C5

VOLUME C: MIDDLE BANKS, MORETON BAY

Marine Ecology

Marine Ecology

CONTENTS

FIGURES AND TABLES

Figures

Tables

APPENDICES

KEY FINDINGS

Impacts on seagrass and other underwater vegetation

- Seagrass was observed in small patches across areas of bare sand in shallow water at Middle Banks. The extent of the seagrass was not widespread and was recorded at 18 of 153 points surveyed at Middle Banks as part of the underwater video survey.
- The dredge footprint has been selected to avoid interference with these sparse areas of seagrass. In addition, the dredge footprint will avoid those areas where seagrass could potentially grow (i.e. unvegetated sand banks up to 10 m in depth).
- Any turbid plume is predicted to be of short duration and limited size and therefore is unlikely to result in long term impacts to seagrasses.
- The extent and duration of turbid plumes will be monitored as part of the project.
- The most extensive seagrass beds in the eastern part of Moreton Bay, which have high ecological value, are located towards the southern end of Moreton Island, approximately 10 – 12 km from Middle Banks. These seagrass areas would not be affected by the proposed sand extraction.

Impacts on Benthic Fauna

- The most immediate impact of the proposed sand extraction at Middle Banks will be the loss of benthic fauna, which typically live within the top 30 cm of the seabed.
- The location selected for the proposed sand extraction avoids the rich and abundant benthic communities in the deep-water environment to the south of Middle Banks.
- The loss of benthic fauna at Middle Banks is predicted to have a moderate or high short term impact at the site of dredging, but minor impacts on a local (i.e. northern Moreton Bay-wide) scale.
- Because of the dredging, there may be a short term increase in the quantity of benthic fauna in the water as fauna that generally lives below the sediment surface will be disturbed. This will increase the vulnerability of these animals to predation during the dredging operation.

Impacts on Dolphins and Whales

- Three species of dolphins and four species of whales have been recorded in the Moreton Bay region, with the common bottlenose and Indo-Pacific humpback dolphin being the most common.
- There have been few sightings of either dolphin species in the vicinity of Middle Banks and surrounds.
- The most common species of whale in the region is the Humpback whale. Individuals are commonly sighted off the South Queensland coast during June and July as they migrate north and between late August and October as they migrate south. They have a tendency to remain in oceanic waters, which limits potential interactions with the dredge vessel while operating at Middle Banks.
- Measures to be implemented in the event of any interaction with marine mammals or other protected marine species are contained in the Dredge Management Plan (Chapter C9).

Impacts on Dugongs

- Moreton Bay contains one of the largest populations of dugongs on the Queensland coast.
- However, Middle Banks is located in the zone of lowest dugong density with the Bay, with highest numbers found around Moreton Banks, approximately 10 – 12 km to the south east.
- The absence of large and stable areas of seagrass food resources is the likely cause of the low reported density of dugongs at Middle Banks.

Impacts on Marine Turtles

- The distribution and abundance of turtles within the Bay is influenced by the availability of food resources. The number of turtles is consistently higher in the eastern (e.g. Moreton Banks) and southern Bay due to the presence of extensive seagrass foraging areas.
- The most common marine turtle species in Moreton Bay is the green turtle. This species is not abundant in the Middle Banks area, most likely due to the scarcity of its preferred food, seagrass. Nevertheless, best practice dredging techniques will be used to further reduce risks to turtles. These measures are explained in the Dredge Management Plan (Chapter C9).

Effects of altering the profile of the seabed

- The proposed dredging will measurably alter the profile of the seabed, with the area to be dredged gradually deepening from depths of 10 m to an average depth of 21 m.
- Coastal hydrodynamic modeling confirms that the design of the area to be dredged will not result in any broad scale changes to tidal flows following sand extraction.
- These models also show a predicted increase in sand movement across the seabed, but this is unlikely to result in major changes in the structure of underwater communities.
- Deeper waters tend to have a greater quantity of animals than shallow water. It is expected that benthic fauna that will colonise the deepened dredge footprint are likely to be, on average, slightly more abundant and richer than presently exist. They may represent a beneficial impact in terms of fisheries resource and biodiversity values.
- Deep dredging over an elongated narrow dredge path, as proposed for this dredging operation, is likely to recolonise more quickly than shallow dredging over a wide and long area.
- The recolonisation process will occur during and following dredging. However, community recovery is likely to occur over a longer period.
- It is considered unlikely that seagrass will colonise the area that is to be dredged below 10 m because of the reduction in the quantity and quality of light that is required for growth.

Noise Impacts

The studies have analysed the potential impact of the noise of the dredging operations on megafauna such as turtles, dugongs and whales. The studies found:

- Given the distance of the dredge area from major dugong and turtle feeding areas, the sound of the dredging activity is unlikely to impose any noise-related adverse impact.
- The dredge operations are likely to produce sound emissions that are at frequencies unlikely to impact on the bottlenose dolphin.

- Whales are not common in the area proposed for dredging and it is unlikely that sound would interfere with whale communication will be generated.
- No residual effects from noise are expected.

Impacts on fisheries, including commercial fisheries

- Surveys undertaken for the project showed that the fish communities within Middle Banks were dominated by a small number of species that are considered common and abundant throughout Moreton Bay.
- The number of fish surveyed was greater in shallow water than it was in deeper water sites such as the area selected for dredging.
- Few fish species of commercial significance occur in the area of Middle Banks selected for dredging.
- Several fish species that occur in the area are targeted by recreational anglers.
- The Middle Banks region, particularly areas to the south of the dredge footprint, is an important prawning area.
- Some commercial crabbing is undertaken in the Middle Banks area.

The main effects from the sand extraction activity on fisheries values include:

- Sand extraction activities are likely to result in localised changes to the structure of fish and shellfish communities.
- It is possible that the reduction in the number of benthic animals in the area to be dredged could lead to a temporary and localised avoidance of that area by benthic feeding fish and invertebrates.

In assessing these potential impacts, the following matters were relevant:

- Middle Banks provides habitats that are not unique to the study region. The benthic communities that will be impacted by the dredging are well represented elsewhere in Moreton Bay.
- With the exception of spotted mackerel, commercial and recreational species potentially occurring in the study area are opportunistic and feed on a wide variety of benthic invertebrates. This means that the study area does not provide unique food sources for these species.
- While the effects of the proposed works on distribution patterns and catchability of commercial species such as prawns cannot be quantified, it is notable that the area to be dredged is not recognised as an important commercial, recreational fishing or trawling ground. Therefore, these activities are unlikely to be directly impacted by the proposed dredging works.
- Sand extraction activities have been sited away from the area south of Middle Banks that are worked by the Moreton Bay trawl fleet. This will avoid any direct impacts from dredging works on commercial fishing grounds or access to these areas.
- It is considered unlikely that the proposed lowering of the seabed will alter its suitability as a spanner or mud crab habitat.

Broader Impacts on Ecosystem Functioning

- No impacts to the status of invertebrate and fish populations, habitats or food resources in Moreton Bay are expected, except at a highly localised scale. Any changes at this level are not expected to result in changes to the ecological character of the Ramsar wetland.
- The area to be dredged is situated well outside the Moreton Bay Ramsar area and no impacts to the Ramsar wetland or its values are expected to occur.
- Overall the proposed works are highly unlikely to result in the loss of ecosystem functions in the Eastern Bay, or result in changes in key components that maintain ecosystem functioning.

5.1 Introduction

The Chapter describes the existing environment of the Middle Banks as it relates to flora and fauna species, communities and habitats. This report section specifically examines the following ecological attributes:

- Patterns (in space and time) in the distribution, abundance, diversity and other community structure attributes of key ecological functional groups.
- Ecological and conservation values of each ecological functional group.
- Processes known or likely to control these patterns.

The key ecological functional groups considered in this chapter are:

- Aquatic macrophyte vegetation (seagrass and other marine vegetation).
- Aquatic micro-algae (phytoplankton and other microscopic plants).
- Zooplankton (tiny crustaceans and other marine animals that drift in the water column like plankton).
- Benthic macro-invertebrates (marine worms, bivalves, starfish).
- Fish and nektobenthic invertebrates (fish, prawns and crabs).
- Marine megafauna (marine mammals and reptiles).

5.2 Proposed Development

The proposed development involves the dredging of 15 Mm^3 of sand from Middle Banks, located in Moreton Bay, to be used in airport land reclamation. Such an activity will alter the bathymetry of the Middle Banks area by deepening some areas from existing depths at or below about 10 m down to depths of about 21 m. There will be a temporary loss of sedentary fauna and flora within the dredging footprint. Furthermore, dredging will create a sediment plume and modify some physio-chemical properties of the water column, potentially resulting in short term impacts to ecological values.

Changes in the local hydrodynamics and morphological processes as a result of changes to bathymetry will result in changes to biological communities that recolonise disturbed areas. The Moreton Bay Sand Extraction Study (WBM Oceanics Australia 2004) showed that these changes would be confined to the local Middle Banks area.

5.3 Methodology

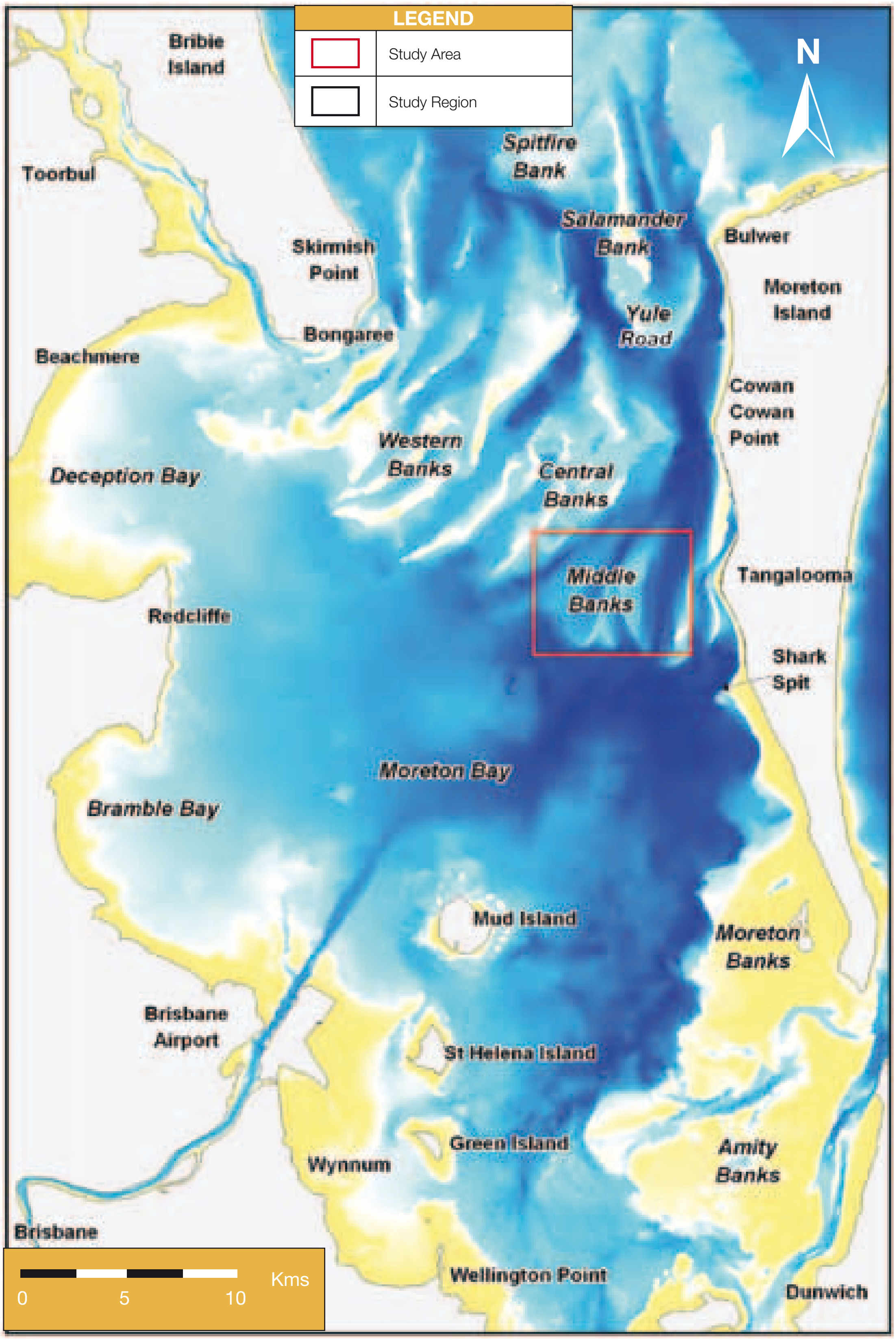
5.3.1 Nomenclature and Terminology

In this report, the study area refers to waters and the seabed within Middle Banks. The study region refers to waters and the seabed within the northern delta sand shoals between Cowan Cowan and Shark Spit on Moreton Island, and Southwest Banks to the west (**Figure 5.3a**). The term surrounding area refers to the lands and waters of eastern Moreton Bay and the western shoreline of Moreton Island.

Within this report, the conservation status of a species may be described as Endangered, Vulnerable, Regionally Vulnerable, Rare, Culturally Significant or Common. These terms are used in accordance with the provisions of the *Queensland Nature Conservation Act 1992 (NC Act)* and its regulations and amendments, and/or the *Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act).* For the purposes of this report, relevant *NC Act* regulations and amendments refer to the *Nature Conservation (Wildlife) Regulation 1994* reprinted as in force on 17 December 2004 (and includes commenced amendments up to 2004 SL No. 316). Threatened is a common term used to collectively describe endangered and vulnerable species.

The term marine plants refers to species listed in the Schedule of Marine Plants under the FHMOP 001 (Department of Primary Industries 2002). The term nektobenthic invertebrates refers to larger mobile invertebrate, such as penaeid prawns and portunid crabs, that easily avoid capture in standard benthic assessments using core or grab samples, but which are be frequently captured by trawling.

Figure 5.3a: *Location of the Study Area and Study Region within Moreton Bay.*



The nomenclature used in this report follows Strahan (2000) for marine mammals, Froese and Pauly (2005) for fish and Cogger (2000) for marine reptiles.

5.3.2 Existing Environment

Existing information regarding the ecological communities and habitats of the study area, study region and surrounding area was collated and reviewed. The following documents and database information were considered in the preparation of this report:

- Fauna databases of Environment Australia, Queensland Museum and Queensland Environment Protection Agency's (QEPA) WildNet.
- Current and historical aerial photography.

The principal information source for this component was the Moreton Bay Sand Extraction Study (MBSES) (WBM Oceanics Australia 2003, 2004). The MBSES involved a detailed review of existing information, and field surveys, to describe the nature of ecological communities in the study region. Information gaps were identified in the initial stages of the impact assessment process, hence supplementary surveys were undertaken to fill these gaps. The following describes the sampling and analysis methods used in the present study.

5.3.2.1 Seagrass and Epifauna Field Survey – Middle Banks

Field Methods

A seagrass survey was undertaken to assess broad-scale seagrass distribution and characterise the epibenthic community and its associated habitat, within and surrounding Middle Banks. Initially, 110 survey points were established at intervals of 500 m over an area of 27.5 km^2 (**Figure 5.3b**). A number of intermediate points (17) were also sampled in between these original points, in order to refine the spatial distribution of seagrass beds. An additional 26 points were sampled further afield from Middle Banks at various intervals around the initial survey grid, to gain a broad appreciation of epibenthic communities and their associated benthic habitats within the study region. In total, 153 points were sampled, which covered an area of around 89 km^2 (**Figure 5.3b**).

At each survey point, a low-light, high-resolution underwater video camera was lowered to within view of the seabed (generally between 0.3 and 1 m from the seabed, depending on local water clarity conditions at each site). The camera fed a digital video image live to a laptop computer on the surface vessel 'Resolution 2'. A one to two-minute digital recording was made of the seabed, during which time, tidal/wind driven surface currents pushed the survey vessel (and therefore the underwater video camera) over a roughly linear transect typically between 30 m and 100 m in length. Concurrently, a differential GPS (dGPS) was used to track the drift of the video camera over the seabed by recording the position of the boat at two-second intervals. In addition to this, the date, depth of the substratum and time (start and finish of transect) were noted at each site.

Data Extraction

Digital video files (MPEG2 format) were stored on digital versatile discs (DVD). The video file associated with each site was reviewed on a PC at the WBM office. Epibenthic taxa (including seagrass and erect macroalgae) and their associated benthic habitats were characterised at each site broadly connected with the methods employed by Stevens and Connolly (2005)[1] in their Bay wide study of Moreton Bay epibenthic fauna communities.

For each video file, any epibenthic taxa encountered were noted and identified (where possible) to species or higher taxonomic level. Further to this, the presence and (qualitative measures of) abundance of bioturbating organisms were recorded by noting any biogenically worked sediment surfaces (e.g. tracks and mounds) and burrows or holes in three different size classes (<3 cm, 3-10 cm, >10 cm; Stevens and Connolly 2005). The density of burrows or holes was also qualitatively assessed with each site being classified (based purely on observations) as being

[1] *It is noted that the present study was designed primarily to characterise epibenthic macrofauna communities and their associated benthic habitats over a broad area, using a rapid and qualitative assessment technique. By comparison, the study by Stevens and Connolly (2005) was designed for more detailed quantitative assessments with less spatial resolution (i.e. more distance between points) over much larger spatial scales (i.e Moreton Bay wide).*

sparse (~1 - 10 holes per m^2), medium (~10 - 25 holes per m^2) or dense (>25 holes per m^2).

Classification and Mapping

Habitat maps were created by allocating survey sites into one of four groups based on their apparent similarity, inferred principally from habitat characteristics, presence/absence and levels of bioturbation in combination with the dominant or associated epibenthic fauna. A thematic habitat map was generated for the study area based on these classifications using Mapinfo (version 8.0) GIS software package.

No multivariate or other statistical analyses were conducted as part of this study.

5.3.2.2 Fish and Nektobenthic Invertebrate Field Survey

Gear Selection and Operation

Standard commercial Moreton Bay otter trawling gear was utilised from a currently commercially endorsed (M1) and operating Moreton Bay prawn trawl vessel (Mar Jean) skippered by Mr Robbie Brock and crewed by Mr Brendon McAtamney.

The trawl gear consisted of two four fathom nets (twin gear) in a "yankee doodle" configuration with a mesh size of 38 mm. The nets remained fitted with both turtle excluder devices (TEDs) and bycatch reduction devices (BRDS). Each trawl shot was of 30 minutes duration.

Site Selection and Survey Timing

The effective work of commercial otter trawl vessels is by the physical aspects of the seabed as well as water depth. Areas of less than 4 m in depth are generally considered unworkable as well as areas where the slope of the seabed is acute (e.g. channel habitat) or where large sand ripples occur. Furthermore, locations known as "hook-up marks"; either natural features such as rocks or lost or dumped material which snags trawl nets, also limits the area that can be effectively trawled. In consultation with the previous president of the Moreton Bay Seafood Industry Association (MBSIA), the most important trawl areas adjacent to the study area were chosen for surveying across a range of depths (**Figure 5.3b**). Two shallow water and two deeper water sites were sampled (**Table 5.3a**).

Table 5.3a: The depth range of the four sites (two shallow and two deep) surveyed.

Site Number	Depth Range
Site 1 (shallow)	12 – 14 m
Site 2 (deep)	26 – 32 m
Site 3 (deep)	30 – 32 m
Site 4 (shallow)	12 – 17 m

Table 5.3b: Summary of the number of trawl shots undertaken at each of the four survey sites during October, November and December in the study area.

Month	Site 1 (shallow)	Site 2 (deep)	Site 3 (deep)	Site 4 (shallow)
Oct	4	4	-	-
Nov	4	4	4	4
Dec	5	4	4	5
Total	13	12	8	9

Surveying was undertaken in October, November and December and focused on the new moon period. This period, constituting part of the main prawning season in Moreton Bay, is a time when diversity, richness and abundance of fish assemblages in Moreton Bay are at a maximum (reviewed in Tibbetts and Connolly, 1998).

The proposed January sampling was abandoned due to inclement weather. Weather and mechanical failure also prevented the completion of a full number of proposed replicate trawls. However, sufficient replicate trawls were completed and the structure of fish and nektobenthic invertebrate assemblages was able to be determined and the identified hypotheses tested.

The number of replicate trawls undertaken at each site is described in **Table 5.3b**. All surveying was conducted at night, the primary period of operation for commercial prawn trawling in Moreton Bay.

Identification and enumeration of captured species was restricted to onboard the vessel (**Figure 5.3c and Figure 5.3d**). All works were undertaken under the umbrella of an approved variation to General Fisheries Permit (PRM 04021E) held by WBM Pty Ltd where all biota were captured and released. For "trawl crabs" (*Charybdis natator, Thalamita prymna and Portunus hastatoides*) it was not feasible to sort them into individual species on board the vessel, therefore abundance values for these species are presented as a species group. All other captured fish and nektobenthic invertebrate were identified and counted. However, for fish species captured, their overall abundance in Moreton Bay was identified as "abundant", "common", "uncommon", and "rare", based upon the qualitative classifications of Johnson (1999).

Data Analyses

Two-Way Nested Analysis of Variance was applied to the abundance (log +1 transformed) of king prawn and tiger prawns in order to test the null hypotheses: the abundances of these two key commercial species are not influenced by water depth in the Middle Banks region. The ANOVA factors were Month, Depth, Month*Depth interaction and sites nested within (Month*Depth).

Spatial variation in the structure of fish and nektobenthic assemblage data was displayed using non-metric Multi Dimensional Scaling (n-MDS) based on the Bray-Curtis Dissimilarity measure on log + 1 transformed data. Variations in assemblages among depths (averaged across all month groups) were analysed using the Analysis of Similarity (ANOSIM) procedure. The SIMPER (SIMilarity PERcentages) procedure was performed on similarity matrices to determine the major taxa responsible for differences between depths. All taxa that contributed > 3 percent of total dissimilarity were identified by the analyses. All multivariate analyses were undertaken using the PRIMER software package.

__Figure 5.3b:__ Location of Benthic Survey Sites and Trawling Survey Locations within Middle Banks Region.

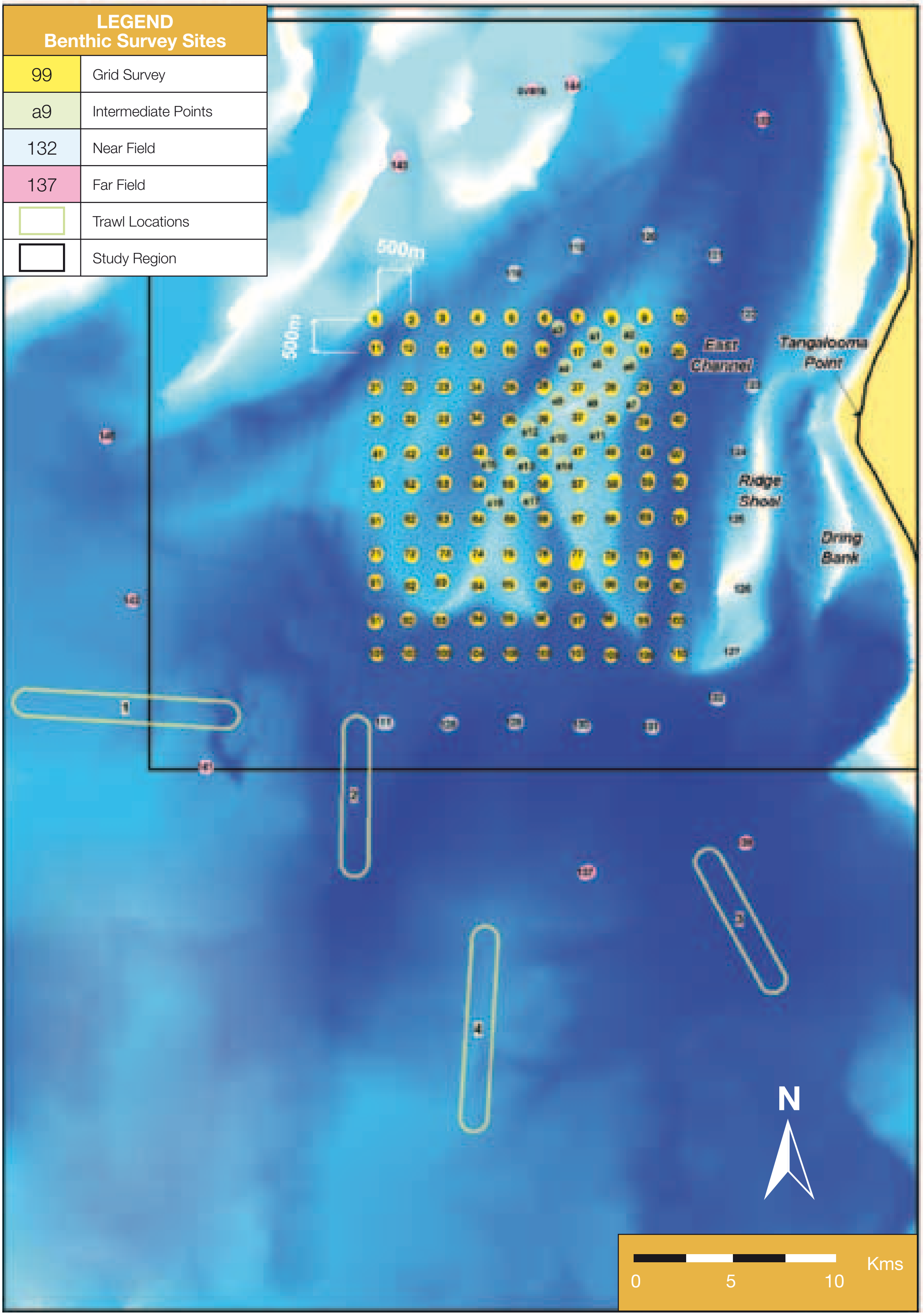
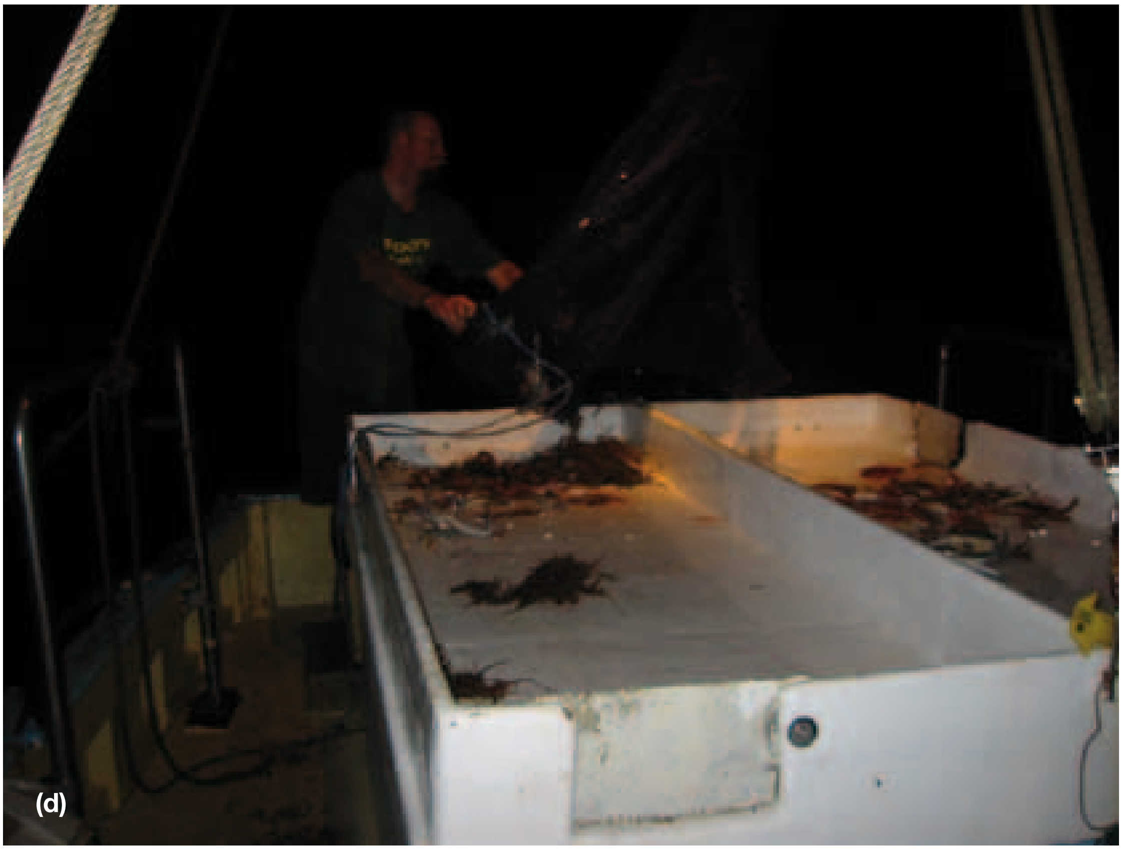


Figure 5.3: ***(c)*** *October 2005 Trawl catch at Site 2 (located to the south of Middle Banks); and*
(d) *Trawl catch being emptied onto a sorting tray.*

(c)



(d)

5.3.3 Impact Assessment

The methodology for Impact Assessment has been provided in section 5.8.

5.4 Limitations and Assumptions

5.4.1 Baseline Assessments

The assessments made in this study are based primarily upon a review of existing literature compiled by WBM Oceanics Australia. The MBSES (WBM Oceanics Australia 2003, 2004) was the principal information source used in the present study. This impact assessment study draws upon the results and conclusions of the 2003/04 studies to describe 'existing conditions' in the area, and to determine the impacts of the proposed dredging on marine ecology.

WBM Oceanics Australia (2004) sampled benthic macro-invertebrate communities at multiple sites within three depth zones at Middle Banks, and three other sand bank locations in the study region, at one time only (June 2003). Consistent depth-related changes in benthic communities were observed among locations. These changes, it has been hypothesised, reflect differences in the intensity of hydrodynamic disturbance (i.e. particularly wave action) among depths. Earlier studies by Stephenson *et al.* (1978) in the study area found distinct differences in community structure between the northern and southern sections of Middle Banks, which they also suggested reflected differences in the degree of wave exposure.

Temporal variations in assemblages at Middle Banks (and other locations in the study region) were also explored by WBM Oceanics Australia (2004). Changes in macro-invertebrate communities were noted at fine (measured in days) and intermediate (measured in months) time scales over the three month sampling period. Other workers (see papers by Stephenson) have noted similar high levels of temporal variability in local benthic macro-invertebrate communities. Together with earlier studies, the Moreton Bay Sand Extraction Study provides a sound basis for describing the nature of variability (in space and time) in these communities.

While the benthic macroinvertebrates of the study area are reasonably well described, there was a paucity of recent fish and nektobenthic invertebrate community data. Sampling described in section 5.3.2.2 was undertaken in order to fill this information gap. The survey was designed to sample nekto-benthic communities (i.e. prawns, crabs and fish), which represent the key species targeted by commercial fishers, and are also likely to be species predominately affected by the proposal. The selected fish sampling equipment has a bias against pelagic species, though all fish sampling equipment displays selective bias to some degree.

When designing this survey a range of sampling equipment was considered including mesh nets and beam trawls. The former was considered too highly selective and unable to sample a wide range of species. The latter was impractical to use. The commercial otter trawl equipment used in this study is able to sample the widest range of fish and nektobenthic species. Using commercial otter trawl equipment also has the added advantage of obtaining results directly relating to the trawling activities of the commercial trawl fleet of Moreton Bay.

A criticism of the otter trawl equipment used is the under representation of pelagic species in catches, particularly larger varieties. The Middle Banks area is well known among recreational fishers as an area for targeting spotted mackerel (*Scomberomorus munroi*) and various tuna species. During daylight site visits to the area in February 2006, spotted mackerel and various tuna species were observed in the Middle Banks area actively feeding on baitfish. These species though were absent in the otter trawl surveys.

The benthic habitats and epi-benthic fauna communities of Moreton Bay have been recently surveyed, including sites in the Middle Banks region (Stevens 2003; Stevens and Connolly 2005). However, this data was of an insufficient spatial resolution and therefore unsuitable to compile habitat maps and epibenthos assemblages at a local scale. As a result, supplementary field assessments were undertaken in December 2005 and January 2006 in order to address this information gap. It should be noted that sampling was undertaken at one time only, and that the seagrass species recorded in the study area can show great variability over time. Furthermore, no studies have examined temporal changes in these beds in the study region.

It is unknown whether the distribution of seagrass described in this report represents the maximum possible seagrass extent in the study area. It is known, however, that winds from the west (W, NW and SW) typically generate the largest waves in the study area (see Chapter 3), and that these wind conditions typically occur in winter and early spring. These wind waves may 'feel' the bed in shallow waters, possibly leading to the resuspension of the seabed and the uprooting of seagrasses. Bureau of Meteorology data indicates for the two-month period leading up to seagrass surveys, winds were generally from the NE to S direction, which would be unlikely to generate large waves in the study area. Consequently, seagrass beds surveyed in the present study are unlikely to represent recently disturbed beds.

There are several functional groups that have not been surveyed within the project area, including plankton and benthic microflora, and interstitial invertebrates. It is acknowledged that these groups are important ecosystem components. However, in the absence of detailed comparable data from other areas (i.e. descriptions of community structure over a range of temporal and spatial scales), sampling of these groups within an impact assessment process has questionable value.

5.4.2 Ecological Values and Impact Assessment

The ecological values, or ecosystem services provided by the study area are described in this report on the basis of:

- Structural habitat characteristics, including water depths, sediment types and benthic epiflora and epifauna community characteristics.
- A review of known functions or ecosystem services provided by similar habitat types in the broader region.
- Interpretation of survey data from the study area and surrounding area describing patterns in fauna movements.
- Comparison of survey results from the study area with other areas in the surrounding area, and from regional data.

To date, no studies have directly examined the fisheries habitat values within different parts of Moreton Bay. In this impact assessment study, fisheries habitat values, and predictions of impacts, have been undertaken using a range of quantitative, semi-quantitative and qualitative indicators, including:

- **Marine vegetation loss.** Quantification of habitat area as a surrogate measure of fisheries habitat value underpins many fisheries habitat-planning decisions. It should be recognised however that the approach of equating habitat loss to fish loss might not always be appropriate, as there is not always a strong relationship between fish assemblages and habitat structure.
- **Examination of habitat condition and structure.** This includes the cover of seagrass, degree of wave disturbance, and degree of disturbance by trawlers.
- **Examination of fish assemblages.** This study compares the fish fauna and habitats of the study area to other parts of the Moreton Bay region, and provides comment on likely fisheries habitat values of the study area. This data provides the context of defining the types of species using the study area, their relative abundance, and their fisheries values.
- **Fishing resource values.** This was determined through a review of existing catch data, and discussions with commercial fishers.

Within the impact assessment sections of this report, specific uncertainties with respect to data quality and degree of confidence in impact predictions are fully documented.

5.5 Baseline

5.5.1 General Context

The study area (Middle Banks) is located approximately 20 km north east of the mouth of the Brisbane River and 4 km due west of Tangalooma Point on Moreton Island (**Figure 5.3a**). Sediment in the study region (northern and eastern side of Moreton Bay) is dominated by sand of marine origin (See Chapter C3).

The study region and surrounding area contains a complex system of sand banks, including: Central Banks, South West Spit and Western Banks, which extend for approximately 10 km to the north and north west of Middle Banks. Two channels run through the area to the north of Middle Banks. Main Channel lies immediately to the north west of Middle Banks where the depth varies between approximately 12 and 17 m. Pearl Channel runs between South West Spit and Western banks with depths between approximately 13 and 17 m. Deeper waters (to 30 m) occur in the area immediately south of Middle Banks.

Morphological and hydraulic processes have a strong influence on the environmental characteristics of the study area, in turn controlling the structure of biological assemblages. As discussed in Chapter C3, waves and currents have caused the sand shoals to develop into a system of mutually evasive ebb and flood-dominated channels, which are separated by linear sand ridges (Stephenson 1978; Harris and Jones 1988), with relatively high bed sheer stresses and a highly mobile surface layer (centimetres to metres thick). Current speeds in excess of 0.3-0.4 m/s indicate active sand, with currents of 0.5-0.6 m/s corresponding to areas with a high degree of mobility. As discussed in Chapter C4, the study area has low ambient turbidity and nutrient concentrations, reflecting the high degree of tidal flushing and limited influence of riverine discharges.

The following sections describe the key ecological communities and species (hereafter referred to collectively as functional groups) of the Middle Banks area, and the main factors/processes likely to control these functional groups. For ease of discussion, these functional groups have been discussed separately as follows: microalgae, seagrass, saltmarsh and mangroves, zooplankton, 'sedentary' benthic invertebrates, mobile crustaceans and fish, dugongs, cetaceans and whales, sea turtles, and other marine megafauna. It is acknowledged that there are linkages between different functional groups, and that the processes controlling groups are generally similar.

5.5.2 Mangroves and Saltmarsh

Key points – Mangroves and Saltmarsh

- No mangroves or saltmarsh occur in the study area due to unsuitable growing conditions.
- The nearest noteworthy areas of mangrove and saltmarsh to Middle Banks are located approximately 13 - 14 km away towards the south-western coast of Moreton Island, at Crab Island, and in central Moreton Bay at Mud Island.

Saltmarsh and mangroves grow in the intertidal zone, typically within quiescent environments. Middle Banks does not contain intertidal banks and consequently, these species do not occur in the study area. Abal *et al.* (1998) mapped the mangrove and saltmarsh resources of Moreton Bay from aerial photographs and limited field inspections (**Figure 5.5a**). The nearest noteworthy areas of mangrove and saltmarsh to Middle Banks are located approximately 13 - 14 km away, on the south-western coast of Moreton Island at Crab Island, and in central Moreton Bay at Mud Island.

Figure 5.5a: *Marine Vegetation in Moreton Bay (after Abal et al.1998).*

5.5.3 Seagrass

Key points – Seagrass
• Two species of seagrass (*Halophila ovalis* and *Halophila spinulosa*) have been recorded at Middle Banks, growing exclusively on shallow (between ~4 and 10 m) sub-tidal sand banks.
• These seagrass beds are highly fragmented, and are numerically dominated by *H. ovalis*, a fast growing species that can show great temporal variation in extent and biomass. Adjacent (unsurveyed) sand banks are also likely to contain similar seagrass communities in a similar depth stratum.
• The nearest previously mapped seagrass meadows occur approximately 2 - 3 km to the east of Middle Banks in the intertidal and shallow sub-tidal areas adjacent to Moreton Island.
• The extensive seagrass beds at Moreton Banks to the south of Middle Banks form important feeding areas for turtles and dugong. The sparse (and possibly ephemeral) seagrass beds at Middle Banks is not recognised as an important foraging area for turtles and dugongs. Nonetheless, these seagrass communities would provide other ecosystem functions, including bed stabilisation and sediment nutrient turnover.

5.5.3.1 Spatial and Temporal Patterns

In November 2005, WBM Oceanics Australia conducted a broad scale (resolution of 250 - 500 m) seagrass survey of the study area. *Halophila ovalis* and *Halophila spinulosa* are both common sub-tidal seagrass species within Moreton Bay, and both were recorded at Middle Banks in the present study. Seven species of seagrass have been previously recorded in Moreton Bay (Hyland *et al.* 1989), namely:

- *Zostera capricorni* Ascherson
- *Halodule uninervis* (Forsk.) Ascherson
- *Syringodium isoetifolium* (Ascherson) Dandy
- *Cymodocea serrulata* (R. Brown) Ascherson and Magnus
- *Halophila spinulosa* (R. Brown) Ascherson
- *Halophila ovalis* (R. Brown) J. Hooker
- *Halophila decipiens* Ostenfeld

One or more *Halophila* seagrass species were recorded at 21 of the 153 points surveyed at Middle Banks and the study region, exclusively on shallow subtidal sand banks at depths ranging from 4 to 10 m relative to AHD (**Figure 5.5b**). Both seagrasses have recently been recorded at water depths around 12 m within the study region at Tangalooma Point by the University of Queensland (Udy and Levy 2002), however the reference depth was not specified in that study (e.g. AHD or LAT).

Two main areas of seagrass (polygons) were identified at Middle Banks, which comprised a total estimated area of 1.87 km^2. Other potentially substantial areas of unmapped seagrass were identified (refer to points 127, 126 and 'Ovalis') on the shallow sand banks to the north and east of the study area[2]. It is likely that seagrass would occur within a similar maximum depth range between 4 and 10 m on sand banks surrounding the Middle Banks region.

Seagrass occurred in discrete patches at Middle Banks that were variable in size and shape, and were interspersed by areas of bare sand i.e. large contiguous beds of seagrass were not observed in the study area. Within these patches, seagrass density was highly variable, ranging between sparse (<5 percent) and moderately dense (~10 - 50 percent) cover.

Reproduction and colonisation of the seabed by *H. ovalis* and *H. spinulosa* can occur via a number of pathways, including germination from sediment seed bank, extension of rhizomes from adjacent beds, and via small vegetative cuttings (e.g. Clarke and Kirkman 1989; Edgar 2001). Both of these species are also well known to rapidly re-colonise areas following various forms of disturbance, for example following dugong grazing (e.g. Preen, 1995) and seasonal light deprivation (e.g. WBM 2005). The latter of these impacting processes can correspond to large shifts (expansions and retractions) in seagrass extent. No studies have examined the temporal changes in these beds in the study region. Consequently, it is unknown whether the distribution of seagrass described in

[2] *These seagrass areas were not mapped in detail during the present study.*

Figure 5.5b: *The Distribution and Extent of Seagrasses Within and Surrounding Middle Banks, Northern Moreton Bay.*

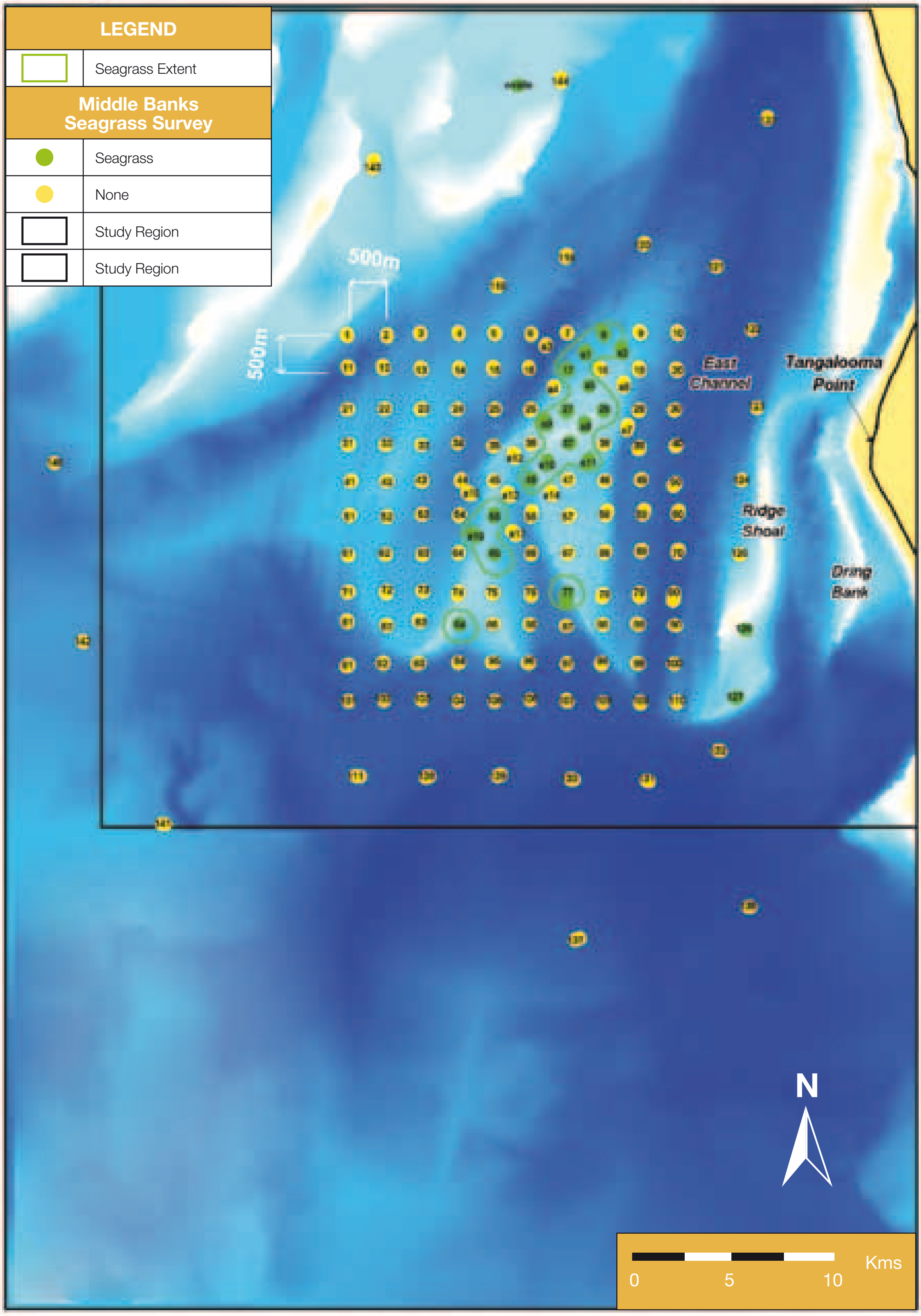


Figure 5.5b represents the maximum seagrass extent in the study area. It is known, however, that winds from the west (W, NW and SW) typically generate the largest waves in the study area (see Chapter C3), and that these wind conditions typically occur in winter and early spring months. These wind waves may 'feel' the bed in shallow waters, possibly leading to resuspension of the seabed and uprooting of seagrasses. Bureau of Meteorology data indicates for the two-month period leading up to seagrass surveys, winds were generally from the NE to S direction, which would be unlikely to generate large waves in the study area.

There is no recent broad-scale seagrass mapping for Moreton Bay, however Abal et al (1998) report the general distribution of seagrasses throughout Moreton Bay based on earlier mapping surveys (**Figure 5.5a**). They show extensive seagrass beds near the southern tip of Moreton Island on the Moreton and Amity Banks and along the western edge of Moreton Bay in Deception and Waterloo Bay. The nearest previously reported seagrass to the Middle Banks area is in the shallow waters adjacent to Moreton Island approximately 2 - 3 km to the east (Abal *et al.* 1998). The most extensive beds, which have high ecological value due to their importance as dugong and turtle feeding grounds, were located towards the southern end of Moreton Island at Moreton Banks, approximately 10 - 12 km from the Middle Banks area.

Prior to 2003, there have been no records of seagrass on Middle Banks or on any of the other sand bank complexes in the northern Moreton Bay delta; however, more recent finer-scale surveys (including the present study) have reported the presence of seagrass in some of these areas. For instance Stevens (2003) recorded seagrass in deep water at the northern entrance to Moreton Bay, an area where no seagrass had previously been reported; even though the species was not recorded by the author, it would most likely have been either or both of the *Halophila* species. More recently (mid-2005), patches of *Halophila ovalis* were recorded in the Spitfire Banks area (WBM unpublished data). As previously mentioned, a recent survey by Udy and Levy (2002) found extensive regions of seagrass species *Halophila spinulosa* and *Halophila ovalis* growing at depths up to 12 m at Tangalooma Point on the west coast of Moreton Island.

It is unknown whether all these new records of seagrass in the northern Moreton Bay area are due to an actual increase in seagrass extent, or (more likely), reflect inadequate sampling effort in these areas in the past. Seagrass meadows within these dynamic and exposed environments are highly fragmented and generally sparse, which may have been difficult to detect in past surveys.

5.5.3.2 Values

Seagrasses are marine flowering plants (angiosperms) that are generally thought to have a range of functions in the maintenance of coastal/estuarine ecosystem, including the following:

- Provide food resources for dugong, green turtles and certain invertebrate species. The value of these resources as food resources depends on factors such as seagrass species and abundance, location/accessibility, water depth and possibly levels of physical disturbance. The extensive seagrass beds located at Moreton Banks (10 - 12 km south of the study area) are recognized as important dugong and turtle feeding areas. The study area is not recognized as an important feeding area for marine turtles and dugongs (see section 5.5.9 and 5.5.10). Nonetheless, both recorded *Halophila* species are important dietary components for these marine animals, and it possible that seagrass beds in the study area would represent a food resource from time to time.
- Provide habitat for adult and juvenile stages of many fish and invertebrate species of fisheries significance (see section 5.5.7).
- Typically have higher taxa richness of fish and invertebrates (including sedentary and mobile species) than unvegetated substrates, and therefore can have high biodiversity values.
- Assist in the stabilization of sediments and sediment nutrient cycling.

Because of these ecological values, seagrass and other marine plants are regulated under the *Fisheries Act 1994* and a permit is required from the Queensland Department of Primary Industries and Fisheries for their disturbance and/or removal.

5.5.4 Microalgae

Key points – Microalgae
• Microalgae composition and abundance can show marked variation over a range of spatial and temporal scales, varying in response to the availability of light and nutrients, as well as biological processes (zooplankton grazing, seasonality etc.).
• Benthic microalgae tends to have moderately high abundance throughout eastern Moreton Bay region.
• Phytoplankton communities in oceanic influenced environments tend to be more rich, but less abundant, than nearshore environments.
• Benthic microalgae and phytoplankton represent the main primary producers in the study area, and are also important in cycling nutrients through coastal food webs.
• Benthic microalgae and phytoplankton can typically quickly re-colonise disturbed areas.

Under the *Fisheries Act 1994*, the classification of 'Marine Plants' includes benthic microalgae and phytoplankton (collectively 'microalgae'). This functional group is comprised of species belonging mainly to the following taxonomic Divisions: Dinophyta (dinoflagellates), Bacillariophyceae (diatoms), Chysophyceae (coccolithophores) and Haptophyceae.

Microbenthic flora are grouped as those microalgae found interstitially in sediments of 'soft' substrates, which may include mud and sand flats, amongst beds of seagrass, sand banks, salt marshes, tidal marshes and estuaries. Phytoplankton is grouped as those microalgae that drift about with the motion in the water column.

5.5.4.1 Spatial and Temporal Patterns

Benthic Microflora

Benthic microflora assemblages are typically comprised of diatoms, dinoflagellates and cyanobacteria living in the upper few centimetres of the sediment column. These assemblages are known to show a high degree of variability over small spatial scales (Underwood *et al.* 1998), as well as over time, which presents difficulties in determining patterns over large scales. However it is known that community structure is strongly influenced by ambient light (which in turn is controlled by turbidity and water depth) and nutrient availability (Dennison and Abal 1999).

The spatial patterns of benthic micro-algae communities in Moreton Bay are generally not well understood. In a study by Dennison and Abal (1999), the micro-benthic flora communities were examined broadly within Moreton Bay to determine any large-scale patterns in spatial distribution and over (limited) temporal scales. The study recorded greatest algal biomass (chlorophyll *a*) within shallow (less than 5 m in depth) nearshore regions of the Bay, but lowest concentrations in central Moreton Bay. Benthic micro-algae biomass was moderately high (30 - 40 mg chlorophyll a m^{-2}) throughout the eastern Moreton Bay region, which includes Middle Banks. It is likely that benthic micro-algae assemblages have a strong influence on nutrient and carbon fluxes in the Bay (Dennison and Abal 1999).

Phytoplankton

As phytoplankton communities are largely passive mobile organisms, they are difficult to accurately sample or characterise for any given area. In Moreton Bay, phytoplankton has received increasing amount of attention in recent years, particularly owing to the development of nutrient bioassay techniques (Jones et al 1998) and use of water column chlorophyll a biomass as bio-indicators of water quality (Dennison and Abal 1999; EHMP 2005). Consequently, most of the work on the ecology of phytoplankton has focussed on anthropogenic effects of nutrient loading on estuary 'health'.

The waters of north-eastern Moreton Bay are oligotrophic (have low nutrient levels), owing to a high degree of oceanic flushing from North and South Passage. Case-studies world-wide (e.g. Gowen and Bradbury, 1987; CSIRO Huon Estuary Study Team, 2000) indicate that phytoplankton can rapidly uptake available inorganic nutrients (e.g. ammonia and nitrate), allowing the biomass of populations to increase ('bloom') on very short temporal scales. However, field experiments by Jones et al (1998) found that phytoplankton assemblages in eastern Moreton Bay demonstrated almost no response to *in vivo* nutrient addition. This may indicate that these phytoplankton assemblages do not show the same responses as phytoplankton assemblages elsewhere, or that the short residence time of waters in this area prevents the rapid utilisation of nutrients (Gowen and Bradbury, 1987).

As discussed in Chapter C4, chlorophyll *a* concentrations in the water column (a surrogate measure of phytoplankton biomass) has been undertaken on a quarterly basis by the Ecosystem Health Monitoring Program (EHMP) for several years throughout Moreton Bay, including sites at Middle Banks. These and other studies have shown a strong east to west gradient in phytoplankton biomass in Moreton Bay, which broadly correspond to gradients in nutrient availability (Dennison and Abal 1999).

By contrast, few studies have examined spatial and temporal patterns in phytoplankton community structure in Moreton Bay. Heil *et al.* (1998) conducted a one-off assessment of the winter phytoplankton assemblage in Moreton Bay (including the central and northern sections). However, this study was of very limited temporal coverage and occurred during a flood period and the findings may not generally be indicative of the assemblage during non-flood periods. This study indicated phytoplankton communities in eastern Moreton Bay were dominated by oceanic species, predominantly diatoms and dinoflagellates.

5.5.4.2 Values

Microalgae have important roles in nearshore marine and estuarine ecosystems. It has been estimated that phytoplankton contribute about 65 percent of primary production by marine plants in Moreton Bay, equivalent to 4.3 x 10^5 C/d^{-1} (Abal *et al.* 1999). Further to this, these assemblages form the basis of most marine food webs, a study by Melville and Connolly (2003) found the in situ production of micro-algae of various marine habitats to be an important source of nutrition for relevant commercial and recreational fish species. Additionally, micro-algae are considered an important component of coastal productivity, energy budgets as well as nutrient and oxygen turnover (Dennison and Abal 1999). As such, micro-algae are important regulators of water quality and in general trophodynamics in estuarine and nearshore environs.

5.5.5 Zooplankton

Key points – Water Column
• The structure of Moreton Bay zooplankton communities is influenced by the influx of larvae (meroplankton) during spring/summer and early autumn.
• Oceanic influenced zooplankton communities appear to be more stable in terms of abundance and diversity than in western Bay assemblages, where disturbance (e.g. seasonal or dramatic reductions in salinity) and nutrient availability are non-important drivers than in the eastern Bay.
• Zooplankters provide an important link between primary production (grazing of phytoplankton) to higher (e.g. benthic and nektonic carnivores) trophic levels, of which some may be important to commercial and recreational fisheries.

5.5.5.1 Spatial and Temporal Patterns

Zooplankton are non-photosynthetic and include protist or animal plankton that require carbon already fixed into organic molecules (i.e. heterotrophic nutrition). The spatial distribution pattern of zooplankton over broad scales (>1 km) is dictated by water movement; e.g. tidal/fetch driven currents, wave resuspension, in which they are suspended. They are, however, often capable of weakly directed swimming movements, with some species actively responding to environmental cues (e.g. diel vertical migration) (Greenwood 1998).

The ecology of zooplankton (particularly Crustaceans) in Moreton Bay is well studied in comparison to the phytoplankton. The zooplankton of Moreton Bay is considered diverse relative to other areas sampled reflecting an overlap of tropical and temperate forms, as well as the high intensity of sampling in the region (Davie and Hooper, 1998; Greenwood, 1998). Much of the focus on the zooplankton of Moreton Bay has been on calanoid copepods because of their abundance and their role as a possible indicator species of water movement (reviewed in Greenwood, 1998).

Greenwood (1998) indicated a relatively high biodiversity for zooplankton fauna in Moreton Bay in his review of around 70 peer reviewed papers and further unpublished theses and reports. This was largely attributed to the well-studied nature of these communities and Moreton Bay's geographical situation in a bio-geographical overlap zone between tropical and temperate regions. Despite this, current estimates of zooplankton faunal abundance and diversity are still considered conservative, principally due to sampling bias with larger net mesh sizes (Greenwood 1998). There are essentially two zooplankton components:

- Meroplankton, which includes the larval stages of epi-benthic and nektonic organisms. The temporal (i.e. seasonal) patterns in spawning of adult nektonic and epibenthic organisms can influence the meroplanktonic larvae component of zooplankton assemblages (Greenwood 1998; Dennison and Abal 1999). Meroplankton can form a large component of zooplankton communities in Moreton Bay throughout the year, particularly between late spring and early autumn where it is believed they reach their maxima in abundances and diversity (Greenwood 1998). Interestingly, this seasonal pulse in meroplankton corresponds to the peak recruitment period of benthic invertebrates in Moreton Bay.
- Holoplanktons are organisms that spend their entire life cycle as zooplankton and are comprised primarily of copepods in Moreton Bay (Greenwood 1998). Holoplanktons tend to numerically dominate catches during winter, comprising 88 percent of the zooplankton assemblage (Greenwood 1998).

Dennison and Abal (1999) examined the 64 and 200 μm zooplankton size fraction in Moreton Bay, however the limited spatial and temporal replication of this study reduced the ability to draw firm conclusions from these patterns. They found a strong west to east gradient, with species richness increasing and abundances decreasing with distance offshore (Dennison and Abal 1999). They concluded that the spatial distribution of zooplankton may be influenced by food and water availability as well as water clarity, allowing them to be potential indicators of ecological 'health' (Dennison and Abal 1999).

Oceanic (i.e. eastern Moreton Bay) influenced zooplankton communities appear to have a more stable in terms of seasonal abundance and diversity than in western Bay assemblages, where disturbance (e.g. seasonal or dramatic reductions in salinity) and nutrient availability may have a strong influence on community structure. Analyses of temporal patterns in zooplankton assemblages in Moreton Bay have shown that there is evidence of greater supply/exchange of subtropical oceanic water, and therefore oceanic derived species during the late summer to mid-winter period (February to July) (reviewed by Greenwood 1998).

5.5.5.2 Values

Zooplankters provide an important link between primary production (grazing of phytoplankton) to higher (e.g. benthic and nektonic carnivores) trophic levels, of which some may be important to commercial and recreational fisheries (Greenwood 1998). In Moreton Bay, microzooplankters were responsible in one study for the majority of herbivorous grazing (ciliates in the <64 μm fraction) (Dennison and Abal 1998). In this study, it was demonstrated that zooplankton grazers could account from between 10 and 100 percent of the total phytoplankton productivity and biomass per day. Therefore, grazing may therefore partially control water quality at local scales.

A large proportion of zooplankton assemblages (particularly coastal areas) are comprised of the larvae (meroplankton) of benthic or nektonic organisms, some of which are important commercial and/or recreational fisheries (e.g. mollusc, fish and crustaceans; Greenwood 1998). Whilst these species spend only part of their life cycle in the zooplankton, they have important trophic links, transferring energy (i.e. feeding) within the water column and via migrations between the water column and sediment (demersal forms) (Greenwood 1998).

5.5.6 Infauna and Epibenthic Macroinvertebrates

Key points – Infauna and Epibenthic Macroinvertebrates
• There are two general zones of invertebrate biodiversity within Moreton Bay. Middle Banks is situated in the marine dominated zone, which is species poor compared to the estuarine dominated zone in the southern and western Bay. However, Middle Banks represents an area of high richness within the marine dominated zone. • Deeper water assemblages typically have higher species richness, abundance and biomass compared to those in shallow waters. It is thought that the relatively limited wave and current disturbance in deep water allows the establishment of these communities, in contrast to the more active shoal environments. • Benthic communities showed marked seasonal variation in abundance, with peak abundances occurring in spring. • Benthic communities can also show marked variation at fine temporal scales, possibly due to movements of organisms, stochastic (random) recruitment and/or population regulation by predation. • Benthic invertebrates have important roles in the control of nutrient fluxes, provision of food resources for fish, and some species are also directly harvested.

All fauna referred to in this section generally refer to invertebrates (i.e. animals without backbones), which can be retained on a 0.5 mm sediment sieve. Benthic infauna are defined as those fauna that generally live within or burrowing through the surface layers of the sediment profile (typically ~ 30 cm) and include for example, polychaete worm, amphipod crustacean and forams. By comparison, epibenthic fauna include those fauna that live on, or move across the sediment surface (e.g. sea stars and sea cucumber), while nektobenthic fauna may spend their time moving between the surface of the sediment and the water column (e.g. prawns).

5.5.6.1 Spatial Patterns of Infauna

The infaunal assemblages within and surrounding Middle Banks have been investigated by a number of authors (e.g. Stephenson *et al.* 1978; Poiner and Kennedy 1984; WBM Oceanics Australia 2004). Stephenson *et al.* (1978) sampled the benthic fauna (grab sampling) at 54 sites located in depths of 7.6 to 30.5 m throughout the eastern portions of Middle Banks. A total of 463 taxa were recorded, which was comprised of 31.8 percent polychaetes, 27.9 percent crustaceans (10.6 percent decapods and 7.2 percent amphipods), 23.5 percent molluscs (10.8 percent gastropods and 12.5 percent bivalves) and 6.3 percent echinoderms.

Stephenson *et al.* (1978) identified two broad fauna assemblage types in the Middle Banks region. The boundary between these assemblages followed the topography of the area, and coincided with the 10 m depth contour on the 'lip' of Middle Banks.

These assemblages were denoted as follows:

- **The northern assemblage:** This assemblage was numerically dominated by the amphipods *Urohaustorius* and *Concholestes*, the polychaete *Prionspio*, the brittle-star *Amphiura octacantha*, and the possum shrimp mysid 4. As noted by Stephenson *et al.* (1978), many of these taxa are mobile organisms, an advantage in a high-energy environment. Stephenson *et al.* (1978) suggested that most individuals in this area were small and unlikely to have reached sexual maturity. Based on this, they speculated that assemblages in this area experienced high turnover, possibly as a result of fish predation pressures.
- **The southern assemblage:** Numerically dominated by the polychaete *Prionspio*, the crustaceans' tanaid 1 and *Callianasa (Trypaea)*, the bivalve *Solemya*, and the foram *Discobotellina*. With the exception of tanaid 1 and Prionspio, these taxa are relatively large species. Furthermore, Stephenson *et al.* (1978) suggest that this area has particular importance as a fisheries resource due to an abundance of food and stable habitat.

Stephenson *et al.* (1978) identified a further 11 sub-groups within these broad assemblages (**Table 5.5a**). Stephenson's results do not indicate that there was a clear, linear gradient in species richness with depth, and a high degree of variation was observed among depth*site strata. The average abundance of macrobenthic invertebrates also showed no clear linear trend with depth;

intermediate abundances were recorded at the 7.6 and 9.1 m strata, lower average abundance in the 11-15 m strata, and high to moderate average abundance between 16 to 30 m. As discussed by WBM Oceanics Australia (2004), Stephenson *et al.* (1978) unfortunately did not have access to the rigorous hierarchical sampling designs or the multi-variate analysis techniques that are available today. As a result, attempts to distinguish spatial and temporal patterns are confounded by the sampling design and pooling of data (see Skilleter 1998).

Table 5.5a: Summary of the Middle Banks macrobenthic invertebrate assemblages identified by cluster analysis by Stephenson *et al.* (1978).

Assemblage no.	Mean depth (m)	Average abundance (per 0.1 m^2)	Species Richness	Numerically dominant species	Sediment grades
10	7.6	113	25	*Urohaustorius (S/C), Platyischnopus (S/C) and Prionospio (S)*	>80 percent med. Sand
6	9.1	143	38	*Urohaustorius and Prionospio*	82 percent med. Sand
5	11.0	79	24	*Prionospio, Urohaustorius and tanaids*	87 percent med. Sand
8	14.0	96	25	*Urohaustorius, Amphiura octacantha and Prionospio*	>80 percent med. Sand
11	14.0	91	30	*Concholestes, Urohaustorius and unidentified mysid*	>80 percent med. Sand
7	14.6	81	25	*Concholestes, Callianassa and Prionospio*	>80 percent med. Sand
4	16.2	215	46	*Rhizammina, Discobotellina, Prionospio and Solemya*	Variable
9	19.2	125	25	*Concholestes, Amphiura octacantha and unidentified mysid*	>80 percent med. Sand
3	22.3	320	48	*Prionospio, unidentified tanaid and Solemya (F)*	69 percent fine sand, 24 percent med. Sand
2	29.9	278	38	*Prionospio, Aglaophamus and Callianassa*	79 percent fine sand, 10 percent med. Sand
1	30.5	197	36	*Schizaster, Nucula and Prionospio*	76 percent fine sand, 16 percent mud

WBM Oceanics Australia (2004) sampled macroinvertebrates at sites situated in the southern sections of Middle Banks, which conformed to zones 1/3, 3 and 4 of Stephenson *et al.* (1978). The main aim of the WBM Oceanics Australia (2004) study was to describe spatial variations in assemblages among sand banks in northern Moreton Bay, and variations in assemblages among four depth zones (zones: 5, 10, 15, 20 m) at sites within each sand bank. All sampling was done in June 2003.

WBM Oceanics Australia (2004) recorded clear gradients in macroinvertebrate assemblage structure among the four depth zones at all four sand bank locations, in particular at Middle Banks and nearby Central Banks. The ordination (**Figure 5.5c**) shows that assemblages in deeper waters (15 and 20 m depth zones) tended to show little 'within-depth zone' variation, with samples from these two zones forming tight, and separate, groupings. However, assemblages from the two shallow strata (5 and 10 m) tended to show a higher degree of 'within-depth zone' variability than deeper strata. This variability with was not due to any consistent variations in assemblages between sites, but rather reflected fine-scale variability among replicate samples within sites. Nonetheless, ANOSIM results indicate that there are significant differences ($P<0.01$) in assemblages among all four-depth zones.

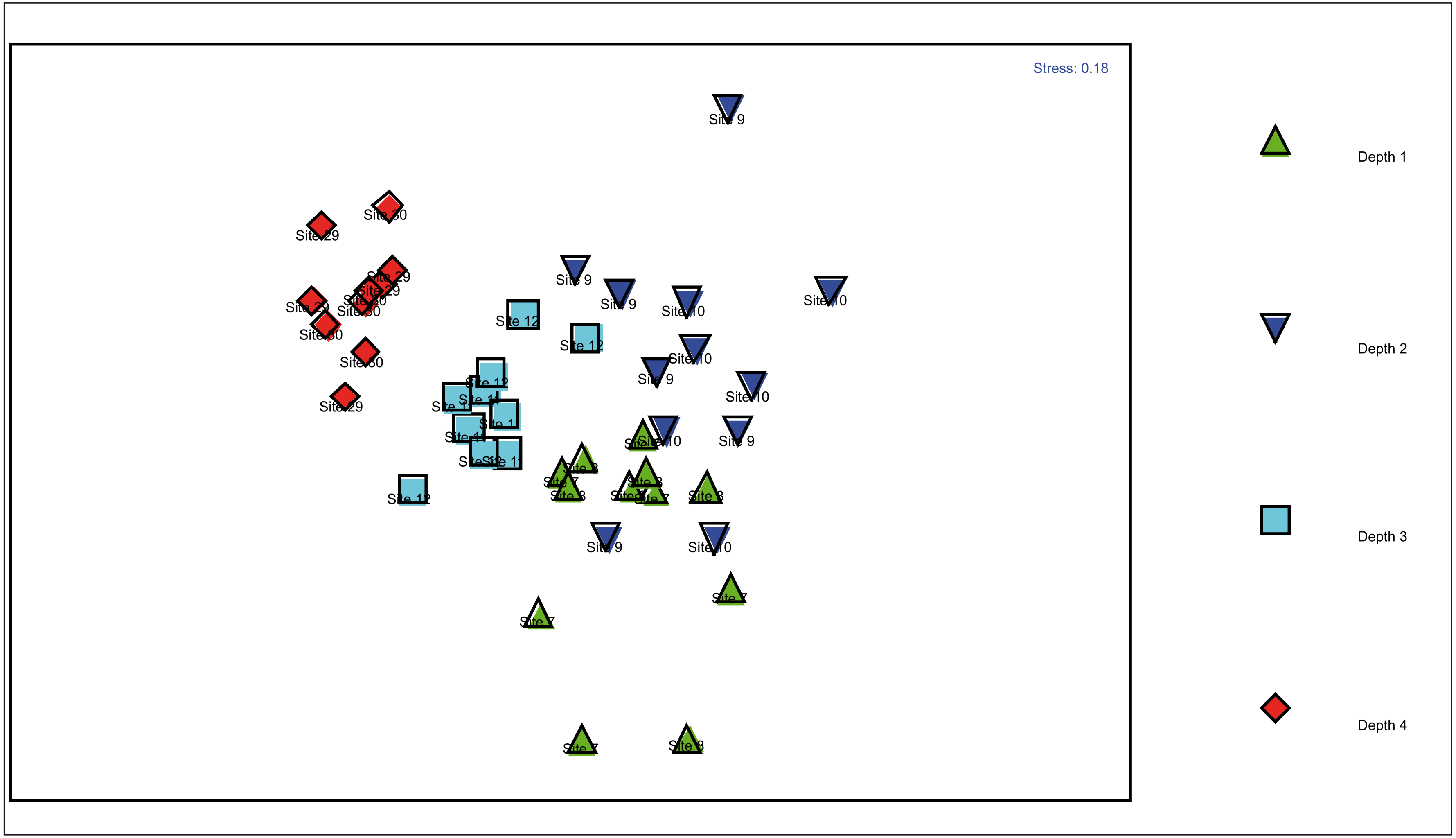
WBM Oceanics Australia (2004) found that assemblages in the deepest zone (16 - 20 m) had noticeably higher numbers of taxa, densities, diversities and biomass than other depth zones at Middle Banks. On a subregional scale (i.e. Northern Moreton Bay), deeper water assemblages at Middle Banks and Curtis Banks were also richer and more abundant (in terms of abundances and biomass) than other locations within northern Moreton Bay (**Figure 5.5d**). An impoverished macro-invertebrate fauna was recorded in shallow waters (5 - 8 m) at all locations, although impoverishment was more acute in the higher energy environments of Spitfire and Yule Banks in far northern Moreton Bay.

Table 5.5b shows the numerically dominant taxa recorded at each depth zone at each of the four locations sampled by WBM Oceanics Australia (2004). Consistent with Stephenson *et al.* (1978), assemblages in shallow waters (5 and 10 m) at Middle Banks were numerically dominated by small polychaetes and crustaceans, although there were differences in species composition within these groups. For example, while Stephenson *et al.* (1978) found that *Urohaustorius*, *Platyischnopus* and *Prionospio sp*. were numerically dominant in shallow waters, whereas WBM Oceanics Australia (2004) found that *Birubius*, *Solen,* Selenaridae and *Cerianthus* sp. were numerically dominant at these depths.

At water depths >14 m, WBM Oceanics Australia (2004), Stephenson *et al.* (1978) and Poiner and Kennedy (1984) found that the large Foram *Discobotellina*, together with various small mobile crustaceans and polychaetes, were numerically dominant. Unlike Stephenson *et al.* (1978), WBM Oceanics Australia (2004) did not find *Callianasa (Trypaea)* representing an important part of the deeper water fauna of Middle Banks. However as discussed below, video assessment of the seabed in the areas show that density of small burrows were quite high, and most likely formed by *Trypaea* species.

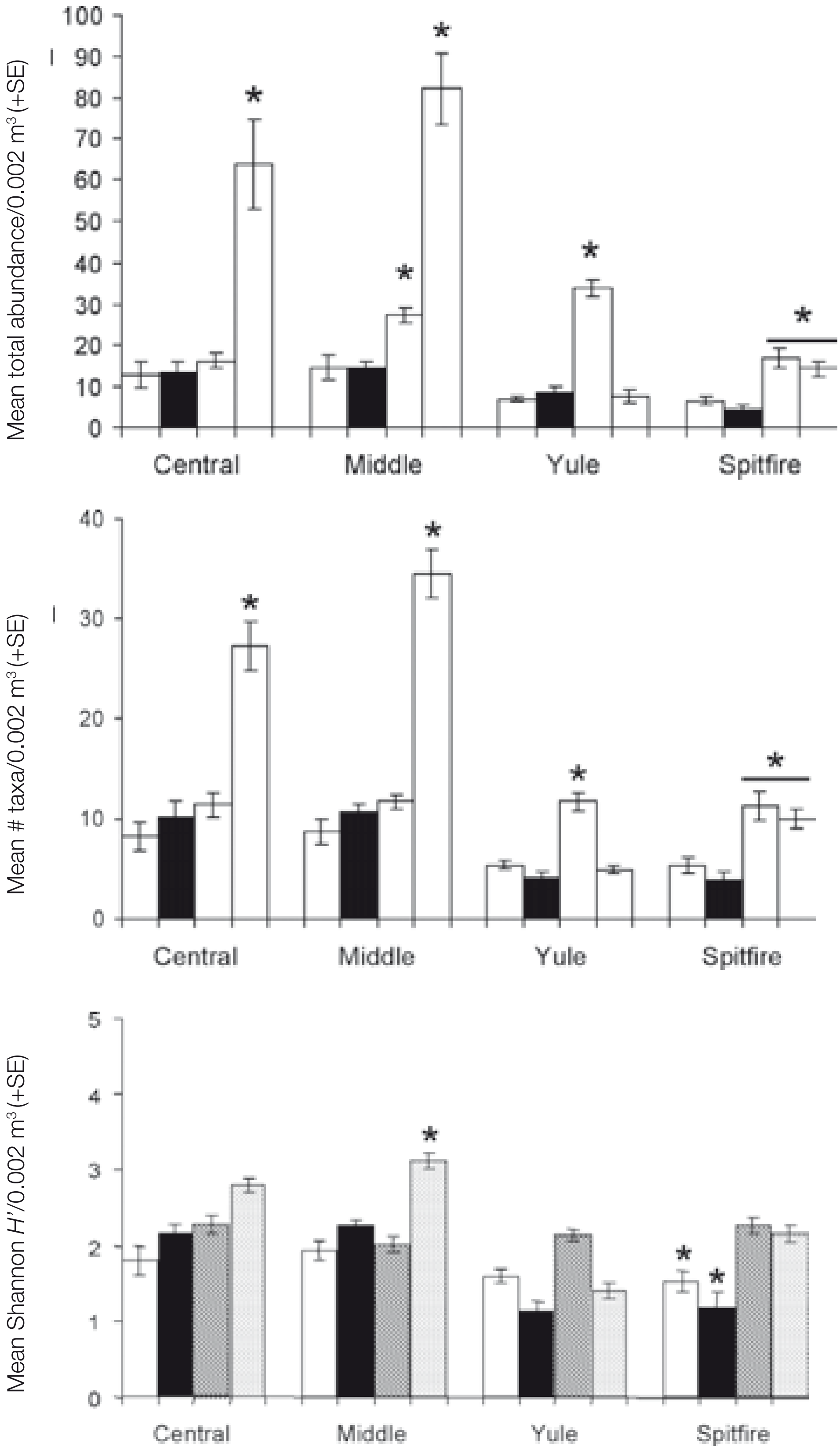
Notably, none of these studies recorded any significant numbers of juvenile or immature crabs of commercial fisheries value, such as spanner crabs or portunid crabs, within the study area. Spanner crabs (post-larvae and adults) tend to burrow into sandy sediments for most of the day, only emerging when food appears. Although relatively sedentary (non-mobile) in habit, it is possible that spanner crabs greater than one month old could evade capture by grab or core samplers used in the above-mentioned studies.

Figure 5.5c: *MDS ordination on data collected from Middle Banks (4th root transformed data, Bray Curtis Similarity measure).*



Source: WBM Oceanics Australia (2004)

Figure 5.5d: *Mean number of taxa, individuals and Shannon H' diversity (+ SE, n=10) of benthic invertebrates sampled by cores at 2 sites within 4 Depth zones at 4 Locations in Northern Moreton Bay. 4 – 6 m (Open bars); 8 – 10 m (Closed bars); 12 – 14 m (Hatched bars); 16 – 18 m (Dotted bars) * = statistical significance P<0.05.*



Source: WBM Oceanics Australia (2004)

Table 5.5b: Dominant taxa at each Depth within location (Source: WBM Oceanics Australia 2004).

Location	Depth	Dominant taxa	Dominant phyla
Middle	Depth 1	*Birubius* > *Solen* = *Cerianthus* = *Selenaridae*	Crust > Poly > Biv
Middle	Depth 2	*Birubius* > *Solen* = *Cerianthus*	Crust > Poly = Biv
Middle	Depth 3	*Ophiura* = *Selenaridae* > *Birubius* = *Discobotellina*	Bry = Crust > Foram = Biv
Middle	Depth 4	*Paraonid* = *Discobotellina* = *Urohaustorius*	Crust = Poly > Foram
Central	Depth 1	*Birubius* = *Barantolla* = *Platyschopus* = *Cyclaspis* = *Eunice* = *Urohaustorius*	Crust > Poly = Biv
Central	Depth 2	*Birubius* = *Platyschopus* = *Eunice*	Crust > Poly > Biv
Central	Depth 3	*Platyschopus*	Crust > Poly > Biv
Central	Depth 4	*Discobotellina* = *Leptognathid* = *Foram 2*	Crust > Foram > Poly
Yule	Depth 1	*Glycera* = *Pisionid*	Poly > Crust
Yule	Depth 2	*Glycera* = *Pisionid* > *Spionid*	Poly
Yule	Depth 3	*Spionid 7* > *Spionid 9* = *Nematode* = *Prionospio* = *Spionid 8*	Poly > Crust = Echino
Yule	Depth 4	*Prionospio* = *Unidentified Megalopa*	Poly = Crust
Spitfire	Depth 1	*Barantolla*	Poly > Crust
Spitfire	Depth 2	*Ophelia* > *Barantolla*	Poly
Spitfire	Depth 3	*Barantolla* > *Platyschopus* = *Urohaustorius* = *Spionid 9* = *Schistomeringos*	Poly = Crust
Spitfire	Depth 4	*Barantolla* > *Platyschopus* = *Urohaustorius* = *Thraciopsis*	Crust = Poly > Biv

5.5.6.2 Temporal Patterns of Infauna

The results of previous investigations in the study area (Stephenson *et al.* 1978; Poiner and Kennedy 1984; WBM Oceanics Australia 2004) indicate that even in the absence of dredging, there can be enormous variation in the assemblages over temporal scales measuring in days, to months, and possibly years.

For example, WBM Oceanics Australia (2004) sampled benthic macroinvertebrates from the sites at Middle, Central, Yule, Spitfire Banks and South-west Spit on three occasions; Episode 1 (June 2003), Episode 2 (one week after Episode 1), and Episode 3 (October 2003). Multivariate analyses (ANOSIM, n-MDS) indicated that there was great within-site variation in assemblages (as measured using Bray-Curtis similarity) observed on all three occasions and at all locations (**Table 5.5c; Figure 5.5e**). The largest differences in assemblages (i.e. highest *R* value) occurred between the June and October sampling, however there were also noticeable variations in assemblages between Episodes 1 and 2 (i.e. temporal scale of days) at all locations except Yule Banks.

Table 5.5c: Multivariate comparisons of assemblages within Locations sampled in June 2003 (Episode 1) and one-week later in June 2003 (Episode 2), and in October 2003. Significant P values are in bold. Bonferroni correction for multiple comparisons, = 0.016 time comparisons.

Comparison	Global R	P
Location 1: Central		
Among Times	0.424	**0.001**
Pairwise comparisons		
Episode 1 v Episode 2	0.206	**0.001**
Episode 1 v Episode 3	0.587	**0.001**
Episode 2 v Episode 3	0.492	**0.001**
Location 2: Middle		
Among Times	0.385	**0.001**
Pairwise comparisons		
Episode 1 v Episode 2	0.207	**0.001**
Episode 1 v Episode 3	0.464	**0.001**
Episode 2 v Episode 3	0.583	**0.001**
Location 3: Yule		
Among Times	0.106	**0.001**
Pairwise comparisons		
Episode 1 v Episode 2	0.125	**0.012**
Episode 1 v Episode 3	0.182	**0.006**
Episode 2 v Episode 3	0.030	0.224
Location 4: East Knoll		
Among Times	0.620	**0.001**
Pairwise comparisons		
Episode 1 v Episode 2	0.416	**0.001**
Episode 1 v Episode 3	0.800	**0.001**
Episode 2 v Episode 3	0.633	**0.001**

Figure 5.5e: *MDS ordination (based on Bray-Curtis similarities, 4th root transformed data) showing relationships between assemblages sampled at Middle Banks before (green triangles), immediately after (dark blue triangles) and 3 months after dredging (light blue squares).*

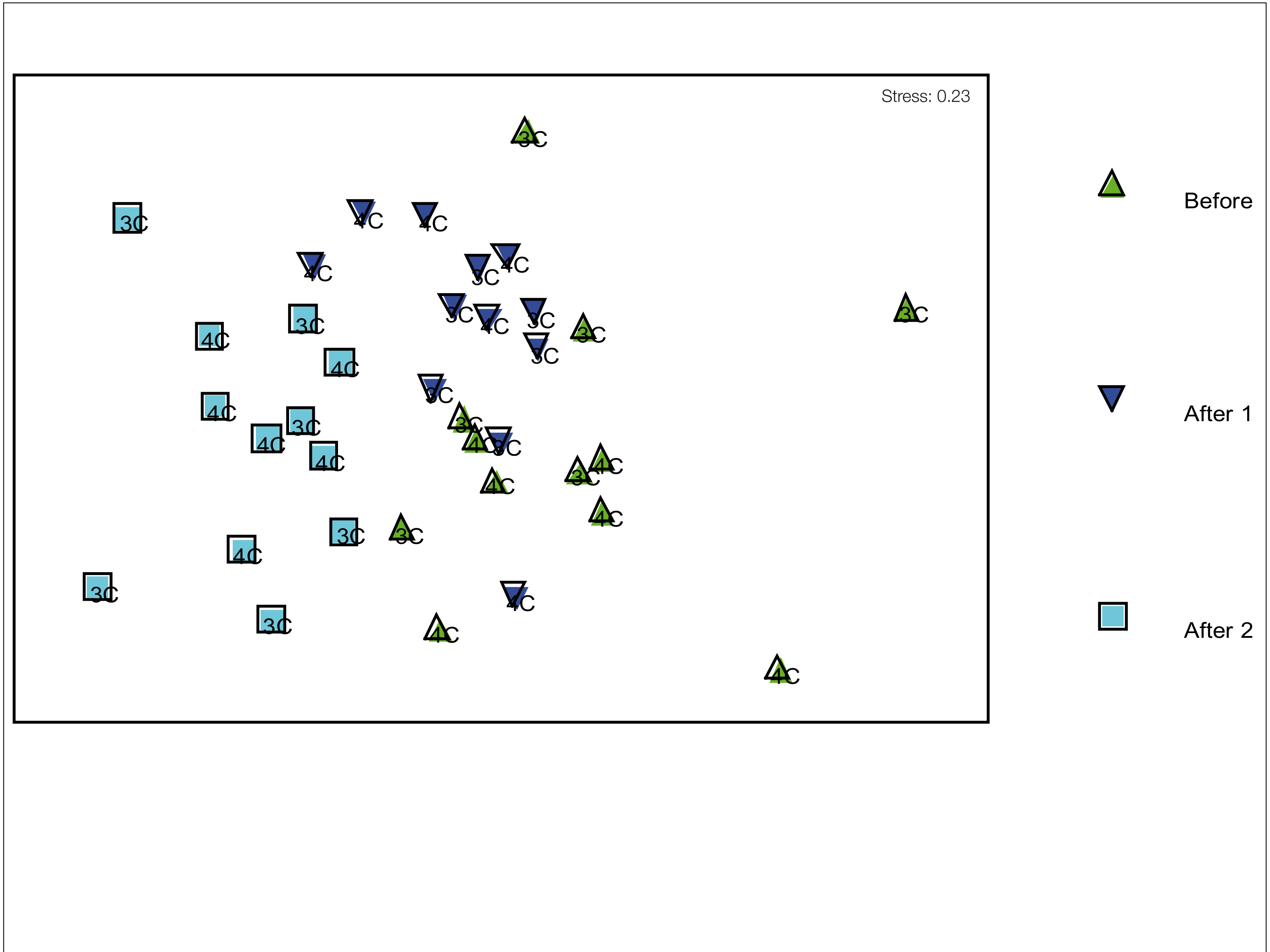


Figure 5.5f shows average numbers of taxa (S), total abundance (N) and Shannon diversity (*H'*) of benthic invertebrates sampled on 3 occasions (*Before* = June 2003; *After* 1 sampled one week after *Before*; After 2 = October 2003) at 2 sites within four locations (Middle Banks = sites 2 and 3) in northern Moreton Bay (WBM Oceanics Australia 2004). Complex patterns were observed among sites and over time. Taxa richness and Shannon diversity did not show any clear trends over time. However, there was a large increase in total abundances observed at most sites between the June and October sampling episodes. An increase in abundance was observed at Central Banks (sites 1 and 2), one site at Middle Banks (site 4), and sites 7 and 8 (East Knoll and SW Spit). There was no apparent change observed at Yule Banks and one site in Middle Banks (site 3).

The apparent increase in abundance between June and October is consistent with past case-studies conducted in Moreton Bay, indicating the September-October period represents a peak recruitment season for many Moreton Bay benthic invertebrates (Stephenson 1980, 1970; Stephenson *et al.* 1978). The increase in abundances between June and October at most sites suggests that the processes responsible for this change were operating over broad spatial scales (measured in km). However, the absence of any clear change at site 3 in Middle Banks suggests that other factors, possibly operating at smaller spatial scales (e.g. biological interactions), could also greatly affect invertebrate abundances.

Over longer temporal scales, there is no evidence to suggest that a stable equilibrium in invertebrate assemblage structure is ever reached in the study area or wider Moreton Bay region (e.g., Poiner, 1977; 1979; 1980; Stephenson, 1981). Such variations in soft sediment macrobenthic assemblages are the rule rather than the exception in these dynamic environments (Skilleter, 1998 and references therein). Comparisons of benthic fauna data sets (1970's, 1980's and 2003) for Middle Banks indicate that the study area experiences major, and apparently acyclic shifts in numerical dominance patterns over time. This is consistent with Stephenson *et al.*'s (1978; 1980) hypothesis that the benthic communities in the study area appear to be in a state of flux, with unpredictable changes in assemblages occurring over a range of temporal and spatial scales. Stephenson *et al.* (1978) argues that a combination of factors, including fish predation, disturbance by trawlers, stochastic (random) recruitment patterns and micro-topographical variability, can all result in observed 'changes' in communities over time. Within the context of an impact assessment study, it is therefore not entirely meaningful to define 'typical' existing benthic community conditions.

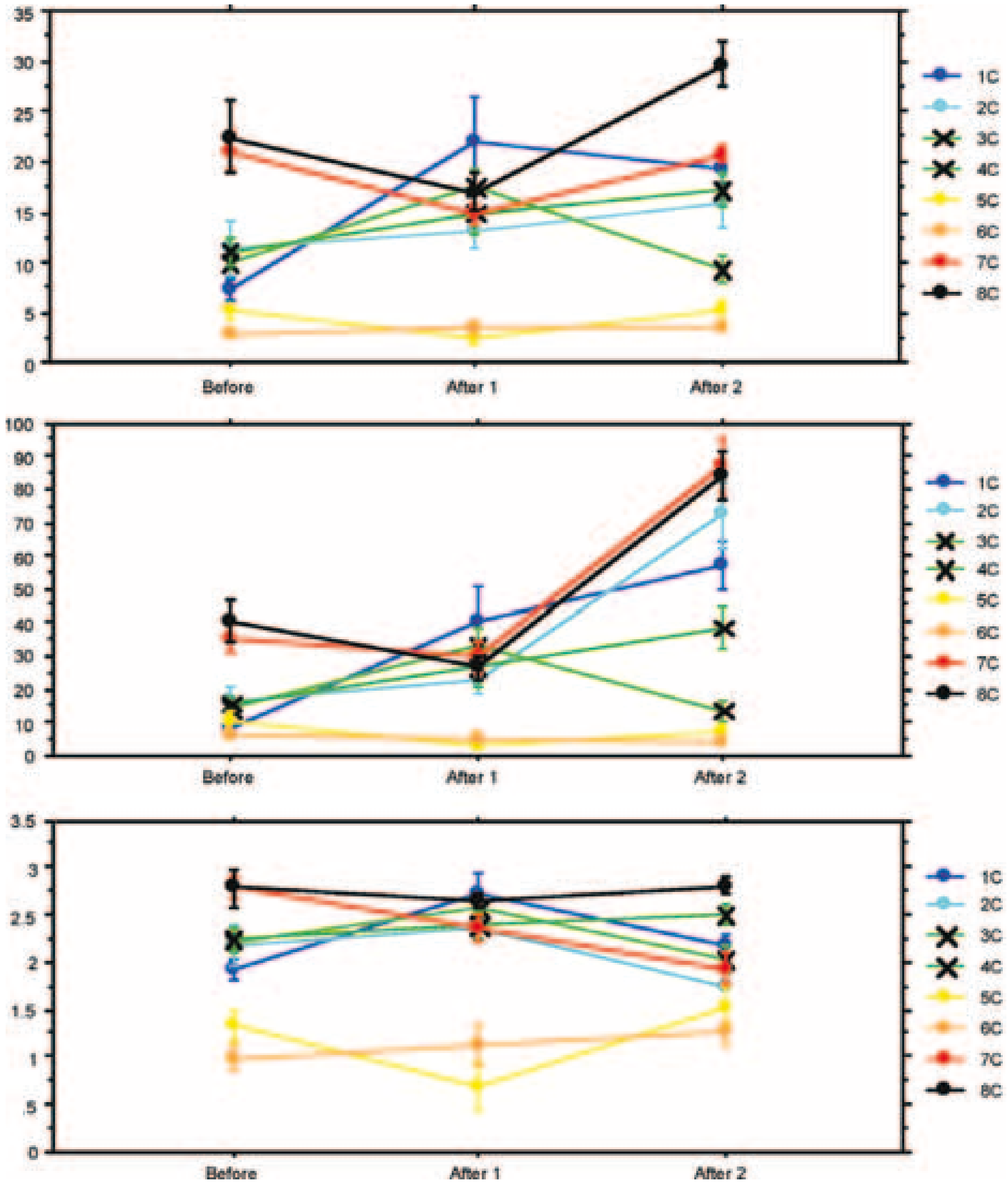
5.5.6.3 Spatial and Temporal Patterns of Epibenthic Fauna

In a review of fauna biodiversity patterns in Moreton Bay, Davie and Hooper (1998) identified two general biodiversity zones within Moreton Bay; (i) an estuarine dominated zone around the mouth of the Brisbane River and the western Bay and (ii) a marine dominated zone in the northern and eastern Bay. Highest fauna species numbers were noted in the estuarine zone while the marine dominated zone was generally species poor. Different faunal groupings showed different distributions within these zones.

The clean sand areas in the northern Bay area were described by Davie and Hooper (1998) as generally "extremely species poor", though Middle Banks was highlighted as one of two 'centres of high biodiversity' within the marine dominated zone. The other area of high diversity is situated near the northern end of North Stradbroke Island (Davie and Hooper 1998). Furthermore, the Middle Banks area had high numbers of mobile epibenthic species of crustaceans, echinoderms and annelids but low numbers of sessile species. It should be noted that this study was based entirely on Museum database records, and therefore results will be confounded by differing collection intensities and effort.

In a large-scale benthic habitat survey of Moreton Bay, Stevens (2003) and Stevens and Connelly (2005) grouped sites into various classifications based on their dominant taxa and abundances (**Figure 5.5g**). Middle Banks was characterized by worked sediment, small and medium burrows and a single anemone species, and was therefore classified as being "Bioturbated/sparse" habitat. This habitat was present in a band approximately 15-20 km long and 10 km wide, extending to the

Figure 5.5f: *Mean number of taxa (S), total abundance (N) and Shannon diversity (H') (± SE, n=6) of benthic invertebrates sampled on 3 occasions at 2 sites within four locations (Middle Banks = sites 2 and 3) in northern Moreton Bay, Winter 2003.*



(Source: WBM 2004)

north west and south east of the Middle Banks area). A total of 19 taxa were recorded in this zone, an intermediate category between the taxa rich "Algae/sponge habitat" (42 taxa), and the taxa poor "Depauperate/sand habitat" (4 taxa).

The WBM assessment (present study) of epibenthic biota assemblages at Middle Banks showed that the structure and habitat characteristics were broadly consistent with the classification by Stevens (2003) and Stevens and Connolly (2005). A total of 15 epibenthic taxa were identified from the present study, which was numerically dominated, by echinoids (particularly sea stars). Small faunal burrows (presence of holes <1 cm in width in the sediment) were evident at all sites, with highest densities located within deeper (~20 - 30 m) water in the southern portion of the study area. This indicates that sediments within deeper southern areas of Middle Banks were generally more heavily worked by bioturbating organisms. By comparison, shallow sub-tidal (4 - 10 m) areas of Middle Banks contained lower densities of burrows and lower incidences of surface biogenic working (e.g. tracks and mounds).

Three further sub-groups were derived for epibenthic biota assemblages at Middle Banks, in order to refine and separate the area grouped as 'Bioturbated/Sparse' by Stevens (2003) and Stevens and Connolly (2005). Derived sub-groups were based on a combination of benthic characteristics, including: structure of the seabed habitat, associated epibiota and bioturbation indicators (**Table 5.5d; Figure 5.5g**). The first of these groups (1a,b) had the lowest in taxa diversity (4 taxa), but contained sparse and isolated patches of seagrass. This group was located within the shallow sandy areas of Middle Banks between 4 and 10 m in depth, and were primarily associated with surface biogenic disturbers (most notably sea stars). The second sub-group (2) covered the greatest spatial extent of the three derived groups, and contained a comparatively rich epibenthic fauna assemblage (11 taxa). These areas contained no seagrass, and were also characterised by a gently undulating seabed, which contained sparse to moderate burrowing densities. Evidence of biogenic working on the sediment surface (i.e. tracks and mounds) was also present at around 66 percent of the sites within this group. The final sub-group (3) contained a fauna assemblage with intermediate taxa diversity (8 taxa) and was characterised by a high density of small to medium burrows, widespread biogenic working of the sediment surface (94 percent of sites), a flat seabed (i.e. no undulations) and finer sandy sediments.

Table 5.5d: Composition of epibenthic fauna and habitat characteristics used to derive groups.

Group and Brief Description	No. of sites	No. of taxa	No. of individuals	Observed taxa and bioturbation indicator (percent of sites where observed / total no. of individual taxa present at transect)
1a – Localised seagrass patches with sparse small (<1 cm) burrows and undulating sandy seabed. Biogenic working of the surface sediment evident.	9	3	66	Tracks, mounds and other biogenic working (60 percent) Sea Stars (80 percent, 59) Acorn Worm (30 percent, 7) Attached Macroalgae (20 percent)
1b – Localised seagrass patches with moderate to dense small burrows (<1 cm) and undulating sandy bottom. Biogenic working of the surface sediment evident..	10	4	20	Mounds and other biogenic working (80 percent) Sea Stars (60 percent, 17) Sea Pens (10 percent, 1) Sea Cucumber (10 percent, 1) Attached Macroalgae (10 percent)
2 – Undulating unvegetated sand with sparse to moderate (small-medium) burrows. Biogenic working of the surface sediment evident.	83	11	132	Mounds and other biogenic working (66 percent) Sea Stars (24 percent, 50) Sea Pens (12 percent, 11) Sea Urchins (6 percent, 14) Hydroids (4 percent, 31) Anemones (3 percent, 4) Sea Cucumber (2 percent, 1) Feathered Star (2 percent, 1) Brittle Star (2 percent, 1) Sponges (2 percent, 3) Dollar Forams (2 percent, 6) Attached Macroalgae (11 percent)
3 – Fine sand typically with shell fragments and no undulations on seabed. Dense burrowing at all sites, and evidence of biogenic working on the sediment surface evident at most sites.	34	8	54	Mounds and other biogenic working (94 percent) Sea Pens (15 percent, 10) Dollar Forams (12 percent, 23) Sea Urchins (12 percent, 7) Hydroids (6 percent, 2) Tritons (6 percent, 2) Sponges (3 percent, 8) Sea Stars (3 percent, 1) Attached Macroalgae (6 percent)

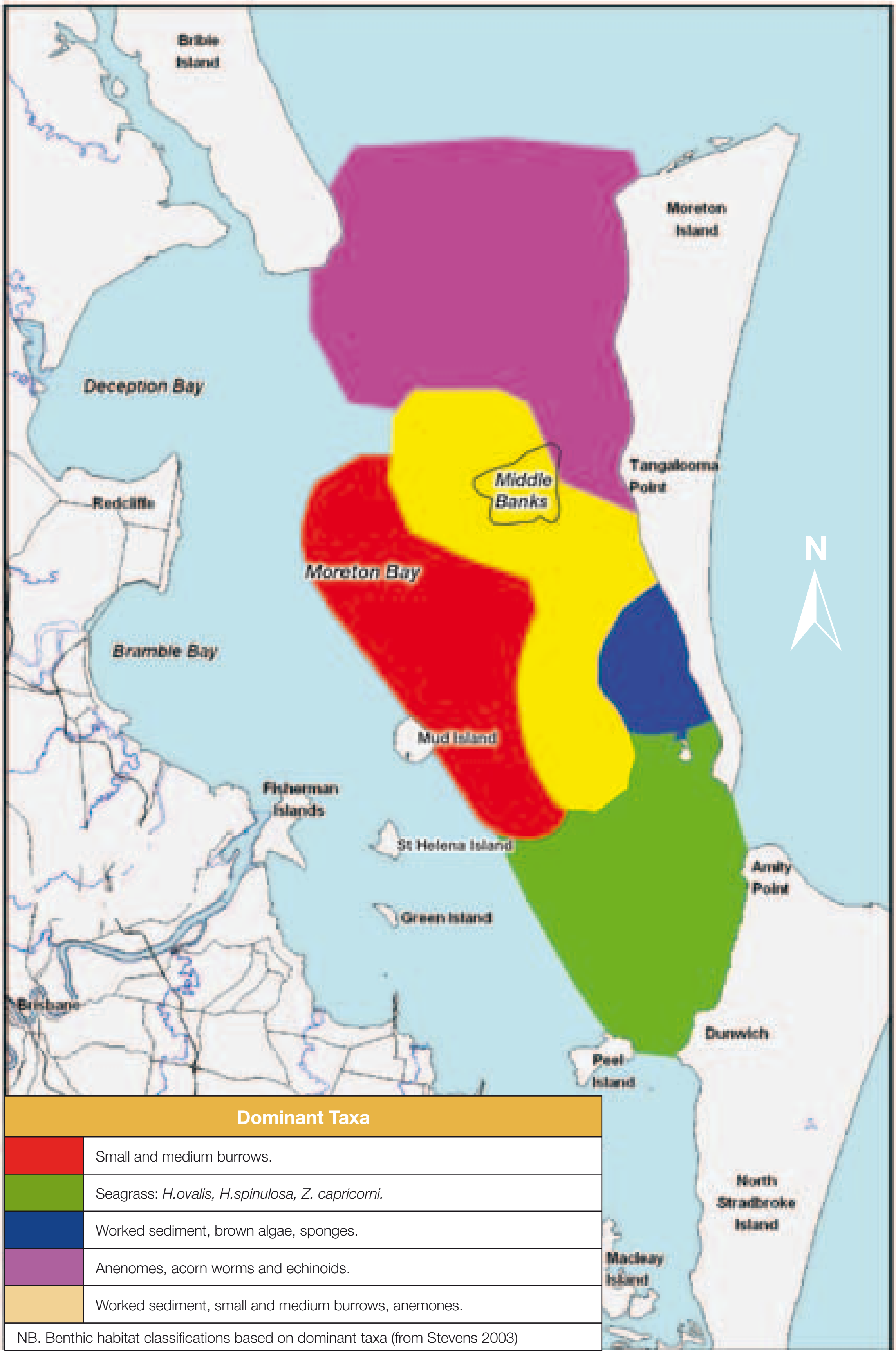
5.5.6.4 Values

Benthic macroinvertebrates (epibenthos and infauna) represent a large proportion of the total biomass and productivity of soft sediment environments, although no studies to date have quantified this in the Moreton Bay estuary. Benthic macroinvertebrates also represent an important link for transferring energy and nutrients between trophic levels and driving pelagic fish and crustacean production. Soft sediment benthic macroinvertebrates provide an important food resource for mobile fish and inverterbrates, avifauna, and humans, therefore forming an integral part of the food web. The numerically dominant macroinvertebrates species at Middle Banks (including polychaete worms and amphipod crustaceans) are largely responsible for intertidal bioturbation and biogenic working. Burrowing in the sediment surface delivers oxygen and nutrients to deeper anaerobic environments, and therefore reduces the redox layer. Deposit feeders (e.g. polychaetes and some amphipods) contribute significantly to biodeposition through regeneration of inorganic nutrients (Day *et al.* 1989), promote decomposition of organic matter and recycle nutrients for photosynthesis (Gaston *et al.* 1998).

The following is a summary of the values of benthic macroinvertebrates (epibenthos and infauna) assemblages within and adjacent to the study area (note that nektobenthic macroinvertebrates are discussed separately in the next report section):

- Most harvested nektobenthic species (such as fish, prawns and crabs) in the study area feed on macroinvertebrates (see review by WBM Oceanics Australia 2004).
- At a Moreton Bay wide scale, the epibenthic and infaunal communities of the Middle Banks area are considered to be moderately rich and abundant fauna (Stephenson *et al.* 1970, 1978; Stevens 2003).
- In general, there is a tendency for richness, biomass and abundance of benthic macroinvertebrates to increase with increasing water depth. These patterns are thought to be greatly influenced by wave action, sand movements and current patterns.
- A taxa rich and abundant macroinvertebrate assemblage was recorded within deeper waters to the south of Middle Banks, outside the study area. This deep water environment to the south of Middle Banks contains relatively stable environmental conditions, and more organically enriched sediments, than the active shoal and channel environments at and adjacent to Middle Banks. This deep water environment is thought to represent an important fisheries resource due to the abundance of food (macroinvertebrates) and stable habitat conditions (Stephenson *et al.* 1978).
- Some epibenthic fauna would form food resources for fish species within the study area. Several species are of direct importance as fisheries resources, most notably:
  - the ghost-nipper (*Trypaea*) can have high densities in the area, particularly in deeper quiescent waters (Stephenson *et al.* 1978; WBM pers. obs.). Although not directly harvested from Middle Banks, local ghost-nipper populations would be expected to form one of the numerous sources of propagules replenishing the local Moreton Bay stock.
  - Nektobenthic species, such as swimmer crabs, spanner crabs and prawns, which have a relatively sedentary post-settlement phase (see section 5.5.7).

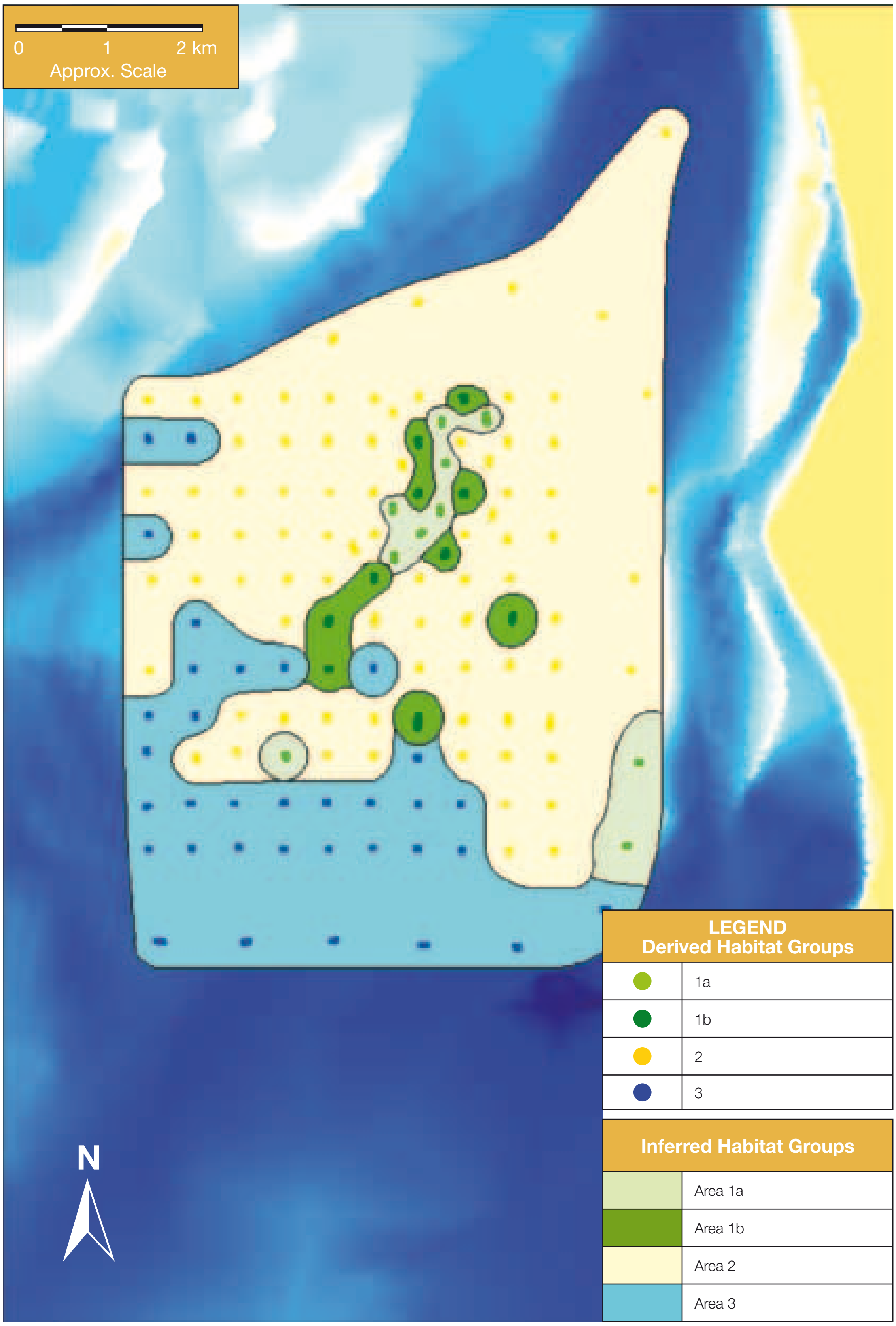
Figure 5.5g: *Benthic Habitat Classifications (adapted from Stevens 2003).*



Dominant Taxa	
(red)	Small and medium burrows.
(green)	Seagrass: *H.ovalis, H.spinulosa, Z. capricorni.*
(blue)	Worked sediment, brown algae, sponges.
(purple)	Anenomes, acorn worms and echinoids.
(beige)	Worked sediment, small and medium burrows, anemones.

NB. Benthic habitat classifications based on dominant taxa (from Stevens 2003)

Figure 5.5h: *Inferred Benthic Habitat Classifications (based on habitat characteristics and epibenthic fauna composition) for Middle Banks (WBM present study).*



5.5.7 Fish, Nektobenthic Invertebrates and Fisheries

Key points – Fish, Nektobenthic Invertebrates and Fisheries
• Fish and nektobenthic invertebrate assemblages in both depth strata surveyed in the Middle Banks Study area were found to be diverse and abundant. Species richness did not differ considerably with depth.
• Both the fish and nektobenthic assemblages in both deep and shallow water strata were dominated by a small number of geographically widespread species.
• No rare or threatened species were encountered and the majority of fish species caught are classified as either "common" or "abundant" in Moreton Bay.
• Species such as tiger prawns *Penaeus esculentus*, common ponyfish *Leiognathus moretonensis* and the cardinal fish were more abundant in shallow water, while coral prawns *Metapenaeus novaguinea*, dragonet *Callionymis limiceps* and small toothed flounder *Pseudorhombus jenynsii* were more abundant in deeper water.
• Only two nektobenthic invertebrate species – the saucer scallop *Amusium balloti* and the coral crab *Charybdis feriatus* were restricted to the shallow water sites sampled, but both these species are known to be abundant in other localities, particularly the former which is a target species in central Queensland trawl fisheries.

The vegetated and unvegetated sand banks that comprise the study area (Middle Banks), are utilised by many fish and nektobenthic invertebrate species, some of which are of commercial and recreational fisheries value (CHRIS database, WBM Oceanics Australia 2003; 2004; present study). The following sections discuss the spatial and temporal patterns, key driving processes and values of fish and nektobenthic assemblages within the study area.

5.5.7.1 Spatial and Temporal Patterns in Fish Fauna

Previous Studies

Moreton Bay is situated in the Tweed-Moreton province, a bio-geographical overlap zone between tropical and temperate regions. Fish fauna is therefore comprised of a suite of tropical, sub-tropical, temperate and cosmopolitan species, with over 700 species recorded in the bioregion (Davie and Hooper 1998).

Existing data has been reviewed (Stephenson 1982 a, b; Dredge and Young 1974) to provide an indication of patterns in fish fauna abundance. The findings of these earlier studies show general consistencies with later work available in other Moreton Bay localities, and is therefore considered useful in the context of the present study.

Dredge and Young (1974) sampled fish fauna of eastern Moreton Bay including Middle Banks. Seventeen species were recorded in total, however WBM Oceanics Australia (2004) argue that this was a gross underestimate of total species richness reflecting the limited temporal coverage of the survey. Numerically dominant species included stout whiting, dragonets, and leather jackets, whereas large bottom dwelling fish were uncommon, consistent with findings of Stephenson *et al.* (1982 b) (see below). Many of the fish captured were juveniles of species capable of digging into sand (e.g. flounder, sole and flathead). However, shoals of bait fish (e.g. juvenile Clupeoids) were common mid-water. Juveniles of commercial/recreational significance such as sand whiting, snapper and yellowfin bream that are abundant elsewhere in Moreton Bay were rare in the study area.

Stephenson *et al.* (1982 a and b) extensively sampled the benthic fish fauna in eastern Moreton using otter trawl gear[3]. The benthic fish fauna was found to be comprised of species with a wide distribution throughout Moreton Bay, dominated by a small number of species. The ten most common species (**Table 5.5e, Table 5.5f**) comprised 89 percent of the fish captured. Fish assemblages surveyed in unvegetated subtidal areas elsewhere in Moreton Bay generally had a similar structure to those recorded at the site of current focus (e.g., Wassenberg and Hill, 1987; 1990; Weng, 1988;

[3] *It should also be noted, however, that the techniques used in the Middle Banks survey (trawls and diver surveys) would not be efficient for recording pelagic fish such as tuna or mackerel which commonly occur in eastern Moreton Bay, or for larger and more mobile demersal species.*

Warburton and Blaber, 1992; Robins-Troeger, 1994). None of the common species were of commercially significance with only diver whiting (*Sillago maculata*) being of recreational significance.

Fish communities can exhibit enormous variation over a range of temporal scales. In the near shore environments of Moreton Bay, several authors have reported higher species richness and abundances in summer (and in some cases spring) compared to winter (reviewed by Tibbets and Connolly 1998). Fish surveys by Stephenson *et al.* (1982b), which included sites at Middle Banks, found that most of the 60 species analysed had maximum richness and abundance in summer, but not necessarily in spring. Furthermore, this seasonal cycle was found to be more apparent in marine dominated sites such as Middle Banks than in nearshore areas. The ultimate control on this seasonality is not however well understood and requires further investigation (Tibbets and Connolly 1998).

Present Study

A total of 5,492 individual fish from 57 species and 21,380 individual nektobenthic invertebrates from 24 species were captured in the present study. For both fish and nektobenthic invertebrate assemblages, species richness was similar between deep and shallow sites. Fifty-four and 52 fish species and 24 and 22 nektobenthic invertebrate species were recorded from shallow and deep sites respectively. No threatened species or listed marine species under the *Environmental Protection and Biodiversity Conservation Act 1999* were captured during sampling. A full list of species captured and their abundances is included in **Appendix C5: A**. The fish assemblage of the Middle Banks region consisted principally of species classified by Johnson (1999) as common or abundant within Moreton Bay. The average abundances (+/- s.e.) per trawl shot of fish and nektobenthic invertebrates (pooled across all species) are shown in **Figure 5.5i**.

Figure 5.5i: *Average abundance per trawl shot (+/- s.e.) of fish and nektobenthic invertebrates (pooled across species) at each of the four sites surveyed. Sites 1 and 4 are shallow water sites and sites 2 and 3 are deep water sites.*

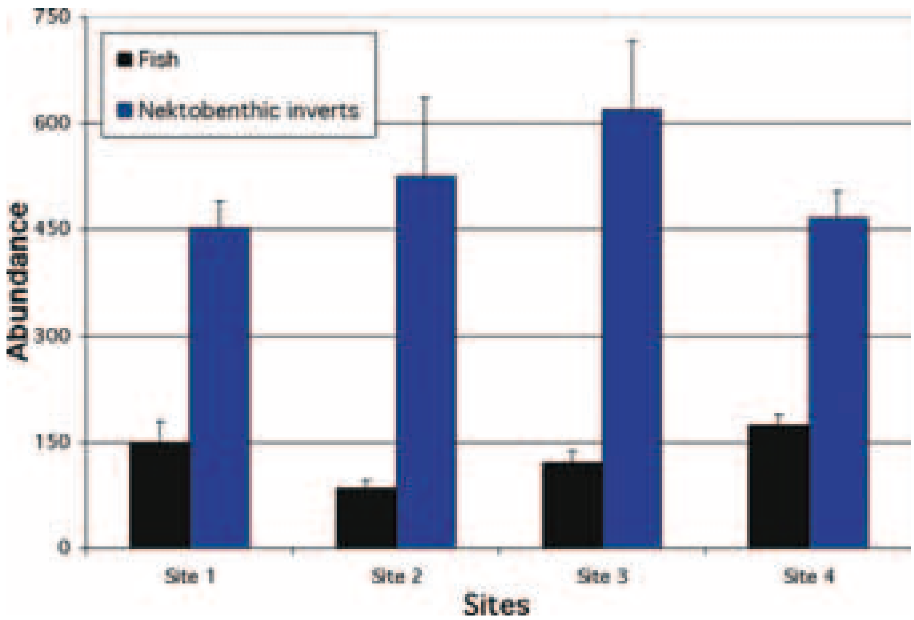
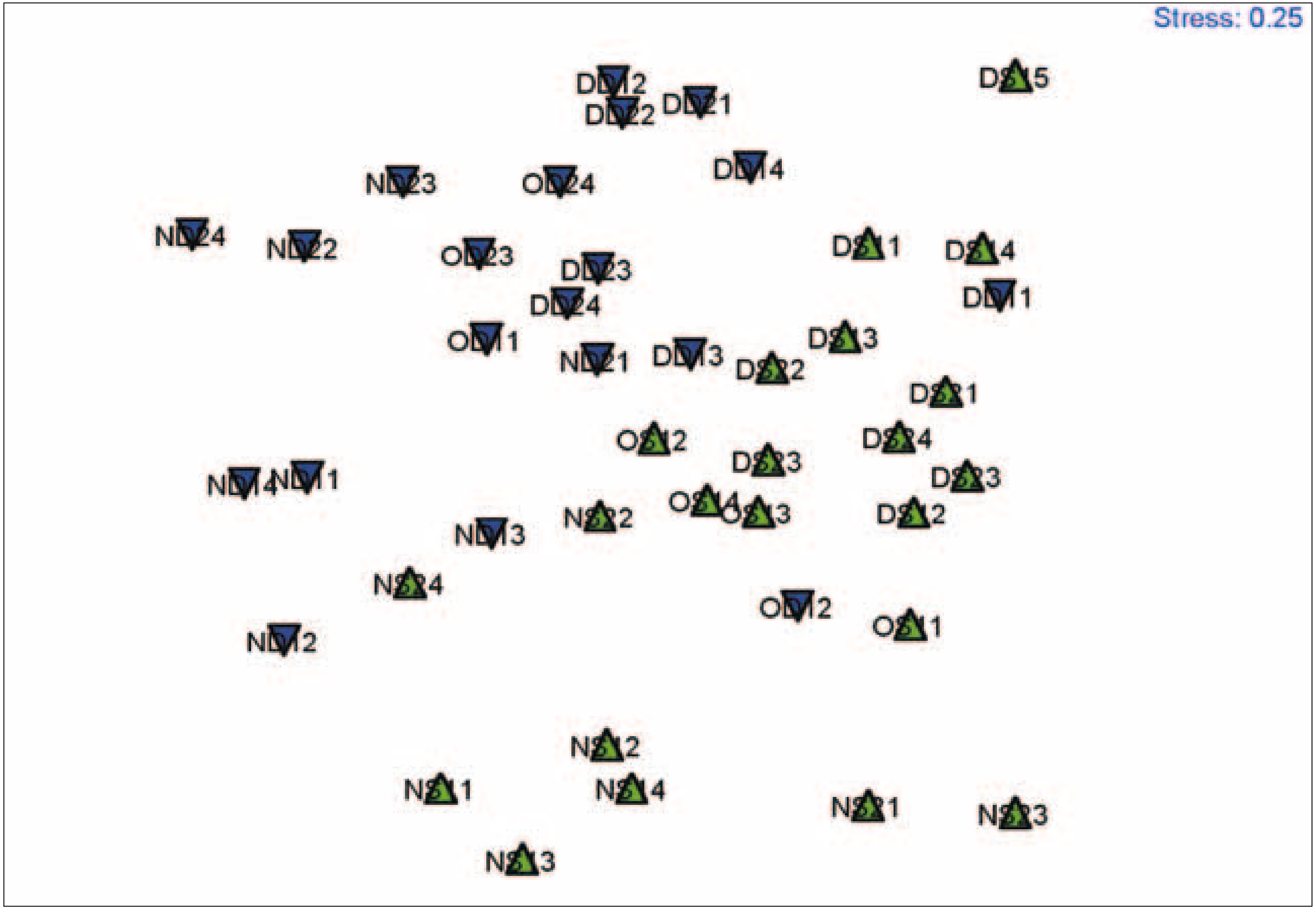


Figure 5.5j: *The results of nMDS on fish assemblages of the study area. Green triangles represent shallow water samples and blue triangles represent deep water samples.*



The average abundance of fish per trawl shot were noticeably higher at the shallow sites in comparison to the deeper sites, but not between the sites at a given depth (**Figure 5.5i**; **Appendix C5: A**). Average abundances also differed on a monthly basis, however the month*depth interaction was not significant ($F_{2,32}$ = 1.113, *p* = 0.34; **Appendix C5: B**)

Graphically, the results of the nMDS demonstrate that the overall structure of the fish assemblage appeared to differ between depths (**Figure 5.5j**). ANOSIM supports this conclusion with a statistically significant difference in fish assemblages between the two depths surveyed (Global *R* value = 0.524, P = 0.001).

Overall for the abundance of fish species, a small number of species dominated the catches with the top ten most abundant species constituting numerically, 84.9 percent of the overall fish fauna sampled. All common fish species were distributed across all sites surveyed and with the exception of the flounder *Pseudorhombus jenysii* and the silver biddy genus *oyena* which had fairly similar rank abundances between the two deep strata sampled.

The dominant taxa in this study were similar to the dominant taxa recorded previously at Middle Banks by Stephenson *et al.* (1982a and b) (**Table 5.5f**). Several of the numerically dominant species at Middle Banks were also found by Stephenson *et al.* (1982 a and b) to be dominant at the other two locations surveyed (**Table 5.5f**).

Some fish species were restricted to either the deep or shallow water locations surveyed. The following species were restricted to shallow water sites only:

- Yellowtail scad *Trachurus novazelandiae* (4 individuals).
- Red bullseye *Priacanthus macracanthus* (5).
- Brown-backed toadfish *Lagocephalus lunaris* (14).
- Porcupine fish *Dicotylichthys punctulatus* (29).
- Black naped ponyfish *Leiognathus decorus* (42).

The following fish species were restricted to deep water sites only:

- Tailor *Pomatomus saltarix* (4 individuals).
- Velvetfish *Bathyaploactis curtisensis* (4).
- The stinging cod *Apistus carinatus* (22).

Only species where more than one individual was captured were included in these analyses.

The results of the SIMPER analysis (**Table 5.5g**) illustrates the numerically dominant taxa contributing most to differences in the average similarity in fish assemblages between the deep and shallow water areas surveyed. The shallow water sites had notably higher average abundances of *P. otisensis, L. moretonensis, G. oyena, A. fasciatus, I. japonica, C. australis and L. decorus.* The deep-water sites had notably higher abundances of *S. maculata, P. jenynsii. C. limiceps and D. papilio.*

Table 5.5e: Summary of the abundances of the ten most common fish species captured in the Middle Banks area (pooled across all sites sampled).

Species	Rank (shallow, deep)	Abundance	Cumulative Percent Abundance
Cardinal fish *Apogon fasciatus*	(1,1)	1,668	30.4
Common ponyfish *Leiognathus moretonensis*	(2,3)	718	43.5
Trawl leatherjacket *Paramonocanthus otisensis*	(3,4)	676	55.7
Common dragonet *Callionymus limiceps*	(4,2)	642	67.5
Common grinner *Saurida undosquamis*	(5,5)	276	72.5
Diver whiting *Sillago maculata*	(8,6)	198	76.1
Trawl flathead *Inogecia japonica*	(7,8)	151	78.8
Small-toothed flounder *Pseudorhombus jenysii*	(13,7)	115	80.9
Long-nosed dragonet *Callionymus grossi*	(11,9)	113	83.0
Silverbiddy *Gerres oyena*	(6,16)	106	84.9

Table 5.5f: The ten numerically dominant taxa in this study compared to the study of Stephenson *et al.*, (1982a and b).

Rank	Middle Banks (present survey)	Middle Banks (Stephenson *et al.* 1982a and b)	Scarborough (Stephenson *et al.* 1982a and b)	Bramble Bay (Stephenson *et al.* 1982a and b)
1	*A. fasciatus*	*L. moretonensis*	*P. oblongus*	*L. moretonensis*
2	*L. moretonensis*	*A. quadrifaciatus* (= *A. fasciatus*)	*L. moretonensis*	*A. quadrifaciatus*
3	*P. otisensis*	*P. oblongus* (= *P.otisensis*)	*A. quadrifasciatus*	*P. multiradiatus*
4	*C. limiceps*	*S. undosquamis*	*P. multiradiatus*	*T. hamiltoni*
5	*S. undosquamis*	*S. maculata*	*P. salatrix*	*P. sexlineatus*
6	*S. maculata*	*C. limiceps*	*T. hamiltoni*	*S. maculata*
7	*I. japonica*	*Caranx spp.*	*H. translucidus*	*J. vogleri*
8	*P. jenysii*	*P. multiradiatus*	*T. novaezealandiae*	*H. castlnaui*
9	*C. grossi*	*A. ellioti* (= *A. poeciliopterus*)	*S. undosquamis*	*G. ovatus* (= *G. oyena*)
10	*G. oyena*	*P. macracanthus*	*J. vogleri*	*H. translucidus*

Table 5.5g: Results of SIMPER showing numerically dominant fish taxa that contributed most to differences in average similarity between shallow and deep sites surveyed.

Species	Av. abundance		Av. Diss	Diss/SD	Contrib percent	Cumulative percent
	Shallow	Deep				
P. otisensis	24.32	7.05	3.29	1.56	7.10	7.10
L. mortenensis	25.64	7.70	2.42	1.32	5.21	12.32
G.oyena	4.36	0.50	2.41	1.53	5.19	17.51
A. fasciatus	52.45	25.70	2.04	1.29	4.40	21.91
S. maculata	4.27	5.20	1.98	1.56	4.26	26.17
P. jenynsii	1.86	3.70	1.81	1.37	3.89	30.06
C. limiceps	8.50	22.75	1.80	1.36	3.87	33.93
I. japonica	4.32	2.80	1.73	1.35	3.72	37.65
C. grossi	2.64	2.75	1.71	1.30	3.68	41.34
C. australis	3.14	1.45	1.70	1.12	3.67	45.01
L. decorus	1.91	0.00	1.47	0.87	3.16	48.17
D. papilio	0.59	1.40	1.42	1.08	3.06	51.23

5.5.7.2 *Spatial and Temporal Patterns in Nektobenthic Invertebrate Fauna*

Previous Studies

Young (1978) and Young and Wadley (1979) described the distribution of nektobenthic species throughout Moreton Bay. Young (1978) found that seagrass beds were particularly important nursery areas for three prawn species. Young and Wadley (1978) found that epibenthic communities were strongly correlated with a variety of environmental variables. Unfortunately, these studies were of insufficient scope to assess spatial and temporal patterns in nektobenthic fauna at Middle Banks.

Although not empirical, trawl catch and effort data provide an indication of seasonal changes in abundance of mobile nektobenthic fauna. The trawl fishery in Moreton Bay can operate twelve months of the year, but there are clear seasonal peaks in catch and effort between November and May (Fenton and Marshall 2001; see also section 5.5.7.3). Commercial logbook data verifies this. For the logbook grid W37 (which encompasses a large portion of northern and western Moreton Bay), the seasonal catch of the key species extracted from the CHRIS database is shown in **Figure 5.5k to Figure 5.5m** It was necessary to use data from the 30-minute grid, rather than the relevant six-minute grids because of the restriction of access to data where the catch was taken by less than five boats.

Figure 5.5k: *The monthly catch of key species taken by trawling in northern Moreton Bay (logbook grid W37) in 2003.*

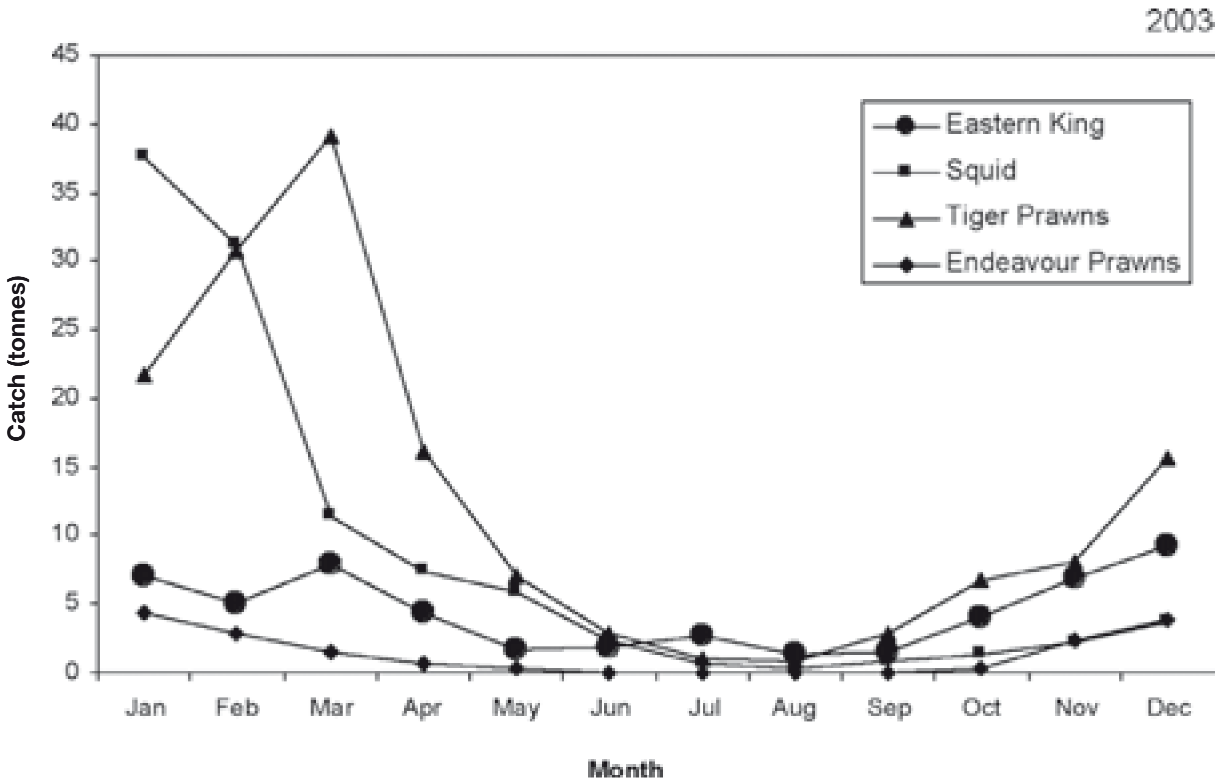


Figure 5.5l: *The monthly catch of key species taken by trawling in northern Moreton Bay (logbook grid W37) in 2002.*

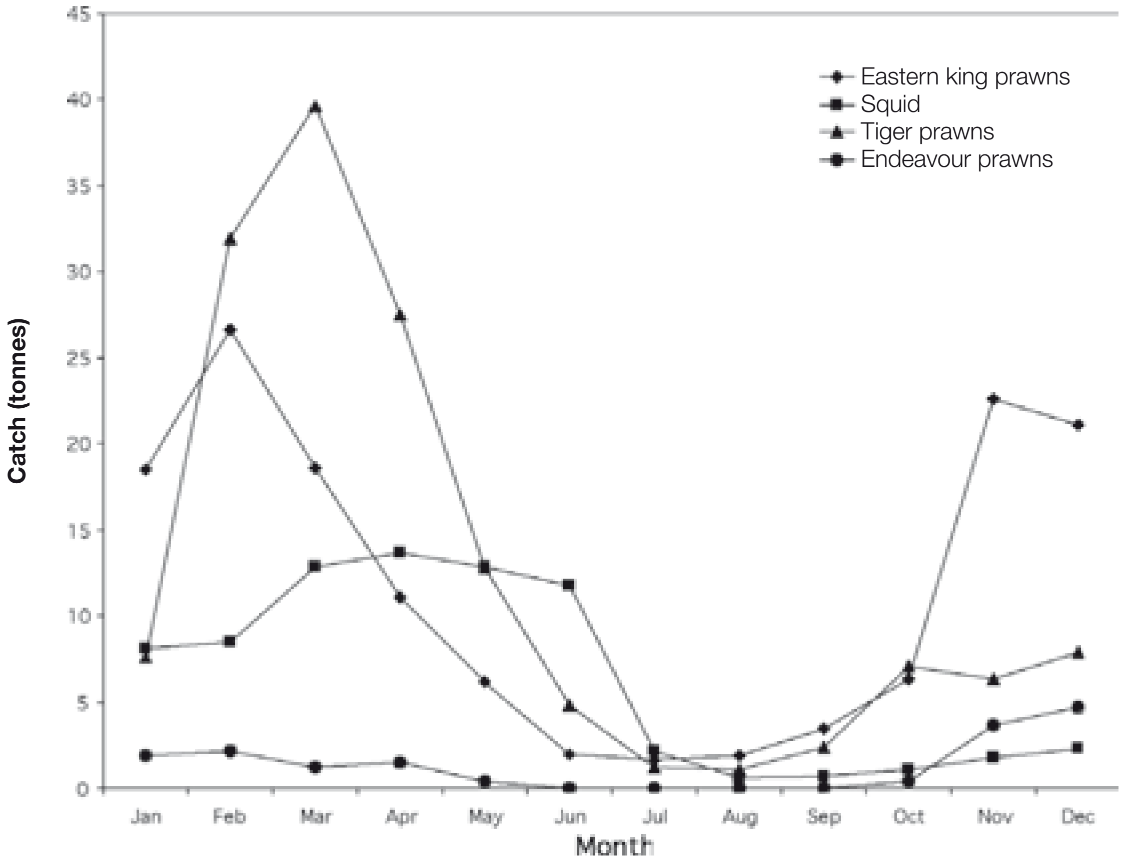
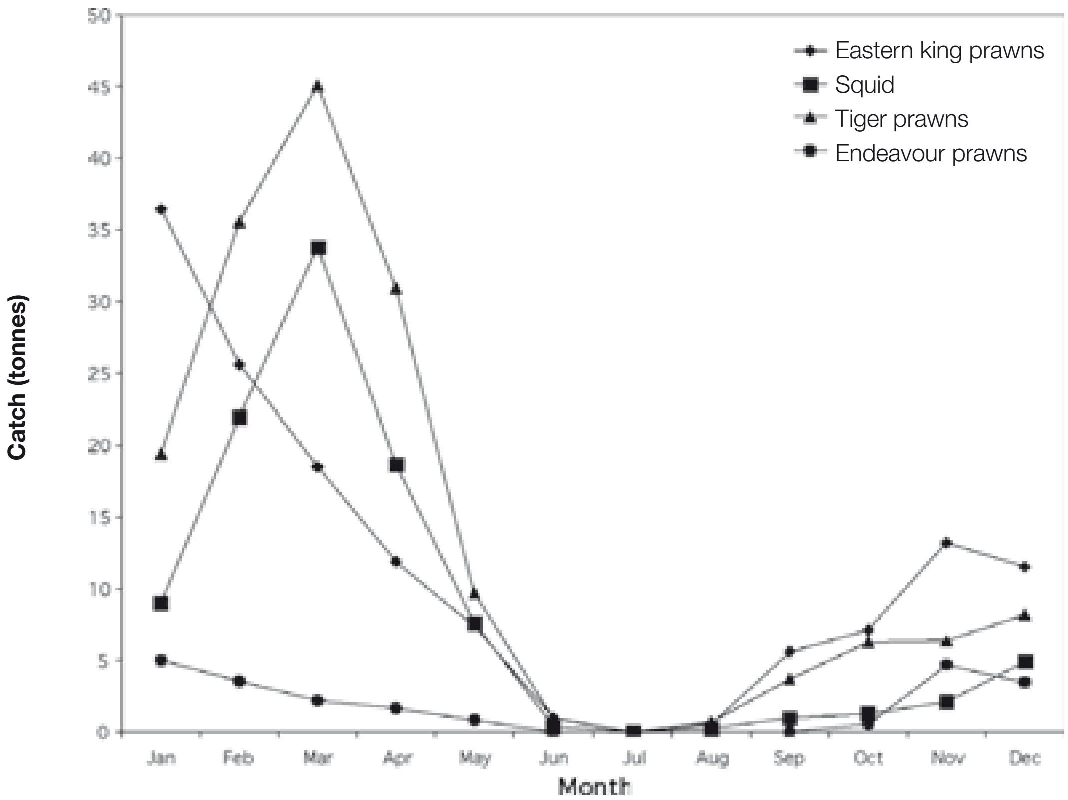


Figure 5.5m: *The monthly catch of key species taken by trawling in northern Moreton Bay (logbook grid W37) in 2001.*



Present Study

Results of the present study indicate that the assemblage of nektobenthic invertebrates was dominated by various species of penaeid prawns and portunid crabs (**Table 5.5h**). For the average abundance of nektobenthic invertebrates, the Month*Depth interaction was statistically significant (**Appendix C5: B**) meaning that the average abundance differed with depth during some months (Nov), but not others (Oct and Dec). The eight most abundant species represented by number 96 percent of the overall nektobenthic invertebrate assemblage.

The rank of the numerically dominant species at deep and shallow water sites varied with trawl crabs, Greasyback prawn *Metapeneaus bennettae* and Pencil squid *Photololigo etheridgei* being more important in shallow areas sampled and Hardback prawn *Trachypeneaus fulvus* and Blue swimmer crab *Portunus pelagicus* being more important in deeper areas sampled.

The nektobenthic assemblage surveyed showed clear similarities in terms of numerically dominant species with that previously sampled from Middle Banks and elsewhere in Moreton Bay (**Table 5.5i**). The average abundance across sites sampled (± s.e.) of the two major target species in the Moreton Bay commercial otter trawl fishery – tiger and king prawns are described in **Figure 5.5n**. For tiger prawns, their average abundance differed statistically with both depth and month (**Appendix C5: B**). On average, tiger prawns were more abundant at the two shallow water sites in comparison to the two deep-water sites. The pattern of abundance for king prawns though was different, with statistically significant differences between sites (taking into consideration depth and month being evident) (**Appendix C5: B**). Sites 3 and 4 had higher catches of king prawns than sites 1 and 2.

Graphically, the results of the nMDS demonstrated that the overall structure of the nektobenthic assemblage appeared to differ between depths (**Figure 5.5o**). ANOSIM supported this conclusion with a statistically significant difference in nektobenthic invertebrate assemblages between the two depths surveyed (Global R value = 0.524, P = 0.001).

Table 5.5h: Summary of the abundances of the ten most common nektobenthic invertebrate species captured in the Middle Banks area (pooled across all sites sampled).

Species	Rank (shallow, deep)	Abundance	Cumulative Percent Abundance
King prawn *Penaeus plebejus*	(1,2)	7,324	34.2
Coral prawn *Metapenaeopsis novaguineae*	(2,1)	5,134	58.3
Hardback prawn *Trachypeneaus fulvus*	(5,3)	2,977	72.2
Trawl crabs	(3,8)	1,259	78.1
Greasyback prawn *Metapeneaus bennettae*	(4,9)	1,188	83.6
Blue swimmer crab *Portunus pelagicus*	(7,4)	960	88.1
Endeavour prawn *Penaeus endeavouri*	(9,5)	912	92.4
Tiger prawn *Penaeus esculentus*	(6,6)	770	96.0
Pencil squid *Photololigo etheridgei*	(8,13)	399	97.9
Mantis shrimp *Oratosquilla spp.*	(10,10)	160	98.6

Table 5.5i: The ten numerically dominant nektobenthic invertebrate taxa in this study compared to the study of Stephenson *et al.*, (1982a and b) and Jones (1986).

Rank	Middle Banks (this survey)	Middle Banks (Stephenson *et al.* 1982a and b)	Scarborough (Stephenson *et al.* 1982a and b)	Bramble Bay (Stephenson *et al.* 1982a and b)	St Helena Is. (Jones 1986)
1	*P. plebejus*	*Loligo spp.*	*C. callianassa*	*M. bennettae*	*M. bennettae*
2	*M. novaguineae*	*P. pelagicus*	*M. bennettae*	*C. callianassa*	*P. plebejus*
3	*T. fulvus*	*C. callianassa (= T. prymna)*	*Loligo spp.*	*P. plebejus*	*P. pelagicus*
4	*Trawl crabs*	*M. novaguineae*	*P. pelagicus*	*Loligo spp.*	*C. callianassa*
5	*M. bennettae*	*P. hastatoides*	*P. hastatoides*	*P. pelagicus*	*T. fulvus*
6	*P. pelagicus*	*P. plebejus*	*P. plebejus*	*P. esculentus*	*P. esculentus*
7	*P. endeavouri*	*T. fulvus*	*T. fulvus*	*T. fulvus*	*P. etheridgei*
8	*P. esculentus*	*P. esculentus*	*P. esculentus*	*O. anomala*	*S. esculenta*
9	*P. etheridgei*	*O. anomala*	*P. sanguinolentus*	*A. stephensoni*	*P. hastatoides*
10	*Oratosquilla spp.*	*P. endeavouri*	*A. stephensoni*	*D. australiensis*	*O. anomala*

Figure 5.5n: *The average abundance per trawl shot (+/- s.e.) of tiger prawns and king prawns at each of the four sites surveyed. Sites 1 and 4 are shallow water sites and sites 2 and 3 are deep water sites.*

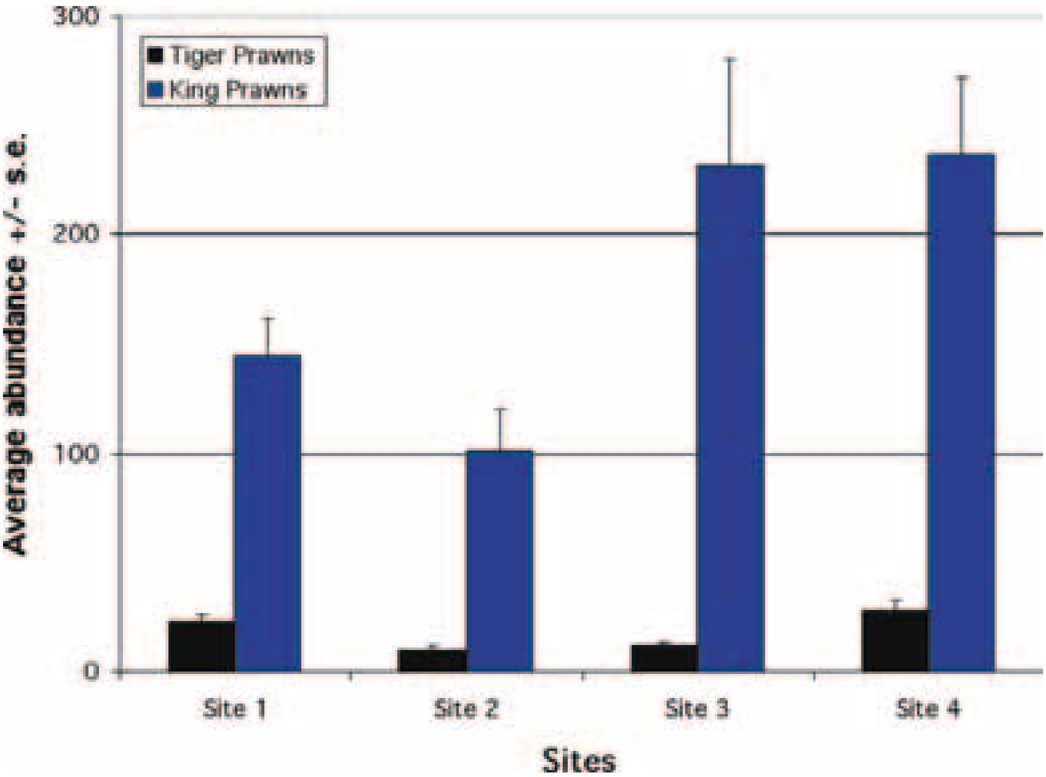


Figure 5.5o: *The results of nMDS on nektobenthic assemblages of the Middle Banks area. Green triangles represent shallow water samples and blue triangles represent deep water samples.*

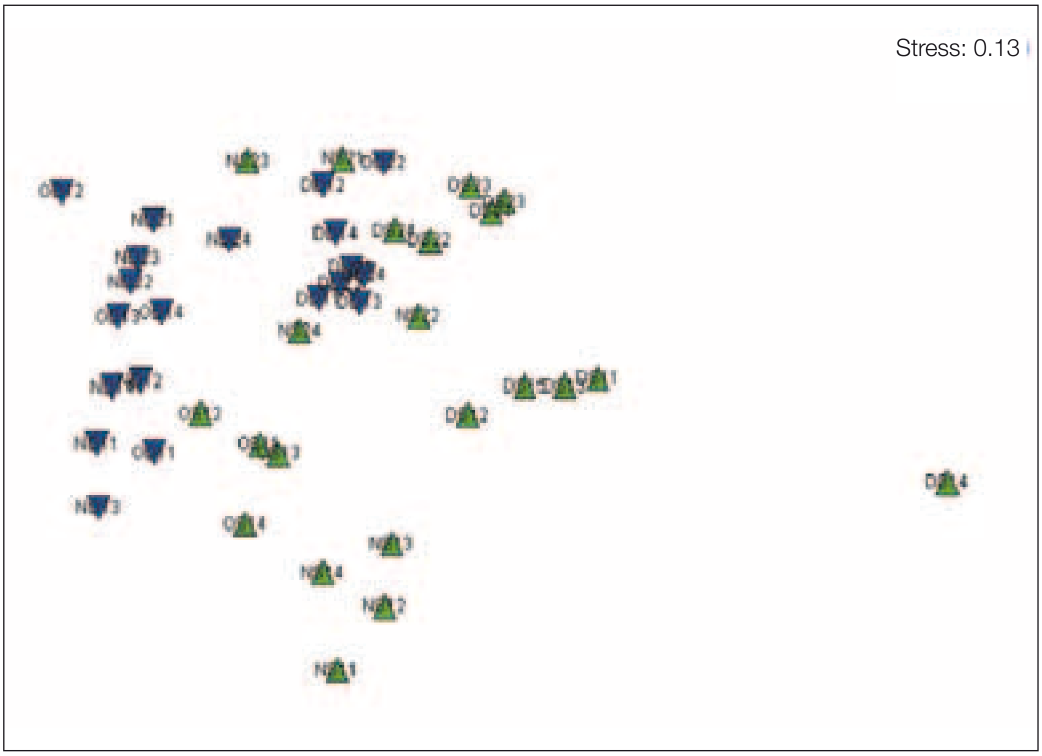


Table 5.5j: Results of SIMPER showing numerically dominant nektobenthic taxa that contributed most to differences in average similarity between shallow and deep sites surveyed.

Species	Av. abundance		Av. Diss	Diss/SD	Contrib Percent	Cumulative Percent
	Deep	Shallow				
M. bennettae	9.20	45.65	3.29	1.28	12.38	12.38
P. endeavouri	26.60	17.27	2.71	1.26	10.19	22.57
Trawl crabs	12.05	46.27	2.56	1.24	9.65	32.22
M. novaguineae	200.60	51.00	2.33	1.38	8.76	40.98
T. fulvus	99.55	44.82	1.91	1.27	7.19	48.17
Sepia spp.	1.10	4.05	1.75	1.25	6.60	54.77
P. esculentus	10.90	25.09	1.55	1.38	5.85	60.62
P. etheridgei	0.80	17.41	1.41	0.70	5.30	65.92
P. plebejus	165.60	182.36	1.38	1.04	5.21	71.13
Oratosquilla spp.	3.95	3.68	1.37	1.30	5.15	76.27
P.pelagicus	28.75	17.50	1.26	1.41	4.74	81.01
V. singaporina	1.20	1.36	1.14	0.91	4.28	85.29
P. antarcticus	0.40	1.55	1.05	1.03	3.94	89.23
A. edwardsii	1.00	0.91	0.85	0.75	3.20	92.41

Two species were restricted to shallow water sites only, *C. feriatus* (2 individuals) and *A. balliotti* (4 individuals). The results of the SIMPER analysis (**Table 5.5j**) shows the numerically dominant taxa that contributed most to differences in the average similarity in the nektobenthic assemblages between deep and shallow water areas surveyed. The deep water sites had notably higher abundances of *P. endeavouri, M. novaguineae, T. fulvus, and P. pelagicus* whereas the shallow water sites had notably higher abundances of *M. bennetti,* trawl crabs, *Sepia spp., P. esculentus, P. etheridgei and P. antarcticus.*

Overall, the results of the present study identified that diverse and abundant fish and nektobenthic invertebrate assemblages occurred between October and December 2005 in both deep and shallow water sites surveyed in the study area. The overall structure of both assemblages though differed between the depths sampled. The structure of the fish assemblage in both deep and shallow water sites surveyed was dominated by four species: cardinal fish (*A. fasciatus*), dragonet (*C. limiceps*), common ponyfish (*L. moretonensis*) and the trawl leatherjacket (*P. otisensis*). The number of fish (pooled across species) was greater in shallow water than it was in deeper water sites surveyed, though this trend was not evident in the nektobenthic assemblage.

Based on the classification of Johnson (1999), 54 of the 58 species captured in this study are either common or abundant in Moreton Bay. For the remaining fish species, Johnson (1999) did not include them in his checklist of fishes in Moreton Bay, and hence an abundance category was not provided. All four of these species: stinging cod (*Apistus carinatus*), yellow-lipped butterfly fish (*Nemipterus theodorei*), blind goby (*Brachyambylopus coecus*) and the elongated ponyfish (*Leiognathus elongatus*) are widely distributed species that are common in similar habitats elsewhere[4].

Although there are limitations in the data collected by Stephenson *et al.* (1982a and b) as identified in the introduction, nonetheless, some general comparisons can be made between the results from these studies and the current research. While, it is not possible to disaggregate the data presented by

[4] *www.fishbase.org provides information on the distribution of these four species. N. theodorei is an important commercial byproduct species for trawl operators in southern and central Queensland.*

Stephenson *et al.* (1982b) to determine exactly how many fish species were captured in that survey, 29 fish species in the survey sites closest to Middle Banks and 40 fish species in all sites surveyed where more than 10 individuals were captured. Despite considerably lower spatial and temporal coverage of sampling in this survey, 31 fish species with abundances of greater than 10 individuals were recorded. The cause of this difference is difficult to determine, it suggests that perhaps the diversity of the current fish assemblage in the Middle Banks area, which has been dredged previously, is at least as diverse, if not more diverse, than that recorded previously by Stephenson *et al.* (1982b).

Many of the numerically dominant fish species recorded by Stephenson *et al.* (1982b) in the Middle Banks region were also numerically dominant in this survey. Of the top ten numerically dominant species in each study, six were common to both. Many of the numerically abundant species have also been found to be numerically abundant in other sub-tidal areas in Moreton Bay (e.g. Wassenberg and Hill, 1989; Warburton and Blaber 1992; Stephenson *et al.*, 1982 a and b).

Similar to the fish assemblage, the assemblage of nektobenthic invertebrates recorded in this study differed with depth. Again though, the majority of species (all but two) were recorded at both depth strata, and some species were more abundant in shallow water sites than deep-water sites and vice versa. The numerically dominant nektobenthic invertebrate species recorded in this study also showed very clear similarities with those previously sampled at Middle Banks by Stephenson *et al.* (1982a and b) as well as other sub-tidal areas in Moreton Bay (Stephenson *et al.*, 1982a and b; Jones, 1986). All of the ten numerically dominant nektobenthic invertebrate taxa in the Middle Banks region were common to both studies. Comparison with other areas in Moreton Bay demonstrates that the common taxa appear widespread throughout sub-tidal areas of Moreton Bay that have been surveyed previously.

5.5.7.3 Values

Recreational and Commercial Fishing

The following sections provide an overview of the primary commercial and recreational fishing practices within northern Moreton Bay and (where possible) the study area:

Trawling

Moreton Bay supports a substantial commercial fishing industry consisting primarily of netting and otter trawling. The commercial trawl fishery in Moreton Bay is a multi-species fishery, which targets a variety of prawn species with incidental catches of squid, cuttlefish and Moreton Bay bugs also taken. The main prawn species targeted are Bay/Greasyback (*Metapeneaus bennettae*), Tiger (*Peneaus semisulcatus and P. esculentus*), Endeavour (*Metapenaeus endeavouri and M. ensis*) and Eastern King prawns (*Peneaus plebejus*). William (1992) estimated that approximately 200 prawn trawlers operate within the Bay, taking 10 percent of the Queensland trawl catch and 41 percent by weight of the total seafood production from Moreton Bay. Sand crabs, mud crabs and spanner crabs are also targeted by commercial operations in Moreton Bay with sand crabs forming the largest crab fishery (WBM Oceanics Australia 2004).

Catch and effort in the trawl fishery was extracted from the CHRIS database administered by the Queensland Department of Primary Industries. This information can be extracted at the spatial scale of 6 minute grids (from 2001-2002) and 30 minute grids (2001-2003; see **Figure 5.5p**). An important limitation is that where catches from less than five boats occur in a given grid, this information is deemed confidential, and is not publicly available.

The one 30 minute grid (W37) covers much of northern and western Moreton Bay, and as such, it is not of sufficient resolution to determine the importance of Middle Banks in terms of its value as a commercial fishery. 6 minute grid information provides greater spatial resolution of commercial trawl data; the W37.14 6 minute grid was of most relevance to this study, encompassing both the Central and Middle Banks region.

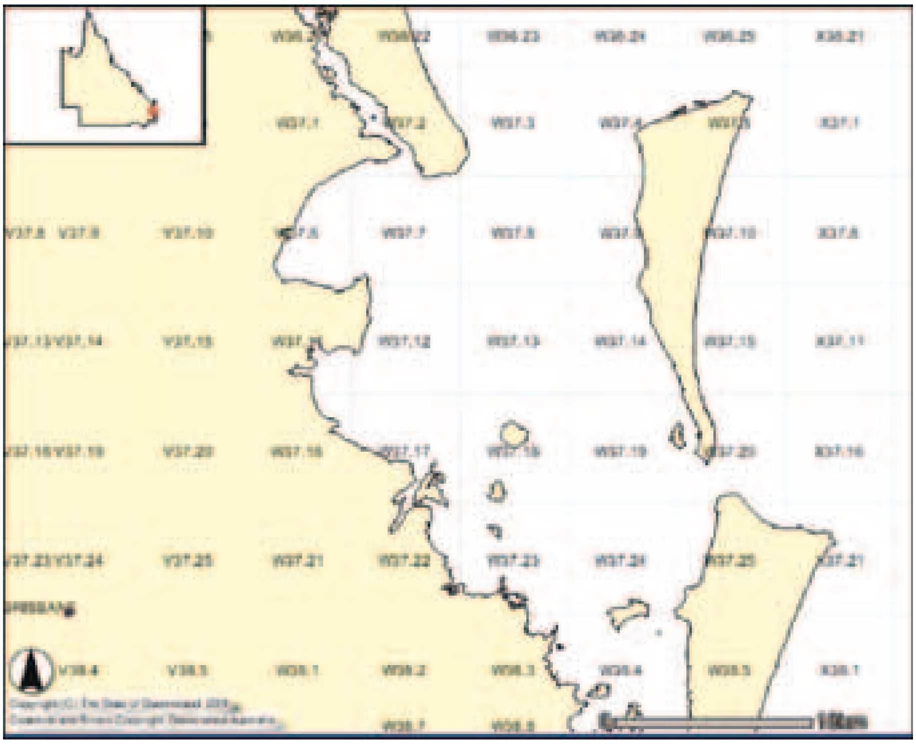
Table 5.5k shows that the catch from grid W37.14 is important and also that it is highly variable between years. In the year 2001, the trawl fishing GVP from the 6 minute grid of W37.14 represented 4.2 percent of the trawl fishing GVP recorded in the entire 30-minute grid of W37 (i.e. northern Moreton Bay). In 2002, the trawl fishing GVP from the 6 minute grid of W37.14 represented 7.5 percent of the trawl fishing GVP recorded in the entire 30-minute grid of W37.

Table 5.5k: Trawl catches in the six-minute logbook grid W37.14 during 2001 and 2002.

Species	2001				2002			
	Tonnes	GVP (AU$)*	No. Boats	No. days	Tonnes	GVP (AU$)	No. Boats	No. days
Tiger prawns	6.5	97,700	24	384	15	225,200	31	675
Squid	2.8	14,200	22	224	7.4	37,200	25	355
King prawns	3.4	41,700	11	159	5.7	68,300	15	291
Endeavour prawns	6.2	74,000	12	184	10.6	127,600	16	373
Prawns - unspecified	1.6	7,900	12	83	3.3	16,300	18	190
Blue swimmer crab	3.1	15,300	20	331	4.3	21,500	26	537
Bay prawns	0.6	3,100	6	33	1.4	7,100	12	74
Greasy prawns	0.3	2,100	5	19	0	0	0	<5
Bugs	0.2	2,000	6	34	0.4	4,400	10	30
Cuttlefish	0.1	600	6	22	0.2	800	9	36
Shark - unspecified	0.1	700	5	18	0	0	0	<5
TOTAL	**24.9**	**259,300**	**25**	**419**	**48.3**	**508,400**	**33**	**713**

** The GVP values were extracted directly from the CHRIS database. Note that no data was available from the CHRIS database (as at April 2006) for the 2003-2005 period.*

Figure 5.5p: *Six minute logbook grids in northern Moreton Bay extracted directly the CHRIS database administered by the Queensland Department of Primary Industries.*



Blue Swimmer Crab Pot Fishery

There has been a general shift in the operation of the commercial blue swimmer crab fishery from inshore areas (e.g. within the northern parts of Moreton Bay) to deeper offshore areas (e.g. offshore of Mooloolaba and Caloundra) where catch rates tend to be higher and the average size of the crab is larger (Sumpton, 2000). This shift by commercial pot fishers to offshore areas may also be a response to conflict between the trawl and pot fisheries which has been endemic to Moreton Bay for many years. No such shift from inshore to offshore areas has been noted in the recreational fishery for blue swimmer crabs (Sumpton, 2000).

The spatial scale of logbook information is insufficient to determine how important the study area is from the perspective of this fishery. Spatial information for this fishery is only available for the period between 2001 and 2003 (**Figure 5.5q**) at the scale of 30 minute grids (W37) and vessels fishing in this fishery are not required to carry VMS.

The logbook information is only sufficient to determine the blue swimmer crab commercial catch in the Moreton Bay region in general (1 x 30-minute grid W37 extends from Cleveland to southern Bribie Island, including eastern and western sections of Moreton Bay). In 2001 this catch was 516 tonnes captured by 96 operators over 9146 days, and had a GVP(AU$) of $4.1 Million. In 2002 the catch was 329 tonnes captured by 87 operators over 7984 days and had a GVP(AU$) of $2.6 Million. In 2003 the catch was 303 tonnes captured by 93 operators over 8091 days and had a GVP (AU$) of $2.4 Million.

Spanner Crab Fishery

Spanner crabs occur in coastal water depths of 10-100 m over sandy substrates in which they bury. They are primarily harvested using ‘dilly’ type crab pots all year round, except between 20 November to 20 December when this fishery is closed; they aggregate to spawn during the warmer months of the year between October and February, peaking during November and December. Most of the Queensland catch is taken in deep oceanic waters

Figure 5.5q: *The commercial (crab-pot) catch of blue swimmer crabs in northern Moreton Bay (logbook grid W37) during 2001, 2002 and 2003.*

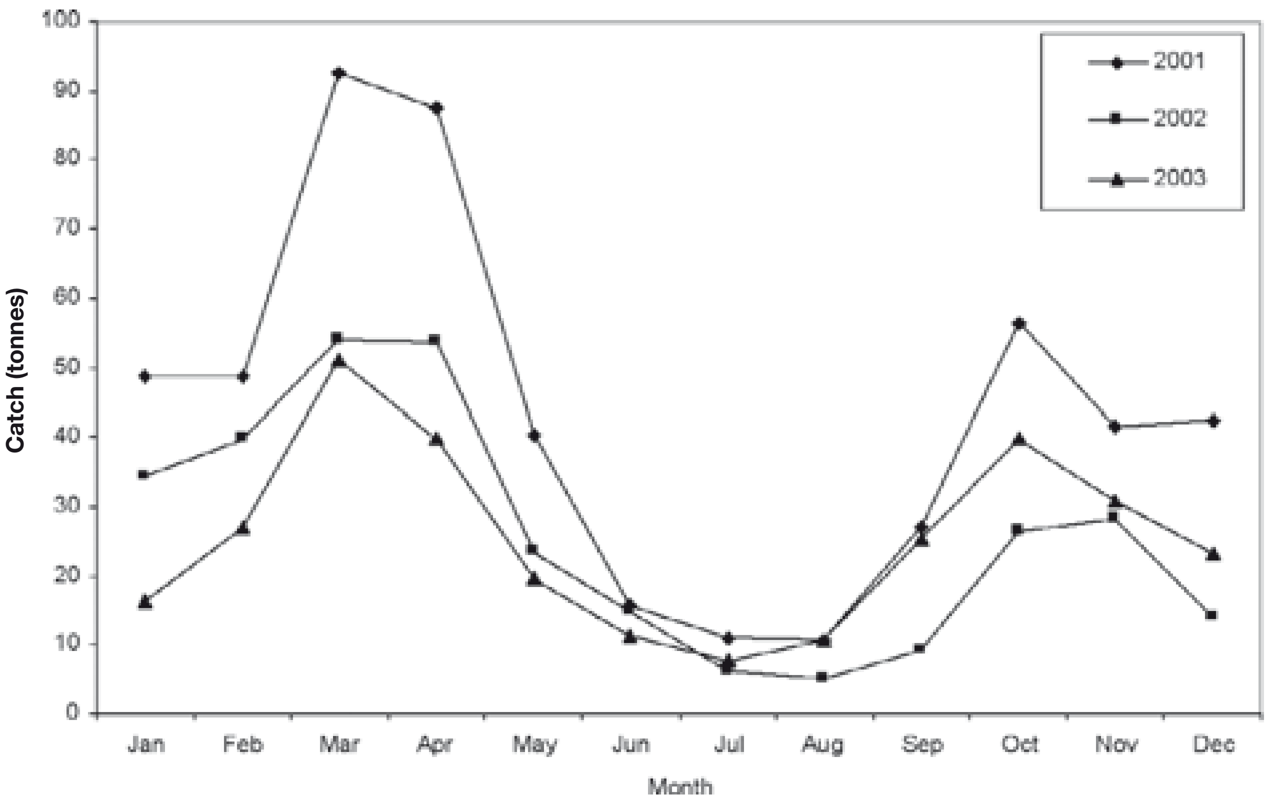


Table 5.5l: Commercial annual catch, fishing effort and gross value product (GVP) of Spanner Crabs within the northern Moreton Bay and offshore (W37 logbook grid) between 2001 and 2003.

Year	Grid	Species	Tonnes	Boats	Days	GVP (AUS $)
2003	W37	Crab - Spanner	14.7	5	84	$51,500
2002	W37	Crab - Spanner	20.5	12	121	$71,900
2001	W37	Crab - Spanner	22.1	15	132	$77,400

south of Yeppoon, however, they are harvested in offshore waters between the New South Wales border to Gladstone in central Queensland.

The commercial spanner crab fishery is generally an offshore fishery. It is unlikely that a significant proportion of the spanner commercial crab catch reported for the northern Moreton Bay W37 logbook grid during 2001-2003 (**Table 5.5l**) was obtained from the Central and Middle Banks region, as this area is well inside Moreton Bay. It is most likely that some of the catch of this species comes from areas that correspond to the six minute grids of W.37.3 and W37.4 (Spitfire Banks and Yule Banks area) as these are the six-minute grids within the W37 thirty minute grids that have a clear oceanic influence. However, it is likely that the majority of the spanner crab catch recorded in the W37 grid was recorded east of Moreton Island (e.g. W37.10 and W37.15, see **Figure 5.5p**).

Diver Whiting Fishery

Historically, the Middle and Central Banks regions were important areas for the commercial capture of diver whiting by trawling, but the retention of diver whiting by trawlers is now prohibited by the Queensland Government for resource allocation reasons.

A recreational fishery for diver whiting still exists in Moreton Bay, but detailed fine scale information on the spatial distribution of this fishery in Moreton Bay is not available. Anecdotal information suggests that the key locations for recreational diver whiting fishing in Moreton Bay include the Compass Adjustment Buoy, the Blue Hole, the entrance to the Rous Channel, the region of Gilligan's Island and the Cockle Banks in northern Moreton Bay.

It is most likely that some recreational fishing effort is directed at diver whiting in the study region.

Spotted Mackerel Fishery

Detailed fine scale information on the spatial distribution of the recreational spotted mackerel fishery is not available. The spatial distribution of spotted mackerel within Moreton Bay is generally considered to vary from year to year. Based on anecdotal evidence Middle Banks is a known area where spotted mackerel can be caught by anglers.

Fisheries Habitat Values

Within Moreton Bay, the Middle Banks region has been highlighted as an area of high fish taxa richness, which was considered likely to be attributed to the wrecks and artificial reefs at Tangalooma and Cowan (Davie and Hooper 1998). The study area contains a diversity of benthic habitat that supports a small number of fish species and a large number of nektobenthic invertebrates of direct commercial and recreational fisheries significance (WBM Oceanics Australia 2004, present study). These include (extracted from WBM Oceanics Australia 2004):

Eastern king prawns (*Penaeus plebejus*)

Information on the life history of eastern king prawns is summarised in Williams (1997) and Dichmont *et al.* (1999) and the following narrative is largely drawn from these publications. Eastern king prawns migrate from inshore areas, across surf bars and banks (e.g. northern entrance to Moreton Bay and South Passage) and into deeper water. Spawning occurs in this area at depths of >100 m. All king prawns in Moreton Bay are juveniles, therefore it is possible that the species is overfished by the trawl fishery operating within Moreton Bay. They recruit through embayments such as Moreton Bay and into shallow waters adjacent to ocean bars in spring and early summer. Spawning activity peaks in winter between May and July, and adults do not generally migrate back into inshore waters after spawning. Planktonic larvae enter Moreton Bay with the flood tide both day and night and settle on bare substrates and seagrass areas.

Importantly, catchability of eastern king prawns in estuaries and shallow waters by trawl vessels is affected by lunar phases, with catch rates increasing leading up to and including the new moon. This suggests that this part of the lunar cycle may be critical for the migration of this species across and out of the Bay and into deeper water.

Brown tiger prawns (*Penaeus esculentus*)

There are two species of tiger prawns captured by commercial fisheries in Queensland – the brown tiger (*Penaeus esculentus*) and the grooved tiger prawn (*Penaeus semisulcatus*). The catch of tiger prawns in Moreton Bay is dominated by the former species (O'Brien, 1994), this is an important point because the timing of spawning and recruitment differs between the two species (Williams, 1997). The brown tiger prawn in Moreton Bay spawns during the warmer months from October to March (O'Brien, 1994; Williams, 1997). Juveniles settle and recruit to seagrass beds (Young and Carpenter, 1977; O'Brien, 1994). Juveniles migrate to deeper waters, such as habitats that occur in the study region, as they grow.

Moreton Bay bugs (*Thenus orientalis*)

Spawning of Moreton Bay Bugs occurs during late spring and summer (Williams, 1997). Spawning is generally considered to occur in offshore waters and larvae are thought to settle and recruit in shallower sub-tidal areas. Larval duration is less than a month (Williams, 1997). It is possible that Middle Banks, like other sand banks in the wider study region, represent areas where juvenile Moreton Bay Bugs settle and recruit. No studies have examined recruitment areas of Moreton Bay bugs, although post-larvae of this species were not found to represent a conspicuous element of the benthos of the study area or wider study region by Stephenson *et al.* (1978) or WBM Oceanics Australia (2004). Neither of these studies was specifically designed to target this species.

Squid (*Photololigo spp.*)

Squid in Moreton Bay are thought to aggregate for spawning on the eastern side of the Bay during the summer months. The exact locations of these spawning areas are unknown. Squid are short lived and complete their life cycle in six to nine months.

Blue swimmer crabs (*Portunus pelagicus*)

Blue swimmer crabs have two peak breeding periods in Moreton Bay. The major peak occurs from around August to October, with a lesser peak occurring around April. During these periods of breeding activity, most egg carrying females are found in the oceanic currents at and just offshore of the entrances to Moreton Bay. Larvae recruit back into Moreton Bay and settle out in shallow estuarine areas, in both the eastern and western parts of the Bay.

Spanner crabs (*Ranina ranina*)

Spawning occurs in offshore waters with larvae remaining in the plankton for 5 to 8 weeks until settlement. The important period for settlement and recruitment of spanner crabs would appear to be November through to April. Within this period, based on the peak in spawning activity, the December through to January may be a major period of recruitment.

The crabs preferred habitat is well-sorted sand in the oceanic environment, with larvae settling out in bare sandy areas. WBM Oceanics Australia (2004) suggested that the Middle and Central Banks region may be part of an important area for settlement and recruitment of spanner crabs. Although definitive data is lacking, it is likely that spanner crabs migrate offshore as they grow.

No studies have examined recruitment areas of this species, although post-larvae of this species were not found to represent a conspicuous element of the benthos of the study area or wider study region by Stephenson *et al.* (1978) or WBM Oceanics Australia (2004). Neither of these studies was specifically designed to target this species.

Mud crabs (*Scylla serrata*)

The mud crab fishery does not operate in the study region, although the life cycle and migration of mud crabs is relevant with respect to this area. Egg bearing females migrate from inshore mangrove areas to deep offshore waters for spawning (Heasman *et al.*, 1985; Hill, 1994). The two main reasons for this migration is the improved dispersal of larvae and the intolerance of early stage larvae to low salinity waters.

Spawning of mud crabs in the Moreton Bay region occurs from September to March with a peak in November to December (Heasman *et al.*, 1985). Female mud crabs are known to return to estuaries after spawning (Hill, 1994). Mud crabs migrate through the study region on the way to offshore spawning areas between September and March.

Diver whiting (*Sillago maculata maculata*)

Weng *et al.* (1994) identifies that diver whiting spawn on the eastern side of Moreton Bay (i.e. inclusive of the study region). Diver whiting spawn in Moreton Bay throughout the year, but a peak in spawning activity occurs in the winter months. Juveniles occur in inshore and estuarine areas year round (Weng, 1990).

Stout whiting (*Sillago robusta*)

Sexually mature stout whiting occur for more than eight months of the year (excluding winter), with a peak in spawning occurring in the summer months (December to February) (Butcher, 1995). Stout whiting recruit to shallow bare sandy areas. Juvenile stout whiting (<10 cm) were recorded as being abundant in the Middle Banks area (Dredge and Young, 1974), but it is likely that they occur in shallow areas throughout eastern Moreton Bay and offshore areas adjacent to the Bay. Stout whiting migrate to deeper water (> 30 m) as they grow (Butcher, 1995).

Key recruitment periods for stout whiting are not clearly identified, but based on the protracted spawning period it is likely that juveniles are presented in inshore areas year round. However, owing to the peak in spawning activity during summer, it is likely that summer and early autumn is the key recruitment period for this species.

Spotted mackerel *(Scomberomorus munroi)*

Spotted mackerel spawn in north Queensland waters during August and September. Spotted mackerel utilise Moreton Bay for feeding during summer and early autumn (Begg and Hopper, 1997; Begg *et al.*, 1997). Spotted mackerel in Moreton Bay feed principally on Engraulis spp. with lesser amounts of Clupeids consumed (Begg and Hopper, 1997).

Overview

All species outlined above utilise the seabed habitats of the study region, inclusive of the study area. It is not possible to define a specific habitat value for the study area relative to other areas in the wider Moreton Bay region, or compared to other areas elsewhere. What can be stated is that Middle Banks provides habitat conditions , in terms of sediment type, wave/current conditions and water depth that are not unique to the study region. Furthermore, with the exception of spotted mackerel, commercial and recreational species potentially occurring in the study area and study region are opportunistic species that feed on a wide variety of benthic invertebrates, which means that the study area does not provide unique food sources for these species. The potential impacts of the proposed development on these values are explored in the impact assessment section.

5.5.8 Dolphins and Whales

Key points – Dolphins and Whales
• Dolphins and whales are protected under State and Commonwealth Government legislation.
• Whales are rarely found west of Moreton and Stradbroke Islands and are unlikely to frequent the Middle Banks area.
• Two commercial whale watching licenses are held for Moreton Bay Marine Park, which operate in areas along the east coast of North Stradbroke and Moreton Islands.
• The Tangalooma Wild Dolphin Resort is situated approximately 3 km east of Middle Banks on Moreton Island and undertakes nightly feeding of bottlenose dolphin as part of resort guest activities.
• Of the three species of dolphin known for Moreton Bay, the bottlenose dolphin is the most frequently encountered species in the Middle Banks area.

5.5.8.1 Spatial and Temporal Patterns

Three species of dolphins and four species of whales are known to visit or inhabit Moreton Bay Marine Park. The two most common dolphin species in Moreton Bay are the bottlenose (*Tursiops truncatus*) and the Indo-Pacific humpback dolphin (*Sousa chinensis*). Sightings of the third species, the Irrawaddy dolphin (*Orcaella brevirostris*) are so rare that the region is not considered to be part of the species' current range, which on the east coast of Australia extends as far south as the Gladstone area (Hale *et al.* 1998).

The bottlenose dolphin is generally found in more oceanic waters such as the central or eastern areas of Moreton Bay (Corkeron *et al.* 1987; Lanyon and Morrice 1997). The inshore or aduncus form of the species occurs in Moreton Bay. The Indo-Pacific humpback dolphin typically occurs in turbid, sheltered waters (Corkeron *et al.* 1998; Hale *et al.* 1998) generally on the western and southern edges of the Bay. There appears to be little seasonal variation in these distribution patterns. Hale *et al.* (1998) estimated there to be approximately 100 Indo-Pacific humpback and 500 common bottlenose dolphins in Moreton Bay. Furthermore, there were few sightings of either dolphin species in the vicinity of Middle Banks and surrounds, with most sightings occurring in central and western Moreton Bay (Hale *et al.* 1998).

The most common species of whale in the region is the Humpback whale (*Megaptera novaeangliae*). Humpback whales visit Moreton Bay Marine Park every winter and spring when migrating to and from their Antarctic feeding grounds. These whales are commonly sighted off the South Queensland coast during June and July as they migrate north, and between late August and October as they migrate south (Paterson 1991). Bryden and Griffith (1980) conducted aerial surveys to determine the width of the whale migration corridor between the coast from North Stradbroke Island and the continental shelf edge. Humpbacks were sighted exclusively within 10 km of the coastline off North Stradbroke Island during this survey, which would suggest a relatively narrow migration corridor in areas adjacent to Moreton Bay.

While migrating whales have a tendency to remain in oceanic waters on the eastern side of Moreton and Stradbroke Islands, anecdotal sightings of these mammals confirm that individuals occasionally enter Moreton Bay, presumably via the northern entrance and typically during their southern migration (Dr M. Noad pers. *comm*. 7 August 2006). There are no available data describing the number of visits to Moreton Bay by whales, although they are not believed to forage or breed during their brief stay.

5.5.8.2 Values

All marine mammals are protected under the *Nature Conservation (Wildlife) Act 1994*, with further protection afforded to Dolphins and Whales under the *Nature Conservation (Whales and Dolphins) Conservation Plan 1997.*

The EPBC "Protect Matters Search Tool" database lists five whale species and eight dolphin species as "species or species habitat likely to occur in the area". Following a review of specific habitat requirements for each species, those species known to or considered likely to, occur in the study area were discussed in section 5.5.8.1. Species marked with an asterisk in **Table 5.5m** are considered highly unlikely to occur in the study area.

Boat-based commercial whale watching operations occur in the Moreton Bay region, with most activities centred around the northern portion of Moreton Island. Hervey Bay and Moreton Bay Marine Parks are the only two areas where the Queensland government permits commercial whale watching, with 18 permitted operators in Hervey Bay and two in Moreton Bay Marine Park (Source: EPA website, accessed August 2006). These tours are highly seasonal, being based around the migration patterns of humpback whales and operate between July and October. The Middle Banks region is not a core area used by whale watching operators.

The Tangalooma Wild Dolphin Resort is situated approximately three km east of Middle Banks on Moreton Island. The resort is licensed to undertake controlled nightly feeding of dolphins as part of resort guest activities.

Table 5.5m: Whale and dolphin species listed under the *EPBC Act 1999* for the Moreton Bay region.

Common name	Species
Whales	
Humpback whale	*Megaptera novaeangliae*
Bryde's whale	*Balaenoptera edeni*
Southern right whale	*Eubalaena australis*
Minke whale	*Balaenoptera acutorostrata*
Killer whale*	*Orcinus orca*
Dolphins	
Bottlenose dolphin	*Tursiops truncatus s. str.*
Indo-Pacific humpback dolphin	*Sousa chinensis*
Irrawddy dolphin	*Orcaella heinsohni*
Common dolphin*	*Delphinus delphis*
Dusky dolphin*	*Lagenorhynchus obscurus*
Spotted dolphin*	*Stenella attenuata*
Spotted bottlenose dolphin*	*Tursiops aduncus*
Risso's dolphin*	*Grampus griseus*

** Species considered unlikely to occur (or a vagrant) in the study area following a review of specific habitat requirements*

5.5.9 Dugongs

Key points – Dugongs
• Moreton Bay contains one of the largest populations of dugongs on the Queensland coast.
• Middle Banks is located in the zone of lowest dugong density within Moreton Bay, with highest numbers found at Moreton Banks, approximately 10 - 12 km to the south (at its closest point).
• The closest dense area of seagrass of potential value to dugong is located between Shark Spit and Tangalooma Point, approximately 2 km to the east of Middle Banks (at its closest point).
• The absence of a large areas of food resources (seagrass beds) in the study region may explain the low reported density of dugongs in the area.
• There were no evidence of dugong foraging (i.e. distinctive feeding trails) during the Middle Banks seagrass and epibenthos survey.

5.5.9.1 Spatial and Temporal Patterns

Moreton Bay represents the southern limit of the dugong's eastern Australian distribution (Lanyon and Morrice, 1997) and currently contains one of the largest populations of dugongs on the east coast of Australia (Marsh *et al.*, 1996). A recent study estimated the Moreton Bay dugong population to be comprised of approximately 500 individuals (GBRMPA 2003) compared with an estimated population of 800 to 900 individuals in 1995 (Lanyon and Morrice, 1997). However as noted by GBRMPA (2003), there were differences in sampling techniques, which preclude direct comparisons between the two studies.

Dugongs are believed to move in and out of Moreton Bay in ranging movement patterns (Dingle, 1996), but principally through the South Passage and not the northern delta region (Lanyon and Morrice, 1997). Dugong densities appear to be concentrated around the extensive seagrass beds associated with the Moreton Banks area (located 10 - 12 km to the south) in the eastern Bay (Lanyon and Morrice, 1997), with relatively few individuals sighted in other portions of Moreton Bay (**Figure 5.5r**) The importance of the Moreton Banks area to the dugong has been recognised by the Environmental Protection Agency in the *Marine Parks (Moreton Bay) Zoning Plan 1997*, with the area designated as a Conservation Zone and the implementation of "go slow zones" in this area.

The Eastern Banks region of Moreton Bay occupies more than 100 km^2 and includes the Moreton, Boolong, Chain, Maroom and Amity Banks. Extensive seagrass beds cover large portions of these sand banks, which are dominated by seagrass species favoured by dugong (*Halophila sp.*) (refer to **Figure 5.5a**). Lanyon and Morrice (1997) have shown that dugong densities in Moreton Bay are concentrated around the broad, shallow seagrass covered sand banks in eastern Moreton Bay (most notably Moreton Banks) approximately 10 - 12 km to the south of Middle Banks at its closest point. Based on the availability of suitable foraging habitat, areas of subtidal seagrass areas located north from Moreton Banks along the Moreton Island foreshore to Tangalooma Point are recognised for their potential importance to dugongs. Therefore, the coastline between Tangalooma Point and Shark Spit represents the closest potential dugong habitat (based principally on availability of seagrass habitat) and both are situated between 2 to 3 km east of Middle Banks. There is little evidence to suggest that large numbers of dugong utilise the Middle Banks region, neither as a key foraging area, nor as part of a movement corridor to the northern delta region (Lanyon and Morrice 1997).

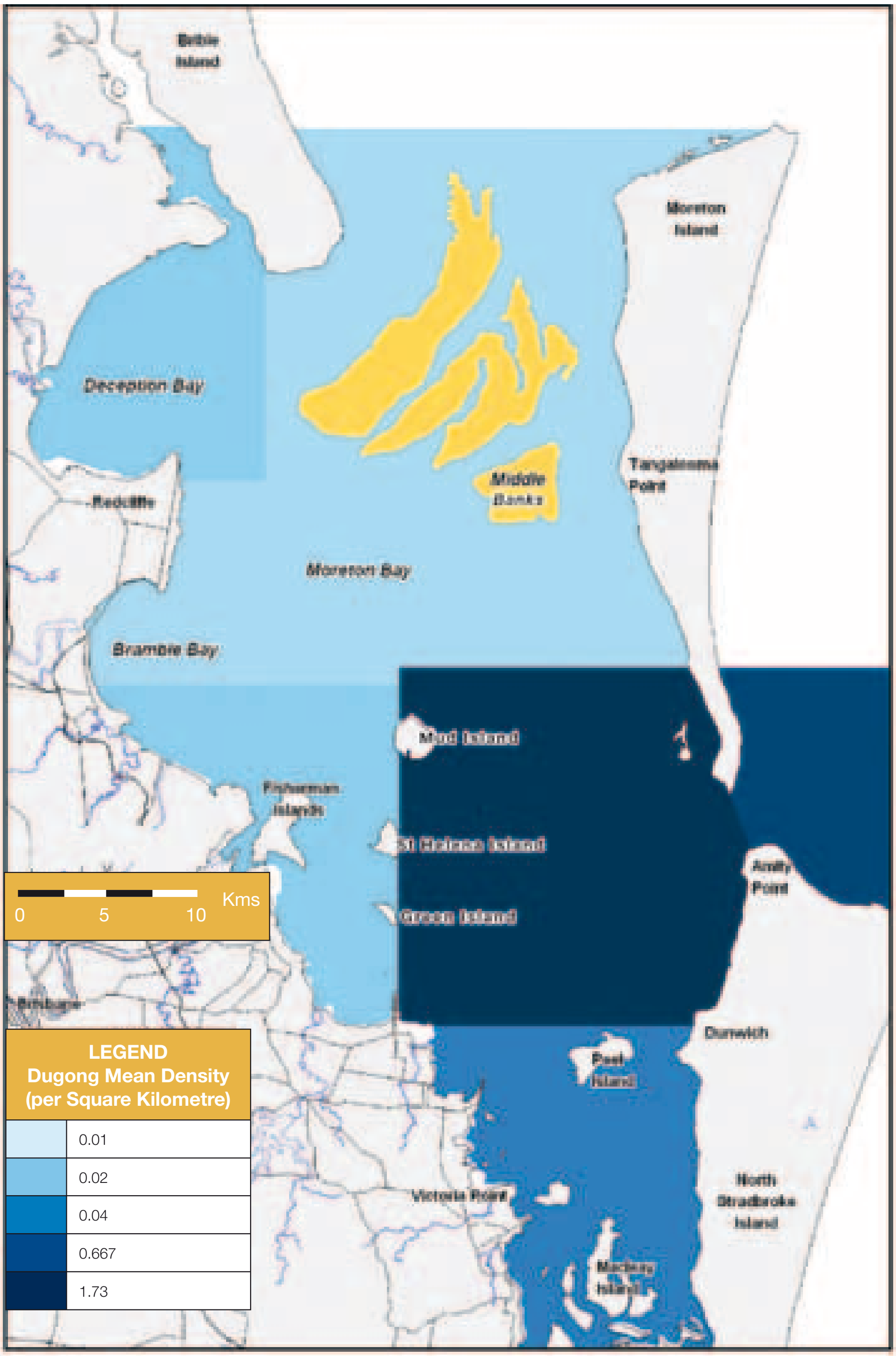
Dugongs are principally herbivores and have been shown to be highly selective feeders, preferring certain species of seagrass to others. Preen (1995a) reported dugongs showing a preference for grazing on seagrass from the genus *Halophila*, three species of which (*H. ovalis, H. spinulosa* and *H. decipiens*) are found in Moreton Bay and two of which were recorded at Middle Banks (refer to section 5.5.3). As dugongs feed, whole plants are uprooted and a telltale-feeding trail is left, however, no such evidence of dugong foraging was recorded during the WBM seagrass survey at Middle Banks. Dugongs in Moreton Bay are also reported to feed deliberately on invertebrates such as ascidians, large populations of which were not recorded at Middle Banks. This omnivory is thought to be a response to nutritional stress caused by seasonality in abundance of seagrasses in Moreton Bay (Preen, 1995b).

5.5.9.2 Values

Dugongs have a global IUCN listing of "vulnerable to extinction" (IUCN 1996), they are 'listed threatened', 'listed migratory' and 'listed marine' species under the *EPBC Act 1999* (Commonwealth) and the Queensland dugong population is considered as "vulnerable" under the *Nature Conservation Act 1992 (Qld)*.

It is possible that the absence of a large and possibly stable (perennial) area of food (seagrass) resource in the Middle Banks area may explain the low reported density of dugongs at this location. Whilst two seagrass species that are important for dugong forage were reported at Middle Banks, the low biomass and patchy nature of these beds is likely to diminish their potential value as food resource for this species.

Figure 5.5r: *Average dugong densities in Moreton Bay (Lanyon and Morrice 1997).*



5.5.10 Marine Turtles

Key points – Marine Turtles
• Six species of marine turtle are known to inhabit (although some intermittently) Moreton Bay. • The green turtle (*Chelonia mydas*) and loggerhead (*Carretta carretta*) are considered the most abundant or common species in the region and have resident populations in Moreton Bay. • A 'critical' green turtle feeding habitat is located approximately 10 - 12 km to the south of Middle Banks at Moreton Banks, near the southern tip of Moreton Island. The closest dense seagrass of potential value to green turtles is located between Shark Spit and Tangalooma Point, 2 km to the east of Middle Banks (at its closest point). • There is paucity in data to describe key foraging habitats for loggerhead turtles within Moreton Bay, however, they are known to be carnivorous, and feed on jellyfish, crustaceans, echinoderms, and bivalve molluscs from seagrasses and reef areas. There are no recorded deep water reef areas within 2 km of Middle Banks. • Two seagrass species that are known forage for the green turtle were reported for Middle Banks, however, it is unlikely that the patchy assemblages formed by these species within this area represent a regionally important (i.e. regular) feeding ground for these marine reptiles.

5.5.10.1 Spatial and Temporal Patterns

Six species of marine turtle are known to use Moreton Bay as a major feeding ground. Three of these species – the green (*Chelonia mydas*), loggerhead (*Caretta caretta*) and hawksbill (*Eretmochelys imbricata*) turtles, have resident populations in Moreton Bay while the leatherback (*Dermochelys coriacea*), Olive Ridley (*Lepidochelys olivacea*) and flatback (*Natator depressus*) turtles are seasonal visitors to the region. Moreton Bay is not an important turtle breeding area, with most turtles in the Bay believed to have originated from rookeries on the central and north Queensland coast and Islands.

The distribution and abundance patterns of marine turtles within Moreton Bay is thought to be greatly influenced by the availability of suitable food resources. Green turtles in Moreton Bay feed directly on seagrasses and algae (Brand-Gardner et al. 1999) with most concentrated numbers of these fauna (c.f. dugongs) also centred around the critical foraging areas at Moreton and (further south) Amity Banks. Based on availability of foraging habitat, areas of subtidal seagrass located north from Moreton Banks along the Moreton Island foreshore to Tangalooma Point are also recognised for their potential importance to green turtles (refer to **Figure 5.5a**). This area is situated approximately 2 km east of the dredge footprint (at its closest point). By comparison, loggerhead turtles are carnivorous, and feed on jellyfish, crustaceans, echinoderms, and bivalve molluscs from seagrasses and reef areas (Limpus et al. 1994). Sponges represent a large proportion of the diet of hawksbill turtles, although they also feed on seagrasses, algae, soft corals and shellfish. There are no known reef environments within 2 km of the study area.

Population estimates of turtles in Moreton Bay range from 800 and 900 individuals in 1995 (Lanyon and Morrice 1997). However, the authors acknowledge that this is likely to be an underestimate due to bias inherent in the survey methodology. The number of green turtles is consistently higher in the eastern and southern Bay than elsewhere due to the presence of extensive (seagrass) foraging areas (section 5.5.3). With the exception of green turtles, there is paucity in data to describe key or preferred foraging habitats for the remaining marine turtles in Moreton Bay, possibly due to the lower resident numbers of these species. It is likely, however, that marine turtles that exist within the Middle Banks area would be transient rather than resident, primarily due to the lack of optimal or perennial feeding resources in this exposed area. It is possible that the sparse seagrass assemblages at Middle Banks may be used sporadically or occasionally by some marine turtles. Loggerhead turtles may also feed on jellyfish that occur in the study area.

5.5.10.2 Values

Marine turtles are protected under the *Nature Conservation (Wildlife) Act 1994*, with the loggerhead and Olive Ridley listed as *Endangered*, and the green, hawksbill and flatback turtles listed as *Vulnerable.* The green, loggerhead, leatherback and Olive Ridley turtles are listed under the *EPBC Act 1999.* The Middle Banks and Northern Delta region are not thought to represent important feeding areas.

5.5.11 Other Species of Conservation Significance

The *EPBC Act 1999* lists a number of additional species of conservation significance that have the potential to occur within the Moreton Bay region (**Table 5.5n**).

Table 5.5n: Sharks, Fish and Seasnakes listed under the *EPBC Act 1999* for the Moreton Bay region.

Common name	Scientific name	Status
Grey nurse shark	*Carcharias taurus*	Critically endangered
Great white shark	*Carcharadon carcharius*	Vulnerable
Whale shark	*Rhincodon typus*	Vulnerable
Hairy pygmy pipehorse	*Acentronura tentaculata*	Listed
Tryon's pipefish	*Campichthys tryoni*	Listed
Fijian banded pipefish Brown-banded pipefish	*Corythoichthys amplexus*	Listed
Orange-spotted pipefish Ocellated pipefish	*Corythoichthys ocellatus*	Listed
Girdled pipefish	*Festucalex cinctus*	Listed
Tiger pipefish	*Filicampus tigris*	Listed
Mud pipefish, Gray's pipefish	*Halicampus grayi*	Listed
Blue-speckled pipefish Blue-spotted pipefish	*Hippichthys cyanospilos*	Listed
Madura pipefish Reticulated freshwater pipefish	*Hippichthys heptagonus*	Listed
Beady pipefish Steep-nosed pipefish	*Hippichthys penicillus*	Listed
Kellogg's seahorse	*Hippocampus kelloggi*	Listed
Spotted seahorse, yellow seahorse	*Hippocampus kuda*	Listed
Flat-face seahorse	*Hippocampus planifrons*	Listed
White's seahorse, crowned seahorse, Sydney seahorse	*Hippocampus whitei*	Listed
Javelin pipefish	*Lissocampus runa*	Listed
Sawtooth pipefish	*Maroubra perserrata*	Listed
Anderson's pipefish Shortnose pipefish	*Micrognathus andersonii*	Listed
Thorn-tailed pipefish	*Micrognathus brevirostris*	Listed
Manado river pipefish Manado pipefish	*Microphis manadensis*	Listed
Duncker's pipehorse	*Solegnathus dunckeri*	Listed
Pipehorse	*Solegnathus hardwickii*	Listed
Spiny pipehorse Australian spiny pipehorse	*Solegnathus spinosissimus*	Listed
Blue-finned ghost pipefish Robust ghost pipefish	*Solenostomus cyanopterus*	Listed
Harlequin ghost pipefish Ornate ghost pipefish	*Solenostomus paradoxus*	Listed

Table 5.5n: Sharks, Fish and Seasnakes listed under the *EPBC Act 1999* for the Moreton Bay region (contd).

Common name	Scientific name	Status
Wide-bodied pipefish Black pipefish	*Stigmatopora nigra*	Listed
Double-ended pipehorse Alligator pipefish	*Syngnathoides biaculeatus*	Listed
Bend stick pipefish Short-tailed pipefish	*Trachyrhamphus bicoarctatus*	Listed
Hairy pipefish	*Urocampus carinirostris*	Listed
Mother-of-pearl pipefish	*Vanacampus margaritifer*	Listed
Olive seasnake	*Aipysurus laevis*	Listed
Stokes' seasnake	*Astrotia stokesii*	Listed
Turtle-headed seasnake	*Emydocephalus annulatus*	Listed
Elegant seasnake	*Hydrophis elegans*	Listed
Sea krait seasnake	*Laticauda laticaudata*	Listed
Yellow-bellied seasnake	*Pelamis platurus*	Listed

The grey nurse shark is listed as one of Australia's most endangered marine species with an estimated population of 500 individuals. Individuals tend to congregate at distinct aggregation sites during the day and may move up to 1 - 2 km from these sites to feed during the night. Four congregation sites are known in south-east Queensland:

- Wolf Rock (off Double Island Point).
- Flat Rock (north-east of North Stradbroke Island).
- Cherub's Cave (east of Moreton Island).
- Henderson Rock (east of Moreton Island).

The closest of these sites is over 30 km away from the Middle Banks area, which is not considered to support preferred habitat for the grey nurse shark.

Moreton Bay is considered likely to occur at or near the northern distribution limit of great white sharks in Australia, which are generally found in temperate and sub-tropical waters. Great whites tend to occur in larger numbers around rocky reefs, particularly areas that support pinniped (seal and sea-lion) colonies, which represent an important dietary component of adults (Bruce *et al.* 2001). Adults, sub-adults and juveniles also feed on fish, and there is evidence that the sharks are attracted to whaling activities and processing stations, one of which operated at Cape Moreton between 1952 and 1962. Following the closure of the station it is unlikely that the area offers any preferred habitat for great white sharks, although individuals are thought to intermittently visit the area.

The whale shark is a highly migratory species with a preference for oceanic and coastal waters. The species filter feeds on nekton and plankton and its seasonal movements are thought to coincide with plankton blooms and changes in water temperature. Moreton Bay is not a known congregation site and any individuals transiting the area are considered more likely to pass to the east of Moreton island than inside the Bay itself.

Pipefish, seahorses and ghost pipefish are all types of syngnathiformes, which are fish with elongated, stiff bodies covered in bony plates and rings. They are generally found in sheltered waters associated with coral reefs, seagrass beds or man-made structures in tropical, sub-tropical and warm temperate regions. They are generally very poor swimmers and rely on camouflage as a defence mechanism and to catch their prey. The excellent camouflage abilities of pipefish, in particular, means that little is known about their distribution. Studies to date suggest that Middle Banks is not an important habitat for this group of fish (see section 5.5.7).

Little is known about the distribution, abundance or ecology of seasnakes. They are generally stealth predators that feed on fish and as such their distribution is likely to be limited to areas of structural habitat that provide suitable feeding grounds, such as coral reefs and possibly seagrass beds.

5.6 Consultation

As part of the survey work and in the preparation of this Chapter, Dr Daryl McPhee, fisheries biologist and lecturer at the University of Queensland, held focussed discussions with commercial fishers representatives. Discussions were held with respect to preferred fishing areas, times and catches in the vicinity of the study area and surrounding areas.

Consultation with commercial and recreational fishers identified several concerns regarding the dredging activities in the Middle Banks area include:

- Loss of access to fishing grounds (see following paragraph).
- Changes to the migration paths of species such as eastern king and tiger prawns, and spotted mackerel, which may alter their catchability (see section 5.8.9.3).
- Short term impacts (turbidity) on the seabed during dredging operations (see section 5.8.9.3).
- Long term changes to the seabed habitat after dredging operations have ceased (see section 5.8.1).

Commercial trawl fishers expressed concerns regarding the potential for dredging activities to limit or prevent fishing access both during the operational phases of dredging and for a long period after dredging has ceased. Of primary concern is if dredging activities overlap with important trawl ground, then the dredging activity will lead to the seabed becoming "untrawlable" due to the physical nature of the dredged area (e.g. too steep). The dredge strategy has been specifically developed to address this issue. In this regard, the dredge footprint has avoided the recognised trawl ground to the south of Middle Banks, and the dredge profile will follow the present-day channel alignment of East Channel. This will have the benefits of (i) avoiding important trawl grounds to the south of Middle Banks; and (ii) not creating a distinct dredge hole, but rather re-creating the existing seabed slope.

Commercial and recreational fishers also expressed concerns about the short and long term effects on the seabed that result from dredging, including impacts to the food chain and impacts on recruitment of fish and invertebrates. Consideration of these issues is also provided in section 5.8.1.

5.7 Policies and Guidelines

5.7.1 Commonwealth

At the Commonwealth level, the *Environment Protection and Biodiversity Conservation Act 1999,* as well as commitments under international conventions apply to dredging operations at Middle Banks.[5]

Australia has a number of commitments under international conventions that apply generally to the operations at Middle Banks:

- *Japan-Australia Migratory Birds Agreement 1974 (JAMBA)* and the *China-Australia Migratory Birds Agreement 1986 (CAMBA).* The two agreements list terrestrial, water and shorebird migratory, and require protection and conservation of migratory birds' habitats.
- *Convention on the Conservation of Migratory Species of Wild Animals* (Bonn Convention) for which Australia is a range state.
- *Ramsar Wetland Convention* for which parts of Moreton Bay are declared a wetland of international importance under the Convention.

The above international commitments are covered in the operation of the *Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act)*. Approval is required pursuant to the *EPBC Act* for activities having a significant impact on a matter of national environmental significance. In relation to the proposed dredging at Middle Banks, the Department of Environment and Heritage nominated the following matters of national environmental significance as being potentially relevant to the project:

[5] *The* Airports Act 1996 *and associated regulations apply only to activities, and to pollution generated, on the airport site. Regulations may deal with environmental standards for airport sites only.*

- Moreton Bay Ramsar wetland.
- Listed migratory species.
- Listed threatened species and ecological communities.

Management of wetlands is considered at the Commonwealth level in the *Wetlands Policy of the Commonwealth of Australia 1997,* which aims to conserve, repair and manage wetlands wisely, and through the listing of wetlands on the *Directory of Nationally Important Wetlands in Australia (DEH).* The Moreton Bay Aggregation is listed under the *Directory,* and was included under the *Ramsar List of Wetlands of International Importance* in 1993. A full description of ecological values of the study area with respect to the Moreton Bay Aggregation Ramsar Listed Wetland is outlined in section 5.8.10.2.

5.7.2 Queensland

Key Queensland government legislation and policies relevant to marine ecology issues for the Middle Banks area includes the following:

- *Coastal Protection and Management Act 1995* and associated *State Coastal Management Plan (2001) and South East Queensland Regional Coastal Management Plan (2006)*
- *Nature Conservation Act 1992,* Regulations and Conservation Plans (in relation to the management of protected areas and wildlife)
- *Marine Parks Act 2004,* Regulations and the *Marine Park (Moreton Bay) Zoning Plan 1997* (see **Figure 5.7**)
- *Fisheries Act 1994* and Regulations in relation to the regulation of marine plants

Further information including regulatory requirements and assessment with regard to these statutes and plans is contained in the dredge management plan (refer Chapter C9).

5.8 Impact Assessment

The process of sand extraction by means of a trailer suction hopper dredge has the capacity to impact upon the marine environment in several ways. This study has identified six primary impacting processes for the sand extraction operations proposed for Middle Banks, namely:

- Direct extraction and loss of benthic fauna (primarily macroinvertebrates).
- Direct extraction and loss of marine plants (seagrass).
- Increase in predation due to disturbance or resuspension of benthic fauna.
- An alteration of benthic hydrodynamic conditions.
- Generation of sediment plumes by the dredge: Shading and smothering impacts.
- Injury and disturbance to mobile marine fauna.

A discussion of each of these impacting processes is provided in subsequent sections, and each are considered in terms of their: (a) potential *impacts*; (b) *mitigation* measures, and; (c) *residual impacts* (if any).

The results of the impact assessment were considered together to categorise the level of residual impact, which ranges from *Beneficial* to *Major-Adverse*[6]. **Table 5.8a** details the criteria used to define each of six impact categories. These impacts are defined on the basis of three considerations:

(i) Magnitude of impacts (**Table 5.8b**).

(ii) The spatial scale of impacts (**Table 5.8c**).

(iii) Duration of impacts (**Table 5.8d**).

The above considerations are input into a decision matrix (**Table 5.8e**) in order to define Impact Categories Ratings used in **Table 5.8a**.

[6] *Impact Categories are based upon those used in Arup's Significance Criteria © scheme as well as the general risk categories developed by the SCFA – FRDC Project Team (2001) for the* Risk Assessment Process for Wild Capture Fisheries (Version 3.2).

Figure 5.7: *Moreton Bay Marine Park Zoning Plan, including Conservation, General Use, Habitat and Protection zones.*

Table 5.8a: Summary of impact category ratings and significance criteria used in this assessment.

Impact Category	Significance	Criteria
6	Major Adverse	• Moderate (or above) impact at National or State scale
5	High Adverse	• Minor impact at National or State scale • Moderate (or above) impact at Regional scale
4	Moderate Adverse	• Major or high (medium to long term) impact at Site-specific scale • High (short term) or Moderate impact at Local scale • Minor impact at Regional scale
3	Minor Adverse	• Moderate or high (short term) impact at Site-specific scale • Minor impact at Local scale
2	Negligible	• Negligible impact at Local, Regional, State/National scale • Minor impact or below at Site-specific scale
1	Beneficial	• The effects of a project can also be beneficial

Table 5.8b: Key to defining impact magnitude.

Category	Habitat	Protected species	Ecosystem functioning
Major	>60 percent habitat removed	Mortality likely local extinction	Total ecosystem collapse;
High	30 - 60 percent removed	Mortality may affect recruitment and capacity to increase	Measurable impact to functions, and some functions are missing/ declining/increasing outside historical range and/or facilitate new species to appear.
Moderate	5 - 30 percent removed	Mortality within some spp. Levels of impact at the max. acceptable level	Measurable changes to ecosystem components but no loss of functions (no loss of components)
Minor	<5 percent removed	Affected but no impact on local population status (Stress or behavioural change to individuals)	Keystone species not affected, minor changes in relative abundance
Negligible	<1 percent removed	No impact	Possible changes, but inside natural variation
Beneficial	Habitat creation	Improvement in population status	N/A

Table 5.8c: Key to defining impact spatial scale.

Spatial scales of impact	Definition
National	Australia
State	Qld
Regional	Moreton Bay (Marine), Bioregion (Terrestrial)
Local	Western Moreton Bay (Inshore Marine) or Northern Moreton Bay (Offshore Marine) Catchment scale (Terrestrial)
Site-specific	Measured in metres to 100's metres: Within site boundary

Table 5.8d: Key to Impact Timeframe.

Temporal scales of impact	Definition
Long term or irreversible	Recovery measured in decades or irreversible
Medium term	Recovery measured in years
Short term	Rapid recovery measured in days to months

Table 5.8e: Decision matrix used to derive impact category ratings.

Duration	Magnitude	Site-specific	Local	Regional	State/National
Med. to Long	Major	4	5	6	6
Short	Major	4	5	6	6
Med. to Long	High	4	5	6	6
Short	High	3	4	5	6
Med. to Long	Moderate	3	4	5	6
Short	Moderate	3	4	5	6
Med. to Long	Minor	2	3	4	5
Short	Minor	2	3	4	5
Med. to Long	Negligible	2	2	2	2
Short	Negligible	2	2	2	2
Med. to Long	Beneficial	1	1	1	1

5.8.1 Direct Loss of Benthic Fauna

5.8.1.1 Impacts

The proposed works at Middle Banks will result in the extraction of 15 Mm^3 of sand over an area of approximately 6.5 km^2. The most immediate impact of the proposed sand extraction at Middle Banks will be the loss of sediments and sediment associated fauna. Given that the majority of benthic macroinvertebrates and epibenthic (e.g. prawns, crabs) fauna live within the top 30 cm of the sediment profile, the extraction of sediment from the seafloor will result in the almost complete, but temporary, defaunation of sediments within the dredge footprint.

Sand extraction operations at Middle Banks will occur over an estimated 12 to 18 month period, and will entail the use of a trailer suction hopper dredge with the capacity to hold between 10,000 and 17,000 m^3 of saturated sand. It is envisaged that the dredger will work on 2 - 3 cycles per day intermittently over this period, where it will collect surface and underlying sediments. The process will create multiple linear depressions or gutters in the sea floor, until an average design depth of RL (Relative Level to Lowest Astronomical Tide) –21 m has been achieved.

Over the course of sand extraction operations at Middle Banks, the dredge operator will be required to move over the same area of sea floor multiple times, resulting in impacts to benthic fauna over the period of sand extraction activities.

The loss of macrobenthic invertebrates would represent a potential reduction in benthic larval supply to other areas in the Bay. However, the types of families recorded at Middle Banks are well represented in northern Moreton Bay and given the habitat conditions within the study area are not unique, but representative of conditions in the wider region, it is highly unlikely locally endemic macroinvertebrate species would occur.

The loss of benthic macroinvertebrates from the sand extraction footprint could also represent a reduction in the available food resources for fish. Most fish species that inhabit the reclamation area are mobile, and have relatively flexible diet requirements allowing them to alter or switch between available food resources in other areas. However, there is no evidence to suggest that food availability limits fish populations in marine/estuarine environments, hence impacts to the populations are not expected. The significance of fauna removal to species of commercial significance is discussed in greater detail in section 5.8.9.

5.8.1.2 Mitigation

There are no practicable means for reducing or eliminating the impacts of sand extraction on benthic fauna; the process requires that surface sediment is extracted, and thus a large proportion of sediment associated macrobenthic invertebrates are removed during the process. However, the dredge footprint has been selected (in part) on the basis that it avoids the biologically rich and abundant benthic communities in the deep central basin environment to the south of the Middle Banks. This deep central basin environment also experiences low levels of physical disturbance by wave and current action and consequently, organisms in this area are probably less tolerant of benthic disturbance. It is also notable that the deep central basin environment is also a key trawling ground, thereby avoiding direct conflicts with trawling activities.

5.8.1.3 Residual Impact

The proposed placement of the sand extraction footprint avoids impacts to the rich and abundant benthic communities in the deep water environments to the south of Middle Banks. Nonetheless, a large proportion of benthic fauna within the dredge footprint will be removed at some stage by dredging, and there will be a short term loss of fauna in the dredged footprint (see section 5.8.8 for discussion on recolonisation processes).

The loss of benthic fauna is predicted to have a *Minor Adverse* (Category 3) residual impact, meaning there will be a moderate or high (short term) impact at a site-specific scale, but minor impacts at local spatial scales (refer to section 5.10; **Table 5.10**).

5.8.2 Direct loss of Marine Plants

5.8.2.1 Impacts

The proposed sand extraction has the potential to impact upon areas of seagrass that inhabit shallow water seabed environments at Middle Banks. Within the wider Middle Banks-Tangalooma area, seagrass has been recorded to depths of up to 10 m. Impacts to seagrasses or potential seagrass habitat may therefore occur if the proposed dredging strategy or footprint requires that sand is extracted from depths shallower than 10 m.

Impacts to seagrasses may also occur if dredging is undertaken immediately adjacent to seagrass areas, which could result in bed slumping and/or movement and smothering of seagrass beds. However, as discussed in Chapter C3, the bed profile will be relatively stable following dredging, so only limited slumping anticipated.

5.8.2.2 Mitigation

The dredge footprint has been selected to exclude those areas where seagrass has been recorded in recent surveys, and those areas where seagrass could potentially grow (i.e. unvegetated sand banks up to 10 m in depth). As a result, the sand extraction will not result in the direct loss of seagrass habitat.

The dredge footprint also avoids shallow unvegetated sand habitat at Middle Banks.

5.8.2.3 Residual Impacts

No direct (bed disturbance) impacts to beds of seagrass (i.e. direct removal) within the study area are planned to occur as a result of the proposed sand extraction at Middle Banks. Negligible level impacts at a site-specific scale are predicted (**Table 5.10**).

5.8.3 Increase in Food Resource Availability Resulting from Dredging

5.8.3.1 Impacts

Benthic invertebrates (i.e. prawns, crabs, polychaete worms etc.) that occur on tidal shoal environments burrow into the sediment, primarily to avoid predation by nekton or other benthic organisms. The removal and disturbance of the sediment during the dredging process can lead to fauna entering the water column as a result of several processes:

- Disturbance of the fauna by the dredge head, propeller disturbance or pressure wave pulses during dredge vessel movement over shallow water.

- Slumping in the sand walls of linear depressions or gutters created by the dragging suction head areas may expose buried fauna.
- Resuspension or entrainment of biota in the water column as they overflow in waters discharged by the hopper (see section 5.8.5 on formation of turbid plumes).

It is also possible that the turbid plume generated by dredging could increase the availability of fine particulate organic matter for zooplankters (e.g. Poiner and Kennedy 1984), although as discussed in Chapter C4, negligible impacts to nutrient levels are predicted.

The increase in food resource available could alter community structure or feeding behavior of estuarine fauna (Skilleter 1998). Experimental studies from overseas demonstrate a change in community structure as a result of bed disturbance. Locally (i.e. within the study area), several studies have observed greater benthic fauna abundance and richness near dredged channels relative to adjacent areas (e.g. Poiner and Kennedy 1984, WBM Oceanics Australia 1995). For example, monitoring at Middle Banks for the previous airport expansion in the 1980s (Poiner and Kennedy 1984) found that while richness, abundance and diversity in the dredge area was low, high numbers of individuals and taxa were recorded adjacent to the dredged channel (within 1.5 to 2 km of the dredged channel)[7]. They suggested that the high abundance and richness of fauna adjacent to the dredged area was an enhancement effect of dredging. However, it is also possible that this pattern simply reflected differences in benthic communities among different habitat types. East Channel (in which previous dredging was undertaken) experiences high current velocities, whereas sites adjacent to the channel experience current energy, and possibly resulting in the richer benthos.

There are comparatively few data describing the response of fish, large nektobenthic crustaceans and marine megafauna to increases in food resource availability. Spanner crabs for example are scavengers, and are known to aggregate in areas where trawlers discard their by-catch. Anecdotal reports from sand extraction operators in eastern Moreton Bay suggest that fish aggregate around the dredger, presumably feeding on dislodged fauna. However, there are no reports of larger fauna, such as dolphins or turtles, aggregating around dredgers or the turbid plume.

5.8.3.2 Mitigation

There are no practicable means for reducing the impacts of predation on water column suspended or exposed benthic fauna following sand extraction. Mitigation strategies are described in section 5.8.6.2 that are designed to minimise the potential interactions between the dredger and marine megafuna.

5.8.3.3 Residual Impacts

The increase in food availability is expected to result in moderate short term impacts to ecosystem functions at a site-specific scale. Negligible level impacts are expected at the local scale. Longer-term flow-on effects to ecosystems are not expected at even highly localised spatial scales.

5.8.4 Alteration to the Benthic Profile

5.8.4.1 Impacts

The proposed dredging will measurably alter the profile of the seabed (see Chapter C3: Coastal Processes). The proposed extraction of sand from Middle Banks will gradually (i.e. over 12 to 15 months) deepen benthic habitats from depths as shallow as 10 m, to an average design depth of around RL 21 m over 6.7 km^2.

Numerous authors have observed difference in benthic fauna populations and community structure along a depth gradient (both natural and as a consequence of dredging e.g. Stephenson *et al.,* 1978; Poiner and Kennedy 1984; Posey *et al.* 1996; Gage *et al.*. 2000). Within the shallow (0-30 m) coastal waters of Moreton Bay, many environmental variables change with water depth, and may therefore be impacted upon with a deepening of the benthic profile at Middle Banks, including:

- Level of seabed disturbance or resuspension by natural processes such as currents and waves.

[7] *Note that the findings of this study were confounded by having no control sites*

- Sediment particle size distribution (accumulation of finer sediments and organic matter in deeper quiescent environments). As discussed in Chapter C3 (Coastal Processes), sediments grain size are unlikely to be measurably alerted by the proposed works.
- Reduction in the light quality and quantity of the receiving benthic environment.
- Differences in biological processes associated with the above physical drivers.

The sand extraction and resultant deepening of the benthic profile at Middle Banks is likely to have the following impacts to benthic habitats:

- A reduction in hydrodynamic stress or bed disturbance from wave action (through deepening of the benthic profile).
- A localised decrease in the tidal current velocities over shallower portions of Middle Banks.
- A localised increase in current velocities and sand transport in the southern sections of East Channel.
- A reduction in the quality and quantity of light received by the seabed (i.e. more attenuation by the water column due to a deepened benthic profile).

These processes and their potential impacts to macrobenthic invertebrate communities are discussed in the following sections.

Effects of Changed Hydrodynamic Conditions on Macroinvertebrates

Hydrodynamic conditions are thought to drive the physical and biological processes that structure benthic macroinvertebrate assemblages at Middle Banks (WBM Oceanics Australia 2004). The northern Moreton Bay sand delta is a highly mobile system, primarily due to strong tidal influences, but also wave energy driven by wind and ocean swell. Wave action (in shallow waters) and tidal currents together scour and resuspend bed sediments, which together are a key control on benthic community structure (see section 5.5).

WBM Oceanics Australia (2004) showed that deeper waters tended to have greater biomass, and numbers of taxa and individuals than shallow waters within the northern Moreton Bay delta, which included Middle Banks. Similar findings have been found by others, and it has been suggested that these patterns reflect a gradient in physical disturbance from wave action with increasing depth. It should be noted however that the section of East Channel within and adjacent to Middle Banks represents a high current energy environment, even at depths of –21 m (see Chapter C3). Consequently, benthic communities tend to be relatively depauperate in this area (Stephenson *et al.*. 1978; Poiner and Kennedy 1984), and have broadly similar bed form morphology and burrow densities as shallow waters (see habitat map in section 5.5).

It is expected that the macrobenthic invertebrate communities that will colonise the deepened dredge footprint are likely to be, on average, slightly more abundant and richer than presently exist, primarily due to lower levels of wave disturbance. This may represent a beneficial impact in terms of fisheries resource and biodiversity values. Further discussion on recolonisation processes are provided in section 5.8.8 of this report.

As discussed in Chapter C3, an increase in the rate of sand transport will occur in a localised area to the south of the dredged footprint, resulting in a gradual deepening of that area and an increase in the rate of sand migration to the southern drop-over margin of the shoal. This drop-over area is presently quite active and extending southward at a rate of the order of 200 m over the past 25 years (8 m/yr). The present-day benthic communities that occur in this area are therefore subject to high levels of ongoing bed disturbance, and are expected to have community structure characteristics that reflect this (i.e. low richness and abundances, dominance of a small number of mobile species). The predicted increase in bed transport rates is therefore unlikely to result in major changes in the structure of these communities.

Effects of Changed Hydrodynamic Conditions on Seagrasses

The mobility of the seabed, and therefore its suitability as seagrass habitat resource, is determined by the velocity or strength of tidal currents. In general, as current velocities increase, the degree of bed mobility and its suitability as a seagrass habitat resource decreases.

Localised tidal current speeds are predicted to be marginally reduced over the shallower parts of Middle Banks and to the east towards Tangalooma Point following the proposed sand extraction at Middle Banks (refer to Chapter C3: Coastal Processes). A small decrease in tidal current velocities over the shallow portions of Middle Banks where seagrasses currently inhabit is unlikely to negatively impact on these beds. There are too few data to determine whether the reduction in current velocities will result in an actual increase in seagrass coverage, as other physical processes such as wave action may represent the key control on seagrass distribution and extent.

Change in Light Climate

Presently, seagrasses grow to a maximum depth of around 10 m (relative to LAT) at Middle Banks. This would indicate that the quantity and quality of light received at (or above) this depth is adequate for seagrass growth and survival. This water depth may represent the 'compensation point' for these seagrasses, which is where levels of plant photosynthesis (energy production) is greater than plant respiration (energy depletion). At depths below this compensation point, light is attenuated by the water column to a quantity where seagrasses are unable to photosynthesize at levels greater than plant respiration, and thus will not establish or survive.

It is therefore considered unlikely that seagrass will colonise the new dredge profile below ~10 m LAT. On the basis that seagrass does not currently occur below these water depths, no change in the distribution of seagrass is anticipated.

5.8.4.2 Mitigation and Residual Impacts

The proposed dredge footprint has been developed to avoid beds of seagrass (refer to Chapter C1). As no significant impacts on seagrass beds are predicted, no further mitigation measures are proposed.

The proposed dredge footprint has been developed on the basis of minimizing impacts to current patterns and processes, and associated with this changes to bed transport and benthic communities. There are no other practical strategies to mitigate impacts to benthic communities. On this basis, moderate level impacts to ecosystem functioning and habitats are predicted at the site-specific scale, whereas at broader local spatial scales, impacts are anticipated to be negligible to minor.

5.8.5 Generation of Turbid Plumes of Water

5.8.5.1 Impacts

Sand extraction works at Middle Banks will involve the use of a trailer suction hopper dredge, which will generate turbid plumes of water (see Chapter C4: Water Quality).

Within the clear and well-flushed waters of the study area, turbid plumes are likely to be highly visually distinctive (more so from the air) for > 2 km during flood or ebb stages of the tide. During slack (high or low) tides, it is likely that the plume will be transported very little, or a short distance by wind driven surface currents. The visual nature of a turbid plume is not, however, always a reliable indicator of the density of the plume. Previous water quality assessments during capital dredging at Middle Banks has shown that the larger fractions of sediment (i.e. marine sand) in turbid plumes of water typically settle within 600 m (Willoughby and Crabb 1983) of the discharge pipe, while the finer component (finer silts and sands) are transported larger distances (i.e. > 2 km).

Potential ecological impacts of turbid plumes are discussed below.

Smothering of Benthic Habitats and Fauna

The suspended sediments entrained within turbid plumes will eventually settle out of suspension. Turbidity monitoring, together with modeling, demonstrates larger particle sizes (sand) generally settle out of suspension within 0.5 hours of dredging, while fine sediments settle and dispersed over a period of several hours following the completion of dredging.

The following important points should be noted when considering the effects of smothering:

- The seabed in which the turbid plume will largely be confined is highly mobile, as a result of strong tidal currents (up to 1 m/s), and the bed of the channel has large mobile sand waves up to 6 m in height in places. The biota that inhabit these mobile bed environments have adaptations that allow them to cope with almost constant sediment movement and deposition.
- Sands are likely to be the only sediments that will settle in these high current areas. Most sandy sediments entrained in the turbid plume will settle out within 200 m of the dredger, however elevated (above background) rates of sediment deposition are unlikely to be detectable >50 m from the dredger (and therefore smothering or sediment deposition impacts to adjacent seagrass beds are also unlikely).
- Most benthic fauna burrow into the sediment as a predator avoidance strategy and are therefore capable of vertical migration to return to the sediment surface. This includes not only the small benthic macroinvertebrates such as polychaete worms, but also juvenile and adult stages of crabs (spanner crabs, blue-swimmer crabs), prawns and several common fish species (flounder, flathead). On the basis of this behaviour, these animals would be expected to cope with variable rates of sediment deposition from turbid plumes, assuming deposition rates are not greater than the rate at which animals could migrate to the surface of the sediment.

On the basis of the above, it is considered highly unlikely that settlement of sediments from the turbid plume would result in detectable impacts to marine benthos or their habitats.

Shading Beds of Seagrass

Suspended sediments from dredging programs have the potential to reduce the quality and quantity of light received by benthic communities, most notably seagrasses. Light is an important driver of the distribution and extent of seagrasses in exposed marine environments (Longstaff and Dennison 1999; Dennison *et al.*. 1993; Abal and Dennison 1996), and therefore, long term dredging programs have the potential to have adversely impact upon seagrass beds.

Seagrass beds at Middle Banks are comprised exclusively of *Halophila ovalis* and *H. spinulosa*, both of which are deeper water seagrass species. *Halophila ovalis* is tolerant of only relatively short term (2 - 3 days) reductions in light availability, such as would occur during sustained wind events causing sediment resuspension (see Longstaff *et al.* 1999). Complete light deprivation over beds of this seagrass for periods of weeks (or greater) would be expected to result in acute (i.e. seagrass death) or sub-lethal impacts (i.e. biomass loss) (Longstaff *et al.*. 1999).

Sand extraction will be undertaken within the proposed dredge footprint along an approximate 7 km length of the East Channel. In some areas, the proposed dredge footprint is proximal to beds of seagrass. Water quality modelling (refer to Chapter C4) indicates that turbid plumes of water generated by dredging will, during certain combinations of onshore wind and ebb/flood tides, be transported over seagrass beds at Middle Banks. In some model simulations, periods of light deprivation will be experienced by seagrass, however, almost all of these plumes were shown to disperse or settle within two hours from the completion of that dredging cycle. In a worst case scenario, turbid plumes dispersed and settled within four to five hours (under a unique tide/wind combination). It is also notable that this modelling predicted that the concentrations of suspended sediments over seagrass beds did not exceed 2 mg/L above background concentrations (assumed to be 3 mg/L) when plumes reached the beds of seagrass.

Given the predicted rapid dispersion and particle settlement of turbid plumes and the low expected concentrations of suspended sediments in plumes over the seagrass beds, measurable impacts to seagrasses are highly unlikely to occur in the short or long term during dredging. In the unlikely event that seagrasses are affected, it would be expected that recovery would occur within a relatively short (measured in months) timeframe. No studies to date have quantified short term changes in turbidity (and seagrass) under such conditions in eastern Moreton Bay, although it is known from case studies in western Moreton Bay that both resident seagrass species recover within months of severe weather.

Movement Patterns of Marine Fauna

The potential impacts of turbid plume formation on the movement of marine fauna of fisheries significance is detailed in section 5.8.9 (see also WBM Oceanics Australia 2004). It is notable the Middle Banks region is not thought to be an important foraging habitat or breeding ground for turtles and dugongs, and turbid plumes of water are therefore unlikely to have any impact on these marine fauna.

5.8.5.2 Mitigation and Residual Impacts

Water quality modelling (refer to Chapter C4) undertaken as part of this EIS has enabled selection of a dredge footprint that will minimize impacts from turbid plumes on adjacent benthic marine biota (in particular seagrasses). The results from turbid plume modelling also predict that the spatial configuration of the vessel (i.e. its direction during dredging) could be important in determining the intensity dispersal and duration of the turbid plume. For instance, the turbid plume is dispersed more rapidly when the dredging vessel was simulated operating against the run of the tide, however the duration of maximum turbidity over the seagrass beds was minimised when the dredge travelled with the prevailing current. It is suggested that no recommended dredging operation (either with or against the prevailing tide) can be made at this stage given the conflicting requirements of minimizing both concentrations and duration over seagrass beds. Monitoring of the dredging plume will be undertaken to determine whether the duration and/or maximum concentrations of turbidity and suspended solids are substantially different to that predicted by the water quality modeling. As outlined in Chapter C4, the dredge vessel may also be fitted with a green or environmental valve to further reduce turbidity impacts. Taking these considerations into account, the risk of impacts to what was already a low risk activity will be further minimised. Impacts are expected to be minor/moderate at the site-specific scale (short term), and minor/negligible at a local scale.

5.8.6 Injury or Harm to Mobile Marine Fauna

5.8.6.1 Impacts

A large trailing suction dredger would be used to extract sand at Middle Banks for use in construction of the proposed NPR development. This type of vessel has the potential to impact on mobile marine fauna through two impacting processes: (i) the generation of underwater noise, and;
(ii) injury to marine megafauna through the suction of the dredge head. The former of these impacting processes is described in detail in section 5.8.7 (see following section).

During active sand extraction, a trailing hopper suction dredge draws water through the dredge head near the seabed. Smaller volumes of water are also drawn through the dredge head when the pumps are operating at idling speed which typically occurs during maneuvering of the dredger or between dredging runs. Therefore, there is a risk of injury or harm to marine fauna located within close proximity to the dredge head, both during the dredging process or when the dredge head moved into or out of position. The fauna of most concern during trailing hopper suction dredging are marine turtles, which feed and rest in shallow coastal waters throughout Moreton Bay. While dolphins, whales and Dugongs are highly mobile and can avoid impacted areas for the duration of dredging activities, marine turtles are at greater risk due in part to their slower swimming ability and seabed resting habits. When active (e.g. during feeding), marine turtles must surface to breathe every few minutes, however, they can also remain underwater for as long as two hours when resting on the seabed.

Marine turtles can use navigation channels as resting or shelter areas, and there are recorded incidents of turtles being injured during dredging operations, especially with trailing hopper suction dredge types (Dr Col Limpus, pers. comm. cited in GHD (2005). GHD (2005), citing personal communication from Dr Col Limpus, suggested that the numbers of turtles captured during dredging across all Queensland Ports has decreased in recent times, with an average of 1.7 loggerhead turtles per year being captured across all ports. Furthermore, it was suggested that current research indicates that the impact of dredging on the overall viability of turtle populations is very low compared to the numbers killed by boat strikes, trawling[8], fishing, ingestion of marine debris and indigenous hunting.

While the seagrass species *Halophila ovalis* is a recognised food resource for the green turtle *Chelonia mydas*, and has been recorded on the shallow sand banks at Middle Banks, available data does not suggest that the Middle Banks area is a key habitat for these or other marine turtles on a Moreton Bay wide scale. This has been primarily attributed to the sparse, fragmented and possibly ephemeral nature of seagrass beds at Middle Banks, which are thought to limit the value of these seagrass beds as food resource for green turtles. The lack of large resident populations of marine turtles within the Middle Banks area would therefore reduce the risk of interactions with the dredging vessel during the proposed sand extraction operations.

The proposed sand extraction at Middle Banks will require an increase of up to three ship movements per day between the proposed dredge footprint and the Port of Brisbane. The use of fast recreational vessels in areas of high dugong or turtle densities is recognised as a threat to these species and has necessitated "go slow zones" in areas such as the Moreton Banks. In contrast, the vessels used for sand extraction in Moreton Bay move slowly and are restricted to areas with low dugong and turtle densities. Thus, vessel strike by the dredger is not considered to pose a threat to dugong and turtle populations.

As discussed in section 5.5.8, whales migrate along the east coast of Australia, typically within 10 km of the east coast of North Stradbroke and Moreton Island. Whales have occasionally been recorded within the waters of Moreton Bay (particularly during their southern migration), although such sightings are rare, and Moreton Bay itself does not represent part of their migration route (Dr M. Noad *pers. comm.* 7 August 2006). The dredging operations are located well outside any known important habitats or migratory routes of whales, hence it is considered highly unlikely that there would be frequent interactions between dredging operations and whales. Mitigation strategies are outlined below in the unlikely event of interactions between marine megafauna and dredging operations.

Bottlenose dolphins, possibly the most abundant cetaceans is the study area, are highly mobile and would be expected to avoid any negative physical interactions with the dredging vessel.

5.8.6.2 Mitigation and Residual Impacts

Management and operational practices to mitigate potential impacts to turtles and other mobile marine megafauna will be employed throughout the duration of dredging at Middle Banks. Turtle deflectors are to be fitted to the drag heads of the dredger, which will further reduce the likelihood of injury or interaction with these animals. Ensuring suction through the dragheads is reduced when dredge pumps are idling will also be a key strategy for reducing the likelihood of impacts to marine turtles. As a precautionary measure for physical injury or harm impacts to cetaceans, principally whales, the dredging contractor will undertake regular visual inspections of the sand extraction area or path throughout dredging during daylight hours. Sand extraction will be delayed until any whales sighted within the area are well clear of the extraction area. Any incidental sightings of marine mammals (including dugongs, dolphins and whales) and/or turtles in the works area or adjacent environments during operations will be reported to the dredge contractor. The contractor will record incidental sightings, with reports stored in a central database developed and maintained by the contractor. Furthermore, the dredging contractor will report any harm to marine mammals or turtles (EPA Hotline 1300 130 372).

[8] *It is noted that since the introduction of turtle exclusion devices (TED) on commercial trawling gear in Queensland, the impacts of this commercial fishing operation has been significantly reduced.*

Taking these considerations into account, the risk of impacts to what was already a low risk activity will be further minimised.

In summary, it is not considered that the proposed dredging will have a significant impact on the mobile marine megafauna within the study area, for the following key reasons:

- There is little evidence of a large resident population of whales, dugong or marine turtles in the Middle Banks area.
- The proposed dredge footprint avoids those areas where seagrass is known or likely to occur (i.e. 4 - 10 m stratum), thus further reducing the likelihood of interaction with marine turtles or dugongs during dredging operations.
- There are no records to suggest that marine turtles nest on western Moreton Island beaches, limiting any possible interactions during nesting season.
- There are relatively low numbers of turtles captured by dredgers compared to other activities.
- Effective management and operational practices to reduce the potential for turtle capture will be used.
- Best practice dredging techniques will be used to further reduce risks to turtles (see Dredge Management Plan).
- The proposed dredging vessel moves slowly and in areas of low dugong and turtle density, therefore, sand extraction activities are not considered to pose a threat to dugong or turtles from boat strike.

5.8.7 Noise Impacts

5.8.7.1 Impacts

Trailing hopper suction dredging operations, including ship movements, can propagate sound[9] which has the potential to impact upon the movement patterns of mobile marine fauna, and their ability to communicate underwater. The most prominent or consistent sound emission from the proposed works at Middle Banks will be during manoeuvring of the dredge within the dredge footprint and in transit to and from Luggage Point.

Sound propagation in northern Moreton Bay is complex due to the spatial configuration of sand banks, barrier islands and deeper channels. The proposed dredging activities at Middle Banks region is likely to propagate sound predominately in north to south directions along the East Channel, with a high level of sound attenuation to the west across Middle Banks and Central Banks and to the east across Ridge Shoal and Dring Bank (i.e. towards Tangalooma Point). Greater attenuation of sound is generally observed in shallow or seagrass covered areas, or when the wavelength of sound in water is similar to or longer than the depth of the water. Shark Spit is used in this impact assessment as a highly conservative reference site for assessing underwater noise impacts on the critical green turtle and dugong habitat at Moreton Banks. Shark Spit is located 6 km to the north of Moreton Banks, and approximately 2 km to the south of Middle Banks in the direction where underwater noise from the proposed dredging operations is most likely to propagate. It is known that dense seagrass beds occur at Shark Spit, and therefore potentially support transient dugong and marine turtle populations.

It is estimated that the proposed sand extraction operations at Middle Banks will propagate a maximum sound pressure level of around 142 dB at a distance of 300 m from the dredging vessel. This estimate is based on sound levels recorded by Greene (1987) for a similar dredge size and configuration. Assuming a conservative 10 dB per doubling of distance (30log r) for the sound emission, this gives a received estimated sound pressure level of 117dB at Shark Spit. This estimated sound pressure level is discussed in the following sub-sections in terms of its likely impacts to mobile marine megafauna.

[9] *All references to sound pressure levels in dB in this section is in RMS (root mean square) with a reference of 1 μPa. Sound pressure levels are normally at a 1 m distance from the sound source unless otherwise stated.*

Dugongs

The propagation of underwater noise could potentially impact on dugongs by producing noise that is beyond their tolerance limits, or by masking their vocalisations, both of which can potentially result in avoidance of important foraging or refuge habitat or movement corridors. The predicted sound pressure of 117 dB at Shark Spit is expected to have a frequency content of below 1 kHz, which is typical of underwater noise generated by slowly rotating propellers and general dredge equipment such as pumps and engines. Dugong and manatee (a relative from the family Sirenia) have similar vocalisation, and it is presumed that they have similar audiograms[10]. The manatee audiogram shows a threshold of audibility at 500 Hz of 105 dB and at 1 kHz it is 80 dB, so dredge operations could be inaudible to dugong if dredge sound emissions predominate in the frequency range below 500 Hz at Shark Spit. It is expected that the underwater noise propagated by the dredger at Shark Spit would be within the normal variability of ambient noise. Although dredge operations would be audible to dugong it is unlikely that the sound levels would be intolerable and cause avoidance. The sound level compensation ability[11] for dugong and their vocalisation frequency range would mean that these animals could continue to communicate within the Shark Spit area during dredging operations at Middle Banks. Although the likelihood of any interactions with dugongs during the proposed dredging operations at Middle Banks is low, transient animals could avoid the area immediately adjacent to and within dredge operations.

Underwater sound propagation towards Tangalooma Point from the dredge area benefits from greater sound attenuation than towards Shark Spit because of the intervening shallow seagrass covered areas of Dring Bank. Tangalooma Point is approximately 2 km from the proposed dredge footprint and sound levels similar to or lower than those predicted for Shark Spit are expected. Furthermore, noise is not predicted to adversely impact dugong inhabiting the critical Moreton Banks area to the south during the proposed dredging operations.

Dolphins

A range of underwater noises will be generated by the proposed operations at Middle Banks, including operation of dredge pumps, noise generated by vessel movements and manoeuvring, and a range of sonar equipment. Sonar will be used to profile the dredge footprint and for normal depth sounding when travelling to and from the dredge footprint and pump-out facility at Luggage Point. A hydrographic survey boat is expected to traverse the proposed dredge footprint for up to 8 hrs every 2 to 4 weeks, and would use a multi-beam and single beam echo sounder.

With the exception of multi-beam sonar (discussed below), such sounds are common in Moreton Bay and within the dredge footprint. Large volumes of shipping vessels use the East Channel each year and operate depth sounding equipment as they move to and from the Port of Brisbane, while small crafts operating fishfinders are also common in the area.

The most sensitive audible frequency range of the dolphin lies between 20 kHz and 100 kHz. The proposed operations will produce sound emissions from the following sources:

1. Operation of dredge pumps, vessel movements and manoeuvring: this will produced sounds <1 kHz which are largely outside the frequencies at which dolphins are most sensitive and therefore impacts are not expected;
2. Single beam sonar (echo-sounding):
    a. ‘Low’ frequency: 30 to 40 kHz (standard 33 kHz). This is within the sensitive audible region of dolphins, and is discussed further below.
    b. ‘High’ frequency: 180 to 210 kHz (standard 210 kHz). This will produce sounds largely outside the frequencies at which dolphins are most sensitive and therefore impacts are not expected.
3. Multi-beam sonar (echo-sounding): >300 kHz. This will produce sounds largely outside the frequencies at which dolphins are most sensitive

*[10] An **audiogram** is a graphical representation of how well different sound frequencies can be perceived in terms of minimum threshold levels in dB.*
[11] An animal can increase the level of vocalisation to combat increased background noise.

and therefore impacts are not expected

'Low' frequency echo sounders could be audible to dolphin in a localised region around dredge operations and it is possible that dolphins could vacate the immediate area (around the vessel), depending on the power of the source used. Higher sound frequencies rapidly attenuate with distance from the source. The attenuation of sound through absorption in water at 50 kHz is approximately 130 dB at 10 km, increasing in absorption rate with increasing frequency. Sonar generally points towards the seabed and at shallow lateral angles, and sound is further attenuated by shallow waters and sand banks. As a result, sonar noise impacts to dolphin in nearshore areas adjacent to Moreton Island (including the area in the vicinity of Tangalooma Resort) are not expected.

Whales

As discussed in section 5.5, Middle Banks and Moreton Bay as a whole are not thought to represent important foraging or breeding areas for whales. In this regard, the likelihood of interactions with these megafauna is very limited during the course of the proposed dredging operations. While there are occasional sightings of whales entering Moreton Bay, their visits are thought to be of short duration and are infrequent. Whales generally inhabit waters several kilometres from the Middle Banks areas, with most animals transiting between wintering grounds at Hervey Bay and southern Antarctic waters along the east coast of Moreton and Stradbroke Islands. Sound propagation from dredge operations is unlikely to be heard by migrating whales outside Moreton Bay, due to the rapid attenuation of sound in shallow water, the many intervening sand banks and the large sand island (Moreton Island) between the proposed dredge footprint and South Passage. During the proposed dredging operations, noise levels outside Moreton Bay is expected to be less than or comparable to ambient sound levels in the areas where whales would be expected to travel. While the likelihood of negative interaction with whales at Middle Banks is low, regular visual inspections of the dredge footprint during sand extraction are proposed.

Marine Turtles

Trailing hopper suction dredges are typically of most concern regarding the potential for interaction with marine turtles. Marine turtles do not have any external auditory organs, although they are believed to have some form of low level auditory perception at frequencies below 1 kHz, that may make trailing suction hopper dredge operations undetectable as a threat. On a Moreton Bay wide scale, Middle Banks is not known to represent a key habitat for marine turtles, which has been attributed to a lack of significant seagrass (food) resources within the area (see section 5.5). While the likelihood of negative interactions with marine turtles at Middle Banks is low, there are simple mechanical modifications available to dredge heads and turtle deflectors can be fitted to further reduce the risk of injury (see section 5.8.6.2).

5.8.7.2 Mitigation

The sound pressure level produced by dredge operations is not expected to cause harmful effects on dugong, whale, turtle or dolphin. 'Low' frequency echo-sounding by the dredge or hydrographic survey vessel will be minimised and only used where required. Turtle deflectors or similar devices are recommended given that a trailing hopper suction dredge is the proposed dredge type.

As a precautionary measure, the dredging contractor will undertake regular visual inspections for whales in the proposed sand extraction area during operation of the dredge (during daylight hours). Sand extraction will be delayed until any whales present within the area are well clear of the extraction area. Any incidental sightings of other mobile marine megafauna in the works area or adjacent environments during operations will be reported to the dredge contractor. The contractor will report these sightings, and store them in a central database developed and maintained by the contractor. Furthermore, the contractor will report any harm to marine mammals or turtles (EPA Hotline 1300 130 372).

5.8.7.3 Residual Impacts

While some localised avoidance of the dredger may occur for dolphin or dugong traversing Moreton Bay, this will not prevent their ability to move freely about other parts of the Bay. The Middle Banks region is not recognised as a key foraging habitat for populations of dugong or marine turtle. Overall, no residual effects from noise are expected from the proposed dredging operations at Middle Banks or from transit operations to the Port of Brisbane area.

5.8.8 Recolonisation of Benthic Habitats

As previously discussed, most macrobenthos live within the top 30 cm of the sediment profile. The extraction of sediment from the seafloor adjacent to the East Channel will result in the temporary defaunation of sediments along the dredge's path. The 800 - 1,000 dredging cycles that are likely to occur within the proposed 12 to 18 month period is likely to result in large scale defaunation of sediments across the dredge footprint. The removal of benthic organisms from the sediment eliminates competition for resources to a large extent, and thus provides an opportunity for the recruitment or recolonisation of new organisms to the impacted area. Recolonisation is defined in this study as an increase in one or more biological variables following a perturbation; these biological variables may be abundance, diversity and richness of macrobenthos assemblages.

The recolonisation rate of macroinvertebrates can vary from place to place, depending on physico-chemical and biological processes operating in the area. Case studies in sub-tropical and tropical Australia indicate that benthic macroinvertebrate communities on mobile sand beds, including Middle Banks, typically rapidly recolonise shortly (within days to weeks) following dredging (Smith and Rule 2001; Cruz-Motta and Collins 2004; WBM Oceanics Australia 2004).

The rapid recolonisation of benthic communities following dredging in these case studies is suspected to be related to adaptations of resident species to natural physical disturbance. Areas with higher natural frequencies of benthic disturbance often have benthic communities comprised of opportunistic species with flexible habitat niche requirements (Alongi 1990; Smith and Rule 2001; WBM Oceanics Australia 2004). These communities are often sited as being in a continual state of flux, with noticeable changes in benthos observed at distances measured in metres, and temporal scales measured in days to weeks (e.g. WBM Oceanics Australia 2001; 2004).

The spatial scale of dredging, configuration of the dredge profile and the frequency of extraction would also influence the rate of recolonisation of a dredged site. In this regard, trailer suction hopper dredging at Middle Banks is proposed to occur over a large spatial scale (i.e. 6.7 km^2), and within a time-scale measured in months (up to 12 to 18 months). This dredging strategy will initially create a mosaic of defaunated and undisturbed sediments.

Recolonisation of defaunated sediments may still occur between dredging cycles, particularly in areas that have been left undisturbed for a larger portion of time, and following peaks in larval recruitment for macrobenthos (between September and October in Moreton Bay; reviewed by Skilleter 1998). Nonetheless, it is unlikely that recolonisation and 'recovery' of macrobenthic fauna within the dredge footprint will occur until the dredging in a given area has been completed.

The recolonisation of benthic macroinvertebrates dredged areas within Middle Banks may occur *via* several processes or mechanisms:

- *Passive Recolonisation*: Passive settlement to the seafloor and/or active re-invasion of sediment by entrained (resuspended) organisms from water overflow. Also recolonisation from collapsing pit walls, facilitating passive transport into dredged area;
- *Larval settlement* from water column: Active and passive recolonisation depending on larval habitat choice and biology;
- *Post-colonisation invasion*: Movement of adult and juvenile fauna from non-disturbed patches in response to new or unexploited resources.

These processes are discussed in more detail in the following sub-sections.

Passive Recolonisation

Initially, the passive settling out of those organisms surviving entrainment in dredge overflow waters may facilitate primary recolonisation of juvenile and adult fauna in the dredged area. It is possible for many mobile species to survive entrainment in dredge overflow waters; molluscs in particular, are resilient to this type of physical disturbance (Morton 1977; van der Veer *et al.* 1985). Given the large spatial scale of the proposed sand extraction, this mode of recolonisation is likely to be an important mechanism of recolonisation for fauna within the dredge footprint at Middle Banks.

Passive recolonisation of dredged habitats can also occur via erosion of the pit wall during and following dredging. This process of recolonisation is unlikely to operate at the spatial scale of the dredging operation proposed for Middle Banks in the present study, primarily due to the width and length of the dredged area, and the relative stability of the deep seafloor sediments (i.e. they are not highly mobile surface sediments).

Passive recolonisation of benthic macrofauna may also occur through the indiscriminate deposition and survival of settling larvae, which can be independent of environmental or physical cues (see 'Larval Settlement' section below).

Larval Settlement

Recolonisation of defaunated sediments by macrobenthos following dredging at Middle Banks, may also occur via the settlement of larvae. It is notable that tidal currents at Middle Banks will push large volumes of marine water carrying water column suspended larvae from both within Moreton Bay and oceanic derived waters. The recruitment of these propagules will contribute greatly to the recolonisation of the site throughout and following dredging at Middle Banks. This can be dependent on sediment and boundary layer conditions, and is typically slower than adult migration (Skilleter 1998). To illustrate the scale of larval recruitment possible, meiofauna (microscopic benthic invertebrates) from a variety of benthic habitats have been shown to be dispersed over large spatial scales (distances of up to 10 km per day) by tidal currents due to resuspension into the water column (Probert 1984).

Larval recruitment may be the most important recolonisation process for semi-mobile or sedentary fauna in the short term, although more mobile fauna such as fish, prawns and crabs could recolonise relatively quickly. However, over time, movements of sub-adults and adults would be expected to gradually become more important recolonisation pathways.

Active Adult Recolonisation (post colonisation invasion)

Adult and sub-adult macrobenthic fauna can actively recruit to an area. This means recolonisation may depend on the mobility of the animals present in adjacent areas i.e. tube dwellers versus mobile burrowers. It is notable that a suite of life history stages, including adults (e.g. gravid amphipods), subadults and larvae, were well represented in the macrobenthic community of dredged sediments within one week following dredging sampled by WBM Oceanics Australia (2004). It is notable that this was a small-scale dredging operation by comparison to the present study, however, this point still illustrates this important mechanism of recolonisation following dredging events in northern Moreton Bay.

The taxa represented in the macrobenthic fauna assemblages within the Middle Banks area can be described as opportunistic, and would be capable of rapid recolonisation of newly disturbed areas at the spatial scales proposed in the present study at Middle Banks.

Conclusion

Taking into account the high recolonisation rates likely to operate at Middle Banks even outside the peak September-October recruitment period for macrobenthos (reviewed by Skilleter 1998, see also WBM Oceanics Australia 2004), macrobenthos are likely to occur in the dredged area within weeks following each dredging cycle. Each of the mechanisms of passive and active recolonisation described in previous sections are likely to contribute to this rapid recolonisation., Recovery of the dredged footprint, however, would be expected to take much longer (months to years), particularly due to the large spatial and temporal scale that these dredging works will be operating over.

5.8.8.1 Mitigation and Residual

Recolonisation of macrobenthic fauna within the dredged footprint at Middle Banks is primarily influenced by the size and configuration of the disturbed area (WBM 2004). The strategy adopted here, which involves deep dredging within a long narrow area, will not only disturb a smaller habitat area than dredging over a wide area but would allow recolonisation from adjacent habitats (through active and passive recolonisation by adults and sub-adults). From a fauna recolonisation perspective, shallow dredging over a wide and long area is likely to recolonise much slower than deep dredging over an elongated narrow dredge path. Nonetheless, given the broad area to be affected, community 'recovery' is likely to occur at time scales measured months to possibly years, varying from place to place within the dredge footprint. It is predicted that recolonisation (i.e. as determined by the presence of individuals in the dredge footprint) will occur in a relatively short- time frame (measured in days to months).

5.8.9 Fisheries Impacts

5.8.9.1 Impacts To Habitats

Numerous fish and crustacean species of commercial and recreational significance may utilise coastal marine environments such as Middle Banks for foraging, recruitment and spawning. These species are listed below (refer to section 5.5 for more details):

- **Eastern king prawns** (*Penaeus plebejus*) spawn in deeper (>90 m) offshore environments through most of the year but predominately during the months of May to July. After short pelagic larval stage Eastern King Prawns recruit into shallow waters adjacent to ocean bars during spring and early summer.
- **Brown tiger prawn** (*Penaeus esculentus*) spawn throughout the warmer months from October to March generally in 13 - 20 meters of water. After a planktonic larval stage of 3 weeks juvenile prawns are recruited into inshore nursery grounds for a several month period before returning to offshore sandy or muddy benthic environments.
- **Moreton Bay bugs** (*Thenus orientalis*) commonly spawn twice annually with peak spawning activity occurring during spring and summer in offshore waters. After a short pelagic stage of less than a month larvae settle upon shallow subtidal regions.
- **Squid** (*Photololigo* spp.) are believed to aggregate to spawn in the eastern regions of the Bay during summer months.
- **Spanner crabs** (*Ranina ranina*) spawn offshore during the warmer months of the year between October and February. The peak in spawning activity occurs during November and December. The crabs preferred habitat is well-sorted sand in the oceanic environment, with larvae settling out in bare sandy areas.
- **Mud crabs** (*Scylla serrata*) migrate from inshore to offshore environments to spawn during September to March with a peak in November to December. Though their larvae do not settle upon subtidal areas, it is necessary for female crabs to migrate through areas such as the study site to spawn.
- **Blue swimmer crabs** (*Portunus pelagicus*) have two spawning periods breeding occurring around August to October and to a lesser degree around April. Spawning occurs in oceanic currents outside Moreton Bay where larval are dispersed back into the Bay.
- **Diver whiting** (*Sillago maculata maculata*) spawn throughout the year, but peak spawning occurs during winter in shallow water on sandy beaches of sheltered bays and estuaries. Juvenile and adult whiting can be found over seagrass beds with adults also existing in deeper channels.
- **Stout whiting** (*Sillago robusta*) recruit to shallow bare sandy areas and are sexually mature in all seasons excluding winter, though the majority of spawning occurs during summer.

Based on the above information, the study area supports potential spawning (i.e. diver whiting) and juvenile (e.g. spanner crab) habitat for several commercially important species. All remaining species may also move through the study area as part of their life-cycle. It is likely that mobile fish and shellfish will avoid the dredge footprint area and surrounds over the 12 to 18 month proposed dredge period. It is unknown whether fish and shellfish display spawning site-fidelity, or whether other nearby areas would be used for spawning at this time.

In the longer-term, the extraction of sand from Middle Banks will deepen the benthic profile (i.e. increase water depths), which may result in changes to the suitability of these deeper areas as habitat for different fisheries species. The results presented in section 5.5 (Baseline) indicate that the structure of adult/sub-adult fish and nektobenthic assemblages differed between two sampled depth strata at Middle Banks (i.e. shallow: 12 - 17 m and deep: 25 - 32 m). As such, sand extraction activities are likely to result in localised changes to the structure of fish and nektobenthic assemblages by reducing the depth of water in Middle Banks area. This impact is over and above any impacts due to initial physical disturbance and any turbidity impacts that occur during the operational phase of dredging activities.

This study also demonstrated that fish were more abundant per trawl in the shallower sites surveyed. This was predominantly due to greater abundance of the numerically dominant and widespread species (e.g. Broad Banded Cardinal Fish, Dusky Leatherjacket and Ponyfish). However, the changing depth profile due to extraction activities is unlikely to extend to a reduction in species richness of assemblages overall within the dredge footprint, as species richness was similar between shallow and deep depth strata. A low number of fish species were restricted to either deep or shallow water sites and two nektobenthic invertebrate species were recorded solely from the shallow water site. It is notable that these species are widespread both in Moreton Bay and Queensland. Furthermore, the deepening of the benthic profile at Middle Banks does not pose a risk to the population of these species, particularly given the putative impact area relative to available similar habitats in the surrounding area. Some fisheries species, such as the saucer scallop, are known to be extremely abundant elsewhere, the former being one of the principal target species in trawl fisheries in Central Queensland.

Overall, sand extraction activities will lead to a depth profile in the area that favours some species, but not others. Based on the results of this study, changes to the depth profile of Middle Banks is predicted to lead to an increase in the abundance of fish species such as the Rough Headed Dragonet, Diver Whiting, Cardinal Fish and Small toothed Flounder, and nektobenthic invertebrate species such as the Northern Velvet Prawn, Endeavour Prawn and Blue Swimmer Crab. However, the abundance of fish species such as the Broad Banded Cardinal Fish, Dusky Leatherjacket, and Yellow-spot Ponyfish and nektobenthic invertebrate species such as the Tiger Prawn, Broad Squid and Eastern King Prawns are likely to measurably decrease.

Spanner crabs, although not recorded in large numbers in trawl surveys during the present study at Middle Banks, are likely to utilise Middle Banks during all post-larval life-stages. This species is known to occur over a wide range of water depths, although surveys by Dempster ***et al.*** (2003) indicate that adult abundances are typically highest in deep waters (>40 m depth), and lowest in shallow waters (1 -10 m depth). There are no available data describing the depth preferences of juveniles, although it is known that the juvenile stages also inhabit a wide range of water depths in clean sand environments. Considering the wide range of water depths in which these species occurs, it is considered unlikely that the proposed lowering of the seabed will negatively alter its suitability as a spanner crab habitat.

While the depths will be altered, major changes in current patterns and bed morphology are not expected to occur, except in the local area at the southern drop-off of Middle Banks. Results from coastal hydraulic modelling (refer to Chapter C3) suggest that a similarly slow and relatively minor morphological response will occur to the proposed works and that the seabed bathymetry as formed by the dredging works is likely to persist for many years. The sand forming the seabed will continue to be mobile and transported by the prevailing tidal currents with a net southward movement. Mobile seabed ripple and dune forms will continue to be a feature of the study area, as at present. Consequently, the hydraulic processes that control the functional ecological habitat properties of the study area will remain largely unchanged; from a bed stability perspective, major changes in habitat values are not expected.

5.8.9.2 Impacts to Food Resource Availability

Fish and nektobenthic invertebrates of fisheries value may be indirectly impacted by a change to the distribution and abundance of the key food resources of these harvested species. In some instances, dredging may lead to an increase in food resources for some scavenging species, possibly leading to elevated populations of some species (e.g. Wassenberg and Hill, 1987; Kaiser and Ramsey, 1997). The initial mechanism by which food resources may increase within the dredge footprint during dredging is through the entrainment or exposure (and eventually settlement) of macrobenthic fauna from dredge overflow waters (see section 5.8.5). Following dredging, fish and mobile invertebrates generally arrive first to scavenge, followed by slower moving animals such as starfish and gastropods (Kaiser and Spencer, 1994).

Two critical considerations when conceptualising the potential impacts of disturbances to benthic assemblages on the foraging of fishery species are:

(a) The spatial scale of the impact relative to the total area of habitat available. The spatial scale of impact is considered further here. Benthic fauna communities and their associated habitats within the dredge footprint are not unique or restricted in distribution, but are well represented within the study area, study region and in northern Moreton Bay. The dredge footprint is situated largely within the 'Bioturbated Sparse' category (H) as described by Stevens and Connolly (2005). These communities were described as having relatively low taxa richness, and were dominated by bioturbators (i.e. small holes, and evidence of biogenic working on the sediment surface). In relative terms, the dredge footprint represents an area that comprises less than 3 percent of the total available 'Bioturbated Sparse' habitat in northern Moreton Bay.

(b) The degree of foraging specialization exhibited by key fishery species. Fish species occurring in unvegetated soft sediment habitats such as those present at Middle Banks are opportunistic benthic foragers (e.g. Hobday et. al, 1999). With the exception of spotted mackerel (discussed further below), all commercial and recreational fisheries species potentially occurring at, and adjacent to proposed dredge footprint can be broadly classified as broadly opportunistic species which feed on a wide variety of benthic invertebrates (**Table 5.8f**). Given the opportunistic foraging behaviour of the benthic foragers listed in **Table 5.8f**, changes in the structure of benthic assemblages are not expected to lead to measurable changes in the foraging ecology of harvested species.

Table 5.8f: Prey of harvested species known or likely to occur at Middle Banks (modified after WBM Oceanics Australia 2004).

Species	Prey	Information Sources
Eastern king prawn	Benthic invertebrates – crustaceans, polychaetes, bivalves and protozoa	Moriarty (1977)
Brown tiger prawn	Benthic invertebrates – molluscs, crustaceans and polychaetes	Kailola *et al.* (1993)
Blue swimmer crab	Benthic invertebrates - crustaceans, molluscs, echinoderms and polychaetes. Discarded trawl by-catch	Williams (1982), Wassenberg and Hill (1987)
Spanner crab	Benthic invertebrates - crustaceans, molluscs echinoderms, and polychaetes. Discarded trawl by-catch	Williams (1997)
Moreton Bay Bug	Juvenile feed on small benthic invertebrates whilst adults are selectively forage upon fish, crustacean and molluscs.	Kailola *et al.* (1993)
Mud crab	Benthic invertebrates – molluscs, crustaceans, sedentary or moribund fish.	Williams (1997)
Diver whiting	Benthic invertebrates – crustaceans, bivalve molluscs, polychaetes	Maclean (1969)
Stout whiting	Benthic invertebrates – crustaceans, molluscs, polychaetes.	McKay (1992)
Spotted mackerel	Engraulis spp., and Clupeidae fishes	Begg and Hopper (1997)

The abundance of spotted mackerel in Moreton Bay in a given year is highly variable and dependent on the presence of baitfish (Begg and Hopper, 1997). If baitfish are not available in sufficient quantities, spotted mackerel may migrate back out of Moreton Bay in search of food resources elsewhere. Thus, a major adverse impact on baitfish resources in Moreton Bay may potentially impact on the use of the Bay by spotted mackerel for feeding.

The mechanism whereby sand extraction activities may impact on baitfish species such as engraulids or clupeids is uncertain. As a pelagic species, baitfish are unlikely to be directly affected by changes in benthic assemblages, however, it is unknown how they would directly respond to localised turbidity that may result during the extractive activities themselves or the increase in water depth resulting from the dredging activities. Overall however, the relatively localised scale of turbidity plumes and area affected by dredging are unlikely to result in detectable impacts to both spotted mackarel and baitfish.

It is likely that reduction in the biomass of benthic invertebrates associated dredging over large spatial and temporal scales, may lead to a temporary and localised avoidance of the dredge footprint by benthic feeding fish and invertebrates. It is notable that these animals are highly mobile or transient, and would move from the dredge footprint to seek food resources in adjacent undisturbed habitats or elsewhere in Moreton Bay.

5.8.9.3 Impacts to Movement Patterns

Tidal Hydrodynamics

The environmental factors that influence distribution patterns and migratory route selection are not well understood, although hydrodynamics may represent a primary environmental control at Middle Banks. For example, Glaister *et al.* (1987) suggested that currents facilitate broad-scale movement patterns of adult Eastern king prawns, although no empirical evidence was provided to support this argument. Furthermore, Vance (1998) found that the distribution and survivorship of banana prawn larvae in the Gulf of Carpentaria was strongly influenced by tidal current patterns. The movement patterns of fish, crabs and other prawn larvae, which typically possess weak powers of locomotion, are also likely to be controlled by tidal current patterns. Juvenile prawns in estuaries and post-larval prawns returning from the ocean to estuaries, can utilise tidal movements for transporting themselves to favourable nursery habitats by 'riding' ebb or flood tides. Changes in tidal hydraulics may therefore result in changes to the movement patterns of larval stages of commercially important species, which could then have flow-on effects to survivorship and patterns in settlement within the Bay.

As discussed in Chapter C3 (Coastal Processes), hydrodynamic modelling shows that the dredging will alter the tidal flow pattern in the local area by attracting some additional flow into the East Channel and away from the adjacent un-dredged areas to the east and west. In summary, these results show that:

- The impacts to the tidal current patterns are confined to the local area in the immediate vicinity of the dredging works and do not extend broadly across Moreton Bay.
- Tidal current speeds would be reduced over the shallower parts of Middle Banks and to the east towards Tangalooma Point.
- Tidal current speeds would be increased northward along the East Channel towards Cowan Cowan Point and southward through the southern section of the East Channel. The increase in current speed does not extend as far north as Cowan Cowan Point itself and in no area does it impinge close to any section of the shoreline.
- There are no discernable impacts on the tidal regime of the Bay as a whole.
- There are no impacts on circulation patterns of the Bay.
- There are no discernible impacts on tidal elevations at any locations.

Overall, impacts to the movement patterns of fisheries species (and other mobile marine fauna) due to changes in tidal hydrodynamics are not likely to be discernable, and only of significance at highly localised spatial scales within, and in some areas surrounding, the dredge footprint.

Assuming that movement patterns of adult prawns and other commercially important crustaceans are controlled by broad-scale currents and/or sediment movements, no major changes are predicted to occur as a result of the proposed dredging works. Furthermore, given the highly localised nature of impacts to current velocities, and the absence of impacts on circulation patterns in the Bay, it is considered unlikely that larvae will be distributed to other, potentially less favourable, areas. Movements in and out of Moreton Bay will not be altered given the absence of any changes to tidal current patterns and velocities at both northern and southern entrances, and general circulation patterns within the Bay.

Turbid Plumes

Dredging at Middle Banks will create a turbid plume of water that will be transported with prevailing tidal currents and winds. The results of water quality modelling from the present study (refer to Chapter C4) and a review of past dredge monitoring studies suggest the turbid plume generated by sand extraction would be limited in both extent and duration. This is primarily due to the 'clean' nature of sediments in the dredge footprint (i.e. larger particle size distribution). Monitoring of previous capital scale dredging operations at Middle Banks (Department of Housing in WBM Oceanics Australia 2002) suggested that turbidity plume widths rarely exceeded 200 m, which is supported by modelling results of the present study.

The ephemeral and dispersed nature of generated turbidity plumes expected will not form a "turbidity barrier" to offshore waters (i.e. across the northern entrance to Moreton Bay). Consequently, measurable disruption to the movements of adult fish, crabs or prawns of commercial or recreational significance are not expected. Although turbid plumes are expected to be of short duration and limited extent, highly localised impacts (i.e. spatial scales measured in 10s to possibly 100s of metres) to the movement of some fisheries species could occur. This is not expected to result in changes to broader scale movement patterns within the Bay and northern Moreton Bay region.

Sand Migration

As discussed in Chapter C3, hydraulic modelling has shown there is likely to be a negligible increase in the rate of sand migration in areas immediately to the south of the proposed dredge footprint as a result of the proposed sand extraction at Middle Banks. However, as noted in this study, this process is already occurring as a natural function of sand migration in the northern Moreton Bay delta. It is expected that there will be no detectable impact to the commercial trawling operations located in deeper waters to the south of the Middle Banks region.

5.8.9.4 Impacts to Fishing Activities

The results of focussed consultation and discussions with commercial fishers representatives are considered in section 5.6 of this report.

The area to the south of the dredge footprint at Middle Banks is utilised by commercial otter trawl vessels that are endorsed to fish in Moreton Bay. The principal target species in the area are eastern king prawns and tiger prawns, with blue swimmer crabs, greasyback prawns and endeavour prawns being retained as by-product. Logbook information that was reviewed as part of the WBM Oceanics Australia (2004) sand extraction study demonstrated that the spatial resolution of the data was insufficient to determine exactly how much trawl effort and catch is taken from the Middle Banks area. Further details on the trawl fishery of the Middle Banks area is contained in section 5.5 of this report.

The Middle Banks area is also utilised by commercial crabbers targeting blue swimmer crabs using pots. Historically, the area was also utilised in the summer months by commercial mesh net fishers targeting spotted mackerel *(Scomberomorus munroi)* using ring nets, however the capture of this species by nets is now prohibited under fisheries regulations due to resource allocation issues.

The Middle Banks area is utilised by boat-based recreational fishers targeting pelagic fish including spotted mackerel, various tuna species, for example mac tuna *(Euthynnus affinis)*, longtail tuna *(Thunnus tonggol)*, and also cobia *(Rachycentron caudatum)* and yellowtail kingfish *(Seriola lalandi)* adjacent to the beacons in the shipping channel. The area is known as one of the best areas within Moreton Bay to target these species. Diver whiting may also be targeted in the area, although other areas in Moreton Bay are far more popular for this particular species. Recreational crabbing for blue swimmer crabs using pots also occurs.

It is notable that the dredge footprint is not recognised as an important commercial, recreational fishing or trawling ground/location. These activities are therefore unlikely to be directly impacted by the proposed dredging works.

5.8.9.5 Mitigation and Residual Impacts

Sand extraction activities have been sited away from the area south of Middle Banks that are worked by the Moreton Bay trawl fleet. This will mitigate any direct impacts from dredging works on commercial fishing grounds or access to these areas. Water quality modelling (refer to Chapter C4) has demonstrated that the selected dredge footprint is unlikely to generate turbid plumes that will have any measurable impacts outside the dredge footprint (i.e. plumes are likely to disperse and settle rapidly). Coastal hydrodynamic modelling (refer to Chapter C3) also confirms that the design of the dredge footprint will not result in any broad scale changes to tidal hydrodynamics following sand extraction at Middle Banks.

It is possible that a reduction in the biomass of benthic invertebrates associated with dredging at the proposed spatial and temporal scales at Middle Banks, could lead to a temporary and localised avoidance of the dredge footprint by benthic feeding fish and invertebrates. However, as discussed above, this residual impact is unlikely to be significant given that the dredge footprint does not contain a unique habitat or benthic fauna assemblage; furthermore, these benthic communities are well represented elsewhere in Moreton Bay.

Impacts to fisheries are expected to be localised, of short duration and of a low magnitude.

5.8.10 Potential Impacts to Ecosystem Functioning and Conservation Values

5.8.10.1 Key Ecosystem Functions

The key physical processes controlling ecosystem functioning in eastern Moreton Bay are tidal currents and wave action. Together these processes control (i) water quality patterns and processes, and (ii) the geomorphological and hydraulic processes (i.e. physical disturbance) that controls patterns in marine vegetation, invertebrates and vertebrate fauna (WBM Oceanics Australia 2004). The proposed works are unlikely to measurably alter tidal current and wave patterns and processes (see Chapter C3) at spatial scales measured in km. However, local scale modifications in the degree of wave disturbance will occur within the sand extraction footprint, as a result of the lowering of the seafloor (i.e. increasing water depths).

As discussed in section 5.8.7, benthic communities that recolonise the deeper dredged area are expected to have higher abundances and richness than assemblages present prior to dredging, due to lower levels of wave disturbance. However, it should be noted that the high levels of sediment movement caused by currents, which is also likely to exert strong influence on benthic community structure, is unlikely to be measurably altered within the dredge footprint. Any potential increase in abundance of macrobenthic invertebrates could increase food resource availability for predators (e.g. fish) at highly localised spatial scales (measured in 100s of metres). This is considered unlikely to result in flow-on effects to productivity or ecosystem functioning at broader spatial scales.

The physio-chemical properties of the water column (water quality) are unlikely to measurably altered in the long term. The main water quality impact associated with the proposed works is the creation of a turbid plume by the dredger. As discussed in Chapter C4, the turbid plume generated by dredging will be largely confined to the East Channel, and will rapidly dissipate within 2 km of the dredge site. Flow-on effects to primary productivity are unlikely to be measurably altered at spatial scales measured at greater than 100s of metres. Some localised, short term impacts to benthic microflora and possibly seagrass within the immediate vicinity (within 200 m) of the plume may occur, although this is not expected to result in changes to ecological functioning at all but these highly localised spatial scales.

Little is known about 'keystone species' that control ecosystem functioning and biological processes in eastern Moreton Bay. Likely candidates include:

- Benthic (microphytobenthos) and planktonic microalgae (phytoplankton), represent the dominant primary producers that ultimately control productivity and food webs in eastern Moreton Bay.
- Large burrowing macroinvertebrates, such as yabbies *(Trypaea)* and burrowing sea urchins, which are likely to be critical in the maintenance of sediment-water nutrient cycling, sediment oxygenation and the physical disturbance of benthic communities and habitats.
- Nekto-benthic predators (primarily fish), are thought to control patterns in benthic community structure in Moreton Bay. There are too few empirical data to determine the importance of predation in regulating estuarine ecosystems.

The population status, ecological functions and ecosystem services provided by these species is unlikely to be measurably altered at all but highly localised spatial scales (i.e. within the dredge footprint, at spatial scales measured in 100s of metres, to possibly km). However, relative abundances of certain species are expected to be altered (i.e. increase and decrease/loss) within the dredge footprint as a result of the increase in water depths, notably:

- Relative abundances of benthic microalgae species may decline in the dredge footprint, particularly in deeper waters. This would primarily be a response to a decrease in the quality and quantity of light associated with deeper water.
- Abundances of large burrowing invertebrate species are unlikely to be greatly altered within the dredge footprint. Seafloor mapping indicates that burrows were small and burrow densities were low along East Channel, especially when compared to the deep mud basin environment in the southern sections of Middle Banks. Hydraulic assessments in this area suggest that current velocities are high, which would result in mobilisation of bed sediments. This high degree of physical disturbance and sediment working does not provide particularly optimal conditions for these large burrowing species. No major changes in abundances are expected to occur as a result of a reduction in water depths.
- As discussed in section 5.8.9, most nektobenthic predators have relatively flexible (plastic) diets and are widespread throughout eastern Moreton Bay. The population status of these species, and the ecological functions that these species provide, is unlikely to measurably altered at all but highly localised spatial scales (i.e. within the dredge footprint).

Overall, the proposed works are highly unlikely to result in the loss of ecosystem functions, or result in changes in key components that maintain ecosystem functioning. Changes in the relative abundance of keystone species (increases and decreases) are expected to occur within the dredge footprint, although impacts are expected to be highly localised (measured in 100s of metres, to km).

5.8.10.2 Ramsar Listed Wetlands

The Moreton Bay Ramsar wetland aggregation (declared in 1993) is located within the larger Moreton Bay Marine Park and managed as part of the Marine Park primarily by the Environmental Protection Agency (EPA). There are around 25 discrete wetland areas of national importance that comprise the Moreton Bay Ramsar aggregation (refer to section 5.5).

The Ramsar Convention has adopted the following broad definition(s) of a 'wetland':

> *"Areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed 6 m".*
>
> *"[Wetlands] may incorporate adjacent riparian and coastal zones, islands or bodies of marine water deeper than 6 m at low tide lying within the wetlands".*

The Moreton Bay Ramsar was declared on the basis that it met eight selection criteria, which are shown in **Table 5.8g**. The table also presents information on the ecological character and values of relevance to each of the criterion, and an assessment of whether these values may be affected by the proposed dredging at Middle Banks.

The Moreton Island section of the Ramsar wetland area includes a perimeter of around 141 km and comprises an area of around 270 km^2 and is located around 2.5 km from the proposed sand extraction at Middle Banks. No impacts to the Ramsar wetland will therefore occur as a result of overlap with the dredge footprint. Indirect effects may include changes to water quality and hydraulic processes, which together ultimately control the 'ecological character' of the wetland.

The recession and accrual of sands from the shoreline along the western coast of Moreton Island is a natural coastal process within the Ramsar wetland area. As discussed in Chapter C3, shoreline stability along the coastlines of Moreton Bay are a function of (i) strong shore-parallel tidal currents, (ii) wave induced longshore transport of the foreshore sand, causing differentials in the transport rates that result in erosion in some areas and accretion in others; and/or (iii) direct storm wave attack causing beach erosion with sand being moved offshore from the foreshore, either to be returned to the beach when predominant swell exists (or lost to the shoreline where the normal waves do not have the capacity to force it back onshore). Any permanent changes in the strength of tidal currents immediately adjacent to the foreshores and/or the height or direction of waves impinging on the shoreline may potentially change the existing natural dynamic pattern of erosion/accretion.

Coastal hydrodynamic modelling (refer to Chapter C3) shows that no significant changes to tidal currents or wave heights near the shorelines are likely to occur as a result of the proposed dredging. Accordingly, the processes that influence sand supply, sand transport and stability at the shoreline of Moreton Island will not be affected in any discernible way, either adversely or beneficially. This is consistent with the findings of the assessments and monitoring relating to the previous dredging. It is concluded that there is negligible risk that the proposed Middle Banks dredging will affect any shoreline areas of Moreton Bay, and therefore, the geomorphological processes that maintain the ecological character of the Ramsar wetland.

Water quality modelling (refer to Chapter C4) has demonstrated that turbid plumes of water generated by dredging at Middle Banks are expected to disperse rapidly and over relatively localised spatial scales, with a majority of the sediment settling within the dredge footprint itself. The modelled scenarios predicted that either turbid plumes of water settled out well before reaching the Moreton Island Ramsar site (most scenarios) or that the coastline experienced negligible increases in turbidity (TSS of less than approximately 0.3 mg/L above background) with plumes dispersing within hours of dredging activity. No impacts to the ecological character to the Ramsar wetland are expected to occur in this regard.

The 'ecological character' of the Ramsar wetland is also dependent on the maintenance of a range of ecosystem processes operating in the wider eastern Moreton Bay region. As discussed in section 5.8.10, the key ecosystem functions within eastern Moreton Bay are unlikely to be measurably altered (at all but highly localised spatial scales) as a result of the proposed dredging works. No detectable impacts to the 'ecological character' of the Ramsar wetland are likely to occur as a result of the predicted changes to the key ecosystem drivers operating in the wider region.

Other ecological attributes cited in the declaration of the Moreton Bay Ramsar site are highly unlikely to be affected by the proposed works. In this regard:

- No impacts to the status of turtle and dugong populations, habitats or food resources in Moreton Bay or the Ramsar wetland are expected.
- No impacts to the status of shorebird populations, habitats or food resources in Moreton Bay or the Ramsar wetland are expected.
- No impacts to the status of invertebrate and fish populations, habitats or food resources in Moreton Bay are expected, except at highly localised spatial scales. Any changes are not expected to result in changes to 'ecological character' of the Ramsar wetland.

Table 5.8g: Ramsar Criteria and Impact Assessment.

Ramsar Criteria	Ramsar Justification	Impact Assessment
1b - It is a particularly good representative example of a natural or near-natural wetland, common to more than one biogeographical region	Moreton Bay is one of the largest estuarine bays in Australia which are enclosed by a barrier island of vegetated sand dunes.	• Morphological character and processes, water quality character and ecological functions largely unaltered in short to long term.
1c - It is a particularly good representative example of a wetland which plays a substantial hydrological, biological or ecological role in the natural functioning of a major river basin or coastal system, especially where it is located in a trans-border position	Moreton Bay plays a substantial role in the natural functioning of a major coastal system through its protection from oceanic swells providing habitat for wetland development, receiving and channelling the flow of all rivers and creeks east of the Great Dividing Range.	• Morphological character and processes, water quality character and ecological functions largely unaltered in short to long term.
2a - It supports an appreciable assemblage of rare, vulnerable or endangered species or subspecies of plant or animal, or an appreciable number of individuals of any one or more of these species	Moreton Bay supports appreciable numbers of the vulnerable green and hawksbill turtles, the endangered loggerhead turtle and is ranked among the top ten dugong habitats in Queensland.	• Overall values of Moreton Bay as a turtle or dugong habitat will not be affected. Proposed works will not affect key turtle or dugong habitats, nor will values of food resources at Middle Banks will altered in the short or long term. • No measurable change to populations of these species is expected to occur. • May be temporary avoidance of dredge area by turtle or dugong during the 12-18 month dredge period (impact measured in 100s of metres). However, this area does not represent an important feeding or breeding ground for these marine animals.
2b - It is of special value for maintaining the genetic and ecological diversity of a region because of the quality and peculiarities of its flora and fauna	Moreton Bay supports over 355 species of marine invertebrates, at least 43 species of shorebirds, 55 species of algae associated with mangroves, seven species of mangrove and seven species of seagrass.	• No unique habitat or locally endemic species present in works area. • Therefore, the population status of resident plant, invertebrate and vertebrate species will not be measurably altered. • There will be changes in the relative abundance of some invertebrate and fish species at spatial scales measured in 100s of metres, but no change to overall population status. • Morphological changes to Moreton Island shoreline will not measurably alter habitat values to shorebirds.

Table 5.8g: Ramsar Criteria and Impact Assessment (contd).

Ramsar Criteria	Ramsar Justification	Impact Assessment
2c - It is of special value as the habitat of plants or animals at a critical stage of their biological cycle	The Bay is a significant feeding ground for green turtles and is a feeding and breeding ground for dugong. The Bay also has the most important concentration of young and mature loggerhead turtles in Australia.	• Overall values of Moreton Bay as a turtle habitat or feeding area will not be affected. Proposed works will not affect key turtle or dugong habitats, nor will values of food resources at Middle Banks be altered in the long term. • No measurable change to populations of these species is expected to occur. • May be temporary avoidance of dredge area during the 12-15 month dredge period (impact measured in 100's of metres).
3a - It regularly supports 20,000 waterfowl	Moreton Bay supports more than 50,000 wintering and staging shorebirds during the non-breeding season.	• Due to distance between dredging area and intertidal/terrestrial lands, no direct impacts to shorebirds or their habitats are predicted to occur. • The recession and accrual of sands from the shoreline along the western coast of Moreton Island is a natural coastal process within the Ramsar wetland area. Coastal modeling (see Chapter C3) has demonstrated that no changes are expected to occur to this shoreline as a consequence of sand extraction at Middle Banks.
3b - It regularly supports substantial numbers of individuals from particular groups of waterfowl, indicative of wetland values, productivity or diversity	At least 43 species of shorebirds use intertidal habitats in the Bay, including 30 migratory species listed by JAMBA and CAMBA.	Refer to point 3a
3c - Where data on populations are available, it regularly supports 1 percent of the individuals in a population of one species or subspecies of waterfowl	The Bay is particularly important for the population of wintering Eastern curlews (3,000 to 5,000) and the Grey-tailed tattler (more than 10,000), both substantially more than 1 percent of the known Flyway population.	Refer to point 3a

5.8.10.3 Moreton Bay Marine Park

The proposed extraction of sand from Middle Banks is situated within Moreton Bay Marine Park. Moreton Bay Marine Park has five zones plus six designated areas, which are designed to provide a balance between human needs and the need to conserve the Bay's special values. Each zone has objectives defining activities that are allowed, those that require permits and those that are prohibited.

Two zones are of relevance to the study area and wider region:

- Middle Banks is situated in the *General Use Zone*. General Use Zone provides for reasonable use and enjoyment while allowing activities such as shipping operations.

- A *Habitat zone* fringes Moreton Island, approximately 2.5 km east of Middle Banks. According to the zone plan, the zones are designated to "*provide areas for reasonable use and enjoyment while maintaining productivity of the natural communities by excluding activities such as shipping operations and mining*".

The zoning plan does not specifically identify particular ecological attributes, values or functional properties used to define the Habitat zone fringing Moreton Island. The Habitat zone does occur in broadly the same area as the Ramsar wetland that fringes Moreton Island, and in broad terms, has the same management intent (i.e. protection of natural values). The assessment of impacts on values and functions of the Ramsar wetland (as defined in section 5.8.10.2) is therefore applicable to this Habitat zone.

In terms of ecological values of the General Use zone (which contains the dredge area and surrounds), it is not expected that there will be long term negative impacts to ecological values, as detailed throughout this report.

5.9 Cumulative and Interactive Effects

Cumulative and interactive effects are considered in relation to (i) impacts associated with the proposed runway expansion works in the nearshore environment; and (ii) potential future projects in offshore waters (i.e. Spitfire Channel dredging and small-scale capital dredging).

The Moreton Bay Sand Extraction Study (MBSES) considered four dredging scenarios: (i) extraction of sand for the current project at Middle Banks; (ii) capital dredging at Spitfire Channel; (iii) small-scale sand extraction at Yule Banks; and (iv) small-scale sand extraction at Central Banks. In broad terms, dredging at Spitfire Channel will result in the same impacting processes as that Middle Banks. However, unlike the short but intense dredging campaign at Middle Banks, dredging at Spitfire Channel will be undertaken over a 15 year time-frame, and will involve dredging multiple small areas over this timeframe (1 Mm^3 extracted per year). The two small-scale capital dredging scenarios at several locations within northern Moreton Bay sand delta (including Middle Banks) were predicted to result in lower levels of impact than the two larger capital dredging scenarios.

Modeling of currents and waves in the MBSES indicated that there would be little if any change to broad-scale hydraulic processes and patterns as a result of the cumulative effects of the four dredging scenarios. Consequently, the main physical controls affecting benthic communities and fisheries were unlikely to be significantly altered by any of the dredging scenarios. The MBSES (WBM Oceanics Australia 2004) indicated that there was insufficient data to predict the direct cumulative effects of multiple dredging episodes on the biological processes (i.e. recovery) controlling benthic fauna communities.

As discussed throughout this impact assessment report, fish and marine invertebrates, particularly those of commercial significance, use offshore and nearshore environments at different stages of their life-history. The findings of this impact assessment report take into consideration the impacts of other (nearshore) components of the study.

5.10 Assessment Summary Matrix

The matrix presented in **Table 5.10** considers each of the main impacting processes associated with the proposed works, together with an assessment of level of impacts (refer to section 5.8.1 for interpretation of impact level category). In summary, the major impacting processes are the loss of fauna in the dredge footprint, potential changes in community structure of benthic communities in the dredge footprint, and changes to movement patterns (i.e. short term, minor impact at local-scales).

Table 5.10: Ecology Assessment Summary Matrix.

EIS Area: Ecology Feature/ description	Defined Values under Planning Instruments	Description of Impact			Additional Compensation (beyond standard practice)
		Impact	Mitigation inherent in design/ standard practice amelioration	Significance Criteria	
Benthic Macroinvertebrates living in and/or on seabed in dredge footprint	State Significance Marine Parks (Moreton Bay) Zoning Plan 1997	Direct Loss of Benthic Fauna	Dredge footprint avoids the biologically rich and abundant benthic communities in the deep central basin environment to the south of the Middle Banks.	**Site-specific (Dredge Footprint):** **Impact Category 3** Ecosystem = Moderate Protected species = Negligible Habitat = N/A **Local (Northern Moreton Bay):** **Impact Category 2** Ecosystem = Minor Protected species = Negligible Habitat = N/A -ve; T; MT	Nil
Seagrass beds growing adjacent to the dredge footprint at Middle Banks	State Significance Marine Parks (Moreton Bay) Zoning Plan 1997	Direct loss of Marine Plants	Dredge footprint avoids areas where seagrass is known or likely to occur at Middle Banks.	**Site-specific (Dredge Footprint):** **Impact Category 2** Ecosystem = Negligible Protected species = Negligible Habitat = Negligible **Local (Northern Moreton Bay):** **Impact Category 2** Ecosystem = Negligible Protected species = Negligible Habitat = Negligible -ve; T; MT	Nil

EIS Area: Ecology Feature/ description	Defined Values under Planning Instruments	Description of Impact			Additional Compensation (beyond standard practice)
		Impact	Mitigation inherent in design/ standard practice amelioration	Significance Criteria	
Resident and transient fish and crustacean communities in the Middle Banks region	State Significance Marine Parks (Moreton Bay) Zoning Plan 1997	Increase food resource availability during dredging	Nil	**Site-specific (Dredge Footprint):** **Impact Category 3** Ecosystem = Moderate Protected species = Negligible Habitat = N/A **Local (Northern Moreton Bay):** **Impact Category 2** Ecosystem = Minor Protected species = Negligible Habitat = N/A -ve; T; ST	Nil
Macroinvertebrate and seagrass communities associated with seabed in the dredge footprint.	State Significance Marine Parks (Moreton Bay) Zoning Plan 1997	Alteration to the Benthic Profile	Dredge footprint avoids beds of seagrass and has been designed to minimise impacts to current patterns and processes, and associated with this changes to bed transport and benthic communities.	**Site-specific (Dredge Footprint):** **Impact Category 3** Ecosystem = Moderate Protected species = Negligible Habitat = Moderate **Local (Northern Moreton Bay):** **Impact Category 3** Ecosystem = Negligible/Minor Protected species = Negligible Habitat = Minor -ve; P	Nil

EIS Area: Ecology Feature/ description	Defined Values under Planning Instruments	Description of Impact			Additional Compensation (beyond standard practice)
		Impact	Mitigation inherent in design/ standard practice amelioration	Significance Criteria	
Seagrass beds and benthic macroinvertebrate communities surrounding the dredge footprint (including southern areas)	State Significance Marine Parks (Moreton Bay) Zoning Plan 1997	Generation of Turbid Plumes of Water	Water quality modelling has enabled selection of a dredge footprint that will minimize impacts from turbid plumes on adjacent benthic marine biota.	**Site-specific (Dredge Footprint):** **Impact Category 2** Ecosystem = Minor/Moderate Protected species = Negligible Habitat = N/A **Local (Northern Moreton Bay):** **Impact Category 2** Ecosystem = Minor/Negligible Protected species = Negligible Habitat = N/A -ve; T; ST	Nil
Fish/crustacean and marine turtle populations within the immediate vicinity of the dredge footprint	State Significance Marine Parks (Moreton Bay) Zoning Plan 1997	Direct Physical Injury to Mobile Marine Fauna	Turtle deflectors are to be fitted to drag heads, and suction through the drag heads will be reduced when dredge pumps are idling. Regular visual inspections of the dredge footprint will be made during daylight hours.	**Site-specific (Dredge Footprint):** **Impact Category 2** Ecosystem = Negligible Protected species = Negligible Habitat = N/A **Local (Northern Moreton Bay):** **Impact Category 2** Ecosystem = Negligible Protected species = Negligible Habitat = N/A -ve; T; ST	Nil

EIS Area: Ecology Feature/ description	Defined Values under Planning Instruments	Description of Impact			Additional Compensation (beyond standard practice)
		Impact	Mitigation inherent in design/ standard practice amelioration	Significance Criteria	
Dugongs, cetaceans (dolphins and whales), and marine turtles within and nearby to the dredge footprint.	International (Ramsar Listed Wetland)	Noise Impacts relating to sand extraction at the dredge footprint (including sonar).	As a precautionary measure, undertake regular visual inspections of the dredge footprint for whales (during daylight hours). Use 'low' frequency sonar only when necessary (i.e. switch off at all other times).	**Site-specific (Dredge Footprint):** **Impact Category 2** Ecosystem = Negligible Protected species = Minor Habitat = N/A **Local (Northern Moreton Bay):** **Impact Category 2** Ecosystem = Minor Protected species = Negligible Habitat = N/A -ve; T; ST	Nil
Adult fish, crabs and/or prawns of commercial or recreational significance within and adjacent to the dredge footprint.	State Significance Marine Parks (Moreton Bay) Zoning Plan 1997	Impacts to Movement Patterns	Sand extraction activities have been sited away from the area south of Middle Banks that are worked by the Moreton Bay trawl fleet.	**Site-specific (Dredge Footprint):** **Impact Category 3** Ecosystem = Moderate Protected species = Negligible Habitat = N/A **Local (Northern Moreton Bay):** **Impact Category 2** Ecosystem = Minor Protected species = Negligible Habitat = N/A -ve; T; MT	Nil

Key:
Significance Criteria: Major, High, Moderate, Minor Negligible
+ve positive; -ve negative
C – cumulative; P – permanent; T – temporary
ST – short term; MT – medium term; LT long term

References

Abal, E. G. and Dennison, W. C. (1996) Seagrass depth range and water quality in southern Moreton Bay, Queensland, Australia. Marine and Freshwater Research, 47: 763-771.

Abal E. G., Dennison W.C. and O'Donohue M.H. (1998) Seagrasses and Mangroves in Moreton Bay. In: Tibbetts, I.R., Hall, N.J. and Dennison, W.C. (eds) Moreton Bay and Catchment, School of Marine Science, The University of Queensland, Brisbane. pp. 269-278.

Alongi, D. M. (1990) The ecology of tropical soft-bottom benthic ecosystems. Oceanography and Marine Biology Annual Review, 28: 381-496.

ANZECC (1992) Australian Water Quality Guidelines for Fresh and Marine Waters. Australian and New Zealand Environment and Conservation Council, Kingston. pp.

Begg, G.A., Cameron, D.S. and Sawynok, W. (1997) Movements and stock structure of school mackerel (Scomberomorus queenslandicus) and spotted mackerel (S. munroi) in Queensland east-coast waters. Marine and Freshwater Research. 48: 295-301.

Begg, G.A. and Hopper, G.A. (1997) Feeding patterns of school mackerel (Scomberomorus queenslandicus) and spotted mackerel (S. munroi) in Queensland east-coast waters. Marine and Freshwater Research. 48: 565-571.

Brand-Gardner, S.J., Lanyon, J.M. and Limpus, C.J. (1999) Diet selection by immature green turtles, Chelonia mydas, in subtropical Moreton Bay, South East Queensland. Australian Journal of Zoology. 47(2): 181-191.

Bruce, B. D., Malcolm H., and Stevens J. D. (2001) A review of the biology and status of white sharks in Australian waters. CSIRO Marine Research, Hobart.

Butcher, A. (1995) Age Structure, Growth and Reproduction of Stout Whiting, Sillago robusta, and Japanese Market Trials.

Corkeron, P.J., Morissette, N.M., Porter, L. and Marsh, H. (1998) Distribution and status of hump-backed dolphins, Sousa chinensis, in Australian waters. Asian Marine Biology. 14: 49-59.

Corkeron, P.J., Morris, R.J. and Bryden, M.M. (1987) Interaction between bottlenose dolphins and sharks in Moreton Bay, Queensland (Australia) Aquatic Mammals. 13(3): 109-113.

Cruz-Motta, J. J. and Collins, J. (2004) Impacts of dredged material disposal on a tropical soft-bottom benthic assemblage. Marine Pollution Bulletin, 48: 270-280.

CSIRO Huon Estuary Study Team (2000) Huon Estuary Study — environmental research for integrated catchment management and aquaculture. Final report to Fisheries Research and Development Corporation. Project number 96/284, CSIRO Division of Marine Research. Marine Laboratories, Hobart.

Cogger, H. (2000) Reptiles and Amphibians of Australia. 6th Edition. eed Books, Chatswood, NSW.

Davie, P. and Hooper, J. (1998) Patterns of biodiversity in marine invertebrate and fish communities of Moreton Bay. In: Tibbetts, I. R. Hall, N. J. and Dennison, W. C. (eds) Moreton Bay and Catchment, (pp 331-346) School of Marine Science, University of Queensland, Brisbane.

Davie, J. D. S. (1984) Structural variation, litter production and nutrient status of mangrove vegetation in Moreton Bay. Australian National University, Darwin, NT, Darwin. August 1984.

Dempster, T, Brown, I, Jebreen, E, Smallwood, D, McGilvray, J and Breddin I, (2004) Fisheries Long Term Monitoring Program – Spanner Crab (Ranina ranina) Report 2000-2003, Department of Primary Industries and Fisheries Queensland, QI04094.

Dennison, W. C., Orth, R. J., Moore, K. A., Stevenson, J. C., Carter, V., Kollar, S., Bergstrom, P. W. and Batiuk, R. A. (1993) Assessing water quality with submersed aquatic vegetation/ Habitat requirements as barometers of Chesapeake Bay health. BioScience, 43: 86-84.

Dennison, W. C. and Abal, E. G. (1999) Moreton Bay Study. A scientific basis for the healthy waterways campaign, South-East Queensalnd Regional Water Quality Management Strategy, Brisbane.

Department of Primary Industries (2002) Policy for the Management and Protection of Marine Plants (FHMOP 001, 2002) Published by the Queensland Government, Brisbane.

Dichmont, C.M., Haddon, M., Yeomans, K. and Kelly, K. (1999) Proceedings of the South-east Queensland Stock Assessment Review Workshop. Queensland Department of Primary Industries Information Series ./QC99003. 179 pp.

Dingle, H. (1996) Migration: the Biology of Life on the Move. Oxford University Press (New York) 474 pp.

Dredge, M. and Young, P.C. (1974) Middle Banks Survey - commercial fish, marine flora and other marine fauna. Brisbane Airport Development, Project environmental study volume II, Marine Study Factor Report, pp79-82.

Ecosystem Health Monitoring Program (2005) 2005 Report Card. Released 21st November 2005. Accessed March 2005. http://www.ehmp.org/ehmp/.

Edgar, G. J. (2001) Australian Marine Habitats in Temperate Waters. Reed New Holland Publishers, Sydney. 224 pp.

Fenton, D.M. and Marshall, N.A. (2001) A Guide to the Fishers of Queensland. Part A. TRC-Analysis and Social Profiles of Queensland Commercial Fishing Industry. CRC Reef Research Centre Technical Report No. 36. 207 Pp.

Fenton, D.M. and N.A. Marshall (2000) A guide to the fishers of Queensland: TRC-Analysis and social profiles of Queensland's commercial fishing industry (Part A). Report for the Cooperative Research Centre for Reef Research, Townsville.

Fisheries Research and Development Corporation Final Report 92/101.

FRC (2003) Brisbane Airport Fauna Study – Aquatic Fauna. Report prepared for Lambert and Rehbein on behalf of the Brisbane Airport Corporation.

Froese, R. and D. Pauly. Editors. (2005) FishBase. World Wide Web electronic publication. www.fishbase.org, version (11/2005).

Gage, J.D., Lamont, P.A., Kroeger, K., Paterson, G.L.J. and Vecino, J.L.G. (2000) Patterns in deep-sea macrobenthos at the continental margin: standing crop, diversity and faunal change on the continental slope off Scotland. Hydrobiologia, 440: 261-271.

GHD Pty Ltd. (2005) Port of Hay Point Apron Areas and Departure Path Capital Dredging: Draft Environmental Impact Statement. GHD Pty Ltd: Brisbane.

Glaister, J. P., Lau, T. and McDonall V. (1987) Growth and migration of tagged Eastern Australian King Prawns, Penaeus plebejus Hess. Australian Journal of Marine and Freshwater Research. 38:225-241.

Great Barrier Reef Marine Park Authority (GBRMPA) (2003) The status of dugongs on the Great Barrier Reef and the southern coast of Queensland. Reef Research Information Sheet No. 2. Great Barrier Reef Marine Park Authority.

Greenwood, J.G, Zooplankton of Moreton Bay: The Hidden Processors In: Tibbetts, I. R., Hall, N.J. and Dennison, W.C eds (1998) Moreton Bay and Catchment. School of Marine Science, The University of Queensland, Brisbane. Pp. 347-364.

Gowen, R. J. and Bradbury, N. B. (1987) The ecological impact of salmonid farming in coastal waters: A review. Oceanogr. Bio. Mar. Ann. Rev, 25: 563-575.

Hale, P. Long, S. ad Tapsall, A. (1998) Distribution and conservation of delphinids in Moreton Bay. In: Tibbetts, I.R., Hall, N.J. and Dennison, W.C. (eds) Moreton Bay and Catchment, School of Marine Science, The University of Queensland, Brisbane. pp. 365-394.

Harris, P.T. and Jones, M.R. (1988) Bedform movement in a marine tidal delta: air photo interpretations. Geological Magazine 125: 31-49.'

Heasman, M.P., Fielder, D.R. and Shpherd, R.K. (1985) Mating and spawning in the mudcrab, Scylla serrata (Forskål) (Decapoda : Portunidae), in Moreton Bay, Queensland. Australian Journal of Marine and Freshwater Research. 36: 773-783.

Heil, C. A., O'Donohue, M. J. and Dennison, W. C. (1998) Aspects of the winter phytoplankton community of Moreton Bay. Moreton Bay and Catchment, Brisbane, I. R. Tibbetts, N. J. Hall and W. C. Dennison. School of Marine Science, The University of Queensland.

Hill, B.J. (1994) Offshore spawning by the portunid crab Scylla serrata (Crustacea: Decapoda) Marine Biology. 120: 379-384.

Hobday, D., Officer, R. and Parry, G. (1999) Changes to demersal fish communities in Port Phillip Bay, Australia, over two decades 1970-1991. Marine and Freshwater Research 50: 397-407.

IUCN (1996) IUCN Red List of Threatened Animals. IUCN, Gland, Switzerland and Cambridge, UK.

Johnson, J. (1999) Annotated checklist of the fishes of Moreton Bay, Queensland, Australia. Memoirs of the Queensland Museum 43 (2): 709-762.

Jones, G. P. and Syms, C. (1998) Disturbance, habitat structure and the ecology of fishes on coral reefs. Australian Journal of Ecology, 23: 287-297.

Jones, A. R. (1986) Spatial and temporal variations in a community of nektobenthic invertebrates from Moreton Bay. Estuarine, Coastal and Shelf Science, 23: 131-146.

Kailola, P. J., Williams, M. J., Stewart, P. C., Reichelt, R. E., McNee, A. and Grieve, C. (1993) Australian Fisheries Resources. Bureau of Resource Sciences, Department of Primary Industries and Energy, and the Fisheries Research and Developement Corporation, Canberra. 422 pp.

Kaiser M.J. and Ramsay K. (1997) Opportunistic feeding by crabs within areas of trawl disturbance: possible implications for increased survival. Marine Ecology Progress Series 152: 307-310.

Kaiser, M.J. and Spencer, B.E. (1994) Fish scavenging behaviour in recently trawled areas. Marine Ecology Progress Series 112: 41-49.

Lanyon, J.M. and Morrice, M.G. (1997) The Distribution and Abundance of Dugongs in Moreton Bay, South East Queensland. Report prepared for the Queensland Department of Environment and Heritage, Brisbane. 36 pp.

Limpus, C.J., Couper, P.J. and Read, M.A. (1994) The loggerhead turtle, Caretta caretta, in Queensland: Population structure in a warm temperate feeding area. Memoirs of the Queensland Museum. 37(1): 195-204.

Maclean, J. L. (1971). The food and feeding of winter whiting (Sillago maculata Quoy and Gaimard) in Moreton Bay. Proceedings of the Linnaean Society of New South Wales 96: 87-92.

Marsh, H. Corkeron, P., Lawler, I.R., Lanyon, J.M. and Preen, A.R. (1996) The status of the dugong in the southern Great Barrier Reef Marine Park. Great Barrier Reef Marine Park Authority Research Publication 41. 80 pp.

McKay, R.J. (1992) FAO Species Catalogue Sillaginid fishes of the whiting. Volume 14 (Food and Agriculture Organization of the United Nations, Rome).

Melville, A. J. and Connolly, R. M. (2003) Spatial analysis of stable isotope data to determine primary sources of nutrition for fish. Oecologia, 136: 499-507.

Moriarty, D.J.W. (1977) Quantification of carbon, nitrogen and bacterial biomass in the food of. some penaeid prawns. Australian Journal of Marine and Freshwater Research 28: 113-118.

Morton, J. W. (1977) Ecological effects of dredging and dredge spoil disposal. A literature review.

Morton, R. M. (1990) Community structure, density and standing-crop of fishes in a subtropical Australian mangrove area. Marine Biology 105: 384-394.

O'Brien, C. J. (1994) Population dynamics of juvenile tiger prawns Penaeus esculentus in South Queensalnd, Australia. Marine Ecology Progress Series, 104: 247-256.

Paterson, R.A. (1991) The migration of humpback whales Megaptera novaeangliae in east Australian waters. Memoirs of the Queensland Museum. 30(2): 333-341.

Poiner, I. R. (1977) Microvariation in the fauna of a sublittoral sand bank, Moreton Bay, Queensland. Australian Journal of Ecology, 2: 297-308.

Poiner, I. R. (1979) The spatial and temporal macrobenthic associations of a sublittoral sandbank, Scholl Bank, northeastern Moreton Bay, Queensland. Ph.D. Thesis, The University of Queensland Brisbane.

Poiner, I. R. (1980) A comparison between species diversity and community flux rates in the macrobenthos of an infaunal sand community and a seagrass community of Moreton Bay, Queensland. Proc. R. Soc. Qld, 91: 21-36.

Poiner, I. R. and Kennedy, R. (1984) Complex patterns of change in the macrobenthos of a large sandbank following dredging. I. Community analysis. Marine Biology, 78: 335-352.

Posey, M., Lindberg, W., Alphin, T. and Vose, F. (1996) Influence of storm disturbance on an offshore benthic community. Bulletin of Marine Science, 59: 523-529.

Preen, A. (1995a) Impacts of dugong foraging on seagrass habitats: observational and experimental evidence for cultivation grazing. Marine Ecology Progress Series. 124(1-3): 201-213.

Preen, A. (1995b) Diet of dugongs: are they omnivores? Journal of Mammalogy. 76(1): 163-171.

Probert, P. K. (1984) Disturbance, sediment stability, and trophic structure of soft-bottom communities. Journal of Marine Research, 42: 893-921.

Robins-Troeger, J. B. (1994) Evaluation of the Morrison soft TED: prawn and bycatch variation in Moreton Bay, Queensland. Fisheries Research, 19: 205-217.

Skilleter, G.A. (1998) Ecology of Benthic Invertebrates in Moreton Bay. In: Tibbetts, I.R., Hall, N.J. and Dennison, W.C. (eds) Moreton Bay and Catchment, School of Marine Science, The University of Queensland, Brisbane. pp. 365-394.

Smith, S.D.A. and Rule, M.J. (2001) The effects of dredge-spoil dumping on a shallow water soft sediment community in the Solitary Islands Marine Park, NSW, Australia. Marine Pollution Bulletin, 42: 1040-1048.

Stevens T. (2003) Mapping benthic habitats for representation in Marine Protected Areas. School of Environmental and Applied Sciences, Griffith University. PhD thesis.

Stevens, T. and Connolly, R. M. (2005) Local scale mapping of benthic habitats to assess representation in a marine protected area. Marine and Freshwater Research, 56: 111-123.

Stephenson, W. (1980a) Flux in the sublittoral macrobenthos of Moreton Bay. Australian Journal of Ecology. 5: 95-116.

Stephenson, W. (1981) Long term cycles caused by patchy predation. Australian Journal of Ecology. 6: 357-364.

Stephenson, W., Chant, D.C. and Cook S.D. (1982a) Trawled catches in northern Moreton Bay. I. Effects of sampling variables. Memoirs of the Queensland Museum. 20: 375-386.

Stephenson, W., Chant, D.C. and Cook S.D. (1982b) Trawled catches in northern Moreton Bay. II. Changes over two years. Memoirs of the Queensland Museum. 20: 387-399.

Stephenson, W., Cook, S.D. and Newlands, S.J. (1978) The macrobenthos of the Middle Banks area of Moreton Bay. Memoirs of the Queensland Museum. 18: 185-212.

Stephenson, W., Williams, W.T. and Cook, S.D. (1970) The macrobenthos of Moreton Bay. Ecological Monographs. 40: 459-494.

Strahan, R. (2000) The Mammals of Australia. Australian Museum and Reed Books, Sydney, Australia.

Sumpton, W. (2000) Assessing the Recreational Fishery for Blue Swimmer Crab in Moreton Bay. Queensland Department of Primary Industries Information Series QO00010. 29 Pp.

Tibbetts, I. R. and Connolly, R. M. (1998) The Nekton of Moreton Bay. In: I. R. Tibbets, N. J. Hall and W. C. Dennison, Moreton Bay and Catchment, (pp School of Marine Science, University of Qld, Brisbane.

Underwood, A. J. and Chapman, M. G. (1998) Variation on algal assemblages on wave-exposed rocky shores in New South Wales. Marine and Freshwater Research, 49: 214-254.

UQ (2005) Light and Seagrass. University of Queensland Marine Botany Publication. http://www.marine.uq.edu.au/marbot/publications/pdffiles/seagrass2.pdf. Accessed 28/09/05.

Vance DJ, Haywood MDE, Heales DS, Kenyon RA, Loneragan NR (1998) Seasonal and annual variation in abundance of postlarval and juvenile banana prawns, Penaeus merguiensis, and environmental variation in two estuaries in tropical northeastern Australia: a six-year study. Marine Ecology Progress Series 163: 21-36.

Warburton, K. and Blaber, S. J. M. (1992) Patterns of recruitment and resource use in a shallow-water fish assemblage in Moreton Bay, Queensland. Marine Ecology Progress Series, 90: 113-126.

Wassenberg, T.J. and Hill, B.J. (1987) Feeding by the sand crab Portunus pelagicus on material discarded from prawn trawlers in Moreton Bay, Australia. Marine Biology. 95: 387-394.

Wassenberg, T.J. and Hill, B.J. (1989) The effect of trawling and subsequent handling on the survival rates of the by-catch of prawn trawlers in Moreton Bay, Australia. Fisheries Research. 7: 99-110.

Weng, H.T. (1988) Trawl-caught fish in Moreton Bay, Australia: value, dominance, diversity and faunal zonation. Asian Fisheries Science. 2: 43-57.

Weng, H.T. (1990) Fish in shallow areas in Moreton Bay, Queensland and factors affecting their distribution. Estuarine, Coastal and Shelf Science. 30: 569-578.

Weng, H.T., Mather, P.B. and Capra, M.F. (1994) An assessment of genetic differentiation in trumpeter whiting (Sillago maculata Quoy and Gaimard) populations in Moreton Bay. Proceedings of the Royal Society of Queensland. 104: 11-17.

Young, P. C. (1978) Moreton Bay, Queensland: a nursery area for juvenile penaeid prawns. Australian Journal of Marine and Freshwater Research, 29: 55-75.

Young, P. C., and Cappanter, S.M. (1977) Recruitment of Postlaval Prawns to Nursery Areas in Moreton Bay, Queensland. Aust. J. Mar. Freshwater Res., 28: 745-773.

Van Der Veer, H.W., Bergman, M.J.N and Beukema, J.J. (1985) Dredging activities in the Dutch Wadden Sea: Effects on macrobenthic infauna. Netherlands Journal of Sea Research, 19: 183-190.

Wassenburg, T. J. and Hill, B. J. (1990) Partitioning of material discarded from prawn trawlers in Moreton Bay. Aust. J. Mar. Freshwater. Res, 41: 27-36.

WBM Oceanics Australia (2005) Port of Brisbane FPE Seagrass Monitoring Report April 2005 – Final Report. Prepared for Port of Brisbane Corporation.

WBM Oceanics Australia (2004) Moreton Bay Sand Extraction Study Phase II – Benthic Fauna Assessments. Prepared for the Moreton Bay Sand Extraction Steering Committee.

WBM Oceanics Australia (1995) Spitfire Channel Benthic Assessment Program. Report prepared for Port of Brisbane Corporation.

WBM Oceanics Australia (2002) Moreton Bay Sand Extraction Study - Phase 1. Report prepared for Moreton Bay Sand Extraction Steering Committee.

Williams, L.E. (1997) Queensland's fisheries resources: current condition and trends 1988-1995, Queensland Department of Primary Industries Information Series QI97007, pp. 101.

Williams, L. (1992) Moreton Bay Fisheries in: Moreton Bay in the Balance (ed. Crimp, O.) Australian Littoral Society/Australian Marine Science Consortium, Brisbane. pp. 71-79

Young, P. C., and Wadley, V. A. (1979) Distribution of shallow-water epibenthic macrofauna in Moreton Bay, Queensland, Australia. Marine Biology (Berlin) 53: 83-97.

Carlton, J. M. (1974) Land-building and Stabilization by Mangroves. Environmental Conservation, 1:

Chapman, M. G. and Underwood, A. J (1995) Mangrove forests. In, Coastal marine ecology of temperate Australia, edited by A.J. Underwood M.G. Chapman, New South Wales University Press, Sydney, pp. 187-204.

Clarke, S.M and Kirkman, H. (1989) Seagrass dynamics In Larkum, A.W.D, McComb, A.J and Sheperd, S.A eds (1989) Biology of seagrasses: A treatise on the biology of seagrasses with special reference to the Australian region. Elsevier, Amsterdam. Pp 304-345.

Department of Environment and Conservation. www.threatenedspecies.environment.nsw.gov.au. NSW (accessed October 2005).

Department of the Environment and Heritage (2005) Environmental Reporting Tool. www.deh.gov.au (accessed October 2005).

Hyland, S. J., Courtney, A. J. and Butler, C. T. (1989) Distribution of Seagrass in the Moreton Region from Coolangatta to Noosa. Queensland Department of Primary Industries Information Series Q189010, December 1988.

King, R. J. (1981) Mangrove and saltmarsh plants. In: M. N. Clayton and R. J. King, Marine Botany: an Australian Perspective, (pp 308-328) Longman Cheshire, Melbourne.

Longstaff, B. J and Dennison W.C. (1999) Seagrass survival during pulsed turbidity events: The effects of light deprivation on the seagrasses Halodule pinifolia and Halophila ovalis: Aquatic Botany 65, 105-121.

Longstaff, B.J., Loneragan, N.R., O'Donohue, M. and Dennison, W.C. (1999) The effects of light deprivation on the survival and recovery of the seagrass Halophila ovalis. Journal of Experimental Marine Biology and Ecology. 234, 1-27.

Odum, W. E., McIvor, C. C. and Smith, T. J. (1985) The ecology of the mangroves of South Florida: a community profile. University of Virginia USA, September 1985.