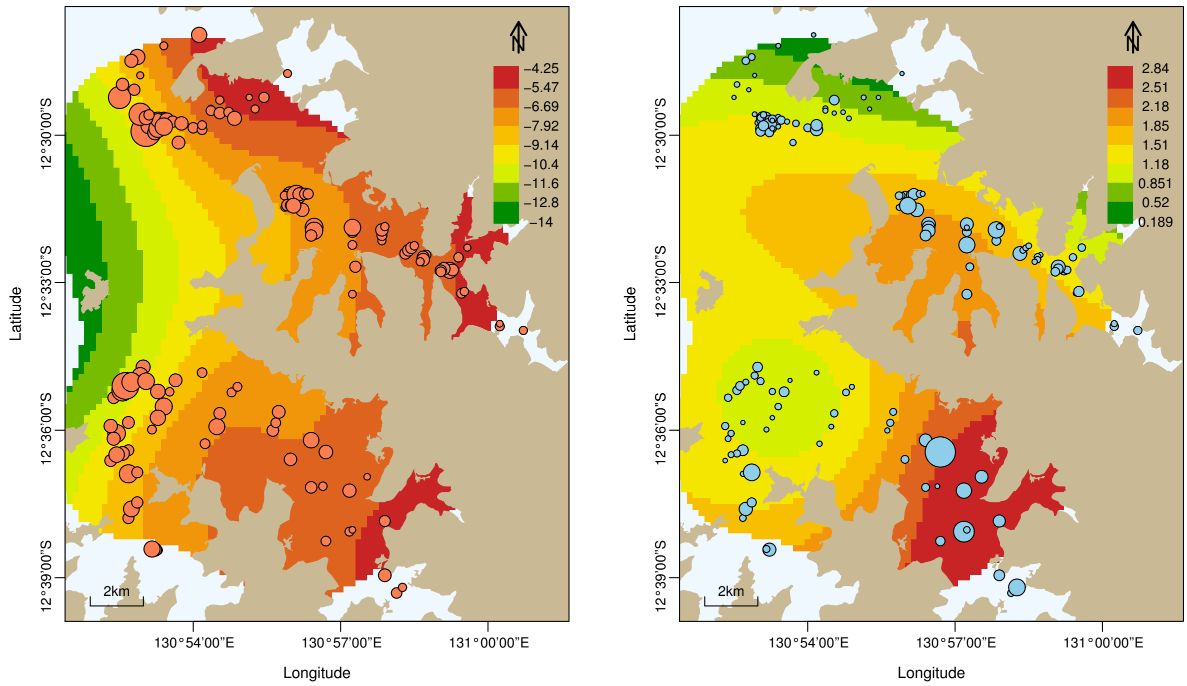


Figure 14: Spatial distribution of Mean Depth (L) and Range of Depth (R)

Mean Depth:

```
Approximate significance of smooth terms:
                edf Ref.df     F  p-value
s(long,lat) 8.475  10.71 3.197 0.000771
R-sq.(adj) =  0.182   Deviance explained = 23.1%
```

Range of Depth:

```
Approximate significance of smooth terms:
                edf Ref.df     F  p-value
s(long,lat) 9.671  11.83 4.071 2.33e-05
R-sq.(adj) =  0.241   Deviance explained = 29.2%
```

Spatial distribution of Depth and SD of Depth

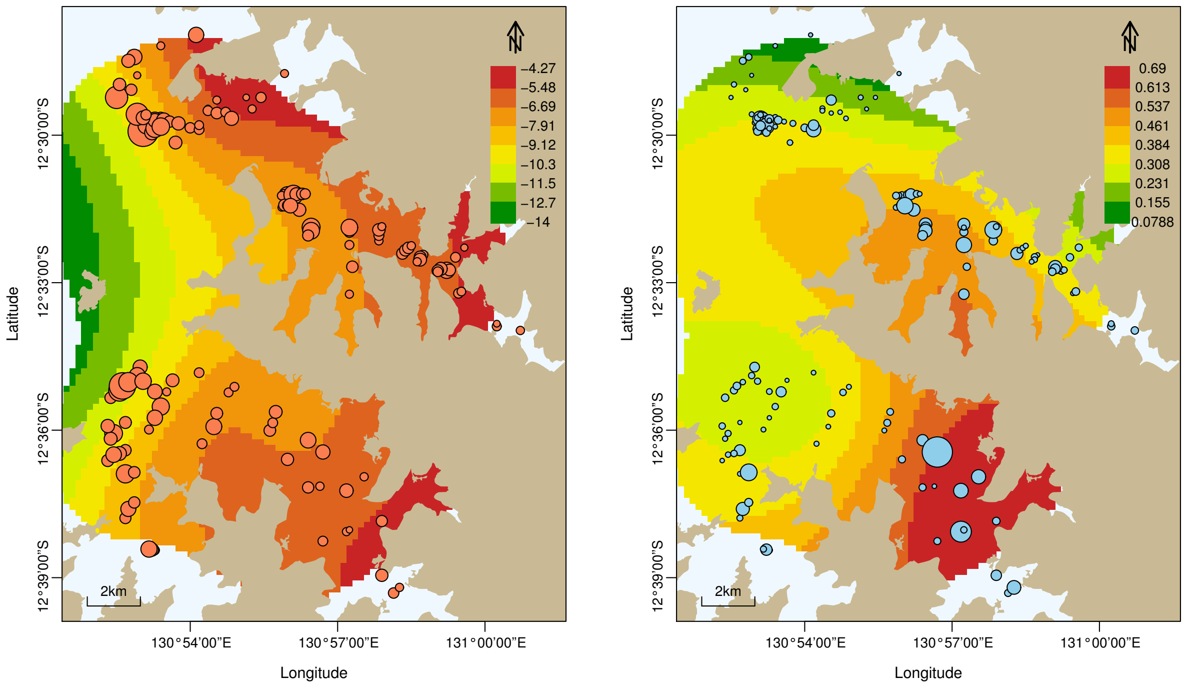


Figure 15: Spatial distribution of Depth (L) and SD of Depth (R)

Depth:

```
Approximate significance of smooth terms:
               edf Ref.df     F  p-value
s(long,lat) 9.612  11.78 3.975 3.35e-05
R-sq.(adj) =  0.235   Deviance explained = 28.6%
```

SD of Depth

```
Approximate significance of smooth terms:
               edf Ref.df     F p-value
s(long,lat) 7.938  10.17 2.467 0.00924
R-sq.(adj) =  0.136   Deviance explained = 18.4%
```

Spatial distribution of Aspect and Curvature

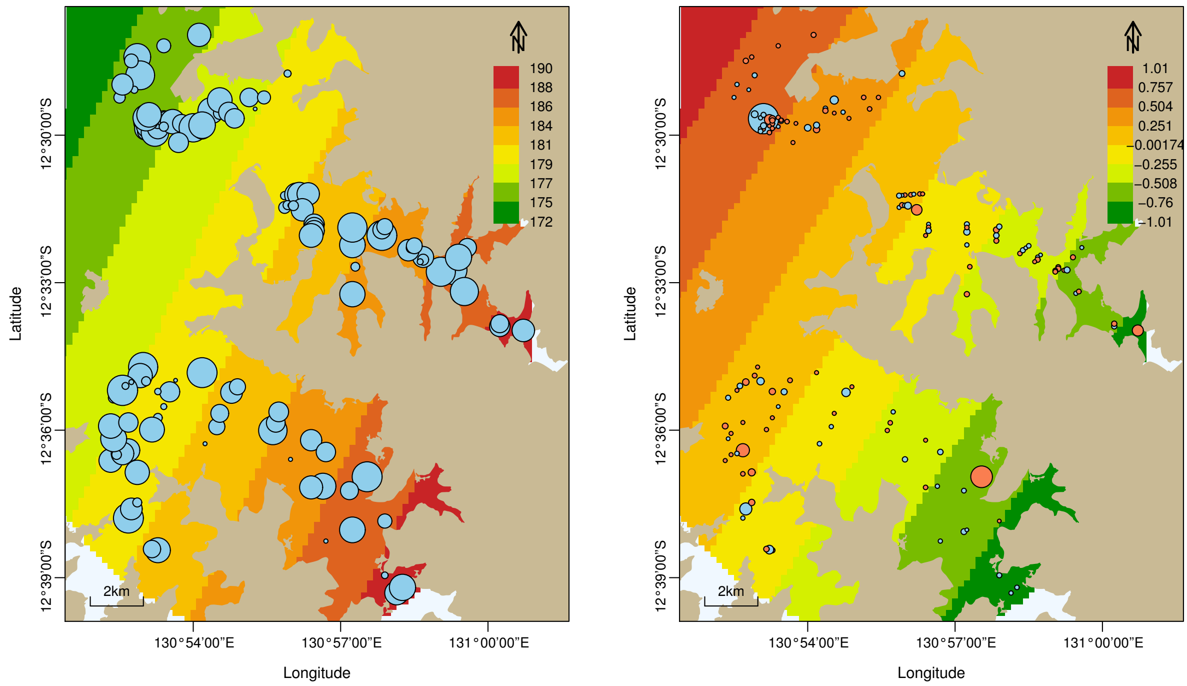


Figure 16: Spatial distribution of Aspect (L) and Curvature (R)

Aspect:

```
Approximate significance of smooth terms:
            edf Ref.df     F p-value
s(long,lat)   2      2 0.096   0.909
R-sq.(adj) =  -0.0127   Deviance explained = 0.134%
```

Curvature:

```
Approximate significance of smooth terms:
            edf Ref.df    F p-value
s(long,lat)   2      2 1.25    0.29
R-sq.(adj) =  0.00346   Deviance explained = 1.73%
```

Spatial distribution of Planar Curvature and Profile Curvature

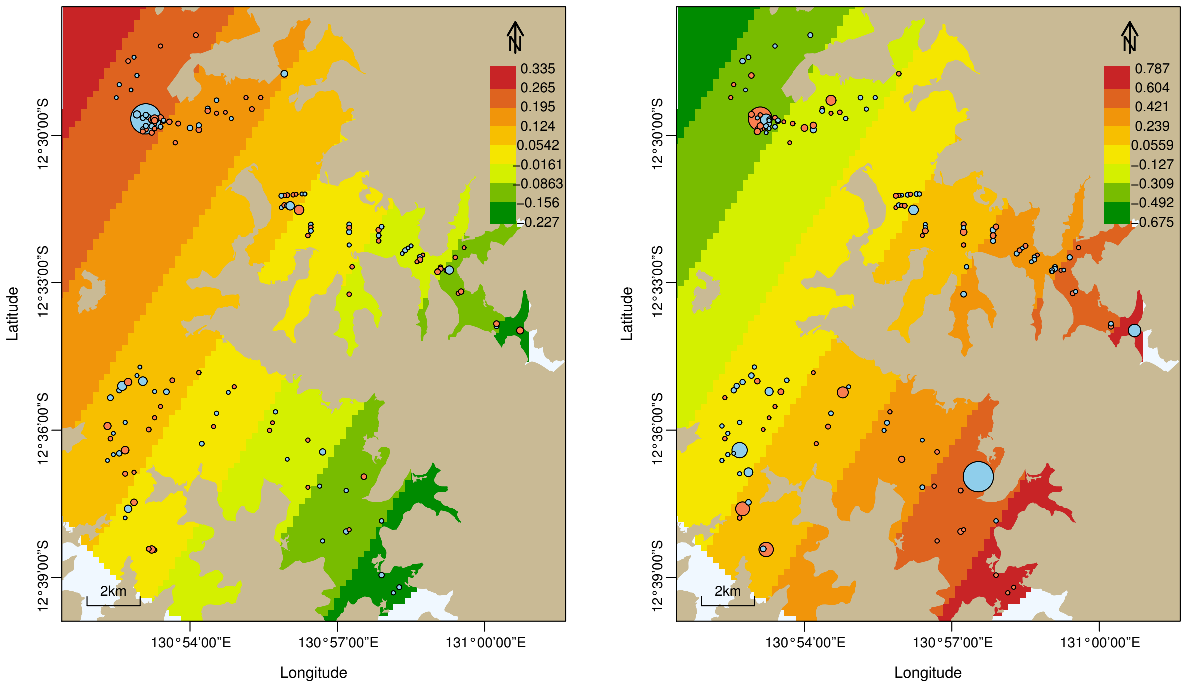


Figure 17: Spatial distribution of (L) and (R)

Planar Curvature:

```
Approximate significance of smooth terms:
            edf Ref.df     F p-value
s(long,lat)   2      2 0.523   0.594
R-sq.(adj) =  -0.00667   Deviance explained = 0.731%
```

Profile Curvature:

```
Approximate significance of smooth terms:
            edf Ref.df     F p-value
s(long,lat)   2      2 1.336   0.266
R-sq.(adj) =  0.00465   Deviance explained = 1.85%
```

Spatial distribution of Slope and Surface Ratio

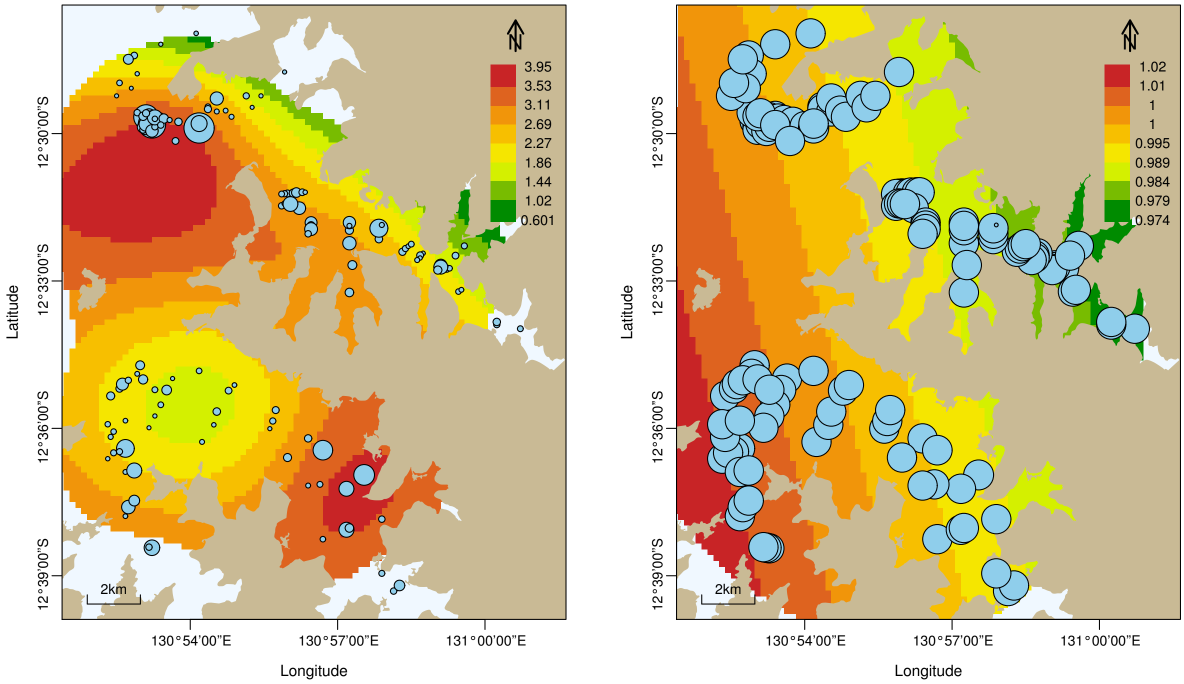


Figure 18: Spatial distribution of (L) and (R)

Slope:

```
Approximate significance of smooth terms:
               edf Ref.df     F p-value
s(long,lat) 8.381  10.62 1.345   0.209
R-sq.(adj) =  0.0762   Deviance explained =   13%
```

Surface Ratio:

```
Approximate significance of smooth terms:
             edf Ref.df     F p-value
s(long,lat)   2      2 0.831   0.438
R-sq.(adj) =  -0.00236   Deviance explained = 1.16%
```

References

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