CENTRAL QUEENSLAND UNIVERSITY
GLADSTONE
LIBRARY

Port Curtis Marine Resources adjacent to the Stage 2 Stuart Oil Shale Development

Prepared by
Centre for Environmental Management/
Centre for Land and Water Resource Management
Central Queensland University
Gladstone Campus

May 1999

Central Queensland
UNIVERSITY

2314021

Central Queensland
UNIVERSITY

Port Curtis Marine Resources
Adjacent to the Stage 2, Stuart Oil Shale Development

Authors

Dr Michael H Walker
Samantha Lewis
Roland Rupp
Kirsty McNamara
Lee Hackney
Damon Shearer

Research Team

Rebecca Dobbie
Jill Gray
Roderick Johnson
Andrew White
Damon Shearer

Marine Environment
May, 1999

Table of Contents

4.7.5.3	Marine Environment	1
4.7.5.3.1	Information and Data Sources	1
4.7.5.3.2	Overview of the Marine Environment	3
4.7.5.3.2.1	Hydrodynamics and Tidal Regimes	3
4.7.5.3.2.2	Major Habitats	5
4.7.5.3.2.2.1	Benthos	6
4.7.5.3.2.2.2	Seagrass	8
4.7.5.3.2.2.3	Mangroves	10
4.7.5.3.2.2.4	Creeks	13
4.7.5.3.2.2.5	Saltflats	13
4.7.5.3.3	Rare and Threatened Species	14
4.7.5.3.4	Habitat Requirements	16
4.7.5.3.5	Fish	16

4.7.5.3 Marine Environment

4.7.5.3.1 Information and Data Sources

Past baseline studies of Port Curtis are primarily restricted to environmental impact assessments and impact assessment studies completed by consultants. Early work was undertaken by Saenger (1988) who produced the Gladstone Environmental Survey for the Queensland Electricity Commission. This provided baseline data to ascertain the effect of thermal discharge from the Gladstone Power Station on the Calliope River and Port Curtis.

In 1990, WBM conducted an impact assessment study for the Gladstone Port Authority investigating the potential impacts of reclamation of 810 hectares of land west of the Calliope River to accommodate industry growth. This involved assessment of the existing marine environment including marine fauna, flora and water quality. In 1991, a second study was undertaken by WBM for the Department of Environment and Heritage to assess the impact on Port Curtis of trade waste effluent as discharged via an outfall on Fisherman's Landing.

The Gladstone Port Authority, together with the Department of Environment, conducted the Curtis Coast Study in 1994, pulling together information from several sources about Port Curtis. This document provided a baseline inventory of land and marine resources of Port Curtis and adjacent coastline.

Over the past 10 years, Environmental Impact Studies have also been undertaken by Envirosciences (1992) for the Stuart Oil Shale Project and in 1998 by Dames and Moore for the proposed Comalco Alumina Project and in 1997 by Connell Wagner for the proposed Nickel/Cobalt processing plant.

Central Queensland University's Centre for Environmental Management has conducted several baseline and research studies in Port Curtis since 1995. These include longterm seagrass, macrobenthos, fish and fisheries and mangrove programs, and short term studies throughout the harbour. A series of unpublished reports have been prepared over

the past 3 years by the Centre for Environmental Management for several clients including the Gladstone Port Authority, SPPD, Department of Environment, Boyne Smelters Ltd and others.

The Gladstone Port Authority is a major sponsor of the centre and has funded the Port Curtis Macrobenthic Monitoring and Research Program since November 1995 as well as mangrove and seagrass work associated with port development. The macrobenthic program involves twice yearly sampling at 16 stations around Port Curtis to determine the impact of local industry on macrobenthic species, which provide excellent indicators of environmental stress. Seagrass stations at Wiggins Island are also surveyed twice yearly to determine seagrass composition and coverage, as well as macrobenthic diversity. Mangrove sites around Port Curtis are sampled quarterly to determine productivity, growth and health of local mangrove communities, while commercially and recreationally important fish and fishery species are also assessed frequently.

SPPD has funded additional sampling in several programs undertaken by the Centre for Environmental Management. Eight new macrobenthic stations have been established (four in November 1995, four in April 1997) to provide longterm data for Stage 1 developments and beyond. Two new seagrass sites (including 8 seagrass stations) were first sampled in September 1998 and will be sampled quarterly to determine seagrass biomass and abundance. Mangrove sites at Gully C were established and sampled for Stage 1 of the Stuart project, and further sites at Friend Point and Scrubby Creek have been established and sampled for Stage 2. Commercially and recreationally important fish and fishery species have also been studied.

The long term nature of these programs precludes interpretation and examination of results for long term trends and changes at this early stage. However, these data sets will in the future allow impacts of industry and development in Port Curtis to be assessed through comparison of sites all over the harbour. Further, they will provide the baseline data sets at present lacking for Port Curtis and the Curtis Coast to enable determination of the impacts of future development.

Other surveys for Stage 2 development undertaken by the Centre for Environmental Management for SPPD include an survey of mangrove communities adjacent to the Stuart Development and a short term study of the fauna of Boat Creek. The mangrove survey was extremely intensive, and resulted in a detailed record of community composition and health of mangroves, which are likely to be directly affected by the Stuart project. It is likely that these communities have already been impacted by other industry and developments in Port Curtis prior to the initiation of the Stuart project in 1998. These impacts and those of the Stuart project must be continually assessed. The macrobenthic fauna, fish and fisheries species of Boat Creek were assessed in December 1998 and January 1999. This creek will be directly affected by the Stuart project, however again impacts on this creek by already established industries are apparent. These two monitoring projects must be repeated in order to elucidate effects on these communities immediately adjacent to the SPPD site since these are most likely to be impacted.

4.7.5.3.2 Overview of the Marine Environment

4.7.5.3.2.1 Hydrodynamics and Tidal Regimes

Port Curtis, a large estuary, is regarded as a drowned landscape (Conaghan, 1966). Rises in sea level submerged the series of coastal river valleys, formed during the Pleistocene Ice Age which comprised the Curtis Coast. Port Curtis and its associated estuaries are today influenced greatly by tides, freshwater flows when they occur from major rainfall events, and by the weather.

Tidal regimes of Port Curtis and the adjacent Curtis Coast are influenced by coastal geology, ocean topography and by the Great Barrier Reef. Inner tidal effects with Port Curtis and neighbouring estuaries amplify the tidal range. Gladstone Harbour, The Narrows and Sea Hill have tidal ranges from 15-50% greater than ocean tides at Gatcombe head (QDEH, 1994). Tidal delays are also experienced towards The Narrows where high and low tides occur over an hour later than corresponding adjacent ocean tides.

Lower tidal ranges and tidal delays are experienced by streams/rivers particularly those with restricted mouths such as the Boyne and Calliope Rivers. Tidal current velocities at such sites tend to be in the range 1-2.3 knots (0.5 – 1.2m/s) (QDEH, 1994). Tidal current velocities vary also according to location. Velocities within Port Curtis are greater in the deeper channels towards the southern end of the estuary eg at Auckland Point where the sediment is correspondingly coarse and long and surface current velocities are estimated to be 3.9-4.9 knots (2.0-2.5 m/s) (ETM, 1980). In the upper Harbour, The Narrows and in the area towards North Entrance, current velocities are lower 1.9-2.9 knots (1.0-1.4m/s). At such locations finer sediment from neighbouring deeper channels is deposited on adjacent shoals. Areas adjacent to the shore tend to become more muddy (Conaghan, 1966). Relatively high tidal current velocities help maintain Port Curtis as a natural deepwater port. This assists with the maintenance of good water quality partly by assuring the rapid dilution of contaminants and freshwater outflows.

For estuaries with multiple entrances such as Port Curtis, average ebb and flood tidal flows via any given entrance are not necessarily equal, resulting in a net flow in one direction. Such a net inflow must be balanced by a net outflow elsewhere creating a net circulation. The net circulation for Port Curtis was predicted by ETM, (1980), using the WBM hydrodynamic model. It basically defines two distinct circulations that occur under average conditions:

- a net flow through The Narrows of $20m^3$/sec (ca 10% of average ebb and flood tide past this point), and
- a northward flow of $300m^3$/sec from South Entrance to North Entrance (ca 1% of average ebb and flood tide past this point).

This understanding of net circulation is vital to prediction of the water borne contaminants and identification of potential impact sites.

The Curtis Coast has a catchment of greater than $1000km^2$ and four major rivers/streams: Raglan Creek, Fitzroy, Calliope and Boyne Rivers. Overall there

are ca 50 streams and rivers which feed the Curtis Coast and affect Port Curtis (QDEH, 1994). Except for the four rivers and nine streams, most of these other 50 have small catchments and discharge low volumes of freshwater into Port Curtis and or the adjacent coastal lagoon.

4.7.5.3.2.2 Major Habitats

The major marine habitats in proximity to the Stuart Oil Shale Deposit can be defined as subtidal and intertidal zones along the lines of Dames and Moore, (1998).

Subtidal habitats consist of:

- the tidal, turbid, well flushed water column that over lies soft silty Port Curtis sediments mostly in the depth range 0-10m LAT.
- the dredged shipping channel and ship turning circle at Fisherman's Landing 7-15m LAT, usually having a coarse sediment composition of cobbles, gravelly silty sands and shelly silty sands.
- the sand and silt substrates of the nearshore shallow subtidal zone. These substrates are often colonised by macroalgae and seagrasses of the genus *Halophila* and by *Zostera capricorni.*
- the winding channels of tidal creek systems which drain across the mudflats at several locations eg Boat Creek and Flying Fox Creek, and the deep channels of the lower Calliope River and its main anabranch.

Intertidal habitats consist of:

- the lower intertidal sand and mudflats often colonised by seagrasses especially *Zostera capricorni* and filamentous algae *Rhizoclonium* sp and *Monostoma* sp. This area may be further defined into an outer channel, an extensive mud/sand flat area and inner, sheltered channel margins.
- the mid intertidal to upper intertidal zone mostly supporting fringing mangrove forests.

- the mostly bare and saline high intertidal mudflats and salt marsh areas.

The landward boundary of the high intertidal zone is characterised in most locations by a slight but obvious change in elevation as well as soil type. It is usually sandy and often dominated by *Sporobolus* sp, saltwater couch and flotsam and jetsam. It lies adjacent to supratidal zone composed of grasslands and scrub or paperbark and/or eucalypt woodlands.

These major marine habitats, which lie adjacent to the Stuart Oil Shale Project, will be discussed further in terms of the communities they support ie benthos, seagrass, mangroves, creeks and saltflats.

4.7.5.3.2.2.1 Benthos

Macrobenthic invertebrate communities (fauna which do not pass through a 1mm sieve) have been shown to be sensitive to environmental stress, especially pollution, and therefore have the potential to detect gross and maybe subtle changes occurring in the aquatic environment (Gray, J.S. *et al*, 1990, Hartley, 1982, Rees, H.L. and Eleftheriou, A., 1989, Steimle, R.S., 1990). Macrobenthic invertebrate communities are sedentary and generally are relatively long lived and thus integrate recent past environmental conditions in terms of species diversity and abundance. They also have an intimate relationship with the sediment where pollutants accumulate and sometimes bioconcentrate.

Macrobenthic fauna are important to marine ecosystems both as a food supply and as nutrient recyclers (QDEH, 1994). Macrobenthic communities in Port Curtis are variable in diversity and equitability both in time and space. The benthic fauna of Port Curtis comprises gastropods, crustaceans, bivalves, polychaete worms, echinoderms and formaniferans. Gastropods are abundant and common throughout the

harbour, while bivalves, polychaetes, formanifera and crustacea are less common and echinoderms are rare.

Macrobenthic communities adjacent to the Stuart Oil Shale sites reflect the variability found elsewhere in Port Curtis. Station 22, at the mouth of Flying Fox Creek, is anomalous to other stations in Port Curtis and is characterised by very high abundances of a relatively small number of species and a large number of rarer species. This reflects a disturbed community, where opportunistic species are able to thrive due to adverse conditions and the resultant loss of competitor species. Other stations in the vicinity of Flying Fox Creek showed low abundances, but were comparable to Port Curtis as a whole. Stations at Friend Point had slightly low diversity when compared to other stations in the harbour, but not significantly less. Abundance per station at SPPD funded stations ranged from 267 to 9094 individuals and number of species ranged from 30 to 137. The remaining 16 stations in Port Curtis had similar ranges with 145 to 10830 individuals and 37 to 170 species recorded.

Species found frequently at Oil Shale sites were also generally high in abundance, with over 50% of the species found being of low abundance (one or two individuals). Several species were present at all sites across the harbour suggesting that these species are tolerant of environmental stress, and may be used in the future as indicators of disturbance.

Sediment composition was also variable throughout the harbour over time. Species composition changed with sediment composition and organic matter at Oil Shale sites, with certain species preferring sandier or siltier sediments, probably as a function of their trophic feeding method or ecology. Further patterns in this will become clear as multivariate analysis continues.

4.7.5.3.2.2.2 Seagrass

Seagrass ecosystems are important contributors to the coastal zone, providing a major food source in detrital based food chains, shelter and habitat for a diverse range of invertebrates and fishes, and a direct food source for grazing animals including dugong and the green turtle (Lanyon, 1986). Additionally, seagrasses assist in binding together unstable sediment. Seagrass distribution is determined by substrate type, tidal exposure, water clarity, nutrient load, salinity and bottom topography.

A total of 3150 ha of seagrasses have been identified within the Curtis Coast area (QDEH. 1994). Eight of the 14 species present in Queensland, have been identified by Lee Long *et al,* (1991) for Port Curtis as follows: *Zostera capricorni, Halodule uninervis, Syringodium isoetifolium, Halophila decipiens, Halophila ovalis, Halophila ovata, Halophila spinulosa and Halophila tricostata.* Seagrass beds within Port Curtis vary in size depending on location from 1-900 ha and are usually of mixed associations dominated by *Zostera capricorni* along with other species. *Z. capricorni* has wide tolerance of environmental conditions and thus is able to inhabit wide ranges (den Hartog, 1977).

The largest seagrass bed within Port Curtis known as Targinnie stretches from the mouth of the Calliope River almost to Fisherman's Landing wharf. It is estimated to be 900 ha. This seagrass bed and the bed south of Friend Point [estimated to be 110 ha (Lee Long *et al*, 1991)] are major beds and are in close proximity to the Stuart Oil Shale Project. Some authors divide the Targinnie seagrass bed into Wiggins Island and Flying Fox (Walker *et al*, 1996). These beds are spatially separated by the deeper channels leading to Flying Fox Creek. Flying Fox is considered to potentially be more impacted by the Stuart Project than Wiggins Island which is potentially impacted by the GPA Wiggins Island Reclamation and outflows from the Calliope River.

Flying Fox and Friend Point seagrass beds, as surveyed during 1998 and 1999, were found to have an average percentage cover of 3.4-16% *Z. capricorni* and 0-13% *Haliphila ovalis* at Flying Fox and 0-60.8% *Z. capricorni* and 0-10% *H. ovalis* at Friend Point. Friend Point additionally had algae coverage of 0-11.5% (*Rhizoclonium* sp and *Monostoma* sp). In general, both the Flying Fox and Friend Point mudflats are dominated by *Z. capricorni* and *H. ovalis* along with the algae *Rhizoclonium* sp and *Monostoma* sp. The mudflats provide three broad habitats: outer channel margins containing a mixture of seagrass and algae often with algae dominant; inner, sheltered channel margins where extensive patches of seagrass cover sometimes occurs and an extensive mudflat/sandflat subjected to regular tidal inundation, dominated by *Z. capricorni* in a relatively low percentage cover.

Seagrass biomass, as sampled in 1998/99, was lower in March than August and greater for *Z. capricorni* than for *H. ovalis,* which in turn was greater than filamentous algae. Biomass corresponded with shoot production. Leaf length was generally longer in August 1998 than March 1999. Leaf length for *Z. capricorni* varied between 5.6-10cm and 0.85 to 1.95cm for *H. ovalis.*

Z. capricorni frequently exhibited reciprocal relationships to *H. ovalis* and filamentous algae, suggestive of a preference for different conditions. Low overall percentage cover suggests that the seagrass community is not fully exploiting the existing environment. Flying Fox appeared to be more consistent in terms of seagrass distribution than Friend Point. Seagrass communities are vulnerable to changes in turbidity, salinity and sediment composition. Changes, however, are likely to be observed in the longer term. Presently there is no evidence of longer term changes to Port Curtis seagrass beds although they clearly exhibit annual and seasonal variations. (DEH, 1994).

4.7.5.3.2.2.3 Mangroves

The mid to upper tidal zones of Port Curtis, and the Curtis Coast between mean sea level (MSL) and mean high water springs (MHWS) is dominated in terms of vegetation by mangroves. Extensive areas of mangrove forest also cover its low islands eg Passage Island and its creeks eg Boat Creek, Flying Fox Creek, Calliope River, Graham Creek and The Narrows.

The key factors determining both the distribution and structure of mangrove communities are soil/sediment type and composition, groundwater salinity and exposure to the sea and light. Most of the zonation of mangrove assemblages can be directly related to differing salinity regimes which alter with elevation, the frequency of tidal inundation and the amount of evaporation verses freshwater seepage from the hinterland (Dames and Moore, 1998).

The most common mangrove of the twelve species encountered within Port Curtis, is *Rhizophora stylosa,* the red mangrove. Iit is often found dominating most of the coastal fringe, islands and lower reaches of tidal creeks and also exists as extensive strands of largely monospecific forests or dense shrubland.

Avicennia marina, the grey mangrove, is widely distributed over a range of habitats throughout the intertidal zone. It mostly occurs as a thin seaward band immediately in front of *Rhizophora stylosa* forest and in association with other species. It is most dominant in the middle to upper reaches of creeks. Substantial mortality of this species has occurred within Port Curtis since the 1940's, caused mostly by a fungal pathogen *Phytofora* sp which was probably aided by environmental stress caused by industrial operations (QDEH, 1994).

Ceriops tagal, the yellow mangrove, is widespread throughout middle to upper tidal zones, especially within the creeks and hinterland fringes. It is typically found in association with other mangrove species and also occurs as dense monospecific shrublands. A severe thunderstorm denuded and killed several hundred trees in an area adjacent to the Calliope River in 1991. There has been little recovery since this event.

Aegiceras corniculatum, the river mangrove, is widespread along the middle and upper reaches of tidal creeks and in some areas dominates forming a dense shrubland.

Osbornia octodonta, the myrtle mangrove, occurs along the middle to upper reaches of creeks in association with *Aegiceras* sp, *Ceriops* sp *and Avicennia* sp shrubland/low forest near the channel's edge. It is also encountered on the cheniers and amongst the communities which lie at the back of the coastal and creek fringes.

Aegialitis annulata, the club mangrove, occurs on the landward edge of the coastal fringes in association with *Ceriops* sp and *Avicennia* sp and on the chenier heath.

Lumnitzera racemosa, the black mangrove, generally only occurs at the hinterland and chenier fringes.

Exocoecaria agallocha, the milky mangrove, occurs at the hinterland fringe and on one of the low cheniers near the mouth of Boat Creek.

The mangrove fringe adjacent to the Stuart Oil Shale Project ranges from 5m to over 230 m in width. Seven mangrove species occur within this area. The low intertidal region on the seaward side of the *R. stylosa* zone is sporadically dotted with mature *A. marina* trees. *A. marina* exists in this zone as solitary trees or in small groupings, but not as an open or semi-closed forest structure for much of the surveyed area. The majority

of trees have one primary stem and range in height from 4-12 m along the surveyed shoreline. Sections of forest with trees from 3-5m with multiple stems and a fused or shared arrangement of prop roots were also observed. The number of established seedlings in the *R. stylosa* zone is generally proportional to the amount of available light (pers.com, Duke, 1996). Within the forest proper there are few seedlings and those present often do not reach maturity due to the restricted light conditions (pers.com, Duke, 1996). There was notable herbivory of leaves in the canopy of *R. stylosa* trees along the surveyed area. Herbivory with Port Curtis ranges from very little (<%5%) to high (≥50%) (Dobbie, 1998, unpublished). Larvae of the cup moth *Doratifera* sp are believed to be largely responsible for this herbivory damage.

Moving landward out of the mature *R. stylosa* zone into the higher mid-intertidal region, tree height decreases and the forest gives way to a *R. stylosa* thicket with trees 4 m or less in height. With the progression landward the number of *R. stylosa* trees decreases until *R. stylosa* drops from the zonation almost entirely with *C. tagal* and *A. marina* becoming more dominant. *Aegiceras corniculatum, Aegialitis annulata, Osbornia octodonta* and *Lummitzer racemosa* can also be found in this zone. Plant height decreases to 1 m or less and then rather abruptly the mangrove zone gives way to saltflats. Depending on the elevation of the land with respect to sea-level and the presence of drainage channels, the mangrove zone can continue to and beyond the mark of highest astronomical tide represented by a beach ridge.

Mangroves, in summary, are a dynamic environment under the influence of tide, current, wind and wave action with forest structure varying according to the combined effect of these factors. Influences from the landward margin including erosion, land reclamation, industrial out-flows, run off from agriculture in addition to fresh water flows from creeks and drainage channels impact mangrove zonation and forest structure.

4.7.5.3.2.2.4 Creeks

The banks of tidal creeks eg Flying Fox, Boat Creek, Targinnie and Scrubby Creek, are generally steep and composed of mud, clay and silt. They are usually vegetated with mangroves and occasionally adjacent to salt flats with their banks being vegetated with *Sporobolus* sp saltwater couch eg Boat Creek in two locations and The Narrows. Mangrove communities downstream consist of communities of *Rhizophora stylosa, Avicennia marina,* and *Aegiceras corniculatom* usually 4-7 m in height. Communities change upstream to those dominated by *Ceriops tagal.* Generally the creeks are too silty and turbid to support seagrasses. Where the creeks are fast flowing the bottom is rocky, pebbly and sandy.

Creeks receive considerable attention from recreational and commercial fishermen seeding to capture mud crabs. The benthic and commercially important fish fauna of Boat Creek is given elsewhere.

4.7.5.3.2.2.5 Saltflats

Coastal saltflats (saltpan/saltmarsh) are a distinctive feature of the Curtis Coast and Port Curtis. They present a harsh environment to flora and fauna having high temperatures, shallow infrequent tidal inundation, high soil salinity and low oxygen permeability (WBM, 1990). They are often extensive in area and usually devoid of all vegetation except for alive or dead blue green algal mats. Sometimes in addition to blue green algae they may contain an occasional thin cover of salt tolerant plants (shrubs, heaths and grasses). Adjacent to the Stuart site they are 20-50 m wide (mangroves – terrestrial) and patchy. Typical plants encountered on saltflats are saltwater couch, (*Sporobolus virginicus*), seablight (*Suaeda australis*), purslane (*Sesuvium portulacastrum*), glasswort (*Sarcocornia quinqueflora*) and samphire (*Halosarcia indica* and *Halosarcia halocnemoides)*. Rainfall events transport eroded sediments onto these

upper intertidal areas on a regular basis leading to areas being smothered and new areas establishing on deposited sediments. Mangrove growth is restricted and mostly precluded from seaward saltflat areas by high groundwater salinities. Mangroves are able to grow along the landward edge of saltflats because of groundwater seepage from the hinterland diluting the normally elevated groundwater salinities which otherwise prevent their establishment.

Coastal saltflats are only available to fishes on spring high tides. Fish species, which frequent the frontal waters of flooding tidal waters, have been shown to utilize such a habitat (WBM, 1990) especially: scalloped perchlet (*Ambassius nalua),* fantail mullet (*Mugil georgii*), longtom (*Strongylura strongylura*), garfish *(Zenarchopterus buffonis)* and toadfish species. It is likely that during spring high tides, juveniles of these species utilise this habitat. This also may be true for the mud crab.

4.7.5.3.3 Rare and Threatened Species

There are no marine plants, invertebrates or fishes recorded for the Curtis Coast and documented in the area adjacent to the Stuart Oil Shale Project, that are regarded as rare and threatened species.

Protected marine fauna, dolphins, turtles and dugongs are commonly seen between Auckland Creek and Friend Point.

The WA museum records four species of dolphin for the Curtis Coast. Only the Irrawaddy dolphin *Orcaella brevirostris* is regarded as rare or threatened. The species is poorly known and Port Curtis is regarded as its southern limits (QDEH, 1990, Barker, 1990). What is thought to be the common Bottlenose dolphin is commonly reported by fishermen in the marina at the mouth of Auckland Creek, on the Targinnie mudflat and in the vicinity of the Fisherman's Landing wharf. Dolphins have been regularly observed at all three locations during studies for the Stuart Stage 2 IAS.

Green turtles *Chelonia mydas,* hawksbill turtles *Eretmochelys imbricata,* flatback turtles *Natator depressus,* loggerhead turtles *Caretta caretta* are all are known to occur along the Curtis Coast (QDEH, 1994 and WBM, 1990). Turtles are highly mobile animals and would be expected to range throughout Port Curtis. The loggerhead is regarded as endangered whilst the other three species (green, flatback and hawksbill) are regarded as vulnerable (QDEH, 1994). Turtles thought to be green turtles are commonly observed feeding on seagrasses at Wiggins Island, Flying Fox and Friend Point. This species is known to nest on Capricorn Bunker Group beaches. Flatback turtles are known to nest on Curtis Island and Facing Island beaches.

The dugong *Dugong dugon* is regarded as in danger of extinction over most of its range. The Australian distribution is from Shark Bay, WA to Moreton Bay, Qld. Except when in transit, dugong stay close to their food supply, predominantly seagrass, in shallow coastal waters. Dugongs feed preferentially on seven species of seagrass in intertidal and subtidal regions to 9.5m below low water datum (Heinsohn *et al.*, 1977; Heinsohn and Birch, 1972). They apparently graze most heavily on seagrass beds of low density with their movements and feeding habits being dependent upon tides and calm weather. They are commonly observed as part of the CQU Centre for Environmental Management activities at Wiggins Island and Flying Fox. The area of the Curtis Coast in general, however, is not recognised as a major population area (QDEH, 1994, Marsh, JCU, pers. com). Major population centres are considered to be Shoalwater Bay and Moreton Bay. Little is understood of their migratory habits. Observations suggest that some might be nomadic whilst others migratory (Heinsohn and Wake, 1976). It is possible that major seagrass beds located at Targinnie and Friend Point may be important feeding locations for migratory animals between known population centres such as Shoalwater Bay and Moreton Bay. However, historically only one or two animals are observed in such locations never in herds as observed in Moreton and Shoalwater Bays.

It is not considered that the Stuart Oil Shale Project directly places any of these rare or threatened vertebrates at risk. Indirectly loss of habitat such as breeding locations or feeding sites such as seagrass beds may contribute to changes in abundance.

4.7.5.3.4 Habitat Requirements

Queensland Fisheries habitats, mangroves and seagrasses in particular are under increasing pressure from infrastructure development eg port and water storage development, urbanisation and other human activity. This pressure has lead/is leading to loss or change to these habitats. Clearly this has long term implications for fish stocks as well as the habitats themselves. Mangroves and seagrasses play a vital role in dissipation of energy from the sea against the coast. Their loss thus has implications for infrastructure itself. Endangered marine vertebrates, turtles and dugong are dependent to varying degrees upon seagrass. The reduction in dugong numbers throughout its range is likely to be due to loss or altered seagrass beds rather than man's activities such as net fishing. It is important that every attempt be made to protect, preserve and manage seagrass, mangrove and other marine and riverine habitats. The Stuart Oil Shale Project is adjacent to important seagrass communities at Flying Fox and Friend Point and surrounded by mangrove communities ie Fisherman's Landing – Friend Point and Friend Point – Targinnie and Scrubby Creek. The proponents of this project have a responsibility to minimise their impact upon such habitats. The proponents have demonstrated by the marine monitoring and research programs they have established since 1995 that they realise their responsibilities in this area.

4.7.5.3.5 Fish

The foreshores and associated tidal creeks adjacent to the Stuart Oil Shale Project support valuable recreational and commercial mud crab and angling fisheries. Additionally, commercial fishers irregularly gill net mullet for bait and salmon and barramundi for food purposes.

The fish species encountered are those typical of Central Queensland sheltered marine embayments or estuaries, such as Port Curtis. The foreshores support schools of bait species such as mullet, herrings and other clupeids which feed either on detritus or plankton associated with seagrass beds, muddy benthic communities or mangroves lining the foreshores or creeks. They in turn are sought out as prey by predatory fishes such as blue, flat and King salmon, grunter and barramundi which move with the tides and after await their prey at the mouths of creeks. Such fishes also prey upon sesarmid crabs, banana and other prawns and juvenile fishes which have a strong association with mangroves.

During a survey undertaken in May 1998 in excess of 650 fishes were caught representative of 44 species and 30 families. This result was more successful than previous IAS surveys eg WBM (1990). Fifteen of these 44 species were assessed as being of commercial or recreational value. They were mullet, flathead, whiting, garfish, narrowbarred mackerel, cod, jewfish and barramundi.

No fish species encountered could be regarded as endangered. However, to maintain populations at existing levels habitat protection is essential ie preservation of saltflats, mangroves and seagrasses as well as good water quality.

Conservation Values
May, 1999

Table of Contents

5.6	**Conservation Values**	1
5.6.1	**Conservation Estate**	1
5.6.1.1	**Potential impacts on Great Barrier Reef Marine Park**	1
5.6.1.2	**Potential impacts on World Heritage values**	2
5.6.1.3	**Protection strategies**	4
5.6.6	**Marine flora**	5
5.6.6.1	**Potential impacts on rare and threatened species**	5
5.6.6.2	**Protection strategies**	6
5.6.7	**Marine fauna**	6
5.6.7.1	**Potential impacts on rare and threatened species**	6
5.6.7.2	**Potential impacts on important habitat**	7
5.6.7.3	**Protection strategies**	7

5.6 Conservation Values

5.6.1 Conservation Estate

5.6.1.1 Potential impacts on Great Barrier Reef Marine Park

The Great Barrier Reef Marine Park (GBRMP) covers areas adjacent to but beyond Port Curtis. Port Curtis and The Narrows are not within the Great Barrier Reef Marine Park, which is administered jointly by the State and Commonwealth through the Great Barrier Reef Marine Park Authority (GBRMPA). The Mackay/Capricorn Marine Park, administered by the Queensland Environmental Protection Authority, includes The Narrows, has Friend Point as its southern boundary. It does not extend into Port Curtis. Some portions of the Mackay/Capricorn Marine Park are contiguous with the adjacent Great Barrier Reef Marine Park. They are of the GBRMPA adjacent to Curtis Island is zoned General use "A".

The Narrows region with the Mackay/Capricorn Marine Park has been declared a Conservation and Mineral Resource Zone with the objective of providing for the conservation of the area while allowing for the possibility of exploitation and development of mineral resources in the longer term.

As the GBRMP lies beyond Port Curtis there is little likelihood of direct impacts from the Stage 2 development of Stuart Oil Shale resources. Indirect impacts by way of The Narrows and Port Curtis are possible, however. These could arise through:

- hydrocarbon spills from storage tanks, loading facilities or from ships
- accidental hydrocarbon discharge associated with shipping accidents or catastrophic equipment failure
- sediment plumes as a consequence of altered freshwater discharges from coastal erosion associated with altered coastline conditions
- increased nutrient discharge to sea following a loss of mangroves and littoral vegetation as well as a redirection of freshwater flows.

Issues related to accidental discharge of hydrocarbons are to be addressed by others.

Sediment discharge is unlikely to be a significant problem given:

- the distance from any likely sources within the project and the GBRMP – about 22 km
- the magnitude of the discharge, in any given event, relative to that from other sources within Port Curtis and The Narrows is likely to be small.

5.6.1.2 Potential impacts on World Heritage values

The World Heritage Area (WHA) extends from the GBRMP to The Narrows and lies immediately adjacent to the Stuart Oil Shale Stage 2 Development. The potential impacts are equivalent to those listed in 5.6.1.1 above. The potential severity of any impact is greater, however, given the proximity of the WHA and the project.

The issues associated with hydrocarbon impacts are addressed by others.

Altered coastal hydrology and stream flows are discussed here. A number of schemes for the management of 'clean water flows' have been raised by Gilbert and Associates, 1999. All will have an impact on WHA.

Scheme 1 will divert water to Humpy Creek estuary that discharges to The Narrows. This will increase event flows at this point by between six and 12 times the predicted pre-mining flows. This will significantly reduce flows in the lower reaches of Gullies C – K and Targinnie Creek. There will be a lesser increase in flows through Gully A and no significant change to Boat Creek flows. The positive consequence of this scheme is that freshwater discharge to The Narrows and Port Curtis will be maintained. The likely negative consequences are:

- Fresh water flows along the coast will be reorganised so that mangrove zonation, the extend of saltflats and the structure of the littoral plant

communities are likely to change in response to the altered hydrological conditions.

- The increased flows through the Humpy Creek – lower Targinnie Creek estuary will rework marine sediments as the channel is resculptured to accommodate the new flows
- The upper Targinnie Creek estuary will probably silt up as a consequence of decreased flows
- There is likely to be some reworking of marine sediments in The Narrows beyond the mouth of the estuary. The extent of this reworking is not known and would require some investigation.

The magnitude of the overall movements of sediment is unclear and the consequences for the seagrass beds in The Narrows and in Port Curtis would require some study.

Scheme 3 results in approximately double flows to the Humpy-Targinnie Creek estuary. Consequently the magnitude of the impacts discussed for Scheme 1 above would be reduced.

Schemes 2 and **4** effectively remove normal freshwater flows from the drainage lines adjacent to the Stuart Oil Shale Stage 2 Development – with the exception of Boat Creek. These options avoid the potential impacts associated particularly with Scheme 1 but alter the freshwater balance in the mangroves, saltflats and associated littoral vegetation. These schemes would result in a reorganisation of the coastal vegetation communities. There will be an impact on marine species that use Humpy Creek and Targinnie Creek during part of their life cycle. However, given the small size of Humpy Creek and the ephemeral nature of Targinnie Creek, the impact is probably very small. More general impacts of the reduction in the freshwater discharge to the WHA are not known.

A possible component of Scheme 2 is a discharge of waters from the final voids to Port Curtis following dilution with seawater. The consequences of this option depend on the final composition of the water in the void.

Assuming the management of dissolved salts and the avoidance of any hydrocarbon contamination of the discharge there is likely to be no significant impact from this option.

5.6.1.3 Protection strategies

It is not possible to avoid some potential impact on the environment of Port Curtis or The Narrows. These potential impacts can be reduced, however. The unknown consequences of significantly increased discharges to The Narrows (Scheme 1) should be avoided unless it can be demonstrated that there would not be a major reworking of the sediments in The Narrows. Alternate schemes which reduce the freshwater flows are probably preferable (given the uncertainty). Although these would lead to altered mangrove communities, those communities would remain and continue to function. There is insufficient scientific understanding of short and longer term impacts of altered freshwater flows upon mangrove communities. Thus it is not possible to predict what changes may occur. SPPD has established three longterm plots at Gully C, north of Friend Point and in Scrubby Creek, as well as extensive survey of the entire mangrove community between Fisherman's Landing and Friend Pint. This survey should be repeated annually and expanded to include communities in Scrubby Creek and Targinnie Creeks. The environment within the Gladstone area in terms of regular flows of permanent and ephemeral creek is irregular and unpredictable. There would be a consequent impact on the biota of Humpy and Targinnie Creeks. This however, would be relatively small in relation to the scale of alternative potential impacts.

More generally:

- strategies should be developed to maintain a fringe of coastal vegetation between the mine and plant and the bay to filter water discharging to Port Curtis.

Boat Creek and associated floodways should be protected from activities which would allow hydrocarbons, sediments or other inappropriate substances to be discharged to Port Curtis and the WHA.

5.6.6 Marine Flora

5.6.6.1 Potential Impacts on Rare and Threatened Species

There are no rare or threatened marine flora species within the Stuart Oil Shale Project Stage 2 Area. However, mangrove forests and seagrass beds are considered to be of major conservation significance (QDEH, 1994) and as such are protected under the Fisheries Act (Connell Wagner, 1997). These communities provide habitat for a broad range of marine fauna and are vital to the sustainability of fisheries.

Altering of freshwater flow regimes provides the largest source of impact from SPPD on aquatic flora. The progressive concentration of runoff waters into Gully D and then Gully E, and eventual diversion into Targinnie Creek (Envirosciences, 1992) has the potential to change mangrove communities associated with these areas. Changes to species composition, health and growth in mangrove communities is known to occur with variation in freshwater flows. Reduced flow downstream in diverted gullies is expected to directly impact mangrove species at the gully mouths and on intertidal flats adjacent to the lease area (Envirosciences, 1992).

At Targinnie Creek, freshwater flows will be eventually increased, with communities here likely to undergo changes to species composition and health also. The nature of the changes that will occur is difficult to predict due to the dynamic nature of mangrove communities. Changes to the hydrological regime are the second biggest cause of death of trees in mangrove forests, after extirpations by man (Hatcher *et al,* 1989). Mangroves thrive in stressful environments and have some tolerance of fluctuating salinities and waterlogging (Naidoo and von Willert, 1995). Reduction in freshwater flows, and subsequent increases in salinity, however, may result in community change and possibly lead to death.

Increases in freshwater flows may initially increase net production, but may also cause community shift (Hatcher *et al,* 1989) because of the differing tolerances of species to altered salinity regimes.

Changes to freshwater flows also causes changes in sediment load. Increased flows in Gully D and E and reduced flows in diverted gullies are likely to lead to changes in sediment loading and scouring at gully mouths communities (Envirosciences, 1992). These are likely to affect mangrove communities.

Seagrass bed communities are also affected by changes to freshwater flows and sediment load. Since seagrass beds are 150-300m offshore from the gully mouths, this effect may be attenuated (Envirosciences, 1992).

It is important to continue to monitor these communities to determine the effect of altering freshwater flows.

5.6.6.2 Protection Strategies

It is important to continue to monitor mangrove and seagrass communities adjacent to the Stuart Oil Shale Stage 2 Development to determine the effect of altering freshwater flows.. It is not possible to predict the changes that might occur. This research will ultimately assist others in management and restoration of mangroves and seagrasses.

5.6.7 Marine Fauna

5.6.7.1 Potential Impacts on Rare and Threatened Species

Rare or threatened marine fauna observed in the Curtis Coast area include the Irrawaddy dolpin, the Loggerhead , Green, Flatback and Hawkesbill turtles and the dugong (QDEH, 1994). Of these species, the turtles and Dugong are known to utilise seagrass beds for feeding. While the Stuart Oil Shale project does not directly place these species at risk, destruction of their

habitat (feeding and breeding) may contribute to changes in their abundance. There is potential to damage/destroy seagrass beds adjacent to the Oil Shale Stage 2 Development by eutrophication, increased siltation and hydrocarbon or heavy metal contamination.

The occurrence of an Oil Spill in Port Curtis is likely to have major effects on marine fauna and flora, with larger vertebrates impacted through destruction of habitat, and altered food supply (Envirosciences, 1992).

5.6.7.2 Potential Impacts on Important Habitat

Changes to major habitats within Port Curtis have the potential to affect marine species. Alteration of freshwater flows and changes in water quality could potentially have impacts on mangrove communities, seagrass communities, saltmarshes, benthic communities and fisheries species. The complexity of the coastal marine ecosystem can not be overlooked, with each community type contributing to the health of the ecosystem as a whole. For example, mangrove communities provide nursery grounds for fishery species, seagrass communities provide food for higher vertebrates. SPPD have a responsibility to minimise the impact on the coastal marine ecosystem as a whole, through protection of these important habitats. All of these habitats are at risk within Port Curtis because of port, industrial and urban development and have been altered considerably within the last 25 years.

5.6.7.3 Protection Strategies

It is important to monitor the fauna of the coastal marine ecosystem to determine the impacts of SPPD on Port Curtis. SPPD has a record of concern and action in this area having supported the establishment of benthic, seagrass, mangroves and fisheries monitoring from as early as December 1995. These programs are in operation but require continued support and expansion into new areas as the SPPD project expands its operation and area.

References for Marine Environment and Conservation Values

Baker, A.N. (1990). Whales and Dolphins of Australia and New Zealand - An Identification Guide. Allen and Unwin.

Conaghan, P. (1966). *Sediments and sedimentary processes in Gladstone Harbour, Queensland. Vol. VI.* University of Queensland Press: St Lucia.

Connel Wagner. (1997). *Draft Impact Assessment Study – Nickel/Cobalt Processing Plant, Gladstone*. Produced for Calliope Metals Corporation, QLD.

Dames & Moore. (1998). *Comalco Alumina Project Gladstone - Impact Assessment Study Environmental Impact Statement, Vol 1& 2.* Brisbane.

den Hartog, C. (1977). Structure, function and classification in seagrass communities. In *Seagrass Ecosystems. A scientific perspective.* (eds. C.P. McRoy and C. Helfferich). Marcel Dekker Inc: New York. p. 89-122.

Dunstan, I.C. and Lewis, J.A. (1980). *The effects of underwater explosions on marine life in Shoalwater Bay, Queensland.* Department of Defence Materials Research Laboratories, Australia.

Envirosciences. (1993). *The Stuart Project Environmental Impact Assessment Study. Vol 1&2.* Prepared for Southern Pacific Petroleum NL and Central Pacific Mineral NL, Queensland.

ETM Consultants Pty Ltd. (1980). *Water Quality Plan for Port Curtis Phase 1 Investigations.* Prepared for Queensland Coordinator-Generals Department, Brisbane.

Gilbert and Associates. (1999). Stuart Oil Shale Project Stage 2 Assessment and Conceptual Design of Clean Water Diversions. Report prepared for SPPD, Queensland.

Grant, E.M. (1985). *Guide to Fishes*. The Department of Harbours and Marine, Brisbane.

Gray, J.S., Clarke, K.R., Warwick, R.M. and Hobbs, G. (1990). Detection of Initial Effects of Pollution on Marine Benthos: An Example from the Ekofisk and Eldfisk Oilfields, North Sea. *Marine Ecology Progress Series* **66**: 285-299

Hartley, J.P. (1982). Methods For Monitoring Offshore Macrobenthos. *Marine Pollution Bulletin* **13**:150-154

Hatcher, B.G., Johannes, R.E. and Robertson, A.I. (1989). Review of research relevant to the conservation of shallow tropical marine ecosystems. *Oceanography and Marine Biology Annual Review* **27**: 337-414.

Heinsohn, G.E. and Birch, W.R. (1972). Foods and feeding habits of the Dugong, *Dugong dugon* (Erxleber) In Northern Queensland, Australia. *Mammalia* **36**: 414-422.

Heinsohn, G.E. and Wake, J.A. (1976). The Importance of the Fraser Island Region to Dugongs. *Operculum* 5: 15-18.

Heinsohn, G.E., Wake, J.A. Marsh, H. and Spain, A. (1977). The Dugong (*Dugong dugon* (Muller)) in the Seagrass System. *Aquaculture* **12**: 235-248.

Lanyon, J. (1986). *Seagrasses of the Great Barrier Reef.* Great Barrier Reef Marine Park Authority Special Publication Series (3), QLD.

Lee Long, W.J., Cole, R.G., Miller, K.J., Vidler, K.P. and Derbyshire, K.J. (1991). *Seagrass beds and juvenile prawn and fish nursery grounds.* Queensland Dept Primary Industries, Brisbane.

Marshall, T.C. (1964). *Fishes of the Great Barrier Reef and Coastal Waters of Queensland.* Angus and Robertson Ltd., Sydney.

Naidoo, G. and von Willert, D.J. (1995). Diurnal gas exchange characteristics and water use of three salt-secreting mangroves at low and high salinities. *Hydrobiologia* **295**: 13-22.

Queensland Department of Environment and Heritage. (1994). *Curtis Coast Study - Resource Report.* Queensland Department of Environment and Heritage, Rockhampton.

Rees, H.L. and Eleftheriou, A. (1989). North Sea Benthos: A Review of Field Investigations into the Biological Effects of Man's Activities. *J. cons. Int. Explor. Mer.* **45**:284-305

Saenger, P. (1988). *Gladstone Environmental Survey - Final Report.* Queensland Electricity Commission.

Steimle, R.S. (1990). *Benthic Macrofauna and Habitat Monitoring on the Continental Shelf of the Northeastern United States. 1. Biomass.* Technical Report NMFS 86, US Department of Commerce.

Walker, M. and Housten, W. (1996). *Mangrove and Seagrass Monitoring at the mouth of the Calliope River.* Centre for Environmental Management, Central Queensland University, Gladstone.

WBM Oceanics Australia. (1990). *Impact Assessment Study Reclamation of Land West of Calliope River.* Report prepared for Gladstone Port Authority, WBM Oceanics, Spring Hill.

WBM Oceanics Australia. (1991). *Fisherman's Landing - Trade Waste Outfall Benthic Monitoring Report 1991-1992.* Report prepared for Queensland Department of Environment and Heritage, WBM Oceanics, Spring Hill.

Environmental Management Plan
May, 1999

Table of Contents

6.	**Environmental Management Plant – Marine Environment Stage 1 & 2**	1
6.1	**Mangroves Stage 1 Ongoing**	1
6.2	**Seagrass – Stages 1 and 2**	1
6.3	**Marine Macrobenthos – Stages 1 and 2**	2
6.4	**Fishes and Fisheries**	2

6. ENVIRONMENTAL MANAGEMENT PLAN – MARINE ENVIRONMENT STAGES 1 AND 2

6.1 Mangroves Stage 1 Ongoing

Mangrove Survey

An annual survey of mangrove communities adjacent to Stage 1 operations should be undertaken using aerial survey techniques and manual ground truthing and mapping. An area of particular interest is the area adjacent to Gully C, the point of discharge of stormwater from stormwater storage facilities.

Mangrove Plot

The established 10 x 10m mangrove plot adjacent to Gully C should be maintained and monitored on a 6 monthly basis. This plot should be compared with other CQU Centre for Environmental Management mangrove plots established elsewhere within Port Curtis especially Site D - Fisherman's Landing, Curtis Island and Graham Creek plots. The plot should be monitored for canopy height, foliage projected cover, growth of individual plants (girth and classification trees. shrubs, saplings), sedimentation/erosion, leaf and bark health, seedlings, sediment and litter fall.

Stage 2

Mangrove Survey

The annual survey of mangrove communities adjacent to Targinnie and Scrubby Creek should be undertaken as the mine progresses towards these creeks.

Mangrove Plots

The recently established plots, in anticipation of Stage 2, north of Friend Point and in Scrubby Creek should be maintained and monitored on a 6 monthly basis. These plots should be monitored as for the Stage 1, Gully C plot.

6.2 Seagrass – Stages 1 and 2

The permanently marked seagrass stations located at Flying Fox and Friend Point should be maintained. They should be mapped annually using aerial survey techniques supported by ground truthing, visual observation transects and biomass sampling.

Visual observation transects involve 6 transects between the 5 established buoys. Six 0.5m quadrats should be assessed for seagrass coverage and composition every 10 metres. A further 10 quadrats assessed around each buoy.

Benthic biomass sampling using a $0.1m^2$ van Veen grab should also be undertaken biannually adjacent to north, south, east and west buoys at Friend Point and Flying Fox. Ten replicate grab samples should be taken at each station and one sample for sediment

analysis (grain size, organic content and sediment chemistry). Benthic invertebrates which do not pass through a 1mm sieve should be identified to family level and where possible genus and species. Statistical analyses of samples should be undertaken using Shannon-Wiener and equitability indices. Seagrass should be separated from benthic samples, sorted into seagrass species and components (leaves, shoots, roots and rhizomes) and weighed both wet and dry.

6.3 Marine Macrobenthos – Stages 1 and 2

Macrobenthic Communities – Tidal Creeks

Macrobenthic sampling stations established for the Stage 2 IAS in Boat Creek should be retained and sampled biannually. As the Stuart operation expands, further stations should be established in Targinnie and Scrubby Creek.

Macrobenthic Communities – Port Curtis

The established macrobenthic sites within Port Curtis at Flying Fox and Fisherman's Landing/Friend Point should be maintained and sampled biannually. These sites were reported as part of the Stage 2 IAS. These 2 sites, funded by SPPD, should be compared annually with the 4 GPA sites established at Auckland Point, Curtis Island and Graham Creek.

6.4 Fishes and Fisheries

Fish surveys undertaken biannually around Friend Point, Fisherman's Landing, Boat Creek and Graham Creek should continue. Species composition and status data should be collected. Both monofilament nets of varying sizes and large and small rectangular crab traps should be utilised. As the Stuart operation expands, the survey should be expanded to include Scrubby and Targinnie Creeks and adjacent areas. It is important to devote some attention to the mud crab because of its importance as a target species for both recreational and commercial fishers and because of its role as a keystone species in mangrove communities.

Port Curtis Macrobenthic Monitoring and Research
May, 1999

Central Queensland
UNIVERSITY

Centre For Environmental Management
Central Queensland University
Gladstone Campus

Port Curtis Macrobenthic Monitoring and Research
May, 1999

Supervisor: Dr. Michael Walker BSc (Hons) (UTas), PhD (JCU)
Senior Research Fellow
Faculty of Applied Science
Central Queensland University

Authors: Samantha Lewis BSc (Hons) (UTas)
Kirsty M^c^Namara ADARM (CQU)

Table of Contents

1.0	**Executive Summary**	1
2.0	**Introduction**	2
3.0	**Project Objectives**	3
4.0	**Methodology**	4
4.1	**Sampling design**	4
4.2	**Replication**	4
4.3	**Sampling frequency**	4
4.4	**Field Collection**	5
4.5	**Laboratory sorting and classification**	5
4.6	**Statistical Analysis**	5
4.6.1	Shannon-Wiener Index	5
4.6.2	Equitability	6
4.7	**Sediment Sampling**	6
4.7.1	Air dry moisture content	6
4.7.2	Particle size analysis	7
4.7.3	Total combustible matter (estimate of organic matter content)	7
4.8	**Augmentation**	7
5.0	**Results**	8
5.1	**Statistical Analysis of Benthos**	8
5.2	**Common and Rare Species**	10
5.3	**Sediment Characteristics**	12
5.4	**Sediment and Benthos**	13
5.5	**Organic Matter**	13
6.0	**Discussion**	14
7.0	**References**	17

List of Figures

Figure 1 Species common to all stations in Port Curtis.
Figure 2 Average Particle Size Distribution for each Station.
Figure 3 Particle size distribution for each station over all sampling events.
Figure 4 Average Organic Matter Composition in Sediment for each Station.
Figure 5 Organic Matter Composition for each Station over all sampling events.

List of Appendices

Appendix 1 Shannon-Wiener diversity, equitability, number of species and abundance.
Appendix 2 Species and their abundance.

1.0 Executive Summary

GPA commissioned the consultants WBM Oceanics, Australia, to design a long term benthic monitoring program for Port Curtis to quantitatively assess whether current or future anthropogenic activities significantly impact benthic fauna and the Port Curtis ecosystem. Since November 1995, GPA has sponsored macrobenthic sampling at 16 Stations across Port Curtis. Southern Pacific Petroleum/Central Pacific Minerals supported an additional area south of Friend Point, before the Narrows, (Stations 17 - 20) from November 1995 and SPPD supported an area near the mouth of Flying Fox Creek from April 1997 (Stations 21 - 24).

Sampling occurred twice a year and involved determination of macrobenthic species diversity, equitability and abundance, as well as sediment composition and organic matter content.

Results to date suggest that Station 22 at the mouth of Flying Fox Creek is particularly low in species diversity and equitability, with high numbers of one species suggesting that the benthic community at this site is disturbed. Other stations near Flying Fox Creek have slightly reduced numbers of species and abundance compared to other Port Curtis stations in general. Stations 17, 18 and 20 at Friend Point are marginally lower in diversity. However, variable diversity in the harbour as a whole prevents this from being significant.

Several species are common across all stations in Port Curtis. These species may become important in the future as indicators of tolerant species. As multivariate analysis work continues it may become possible to use certain species as indicators of environmental stress. Analysis of species composition at Oil Shale stations reveals a high number of species of low abundance and few species of high abundance, suggesting that benthic fauna are not stable climax communities due to disturbance. Whether this is natural disturbance or anthropogenic can not be determined at this stage of the program.

Sediment composition and organic matter are important in determining the benthic community present at a site. Preliminary observations suggest changes in species composition with sediment type. Further sampling and multivariate analysis are required to further elucidate these trends. Changes in sediment composition and organic matter over time may reflect changes to Port Curtis in the past 3 years.

2. Introduction

Macrobenthic invertebrate communities have been shown to be sensitive to environmental stress, especially pollution, and therefore have the potential to detect gross and maybe subtle changes occurring in the aquatic environment (Gray, J.S. *et al*, 1990, Hartley, 1982, Rees, H.L. and Eleftheriou, A., 1989, Steimle, R.S., 1990). Macrobenthic invertebrate communities are sedentary and generally are relatively long lived and thus integrate recent past environmental conditions in terms of species diversity and abundance. They also have an intimate relationship with the sediment where pollutants accumulate and sometimes bioconcentrate.

Macrobenthic communities, both those living on the sediment or burrowing into it, directly interact with biological, physical and chemical components of the marine environment especially the sediment. Macrobenthos thus has considerable potential to detect environmental changes and disturbance and to be an indicator of ecosystem health. Scientific evidence of impacts and or changes in the marine macrobenthic community relies upon detection of statistically significant community changes in treatment/disturbed areas, which do not occur in undisturbed/control areas.

The Gladstone Port Authority (GPA) determined in consultation with the Queensland Department of Environment and the consultants WBM Oceanics, Australia, that macrobenthic communities will serve as the primary indicators for the long term monitoring of Gladstone Harbour (WBM, 1993). GPA together with the Department of Environment conducted the Curtis Coast Study (QDEH, 1994), which encompassed Port Curtis and adjacent coastline known as the Curtis Coast. This provides a baseline inventory of land and marine resources. During the period of this study GPA commissioned the consultants WBM Oceanics, Australia, to design **a long term** benthic monitoring program for Port Curtis (WBM, 1993). A sampling design was mutually determined by GPA and WBM. This utilised power analysis techniques to predict an appropriate level of replication of sampling necessary to achieve the primary objective of such a monitoring program, namely **"to quantitatively assess whether current or future anthropogenic activities significantly impact benthic fauna and the Port Curtis ecosystem".** WBM Oceanics Australia have undertaken short term macrobenthic studies within Port Curtis for GPA and the Queensland Department of Environment, (WBM, 1990, 1991).

The Gladstone Port Authority in 1995 invited Central Queensland University (CQU), through its developing Centre for Environmental Management (CEM), to instigate long term marine environmental programs for Port Curtis involving initially benthos and later seagrass and

mangroves under the direction of Senior Research Fellow/Senior Lecturer, Dr Michael Walker. The macrobenthic program is the cornerstone of marine environmental research and monitoring undertaken by the CQU Centre for Environmental Management. This marine environmental research and monitoring program will soon become part of the work of the newly funded Cooperative Research Centre for Centre for Coastal Zone, Estuary and Waterway Management. The macrobenthic program in terms of design and implementation follows the program developed by GPA and WBM in 1993.

The WBM/GPA sampling design regime allowed for future expansion if required. SPP/CPM supported an additional area south of Friend Point before the Narrows (Stations 17 - 20) from November 1995 and SPPD supported an area near the mouth of Flying Fox Creek from April 1997 (Stations 21 - 24). Friend Point Stations were established as part of the monitoring for the Stuart Oil Shale Development Stage 1 project. Flying Fox stations were for the Stage 2 development. This report analyses data for sampling periods up to and including April 1998. Subsequent samples are yet to be processed. Processing of samples is a lengthy time consuming task and there is always a lag or one or two sampling events.

3. Project objectives

GPA and WBM defined the research aims and objectives of the macrobenthic program in 1993 as follows **"to quantitatively assess whether current or future anthropogenic activities significantly impact benthic fauna and the Port Curtis ecosystem".**

The current research goal of the Port Curtis marine environmental research program is to **produce scientifically credible protocols, tools and techniques to predict the combined effects of important stressors on the Port Curtis marine ecosystem and its components.**

Anthropogenic stressors which jeopardise/threaten the Port Curtis and Central Queensland marine ecosystem include:

- catchment alteration resulting in changing nutrient and sedimentation loads
- habitat loss and alteration
- planned and unplanned biotic introductions
- pollution from industrial, shipping, agricultural and urban sources.

Research aims include:

- determination of simple and multiple stressor response relationships
- development of spatial and temporal sampling procedures and models
- quantification of variability of multiple stressor effects
- separation of stressor effects from natural variability.

4.0 Methodology

4.1 Sampling design

The Port Curtis macrobenthic monitoring program was recommended to GPA by WBM to be a stratified sampling design using two environmental types, treatment/disturbed and control/undisturbed areas. Treatment areas were originally located in the vicinity of Auckland Point Wharf and Clinton Coal/R G Tanna Wharf. Control areas are located adjacent to Curtis Island and at Grahams Creek in the Narrows. Within each area 4 sampling sites were selected by GPA giving a maximum pooled data set of 8 stations in treatment and control areas. Two additional treatment sites (8 stations) have been located at Friend Point and adjacent to Flying Fox Creek (Oil Shale) making a total of 24 stations (16 treatment and 8 control).

4.2 Replication

Statistical power analysis techniques based on WBM data (WBM, 1993) were used by WBM to predict the number of replicate samples needed per site. Results indicated that a replication of 10 samples per station effectively detects (with a power of >80%) changes of ca 14% in benthic parameters between each of the 4 areas (2 treatment, 2 controls) and between treatment and control areas (WBM, 1993).

4.3 Sampling frequency

Sampling frequency was recommended to be 2 sampling periods per annum i.e. late dry season sample, November and a late wet season sample, April (WBM, 1993). Sampling periods are representative of previous benthic surveys within Port Curtis and of periods of maximum and minimum benthic populations respectively (Saenger, P., Moverley, J. and Stephenson, W., 1980).

4.4 Field collection

Samples were collected in the field from a chartered stable platform (MV RUYS) using a $0.1m^2$ van Veen grab in November 1995, April 1996, November 1996, April 1997, November 1997, April 1998, November 1998 and April 1999. A small portion of sediment was collected from each sample and retained for particle size analysis. Samples were sieved through 1mm sieves and preserved in 5% formalin/seawater for at least 72 hours. Samples were later changed into 70% ethanol sometimes to which glycerol has been added and stored for future sorting.

4.5 Laboratory sorting and classification

Samples were sorted in the laboratory using dissection microscopes and abundance noted. The benthic fauna was identified in the laboratory to family level but was separated and preserved for identification to the species level in the future as required. Line drawings were prepared for all fauna identified.

4.6 Statistical Analysis

4.6.1 Shannon-Wiener Index

As an ecological concept, abundance is an important component of diversity. A greater number of species increases species diversity, and a more even or equitable distribution among species also increases diversity.

The recommended and most commonly used index is the Shannon-Wiener Index, H',

$$H' = -\sum_{i=1}^{S} (P_i \log_e P_i)$$

Where N is the total number of individuals of all species in sample ;

n_i is the number of individuals of the ith species in sample, $n > 0$;

P_i is the relative frequency n_i /N for the ith species;

S = total number of species.

Thus the value of H' is dependent upon the number of species present, their relative proportions, sample size (N), and the logarithm base. The choice of the base of logarithm is arbitrary but in comparing indices the base used should be stated and be the same. In this paper the natural base of the logarithms *e* is used.

4.6.2 Equitability

Equitability is the ratio of observed diversity to that of a completely equal species frequency distribution (range 0-1). It can be quantified separately using the Shannon-Wiener Index as

$$J' = \frac{H'}{H'_{max}}$$

where H' is the observed species diversity and H'_{max} is the logarithm of the total number of species (S).

4.7 Sediment Sampling

4.7.1 Air dry moisture content

Sediment samples were obtained using a van Veen grab from each benthic site in November 1995 to April 1999. Prior to the analysis of particle size distribution and organic matter content, the moisture content of air dry soil was determined to correct for the extra mass of water present in air dried samples (Bruce and Rayment, 1982). An approximate 100g sample of air dried sediment from each mangrove site was weighed and placed in an oven at 105°C until constant mass was achieved through subsequent weighing. Air dry moisture content was taken as the water remaining in the air dry sample expressed as a percentage of the oven dry sample mass (AS1289. B1.1, 1977). The formula used was an Australian Standard (AS1289. B1.1, 1977) for moisture content (w) of sediment as a percentage of dry soil mass:

$$W = \frac{m_b - m_c}{m_c - m_a} \times 100$$

Where: m_a = mass of the container
m_b = mass of container and air dry soil
m_c = mass of container and oven dry soil

4.7.2 Particle size analysis

Approximately 100 g (for sediment with a range of very coarse to fine particles, at least one kilogram of sediment is needed to establish a more accurate distribution) of air dried sediment was ground with mortar and pestle so as to retain discreet particles. The resultant sample was weighed and then sieved through a stacked array of Endecott test sieves with apertures of 2mm, 1mm, 500μm, 250μm, 125μm and 63μm respectively. A Fritsch Analysette 3.0 mechanical shaker was used to agitate the sieves. After dry sieving (the dry sieving process is only applicable for coarse sediment, sediment with a mixture of very coarse and fine particles may undergo both dry and wet sieving), the sediment fractions remaining on the sieves were then wet with sodium hexametaphosphate dispersing solution (sodium hexametaphosphate was initially diluted with demineralised water at 40mL/1000mL to make a stock solution and this was further diluted at 100mL/500mL to wash the sediment). This was allowed to stand for approximately one day. The resultant slurry was then hand washed through the sieve stack until the wash water was clear and the remaining material air dried at 40°C until constant mass was reached. Each fraction's mass was calculated as a percentage of the total samples mass and corrected for air dry moisture content. The fraction less than 63μm was calculated as the difference between the sum of the fractions greater than 63μm and the total mass of the sample (AS 1289. C6.1, 1977).

4.7.3 Total combustible matter (estimate of organic matter content)

Approximately 100 grams of sediment from each site was ground, placed in a crucible with lid, and oven dried at 105°C until constant mass was reached. Mass was recorded and the samples placed in an ashing furnace to be combusted for one hour at a temperature of 850°C (AS 3580. 10.1, 1991). Samples were then removed and replaced in the drying oven at 105°C to cool before further weighing. The difference in mass between initial and final weighing was expressed as a percentage of the initial mass and used as an estimate of the percentage organic matter.

4.8 Augmentation

The macrobenthic program allows additional sampling areas to be added over time and compared with existing control blocks (as occurred with Oil Shale sites). Parallel marine monitoring and research studies are currently undertaken by the Centre for Environmental Management involves mangroves, seagrass and mud crabs. Data from these studies in the future will assist greatly in the interpretation of benthic monitoring program results.

5.0 Results

5.1 Statistical Analysis of Benthos

Macrobenthic fauna abundance and diversity have been analysed from both station and site perspectives. Shannon-Wiener diversity, equitability, species diversity and abundance for Stations 17-24 (Sites 5 and 6) are presented in Tables 1-8.

Table 1. Shannon-wiener Diversity for Stations 17 - 24

	17	18	19	20	21	22	23	24
Nov-95	2.63	2.66	3.47	3.00				
Apr-96	2.90	2.87	3.33	3.25				
Nov-96	2.91	2.72	3.55	3.33				
Apr-97	2.91	2.88	3.14	2.99	3.02	1.48	2.57	2.64
Nov-97	3.04	2.89	3.55	3.20	2.96	1.53	2.80	2.95
Apr-98	2.79	2.83	2.75	2.78	2.67	1.08	2.64	2.84

Table 2. Equitability for Stations 17 - 24

	17	18	19	20	21	22	23	24
Nov-95	0.58	0.59	0.71	0.68				
Apr-96	0.67	0.64	0.73	0.73				
Nov-96	0.69	0.66	0.75	0.72				
Apr-97	0.65	0.69	0.70	0.73	0.81	0.35	0.67	0.68
Nov-97	0.69	0.67	0.75	0.71	0.74	0.36	0.77	0.72
Apr-98	0.65	0.67	0.70	0.77	0.75	0.29	0.78	0.77

Table 3. Total number of Species for Stations 17 - 24

	17	18	19	20	21	22	23	24
Nov-95	91	90	137	84				
Apr-96	75	86	97	87				
Nov-96	68	61	114	105				
Apr-97	87	67	90	59	41	70	46	50
Nov-97	82	74	113	91	53	73	39	61
Apr-98	75	69	51	37	35	44	30	41

Table 4. Abundance of Species for Stations 17 - 24

	17	18	19	20	21	22	23	24
Nov-95	3839	9094	2595	1248				
Apr-96	5170	4575	2427	1162				
Nov-96	2366	2612	1290	1708				
Apr-97	3001	2821	1737	840	280	4037	722	1476
Nov-97	1988	2450	2059	1021	483	3028	374	782
Apr-98	2269	2161	1111	312	358	6722	267	464

Table 5. Shannon-Wiener for sites 5 -6

	5	6
Nov-95	3.12	
Apr-96	3.31	
Nov-96	3.41	
Apr-97	3.24	2.47
Nov-97	3.48	2.49
Apr-98	2.97	1.54

Table 6. Equitability for sites 5 -6

	5	6
Nov-95	0.59	
Apr-96	0.65	
Nov-96	0.67	
Apr-97	0.66	0.53
Nov-97	0.68	0.52
Apr-98	0.62	0.36

Table 7. Total species for sites 5- 6

	5	6
Nov-95	199	
Apr-96	165	
Nov-96	161	
Apr-97	138	109
Nov-97	164	124
Apr-98	116	76

Table 8. Total abundance for sites 5 - 6

	5	6
Nov-95	16746	
Apr-96	13334	
Nov-96	7976	
Apr-97	8399	6515
Nov-97	7518	4667
Apr-98	5853	7811

Shannon-Wiener was similar between stations, with the exception of Station 22. Station 19 and 20 showed marginally higher diversity, and variation in diversity occurred between sampling periods for all stations. Seasonal variation was not apparent from this data. Equitability was again lower at Station 22, but similar between other stations. Station 19 had high numbers of species, while 21 and 23, 24 had lower numbers of species. Abundance was high at Stations 17, 18 and 22.

Site 6 has low Shannon-Wiener diversity, equitability and number of species. Abundance is similar to those elsewhere. When assessing these parameters by station it is apparent that the indices for Site 6 are greatly affected by the low diversity and equitability of Station 22. Station

21, 23 and 24 have comparable diversity and equitability to other sites, despite generally low numbers of species and abundance. High abundance of a few species at Station 22, as indicative of a disturbed community, cause diversity and equitability indices to be lowered.

Stations 17-24 can be compared to other stations within the Harbour. Shannon-Wiener diversity, equitability, number of species and abundance have been tabulated in Appendix 1 for other stations and sites presently being monitored in Port Curtis (as sponsored by the Gladstone Port Authority).

It is apparent that Station 22 in particular and Site 6 as a whole has low diversity compared to other stations in Port Curtis. Stations 17, 18 and 20 are also marginally lower in diversity, as are Stations 1, 2 and 14. Equitability was dramatically reduced at Station 22 and at Site 6 as whole. Number of species and abundance at stations across the harbour were highly variable with Station 21, 22 and 24 recording comparatively low species numbers and Station 22 having particularly high abundance.

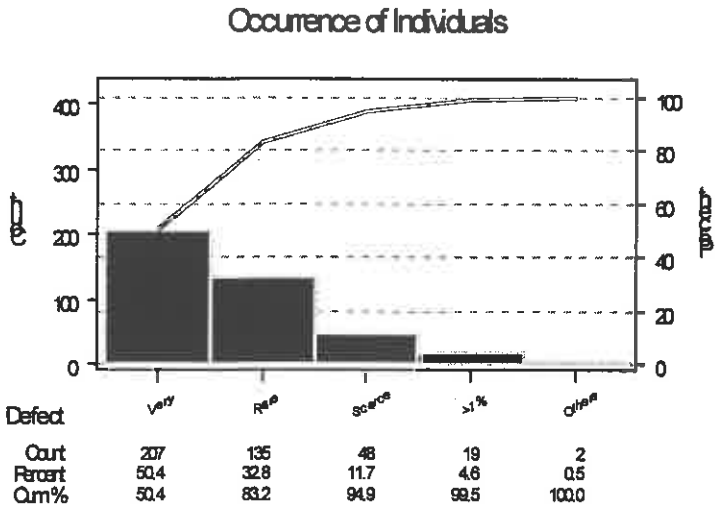
Site 5 has comparable diversity and equitability to other sites, though perhaps tending to be lower than average. This reflects the high abundance at this site. Station 19 had higher diversity and equitability than other stations.

5.2 Common and Rare Species

Abundance of the Species

Across the 8 stations and 6 sampling events, two species were found to be particularly abundant. Family Rissoidae sp. 1 and *Ringicula* sp. had more than ten percent of the total abundance (15.49% and 14.28% respectively).

Of the 411 species (78, 819 individuals) found at the 8 stations over the 6 sampling events, most were most fall in the category of rare and very rare with many examples of only one or two individuals. Species are categorised according to their abundance in Appendix 2. 207 species are classed as very rare (<0.01% of the total abundance), 135 as rare (0.01-0.1% of the total abundance), 48 as scarce (0.1% to 1.0% of the total abundance), 19 as common (1-10% of the total abundance) and 2 species as abundant (>10% of the total abundance). The figure below illustrates this data.



Occurrence of the Species

While no species has been found at every station in every sampling period 28 species have been found at every station in at least one sampling period. The 28 species that occurred at each station are shown in the table below.

Species	Abundance	Species	Abundance
Glycera sp.	35	Family Collumbellidae 1	3609
Nassarius sp.	26	*Plicarcularia burchardi*	676
Cyclostremiscus sp. 1	493	*Dentalium* sp.	2048
Anodontia omissa	40	*Epitonium* sp. 3	1159
Cyclostremiscus sp. 2a	409	*Epitonium* sp. 4	1281
Cyclostremiscus sp. 2	352	Family Rissoidae 1	12212
Cyclostremiscus sp. 1a	1796	Family Collumbellidae 2	2153
Nassarius sp.	815	*Nassarius dorsatus*	228
Turritella sp. 3	324	Class Gastropoda 25	510
Family Pyramidellidae 2	305	*Atys cylindricus*	1031
Epitonium sp. 2	432	*Syrnola* sp.	3528
Class Gastropoda 38	496	*Cellanthus* sp.	2639
Family Littorinidae 1	901	*Nassarius* sp.	4629
Family Neritidae 1	1346	*Ringicula* sp.	11259
Mactra abbreviata	239		

Of the 29 species, 23 are gastropods comprising of 13 families; 2 are bivalves of 2 families; 1 is a polychaete; 2 are foraminifera and one is a scaphopod. Distribution and ecology of these families are discussed in Table 10. Many species on this list occur worldwide, and a variety of trophic feeding mechanisms are present, including carnivores, herbivores, parasites and scavengers.

Species that were found in all 8 Oil Shale stations were frequently high in abundance. Of the 29 species, 2 species were abundant (Rissoidae and *Ringicula* sp.), 14 were common and 8 were scarce. This means that species that are found frequently are often also found in high numbers. Species that are rarely found are generally found in low numbers.

Eleven species were found at all 24 stations throughout Port Curtis (Oil Shale and GPA) in least one sampling period. These species are listed below and illustrated in Figure 1.

Family Atyidae (*Atys cylindricus*)
Family Collumbellidae (Species 1 and 2)
Family Epitonidae (Species 2 and 3)
Family Nassaridae (Species 1 and 3)
Family Pyramidellidae (*Syrnola* sp.)
Family Turritellidae (*Turritella* sp 3)
Family Vitrinellidae (*Cyclostremiscus* sp. 1)
Formanifera (Cellanthus sp.)

These species are therefore tolerant of many different environmental conditions and sediment types.

5.3 Sediment Characteristics

Particle size distribution was analysed for each sampling station and each sampling period (for both GPA and Oil Shale sites). An average was calculated for each station over all sampling times to create a description of each station. Table 9 outlines the sediment characteristics of each station.

Figure 2 shows the average particle size distributions for each station, while Figure 3 shows the change in particle size distribution for each station over the sampling periods. Several stations exhibit change over time.

Station 1 was moved in April 1998 due to land reclamation for a container wharf and hard stand area at that site. Therefore soil and benthic samples from prior to April 1998 cannot be compared to those after this date. Sediment samples from Station 7 were not taken in April 1998 due to high rock content (consistent with previous particle size distribution). In April, 1998 Stations 18 and 21 had less silt, while Station 19 had more silt. Particle size distribution also varied at Stations 6, 5, 10, 12 and 16. Station 19 had increased silt and clay content in April 1998 and a corresponding decrease in Shannon-Wiener diversity, number of species and abundance.

5.4 Sediment and benthos

Within Stations 17-24, several sites are primarily silt and clay (Station 17, 18, 20, 21, 23). These sites had several common benthic species: Family Collumbellidae, Epitoniidae, Nassaridae, Rissoidae, Ringiculidae, Neritidae, Littorinidae and Vitrinellidae. Stations 19, 22 and 24 were more sandy in composition and had common species also: Family Collumbellidae, Epitoniidae, Rissoidae, Ringiculidae, Littorinidae, Vitrinellidae, Scaphopoda and Formanifera. In several cases, the distribution agrees with that stated in the literature (Table 10). It is interesting to note that several of these families are common to both sandy and silty sites, suggesting they have wide spread distribution in the harbour. This is evidenced by their presence at all stations in Port Curtis at one sampling period.

Station 22 had the lowest silt content, and also the lowest Shannon-Wiener diversity and equitability.

5.5 Organic Matter

Organic matter content is presented for each station (GPA and Oil Shale) over sampling periods (Figure 3) and also as an average for each station within sites (Figure 4). Generally organic matter correlates closely with silt content of the sediment. This is as would be expected. There are a few exceptions to this where organic content is high despite large proportions of sand in the sediment. Stations 17, 18, 20, 21 were generally high in organic matter, consistent with their high silt content. Station 19 however has relatively high organic content despite its sandy nature. Stations 22 and 24 had low organic matter composition, correlating with their sandy sediment, however 23 had less organic matter than expected with its high silt load. Changes in organic matter composition over time often also correlated with changes in silt composition over time, however there were many exceptions to this.

There appears to be no correlation between diversity indices and organic matter. Since silt and organic matter are generally closely related, benthic fauna found in silty areas would probably reflect those that prefer high organic loads. Shannon-Wiener diversity was low at Station 22, where organic content was also low.

6.0 Discussion

Shannon-Wiener diversity is a common and widely used index reflecting both the number of species present and the abundance of each species. High Shannon-Wiener reflects high numbers of species. Equitability refers to the way abundance is distributed between species. High equitability suggests an even spread of abundance between species (e.g. ten species all with 10 individuals). Reduced equitability reflects skewed distribution, such that there are increased numbers of species with low or high abundance compared to the mean.

Classic competition theory explains the change in community composition with disturbance. Under stable conditions, communities comprise competitive species which are adapted to the particular conditions of the site. Species composition is fairly stable, with species having generally similar abundance, leading to high equitability. Under conditions of disturbance or stress (such as changes in salinity, contaminants etc) a shift in community composition occurs, with opportunistic species – those which are not normally good competitors but thrive in adverse conditions, becoming more prevalent. These species can then increase in numbers due to a decline in other competitive species, leading to lower equitability.

At Station 22, disturbance is suggested by the prevalence of Rissoidae species and the low equitability. Diversity is also reduced. Station 22 is located in the mouth of Flying Fox Creek and may be an example of a disturbed community. Flying Fox Creek itself has been sampled by WBM (1990) and is known to be poor in benthos compared to other sites in the Harbour. Boat Creek was also found to be depauperate (WBM, 1990). CEM has unpublished data for Boat Creek which also supports this observation.

Other Stations in Site 6 had relatively low abundances, however they were not particularly unusual when compared to other stations in Port Curtis.

The macrobenthic communities of Port Curtis are variable with time and location. This was also observed by WBM (1990) who suggested that the frequency of flood events prevents benthic communities from reaching a stable climax community. Creeks appear to be more depauperate, while intertidal flats support higher diversity, increasing with distance from the shore and seagrass composition (WBM, 1990).

Species that were found frequently at Oil Shale sites were also generally high in abundance. Over 50% of the species found were of very low abundance (one or two individuals). Several

species are present all several sites across the harbour. This implies that those species are more tolerant of environmental stress, and thus are able to thrive in environments where other species are depauperate in numbers. These may be the opportunistic species mentioned earlier, and therefore may reflect disturbed environments. With long term and multivariate analysis of the current data (being undertaken) it will be possible to further isolate these species and possibly determine a suite of species capable of indicating environmental change. Trophic analysis may also be available, and prove to be a valuable research tool, over time as research into benthic fauna continues.

Sediment composition varied throughout the harbour and over time. Differences at stations within the harbour may be attributed to variations in current, wave energy, and tidal flow. Larger sediment material predominates in high energy locations (such as tidal and shipping channels and mouths of tidal creeks and inlets) while in low energy locations silt, clay and organic matter will be present and accrete with time. Clay particles are small and provide a large surface area onto which organic material binds, thus as the percentage of clay in the sediment increases so does the amount of organic material.

The composition of organic material in the sediment is important as it determines the ability of sediment to bind contaminants or pollutants and the quality of the water above the sediment. Contaminants/pollutants in the water may bind directly to clay and organic matter, or may bioaccumulate and bioconcentrate in seagrass and enter the organic chain when seagrass leaves break free and decompose. Decomposition of organic matter requires oxygen such that high levels of organic matter can cause overlying water to become oxygen depleted. Thus it is possible in seabed areas of high organic matter, high temperature and little water circulation that oxygen may be depleted to a point that the sediment becomes anaerobic and H_2S becomes abundant. Further, levels of contaminants may become high. Organic matter in the Oil Shale seagrass beds was higher at Station 17, 18, 20 and 21 and so contaminants may be bound more readily at these stations.

Sediment type also affects the benthic fauna present at a station. Trends were observed at Oil Shale stations in the species composition with sediment type, such that slightly different species were found at sandy sites and silty sites. At present this represents observations only and these patterns can only be fully elucidated with further sampling to enable long term data sets and using multivariate analysis techniques.

The distribution of infaunal and some other benthic invertebrates is known to be determined by the sediment. There are close relationships between infaunal feeding habitats, organic content and the mechanical nature of the substrate. Silty sediments are usually soft, have little overlying water circulation, and have high organic content within and on the bottom. This habitat favours filter feeders which feed on the organic matter present, however these can not live in areas devoid of circulation, as they rely upon constantly suspended food in the water. Fauna which live in silty areas usually burrow into the mud as defense from predators. Maintenance of burrows in extremely silty areas is often difficult as burrows collapse, with increased sand content facilitating burrow stability.

Sandy sediments usually occur in areas with more current and generally are less rich in organic material than silty sediments (as observed in this study). Such sediments support filter feeders which feed on suspended material in the water. The more pronounced the current the higher the potential food availability. Intermediate sand content is required to prevent burrow collapse but allow burrow excavation.

In areas where the current is very strong, sediment transport occurs routinely and benthic invertebrates have trouble maintaining their position. These areas are usually gravelly, shelly or rocky and often unfavourable to filter feeders.

Generally silty, sandy sediments or sediments composed of a mixture of clay, silt and sand support the greatest diversities of macrobenthic invertebrates. Further sampling and research into the trophic ecology of the species of Port Curtis may elucidate these trends.

Shipping movements either large ships, service or recreational vessels all have the capacity to alter, and have altered, bottom sediments. The natural sediments of Port Curtis ie sediments prior to major port development, were well described historically in 'Sediments and sedimentary processes in Gladstone Harbour, Queensland' (Conaghan, 1966). Changes recorded in our study may reflect the changes occurring around Port Curtis over the past 3 years, which include major reclamations and Port developments e.g. Auckland container wharf and Fishermans Landing wharf.

7.0 References

Abbott, R.T. and Dance, S.P. (1982). *Compendium of Seashells*. E.P. Dutton, New York.

Australian Standard AS 1289.B1.1 (1977) *Methods of testing soil for engineering purposes: Determination of the moisture content of a soil - oven drying method (standard method)* Standards Association Australia.

Australian Standard AS 1289.C6.1 (1977) *Methods of testing soil for engineering purposes: Determination of the particle size distribution of a soil - standard method of analysis by sieving.* Standards Association Australia.

Australian Standard AS 3580.10.1 (1991) *Methods for sampling and analysis of ambient air: Method 10.1 Determination of particulates - deposited matter - gravimetric method.* Standards Association Australia.

Bruce, R.C. and Rayment, G.E. (1982) *Analytical methods and interpretations used by the Agricultural Chemistry Branch for soil and land use surveys*. Queensland Department of Primary Industries Bulletin QB820004.

Conaghan, P., *Sediments and sedimentary processes in Gladstone Harbour, Queensland.* Vol. VI. 1966, St Lucia: University of Queensland Press.

Gray, J.S., Clarke, K.R., Warwick, R.M. and Hobbs, G. (1990) Detection of Initial Effects of Pollution on Marine Benthos: An Example from the Ekofisk and Eldfisk Oilfields, North Sea. *Marine Ecology Progress Series* **66**: 285-299

Hartley, J.P. (1982) Methods For Monitoring Offshore Macrobenthos. *Marine Pollution Bulletin* **13**:150-154

Hutchings, P. (1984) *An illustrated guide to the estuarine polychaete worms of New South Wales.* Coast and Wetlands Society, Sydney.

Mather, P and Bennett, I. (1993) A Coral Reef Handbook: a guide to the geology, flora and fauna of the Great Barrier Reef. Surrey Beatty & Sons Pty Limited, NSW.

Queensland Department of Environment and Heritage (1994) *Curtis Coast Study - Resource Report.* Queensland Department of Environment and Heritage, Rockhampton.

Rees, H.L. and Eleftheriou, A. (1989) North Sea Benthos: A Review of Field Investigations into the Biological Effects of Man's Activities. *J. cons. Int. Explor. Mer.* **45**:284-305

Saenger, P., Moverley, J. and Stephenson, W. (1980) Seasonal and Long Term Patterns in the Macrobenthos Verses Benthic Stability in a Subtropical Estuary. In *Proceedings of the Ecological Society of Australia* **15**:229-237

Steimle, R.S. (1990) Benthic Macrofauna and Habitat Monitoring on the Continental Shelf of the Northeastern United States. 1. Biomass. *Technical Report NMFS 86,* US Department of Commerce.

WBM Oceanics Australia (1990) *Impact Assessment Study Reclamation of Land West of Calliope River.* Report prepared for Gladstone Port Authority, WBM Oceanics, Spring Hill. 1-175.

WBM Oceanics Australia (1991) *Fisherman's Landing - Trade Waste Outfall Benthic Monitoring Report 1991-1992.* Report prepared for Queensland Department of Environment and Heritage, WBM Oceanics, Spring Hill. 1-44.

WBM Oceanics Australia (1993) *Proposed Sample Design for Benthic Monitoring Programme of Gladstone Harbour.* Report prepared for Gladstone Port Authority, WBM Oceanics, Spring Hill. 1-21.

Wye, K.R. (1991). *The Illustrated Encyclopedia of Shells.* Sandstone Books, NSW.

Table 9. Sediment Characteristics for November 1995 to April 1998 for each Station in Port Curtis.

Site	Station	Sediment Description
1	1	Mostly clay and silt, some very fine sand
1	2	Clay, silt
1	3	Large rocks and very coarse sand
1	4	Large rocks and very coarse sand
2	5	Medium sand, silt and clay
2	6	Rocks and sand
2	7	Large rocks and sand
2	8	Large rocks and medium sand
3	9	Large rocks and fine to medium sand
3	10	Mostly clay and silt, fine sand and rocks
3	11	Mostly clay and silt, fine sand and rocks
3	12	Large rocks, medium to very coarse sand
4	13	Large rocks, clay and silt
4	14	Mostly clay and silt
4	15	Large rocks, coarse sand, silt and clay
4	16	Large rocks, coarse sand, silt and clay
5	17	Mostly clay, silt and fine sand
5	18	Mostly clay, silt and fine sand
5	19	Mostly clay, silt and fine to coarse sand
5	20	Mostly clay, silt and fine sand
6	21	Clay, silt and very fine sand
6	22	Clay, silt and fine to very coarse sand
6	23	Mostly clay, silt and very fine to course sand
6	24	Some silt, clay and very coarse sand

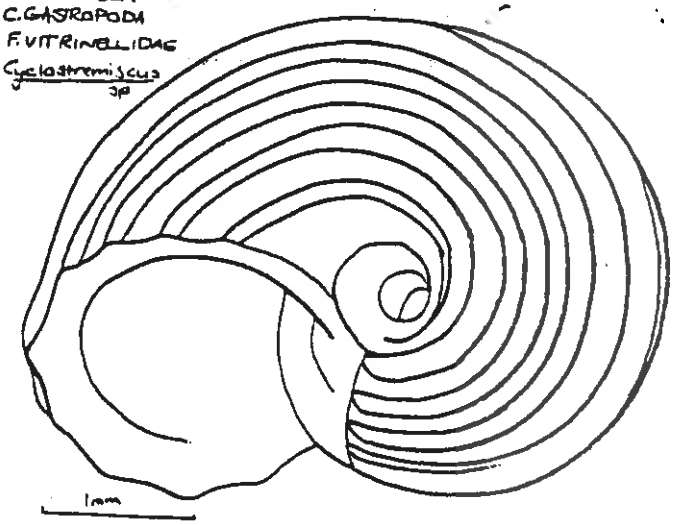
Table 10. Common families and their distribution and ecology.

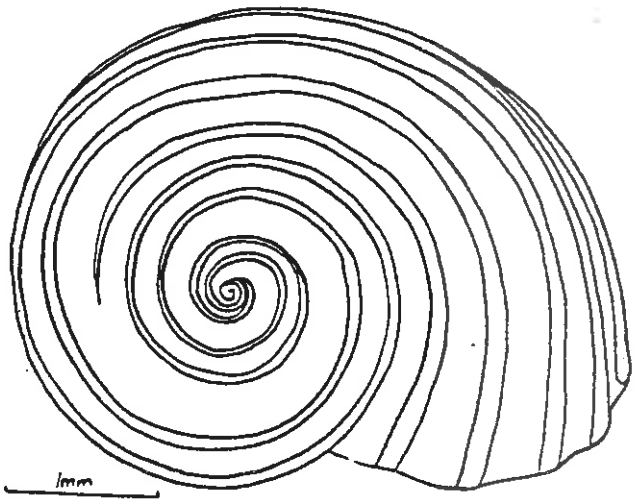
Family	Distribution and Ecology
Scaphopoda *Dentalium* sp.	Occur in worldwide locations, inhabiting either shallow or, more likely, deep water, where they can burrow in sand or mud with their posterior end exposed. They are carnivorous group, feeding on protozoa, foraminifera and other micro-organisms. [1]
Foraminifera	Usually feed on minute organisms, larvae and eggs.[2]
Lucinidae	Inhabit both shallow and deep water and occur world wide [1]
Mactridae	Distributed worldwide mainly in shallow water.[1]
Glyceridae *Glycera sp*	Active burrowers in sandy substrates. It is likely that most glycerids are active carnivores. [3]
Nassariidae	Live shallow intertidal waters in muddy substrates and are scavengers and carnivores. Live together in large colonies. [1]
Vitrinellidae	Many are freshwater , a few parasitic.[4]
Turritellidae	Herbivorous and inhabit offshore waters in coarse sand or mud. [1]
Pyramidellidae	Many are parasitic [4]
Epitoniidae	Distributed worldwide and mostly living in shallow water and found among soft corals and sea anemones on which they feed. [1]
Littorinidae	Some live on rocky coasts, others prefer the mangroves. They are herbivorous and feed on seaweed and algae.[1]
Neritidae	Live either on rocks or mangrove trees. Well suited to intertidal locations and are herbivores. [4]
Collumbellidae	Live in warm and tropical seas either on the shore or in deeper waters. They are carnivorous scavengers, feeding mainly at night. [1]
Rissoidae	Often herbivores, sometimes found on algae [2]
Atyidae	Intertidal sand dweller[1]
Ringiculidae	Burrowers in fine sand and mud. Found from the intertidal to 5000m.

[1] Wye, 1991 [2] Mather and Bennett, 1993 [3] Hutchings, 1984 [4] Abbott and Dance, 1982

Figure 1. Common species occurring at all stations in Port Curtis.

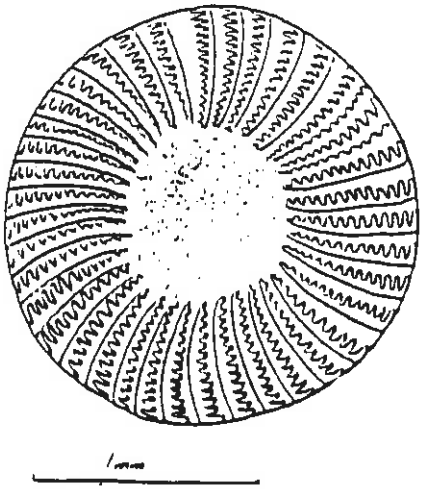
P. MOLLUSCA
C. GASTROPODA
F. VITRINELLIDAE
Cyclostremiscus sp

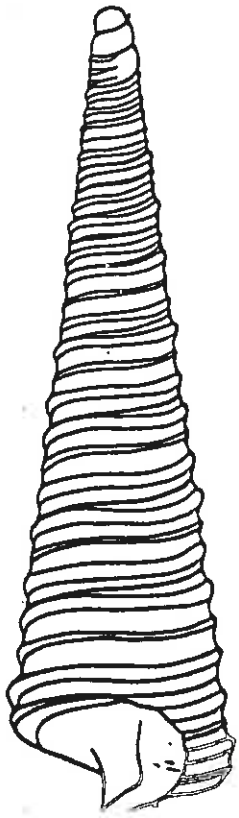




C GASTROPODA
F TURRITELLIDAE
G. Turritella sp

P. PROTOZOA
C. RHIZOPODEA
O FORAMINIFERA
F. ELPHIDIIDAE
Cellanthus sp

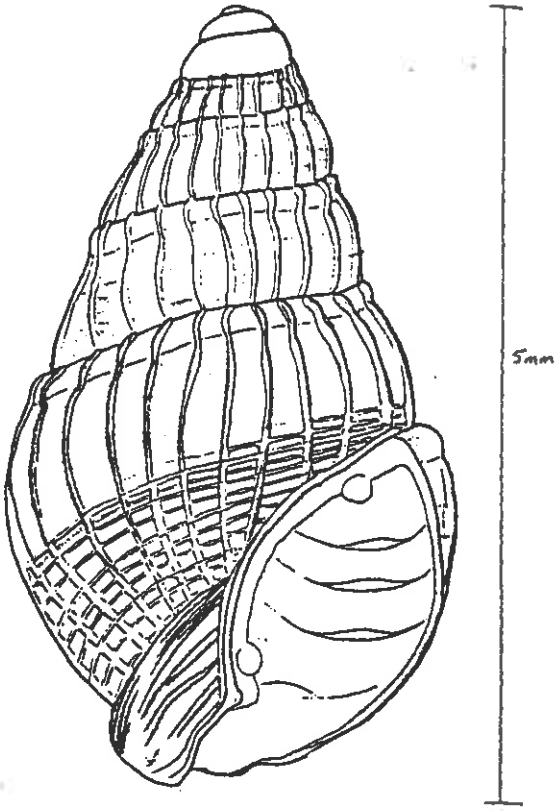


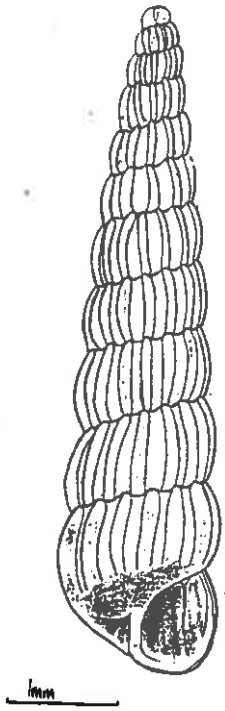


GASTEOPODA
NASSARIDAE
Nassarius sp (australis ?)

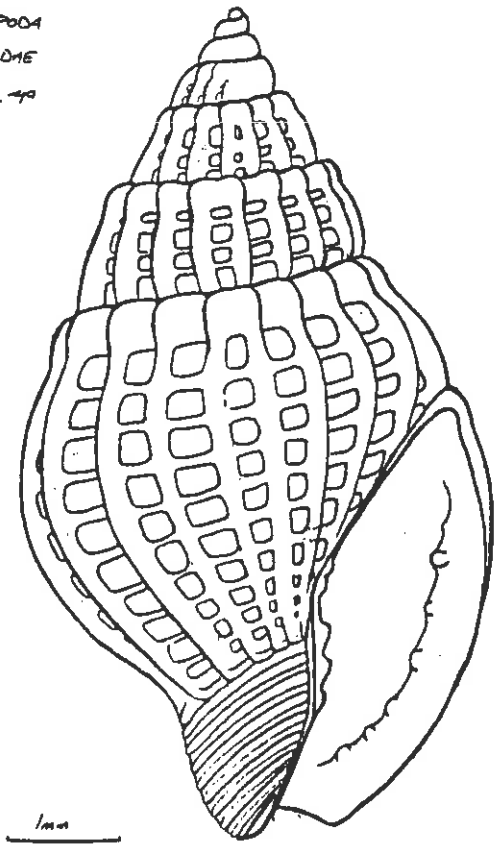
Figure 1 cont...

P. MOLLUSCA
C. GASTROPODA
O.
F. EPITONIIDAE
Epitonium sp.



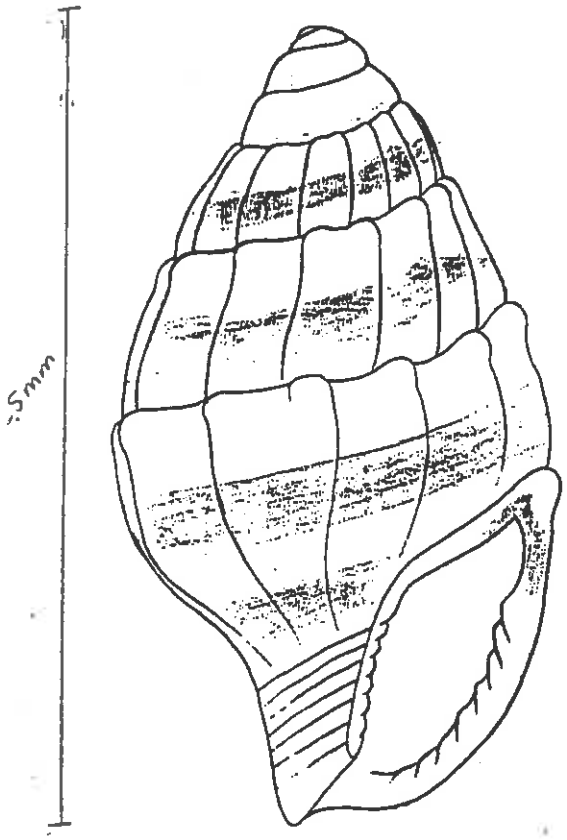


P. MOLLUSCA
C. GASTROPODA
F. NASSARIDAE
Nassarius sp

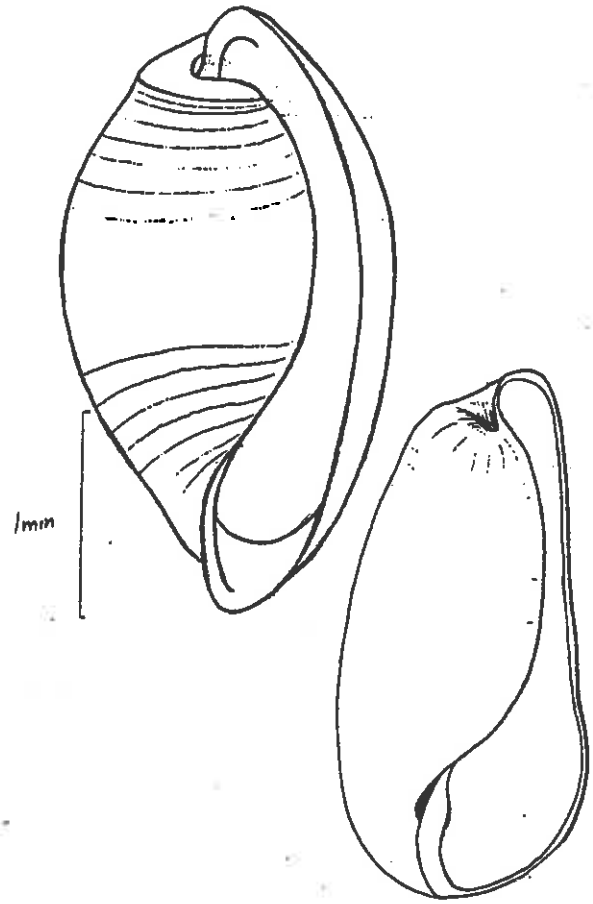


P. MOLLUSCA
C. GASTROPODA
F. PYRAMIDELLIDAE
Syrnola sp

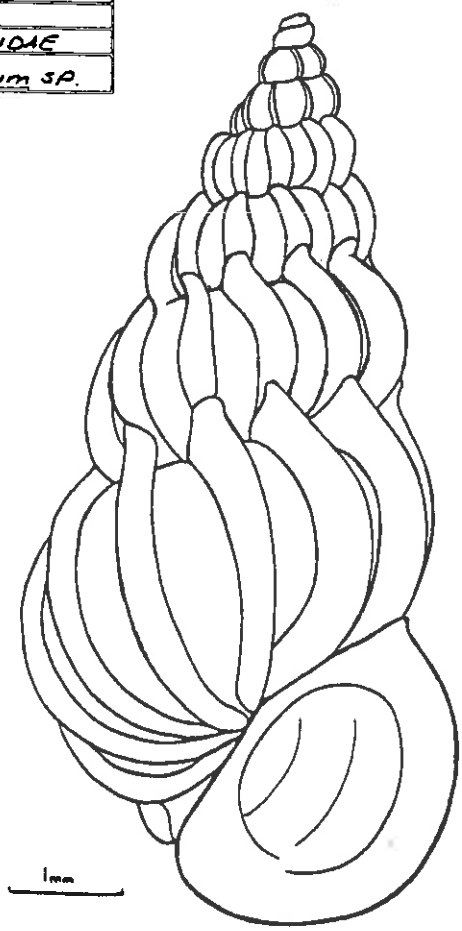
ASTROPODA
OLUMBELLIDAE



C. GASTROPODA
F. ATYIDAE
G. Atys cylindricus (cf) Hebling, 1779



OLLUSCA
ASTROPODA
EPITONIIDAE
Epitonium sp.



P. MOLLUSCA
C. GASTROPODA
F. COLUMBELLIDAE

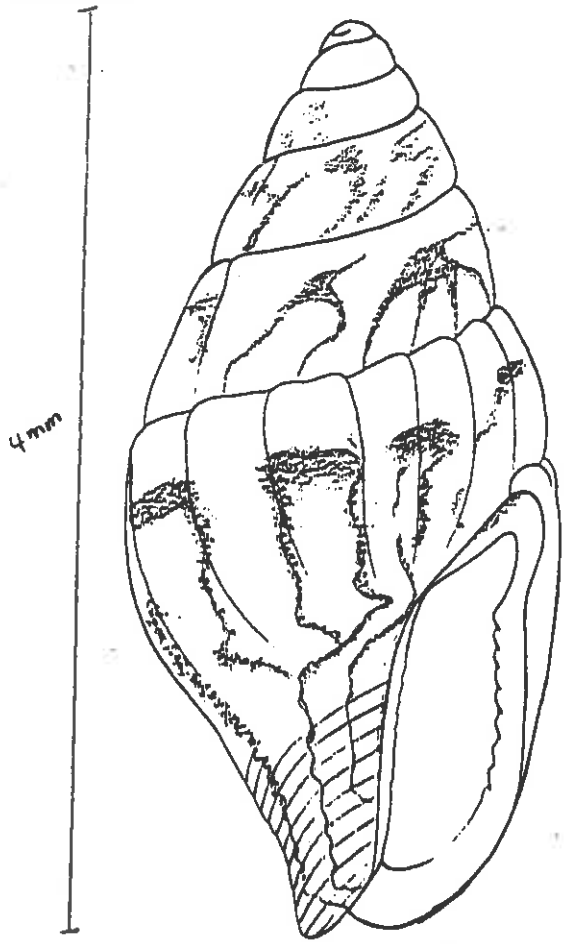
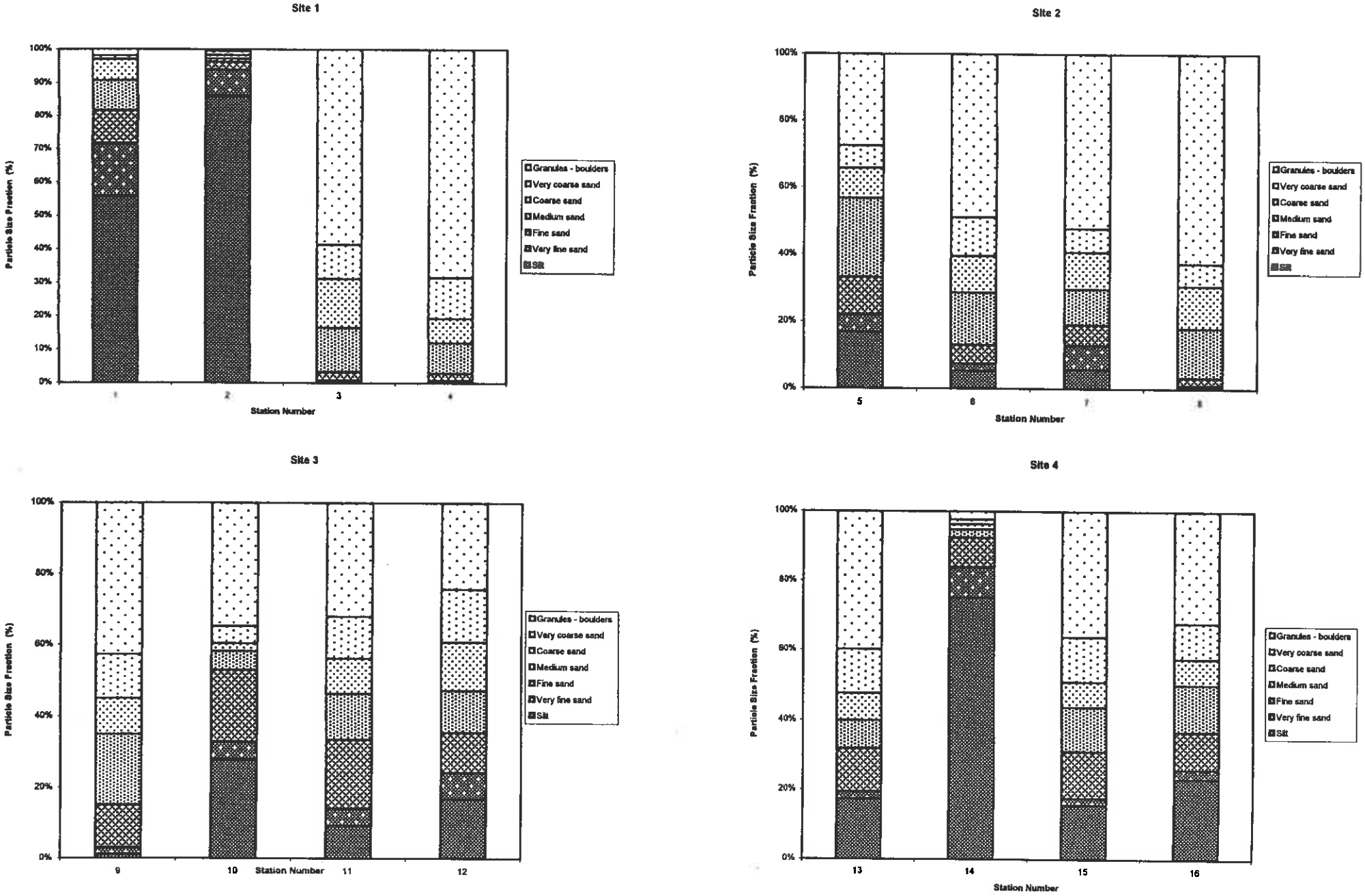
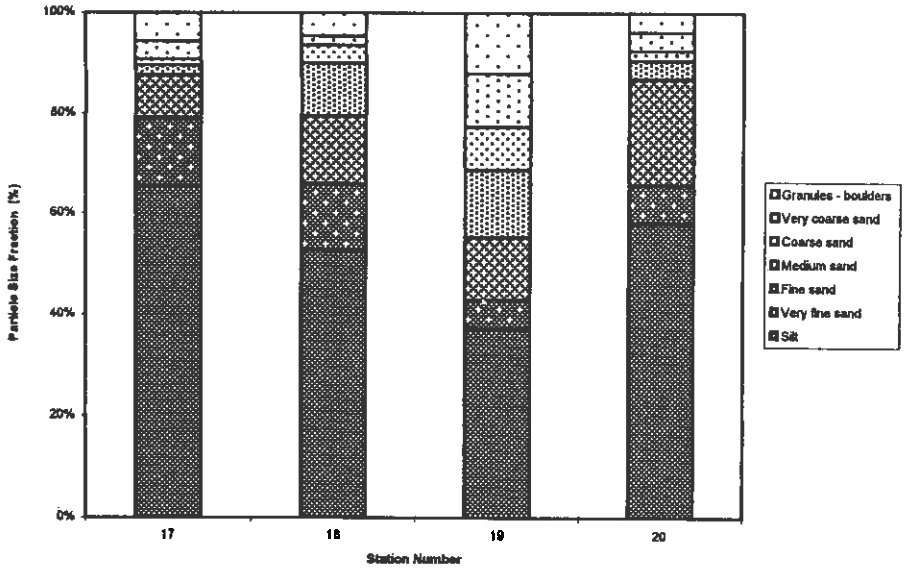


Figure 2. Average Particle Size Distribution for 24 stations in Port Curtis between November 1995 and April 1998.



Site 5


100%
80%
60%
40%
20%
0%
Particle Size Fraction (%)
17
18
19
20
Station Number
Granules - boulders
Very coarse sand
Coarse sand
Medium sand
Fine sand
Very fine sand
Silt

Site 6

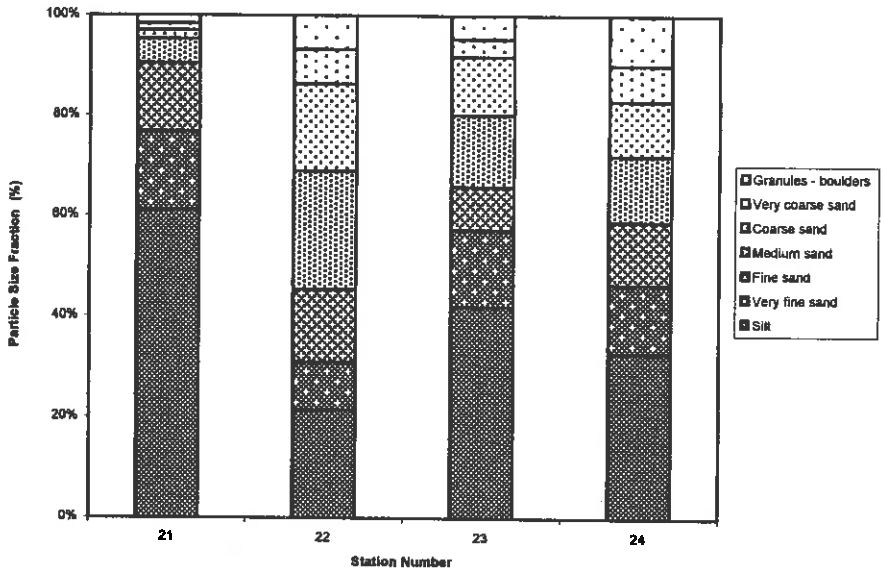
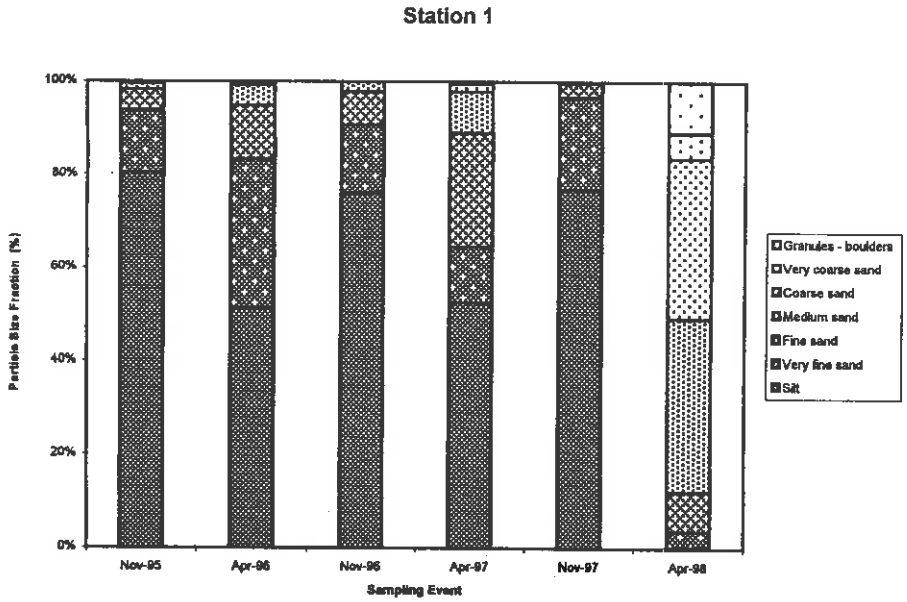
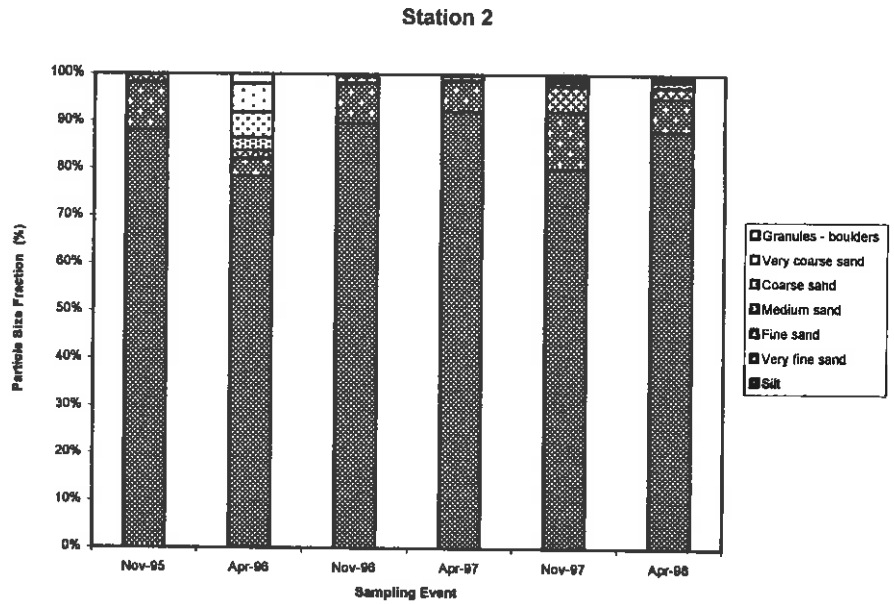
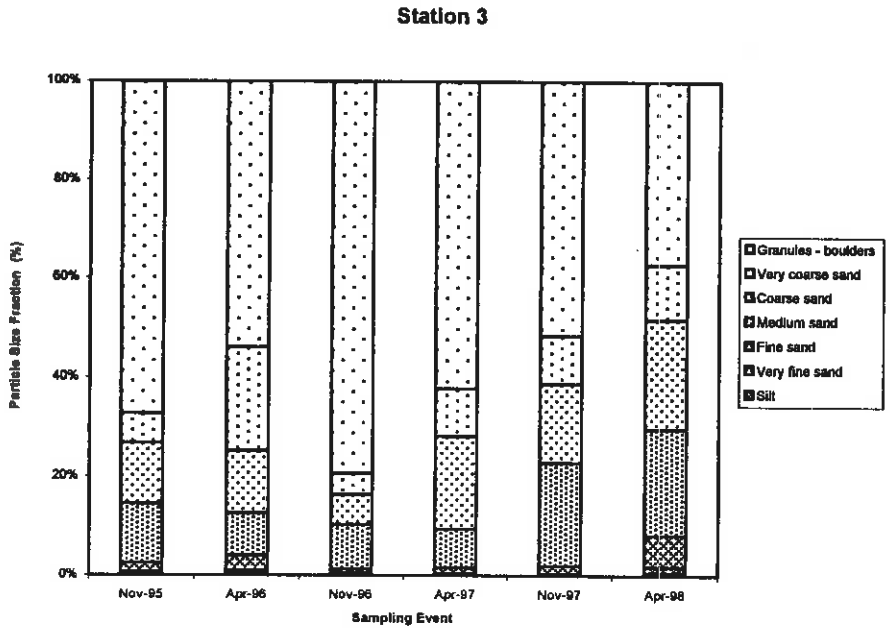
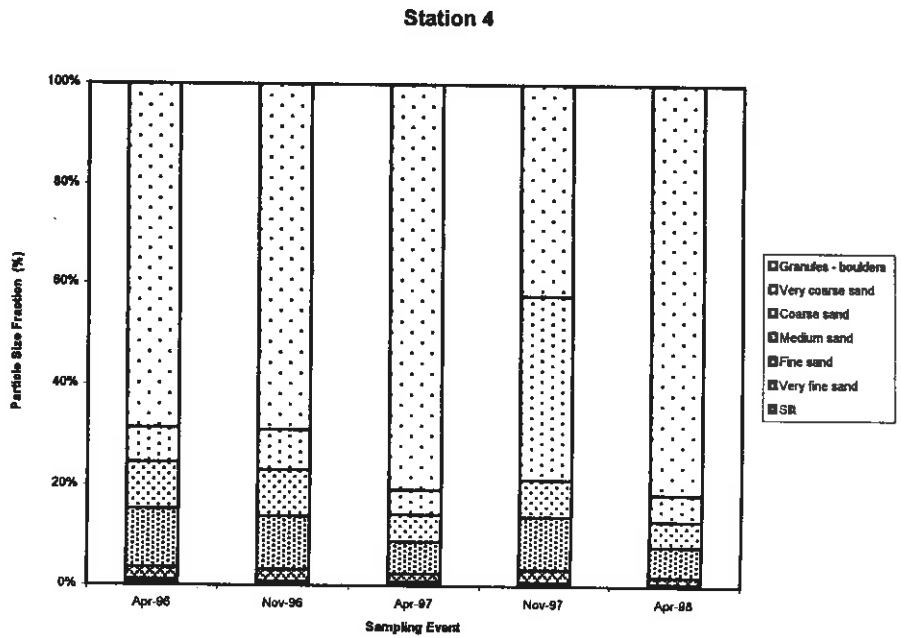

100%
80%
60%
40%
20%
0%
Particle Size Fraction (%)
21
22
23
24
Station Number
Granules - boulders
Very coarse sand
Coarse sand
Medium sand
Fine sand
Very fine sand
Silt

Figure 3. Particle size distribution of sediment for 24 stations in Port Curtis in sampling periods between November 1995 and April 1998.

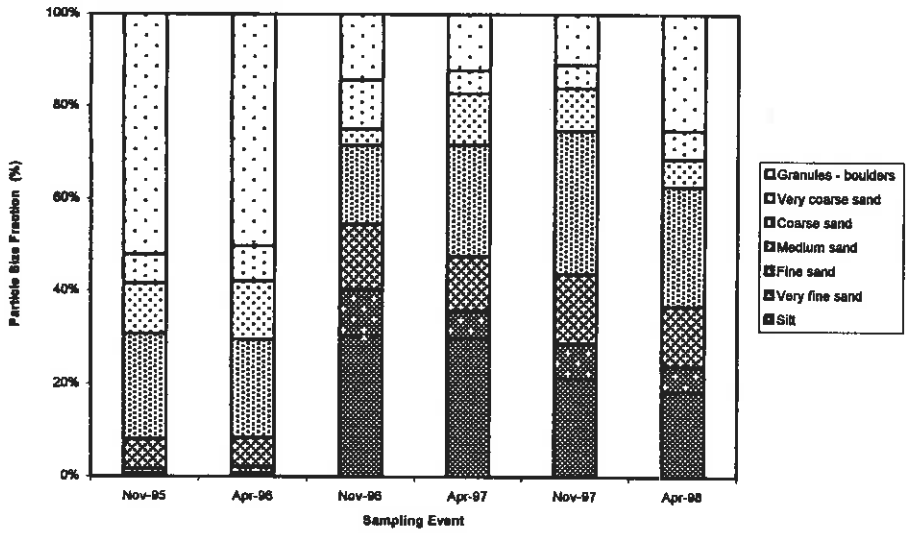




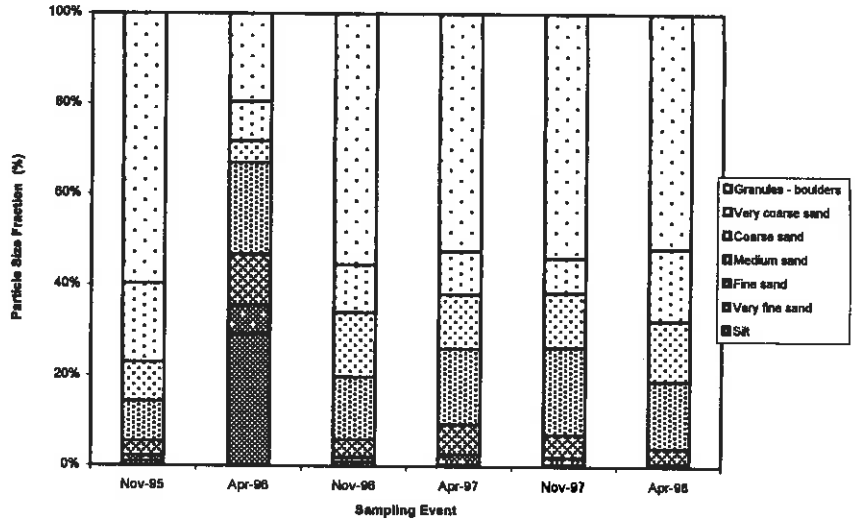




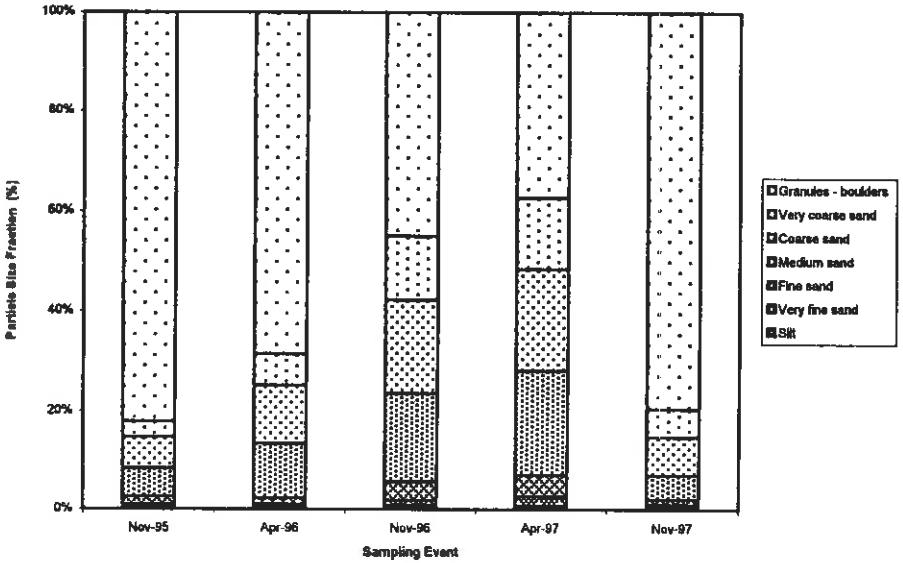
Station 5



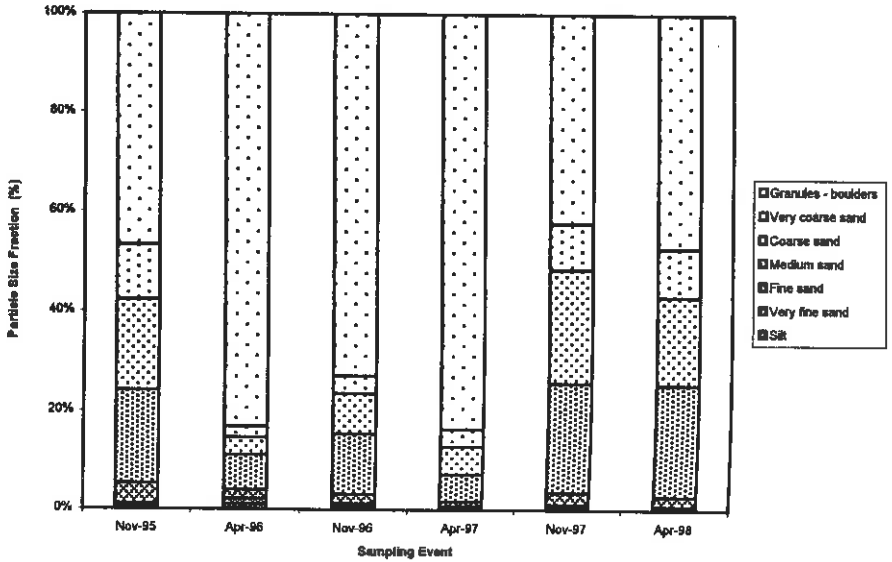
Station 6



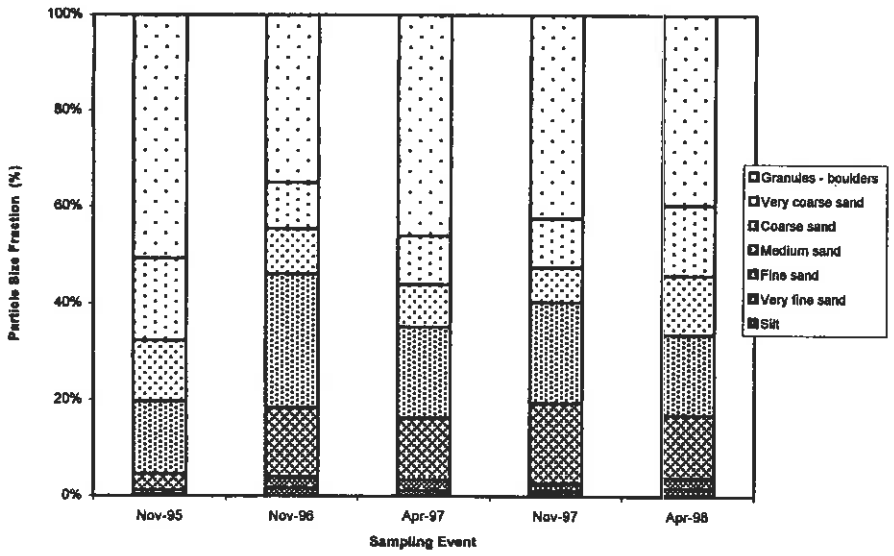
Station 7



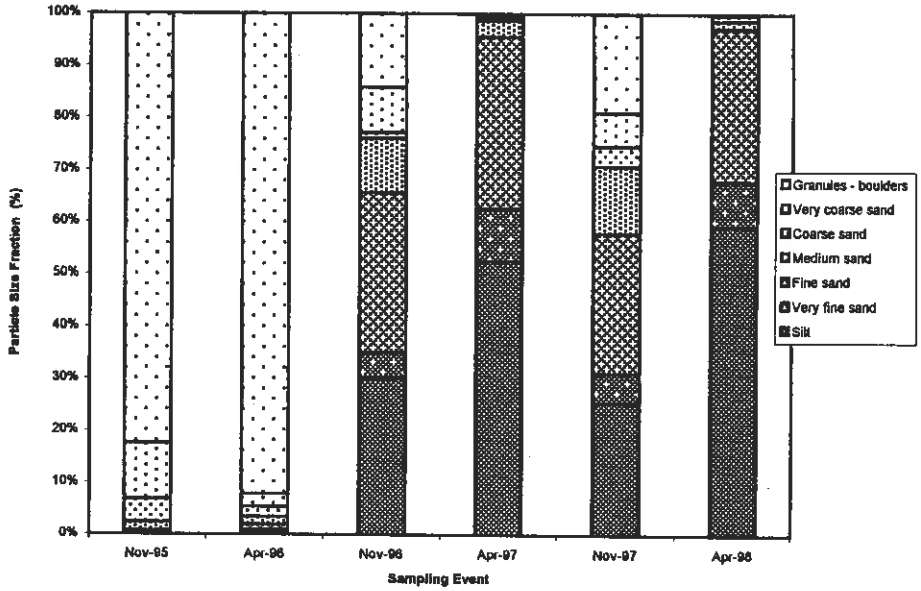
Station 8



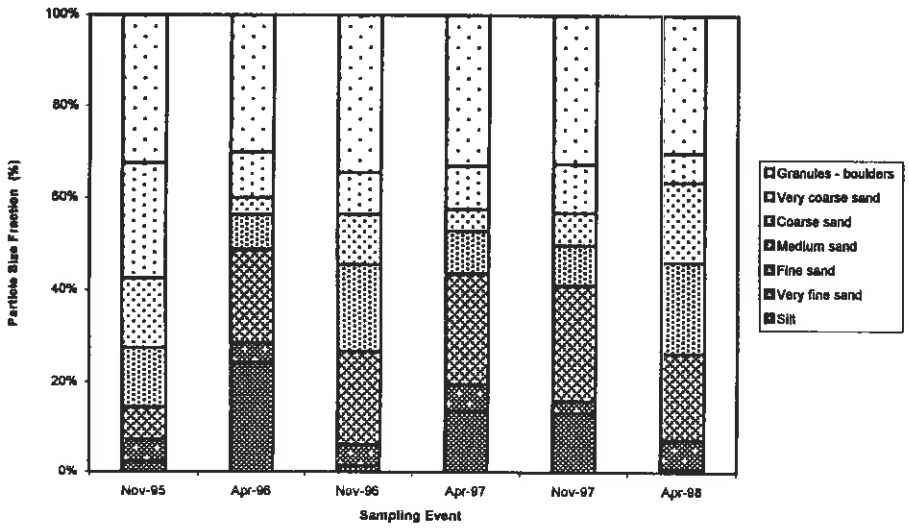
Station 9



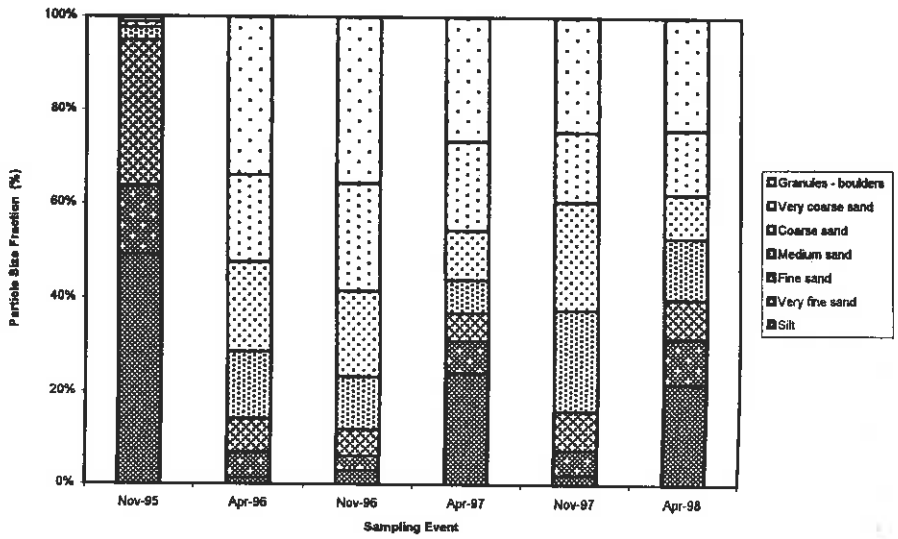
Station 10



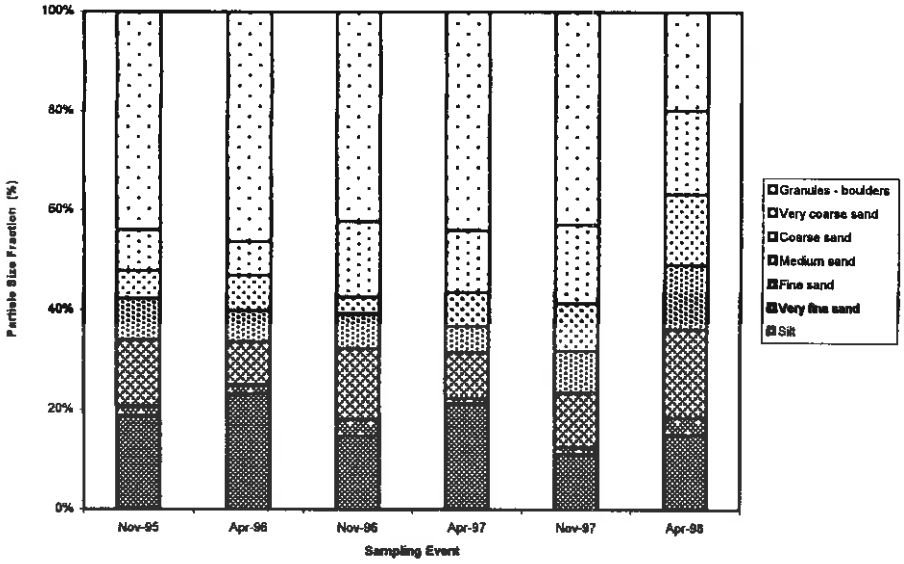
Station 11



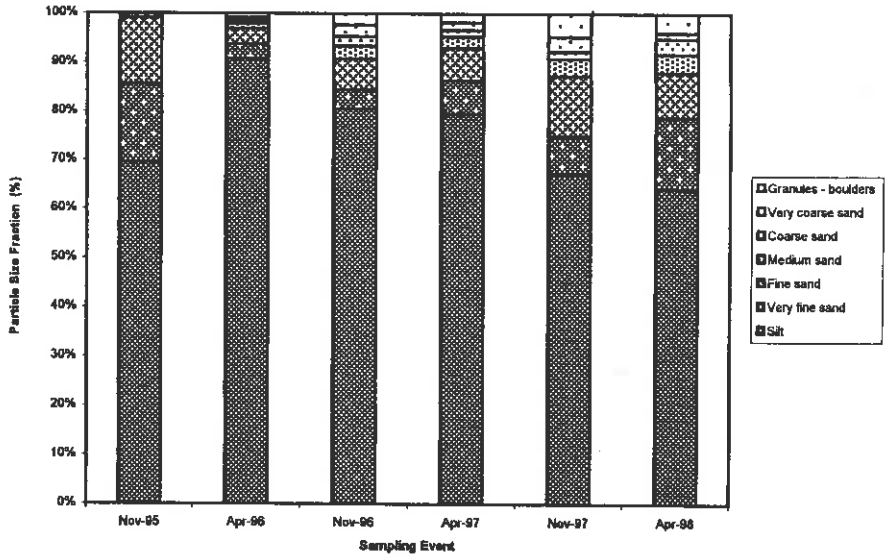
Station 12



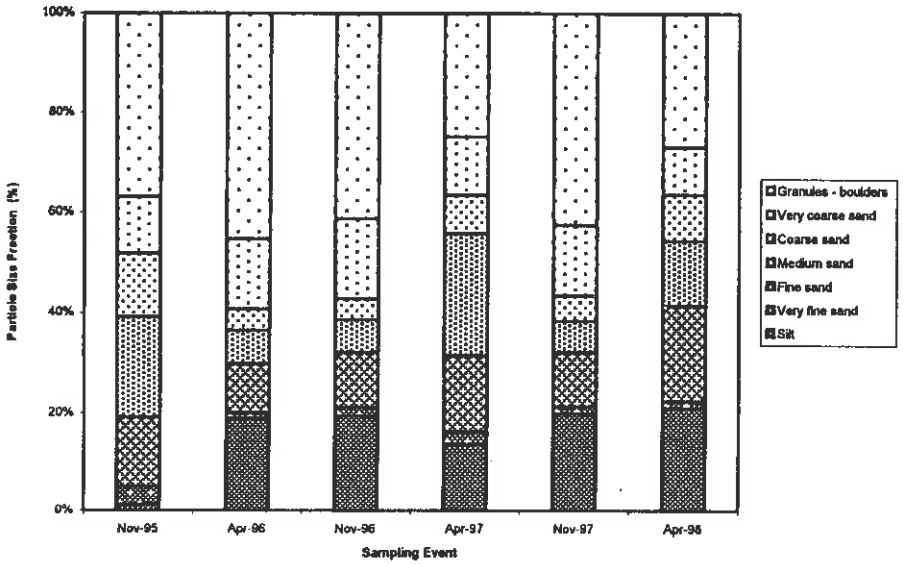
Station 13



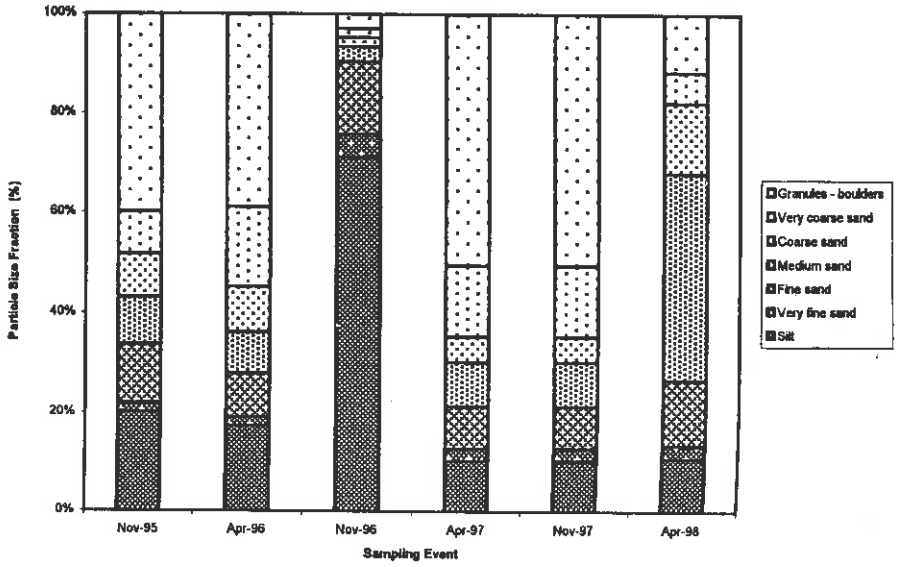
Station 14



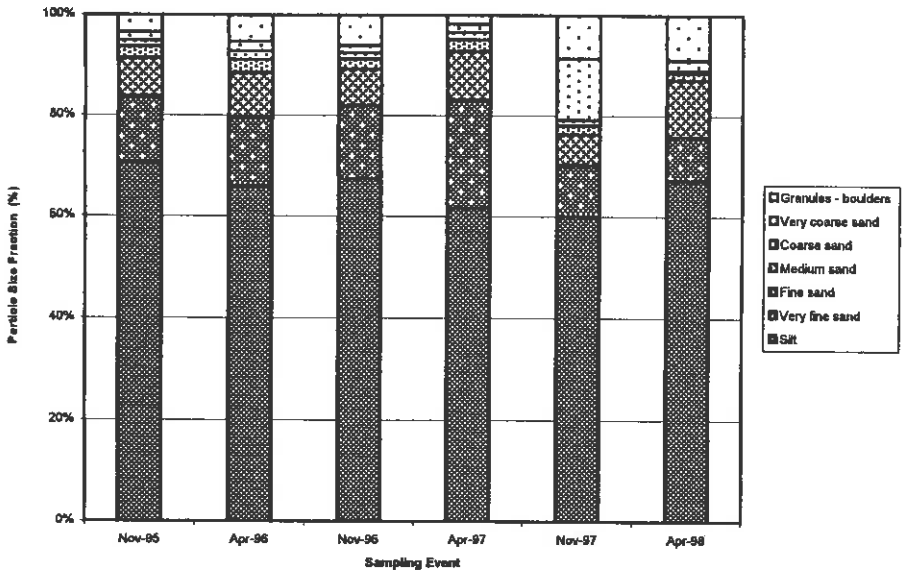
Station 15



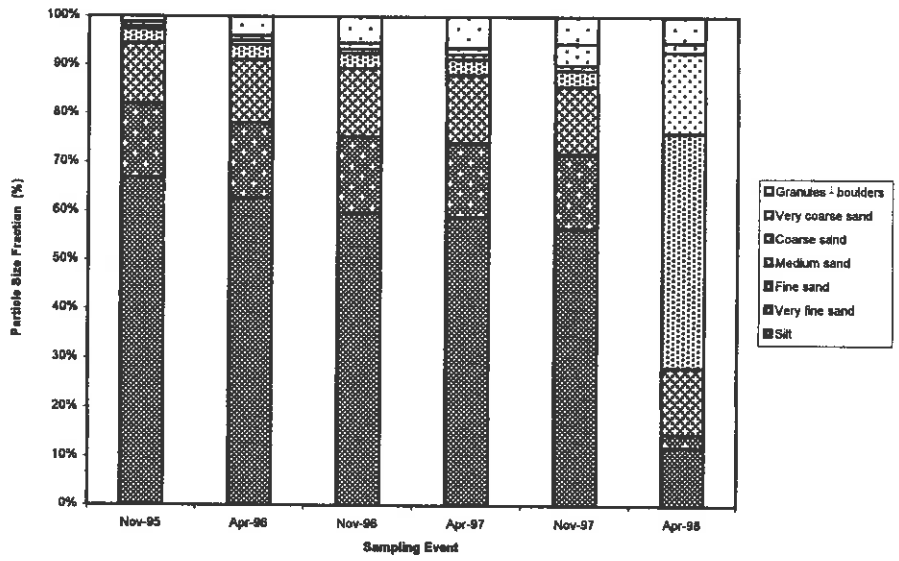
Station 16



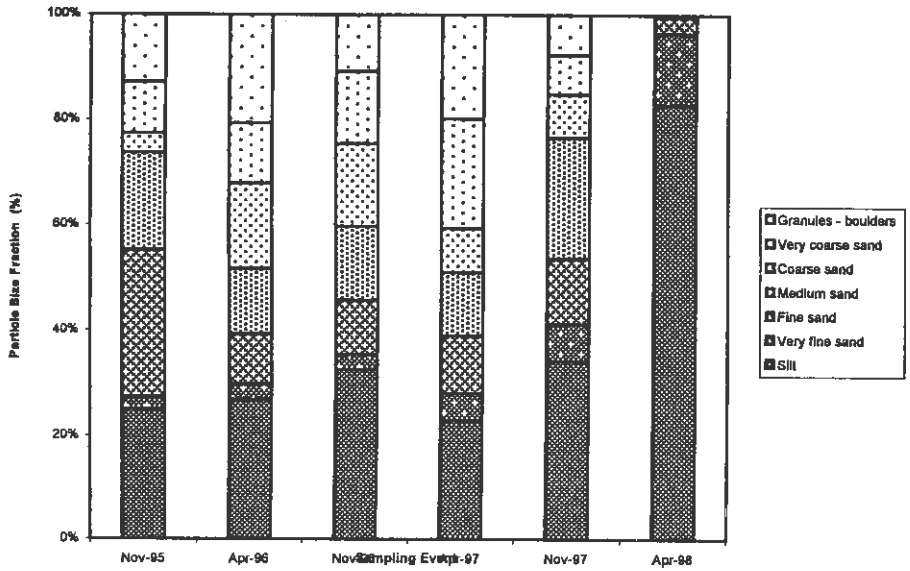
Station 17



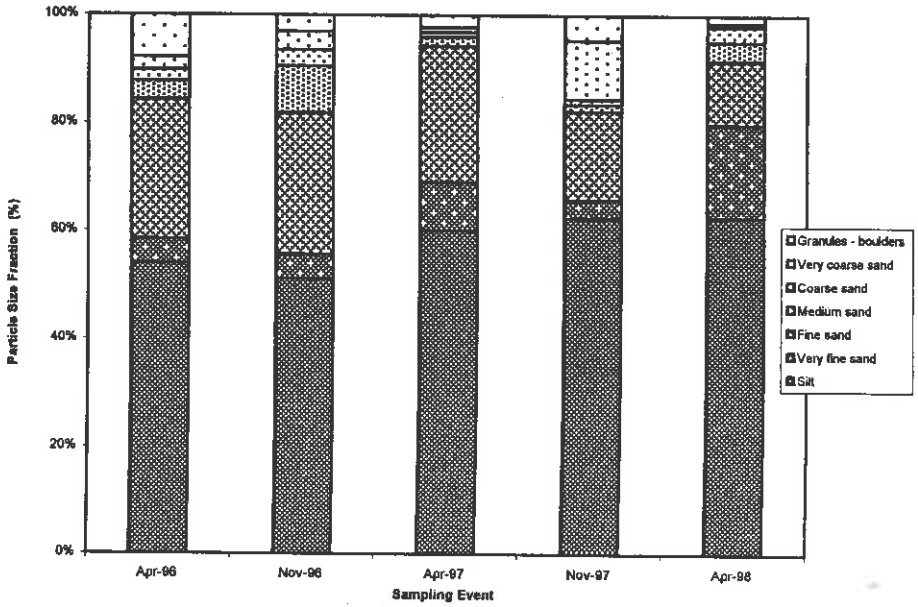
Station 18



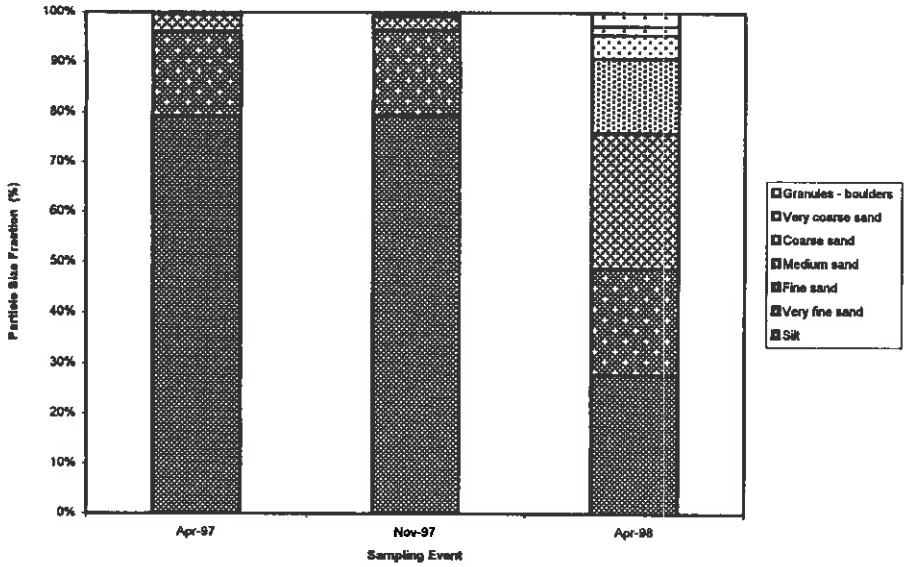
Station 19



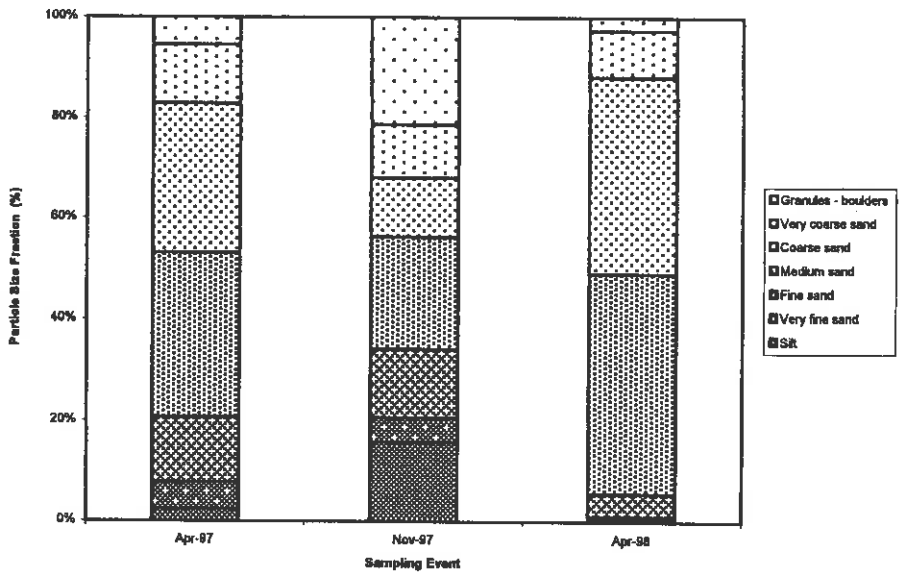
Station 20



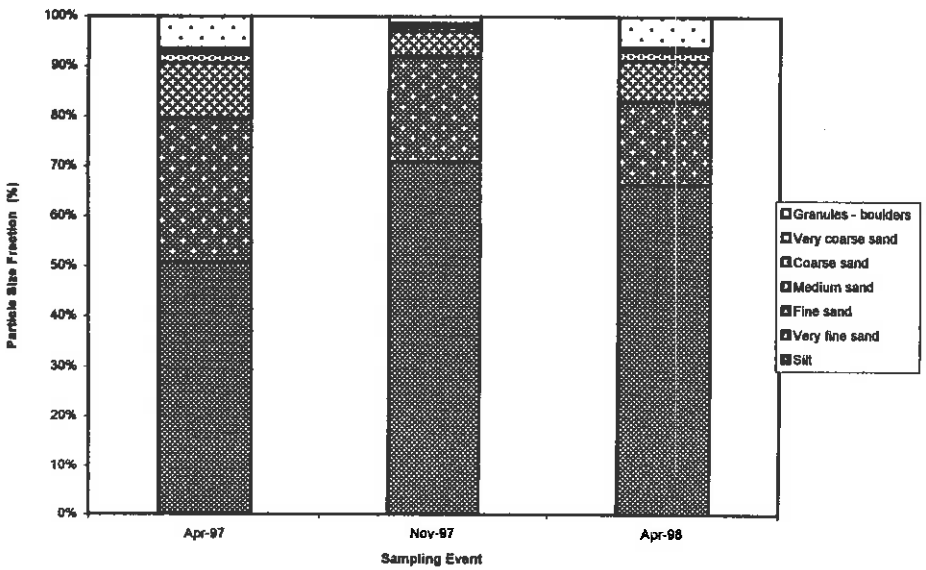
Station 21



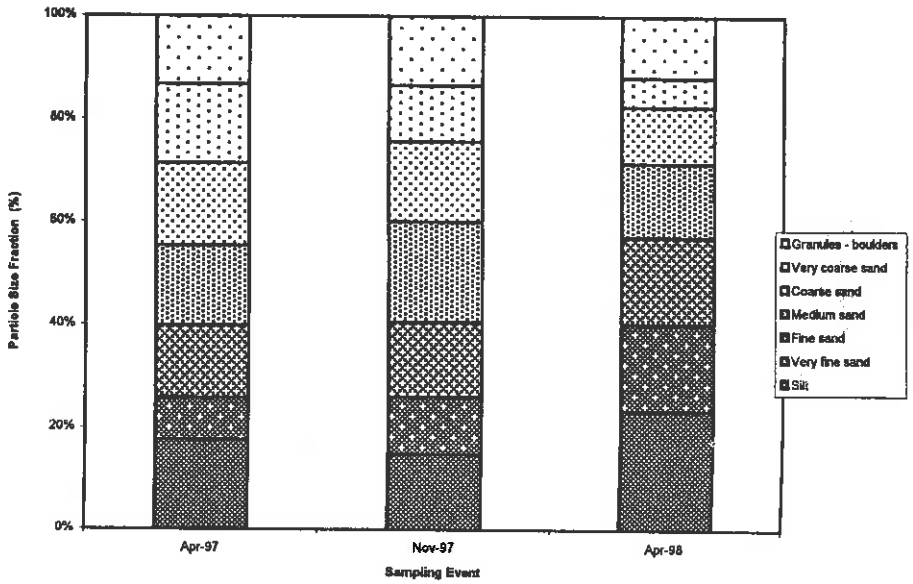
Station 22



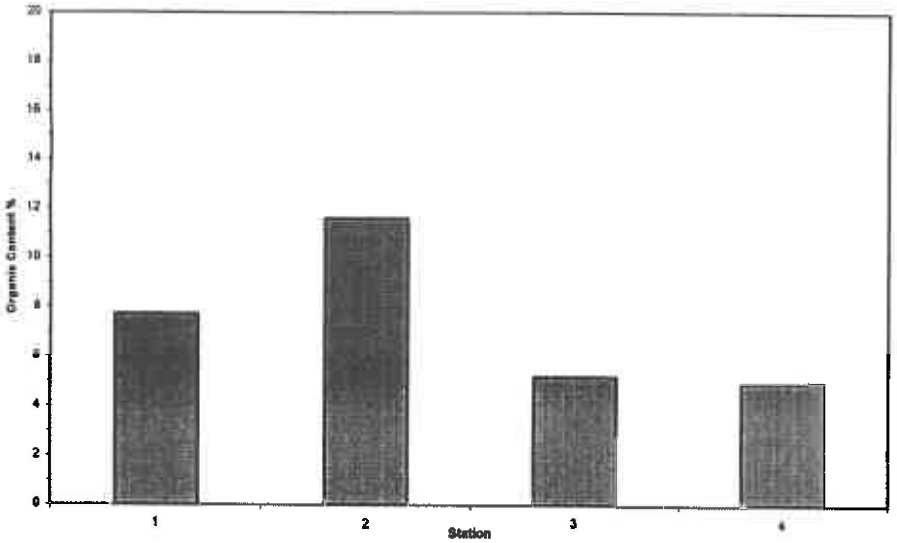
Station 23



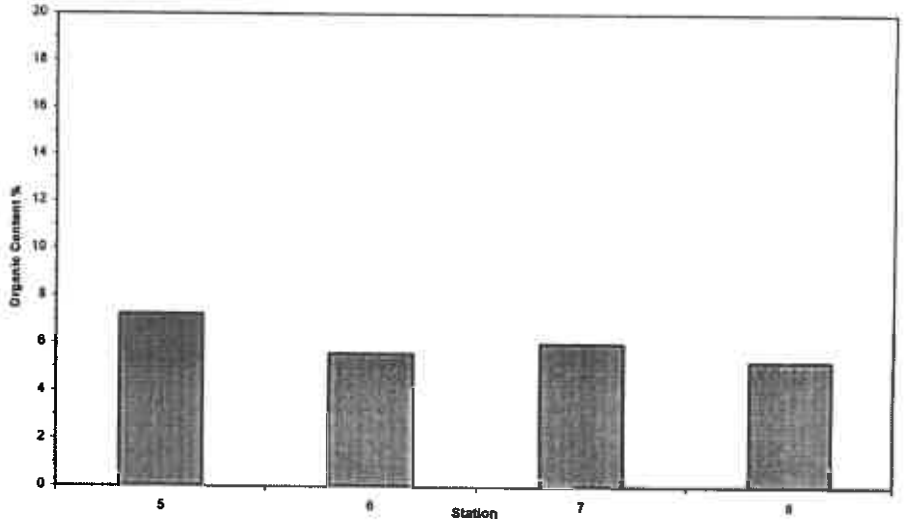
Station 24



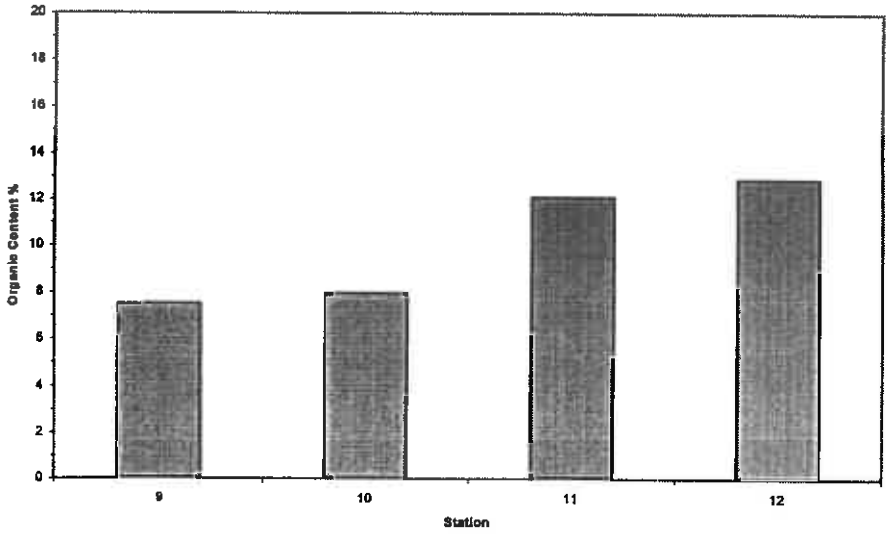
Organic Content in Sediment for Site 1



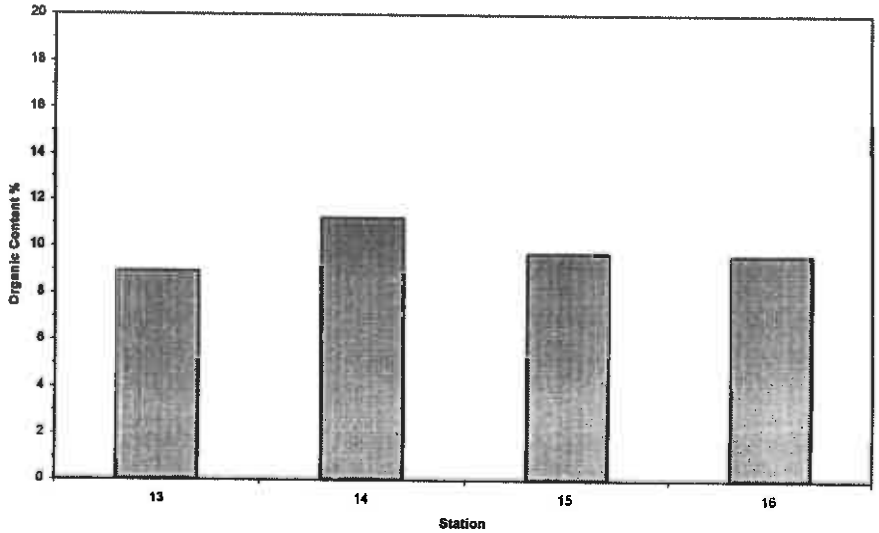
Organic Content in Sediment for Site 2



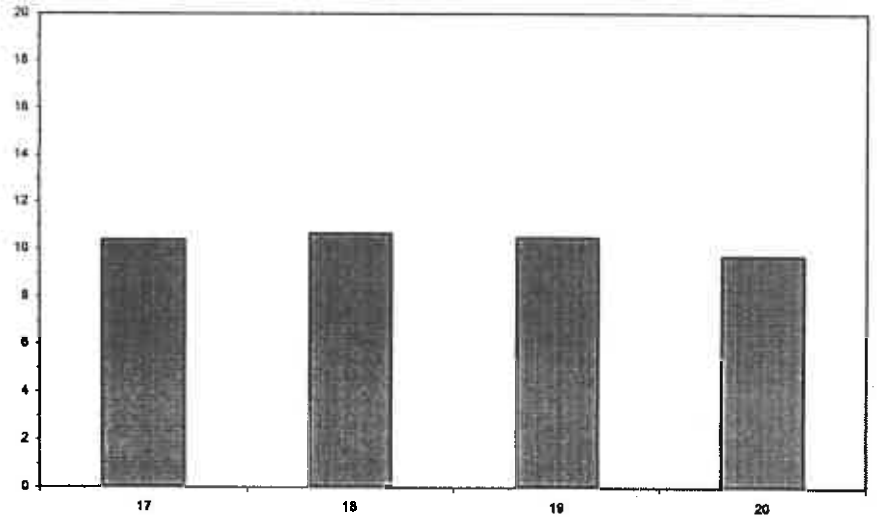
Organic Content in Sediment for Site 3



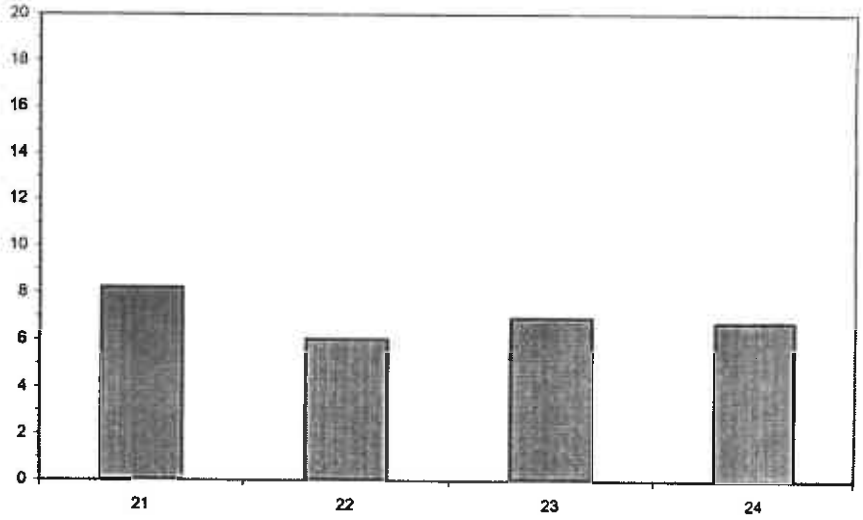
Organic Content in Sediment for Site 4



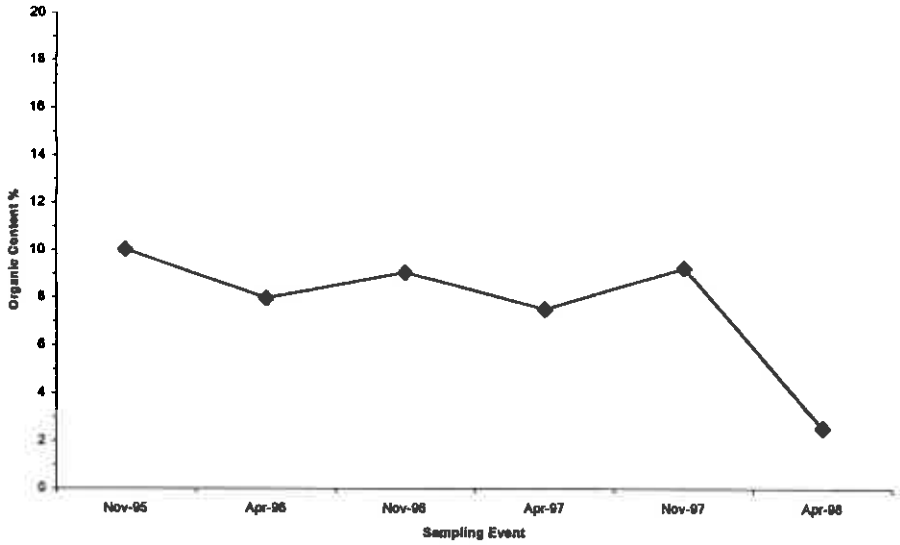
Organic Content in Sediment for Site 5



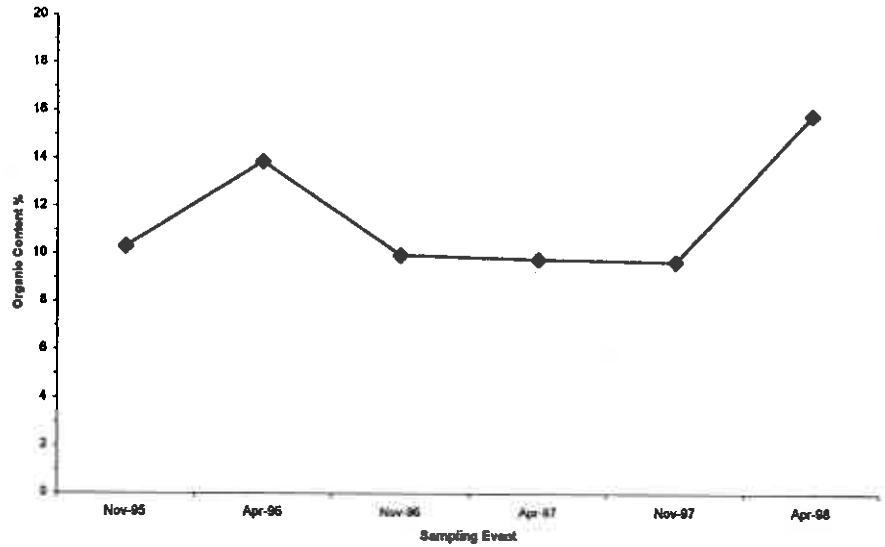
Organic Content in Sediment for Site 6



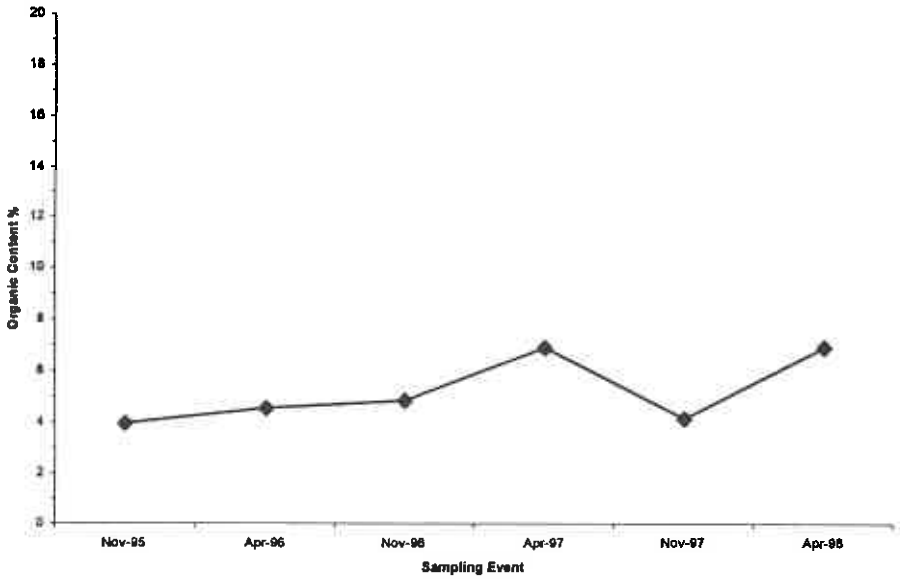
Organic Content of Sediment at Station 1



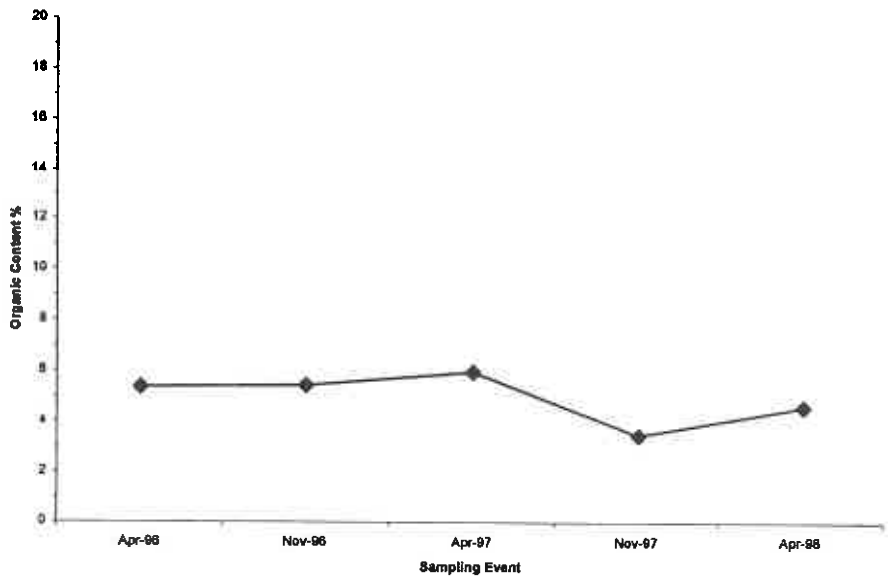
Organic Content of Sediment at Station 2

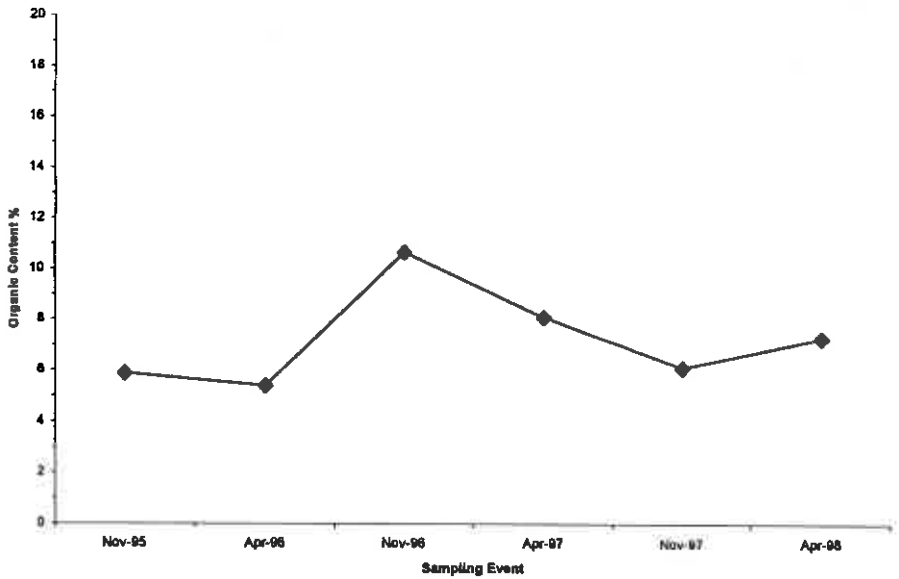


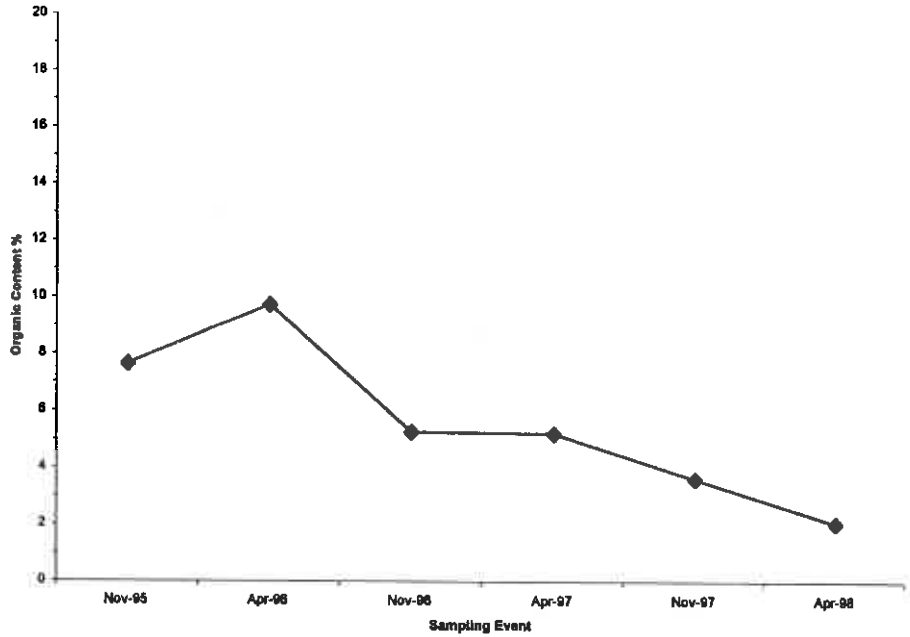
Organic Content of Sediment at Station 3



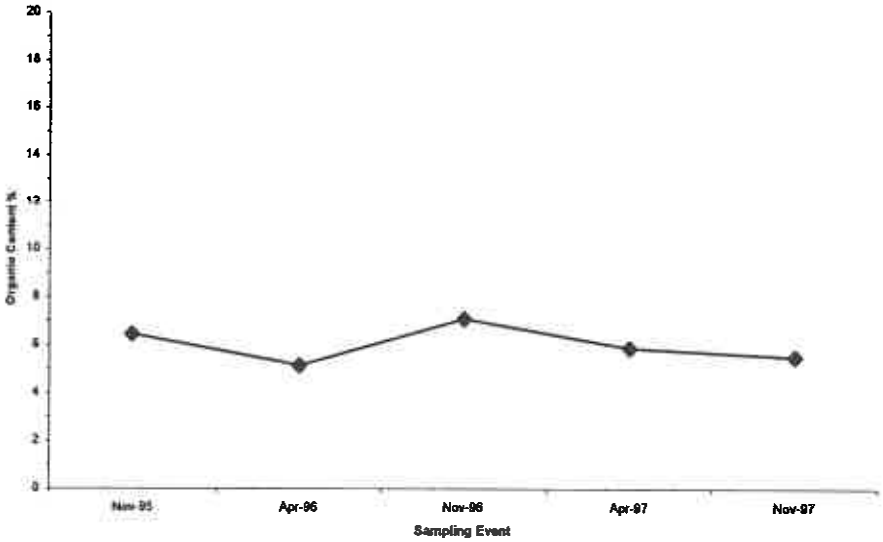
Organic Content of Sediment at Station 4



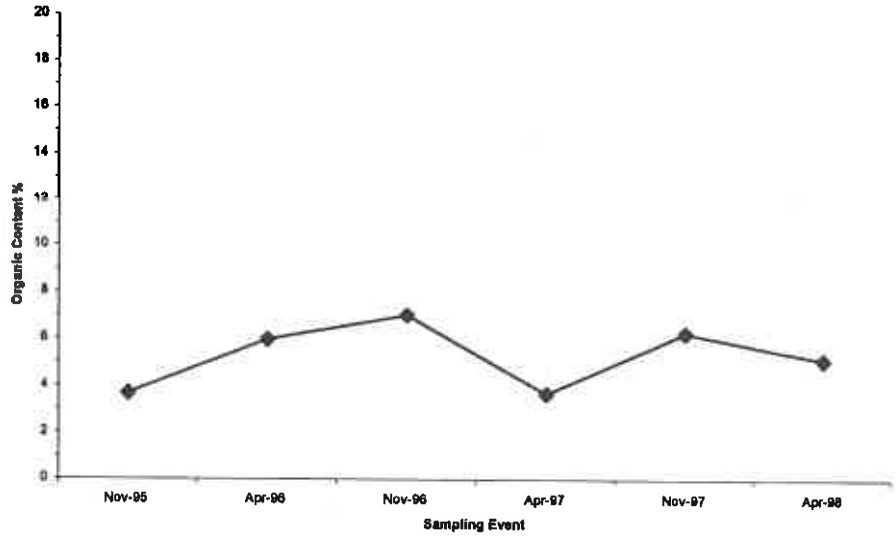


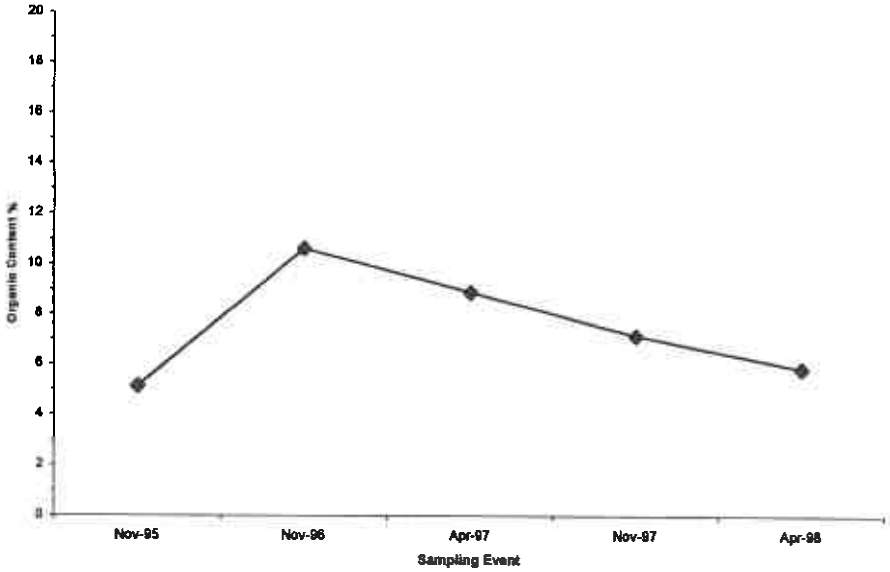


Organic Content of Sediment at Station 7

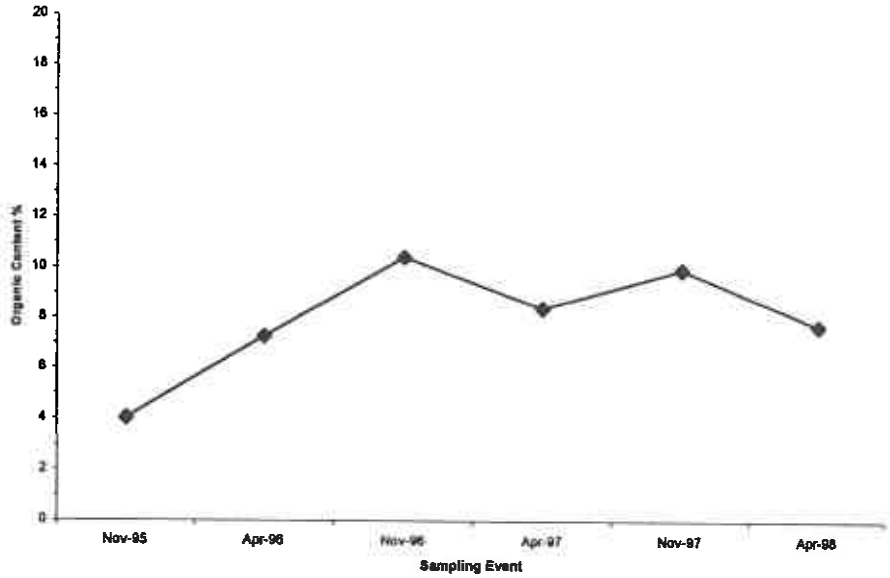


Organic Content of Sediment at Station 8

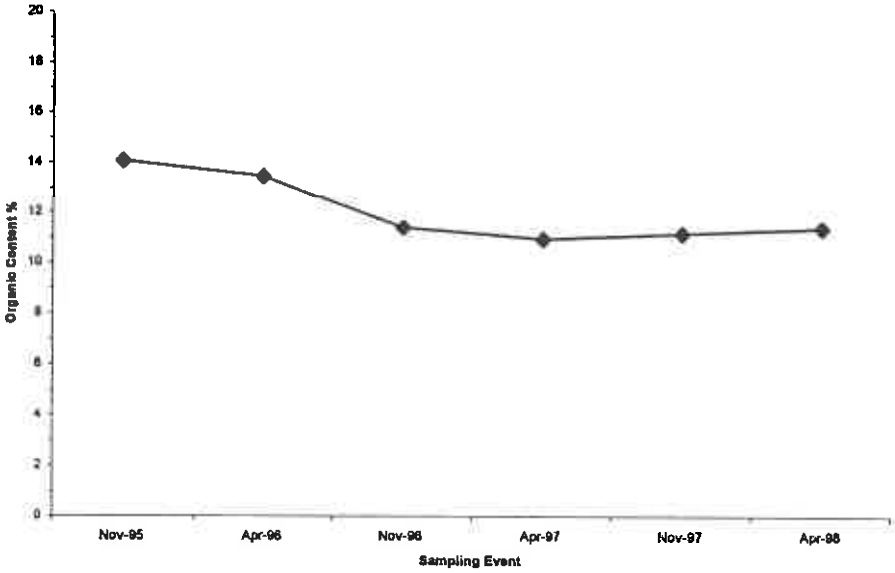




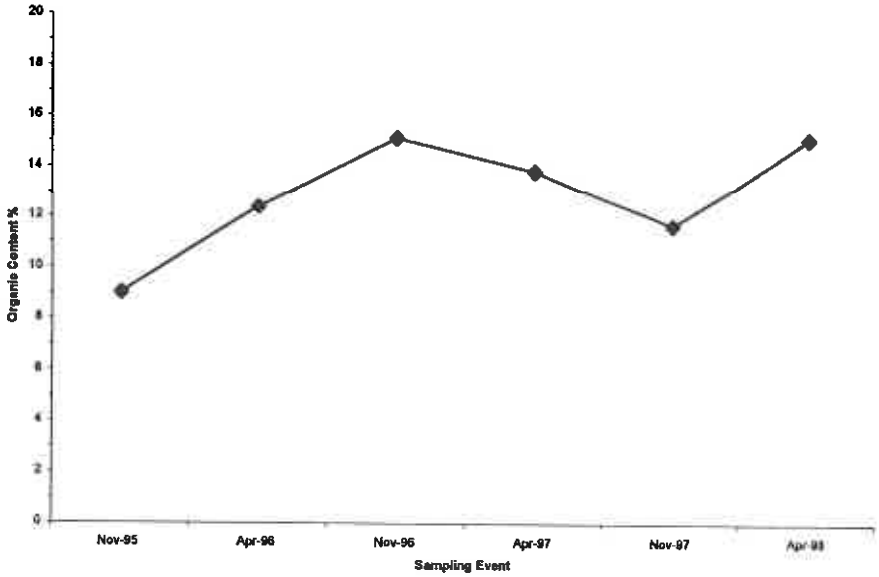
Organic Content of Sediment at Station 10

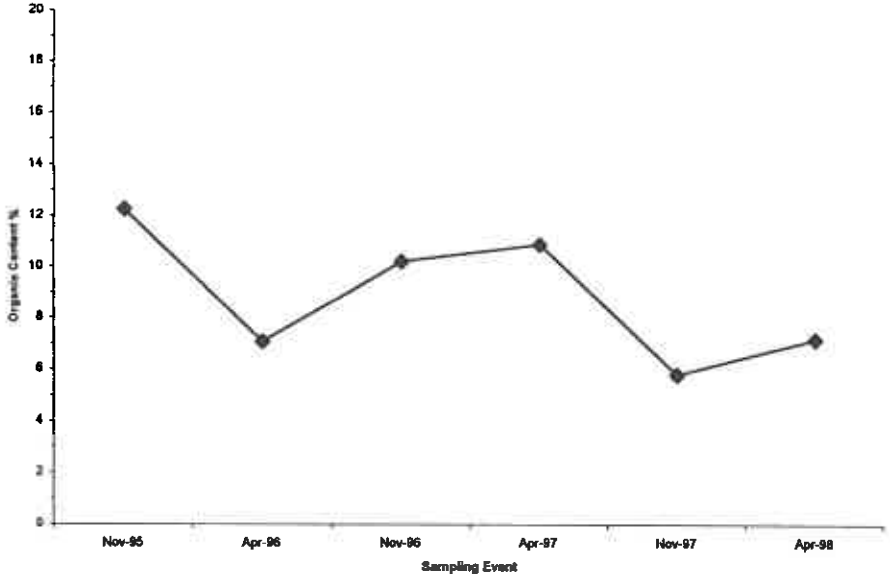


Organic Content of Sediment at Station 11

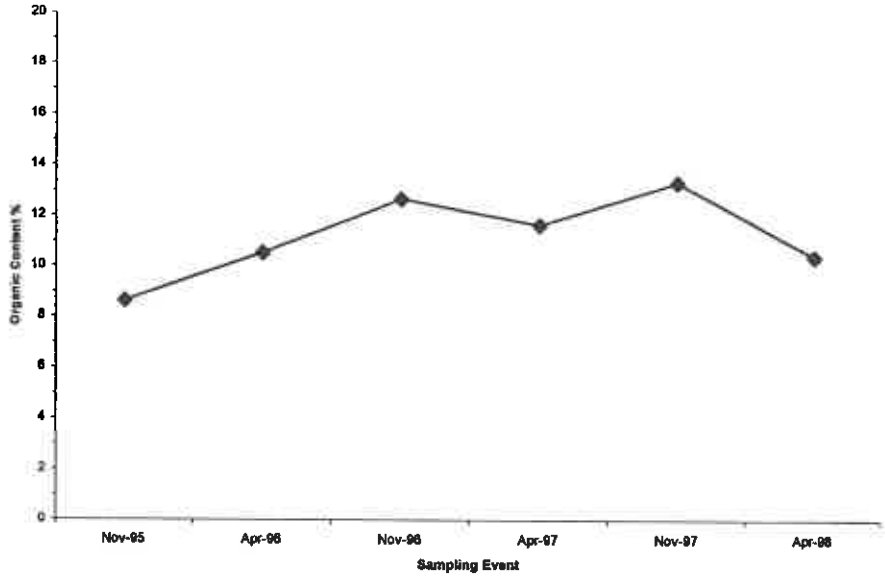


Organic Content of Sediment at Station 12

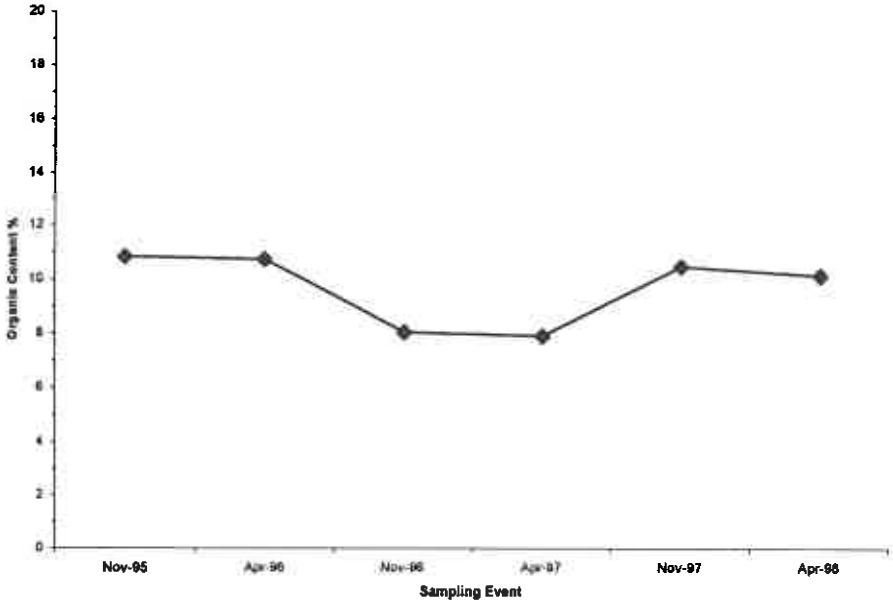




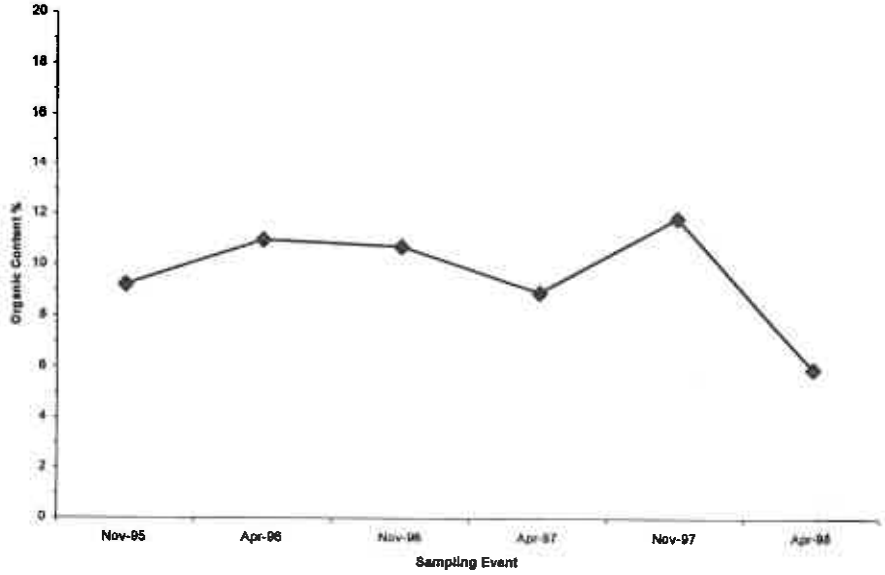
Organic Content of Sediment at Station 14



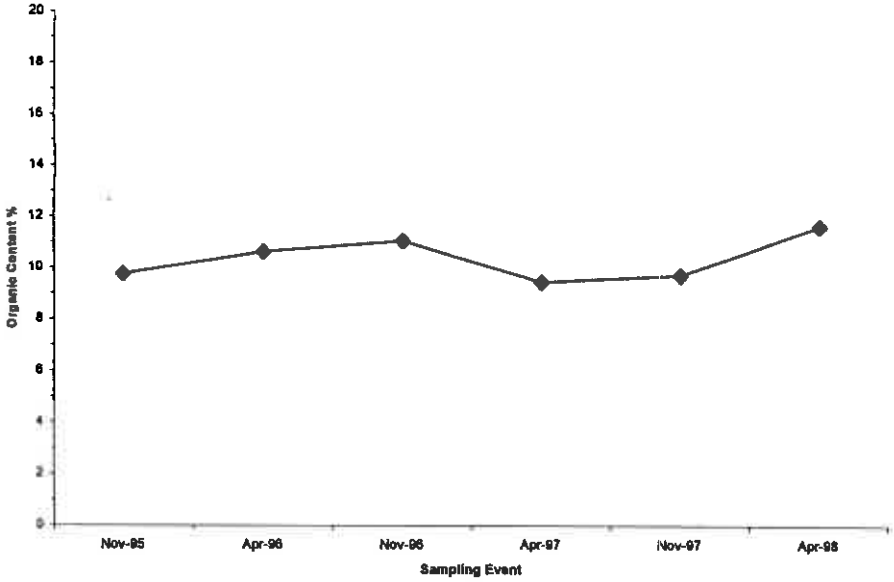
Organic Content of Sediment at Station 15



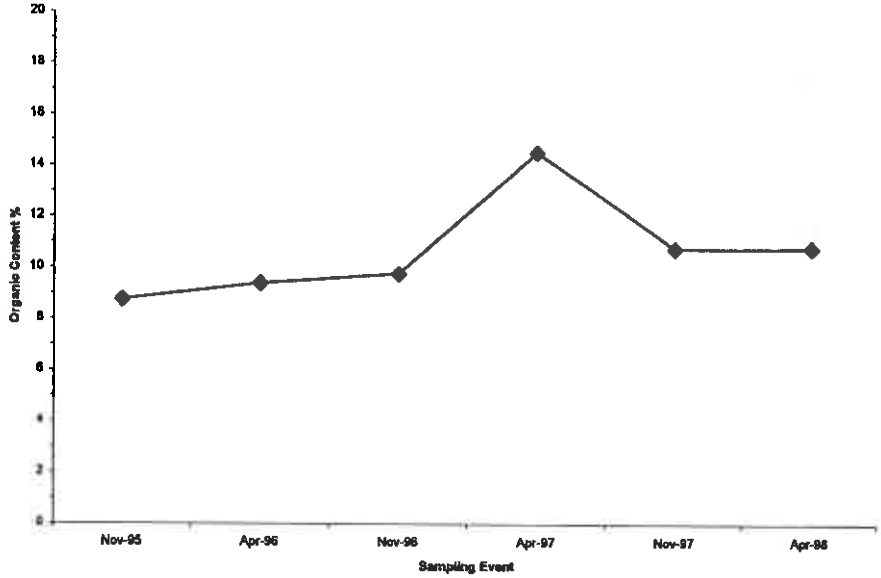
Organic Content of Sediment at Station 16



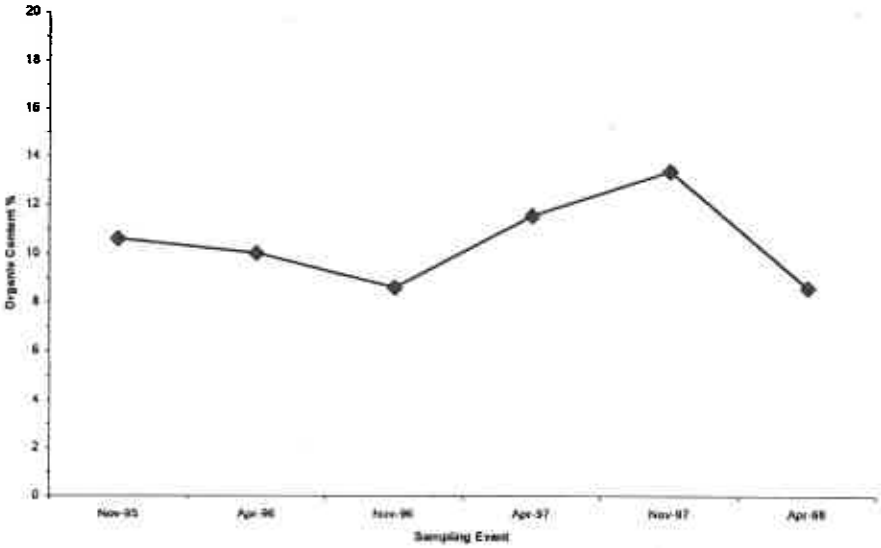
Organic Content of Sediment at Station 17



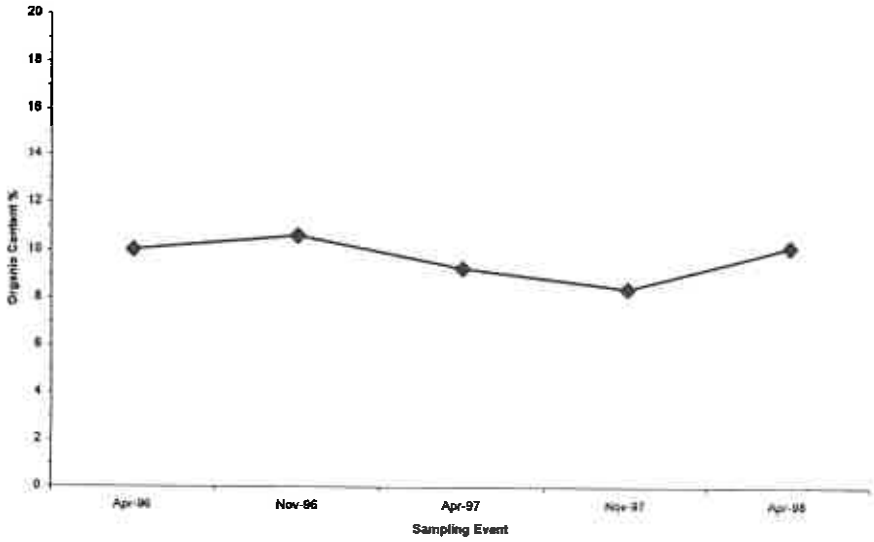
Organic Content of Sediment at Station 18



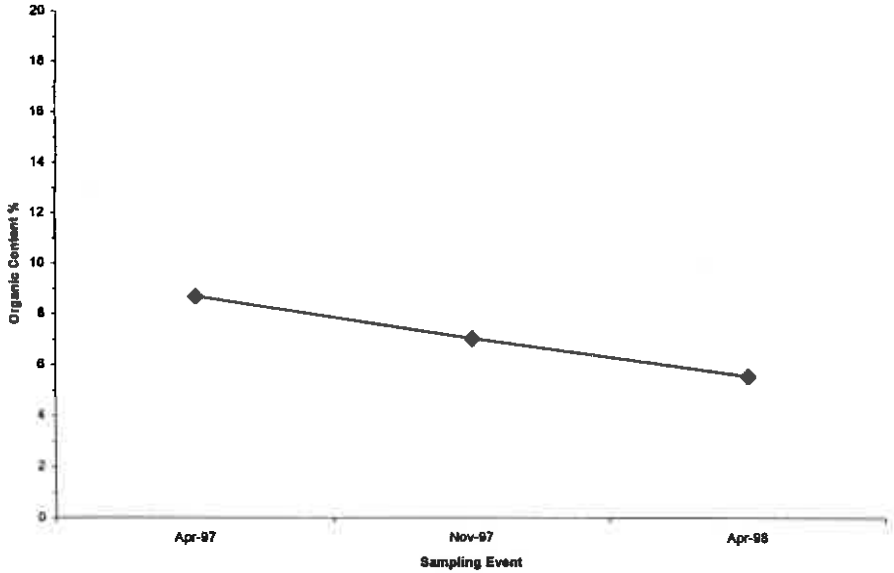
Organic Content of Sediment at Station 19



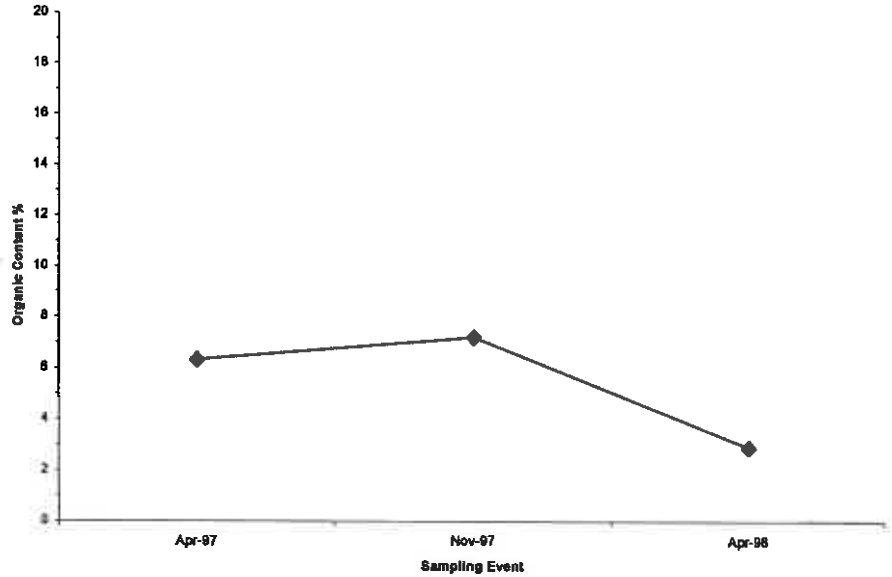
Organic Content of Sediment at Station 20



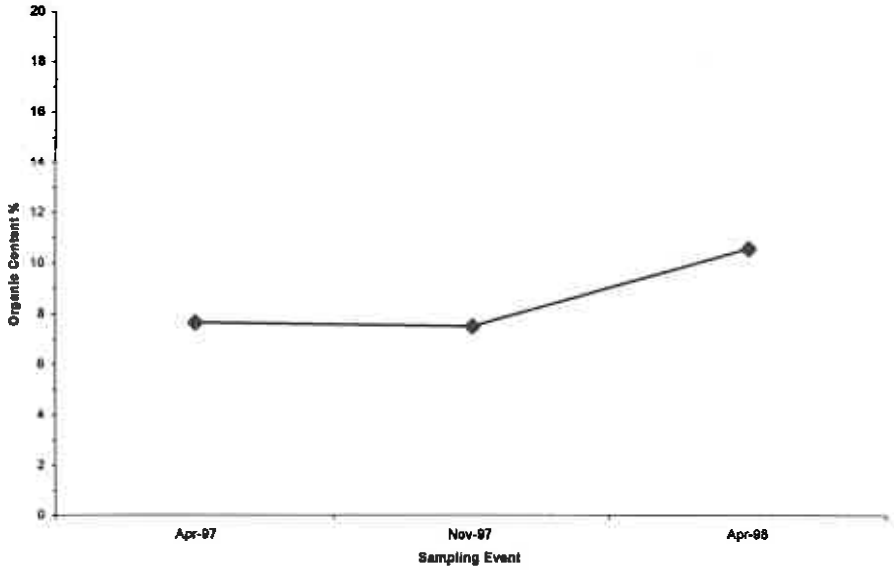
Organic Content of Sediment at Station 21



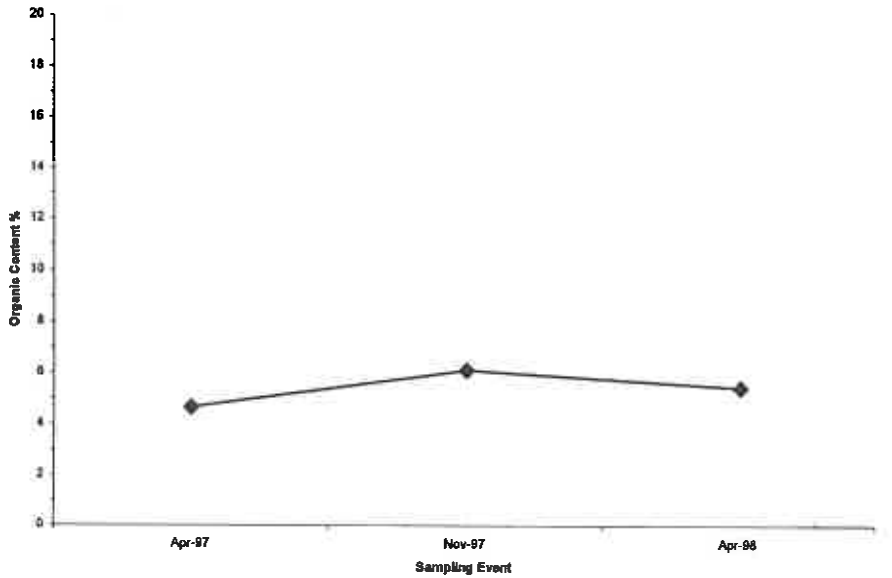
Organic Content of Sediment at Station 22



Organic Content of Sediment at Station 23



Organic Content of Sediment at Station 24



Appendix 1. The Shannon-Wiener diversity, equitability, number of species and abundance for macrobenthic species at 24 stations and 6 sites within Port Curtis over 6 sampling periods.

Shannon Wiener Indices by Stations

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Nov-95	2.93	3.29	2.97	3.54	3.33	3.44	3.78	3.83	4.14	3.30	3.73	2.91	3.14	2.96	3.31	2.91	2.63	2.66	3.47	3.00				
Apr-96	2.79	2.83	2.68	3.18	3.38	3.76	3.68	3.06	3.00	3.44	3.52	3.24	3.17	2.68	3.15	3.05	2.90	2.87	3.33	3.25				
Nov-96	2.81	2.20	3.48	3.17	3.70	3.74	3.73	3.14	3.57	2.59	3.70	3.47	3.18	2.80	3.26	2.81	2.91	2.72	3.55	3.33				
Apr-97	2.76	2.33	3.29	3.34	3.20	3.78	3.62	3.20	3.11	3.44	3.60	3.13	3.05	2.69	3.06	2.73	2.91	2.88	3.14	2.99	3.02	1.48	2.57	2.64
Nov-97	2.96	3.33	3.26	3.06	3.52	3.78	2.77	3.24	2.94	3.73	3.56	2.26	3.39	2.92	3.36	3.32	3.04	2.89	3.55	3.20	2.96	1.53	2.80	2.95
Apr-98																	2.79	2.83	2.75	2.78	2.67	1.08	2.64	2.84

Equitability by Stations

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Nov-95	0.67	0.77	0.75	0.81	0.73	0.71	0.81	0.83	0.84	0.69	0.78	0.59	0.67	0.70	0.73	0.66	0.58	0.59	0.71	0.68				
Apr-96	0.77	0.72	0.72	0.75	0.72	0.76	0.85	0.67	0.62	0.76	0.69	0.65	0.79	0.64	0.73	0.67	0.67	0.64	0.73	0.73				
Nov-96	0.69	0.54	0.82	0.76	0.81	0.81	0.82	0.79	0.73	0.60	0.76	0.70	0.72	0.66	0.73	0.70	0.69	0.66	0.75	0.72				
Apr-97	0.68	0.64	0.79	0.82	0.78	0.86	0.85	0.84	0.78	0.79	0.77	0.65	0.67	0.68	0.69	0.62	0.65	0.69	0.70	0.73	0.81	0.35	0.67	0.68
Nov-97	0.81	0.76	0.78	0.75	0.76	0.87	0.77	0.80	0.68	0.78	0.73	0.46	0.71	0.65	0.72	0.73	0.69	0.67	0.75	0.71	0.74	0.36	0.77	0.72
Apr-98																	0.65	0.67	0.70	0.77	0.75	0.29	0.78	0.77

Total number of species for each station

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Nov-95	80	73	53	78	96	127	104	99	141	105	116	140	108	70	93	84	91	90	137	84				
Apr-96	37	50	42	71	110	140	76	98	126	119	170	147	57	64	74	94	75	86	97	87				
Nov-96	59	59	71	66	99	101	97	53	133	95	131	142	81	72	87	57	68	61	114	105				
Apr-97	59	38	65	59	52	81	70	45	54	76	104	121	97	53	83	83	87	67	90	59	41	70	46	50
Nov-97	39	80	66	60	100	76	37	56	73	76	131	131	120	92	108	95	82	74	113	91	53	73	39	61
Apr-98																	75	69	51	37	44	35	30	41

Total abundance for each station

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Nov-95	1155	657	416	300	897	2772	575	557	1061	761	1069	7857	4101	728	1930	2114	3839	9094	2595	1248				
Apr-96	234	465	175	443	1975	2243	380	816	2156	2940	10830	6751	462	844	1903	4226	5170	4575	2427	1162				
Nov-96	733	1261	312	462	714	849	690	301	1453	1451	1579	5486	1413	722	870	617	2366	2612	1290	1708				
Apr-97	460	307	355	274	700	354	370	145	504	915	1669	3668	1469	500	2378	3662	3001	2821	1737	840	280	4037	722	1476
Nov-97	223	1287	364	509	1293	395	145	220	912	812	1804	8923	1816	1495	1999	1274	1988	2450	2059	1021	483	3028	374	782
Apr-98																	2269	2161	1111	312	358	6722	267	464

Appendix 1 cont..

Shannon Wiener for sites 1 - 6

	1	2	3	4	5	6
Nov-95	3.75	3.97	3.52	3.4	3.12	
Apr-96	3.72	3.8	3.63	3.33	3.31	
Nov-96	3.34	3.93	3.74	3.3	3.41	
Apr-97	3.54	3.78	3.47	3.16	3.24	2.47
Nov-97	3.81	3.95	2.88	3.52	3.48	2.49
Apr-98					2.97	1.54

Equitability for sites 1 - 6

	1	2	3	4	5	6
Nov-95	0.72	0.74	0.64	0.65	0.59	
Apr-96	0.76	0.71	0.65	0.68	0.65	
Nov-96	0.67	0.78	0.69	0.69	0.67	
Apr-97	0.73	0.78	0.68	0.63	0.66	0.53
Nov-97	0.77	0.79	0.54	0.67	0.68	0.52
Apr-98					0.62	0.36

Total species for sites 1 - 6

	1	2	3	4	5	6
Nov-95	180	215	249	187	199	
Apr-96	132	205	260	134	165	
Nov-96	150	158	227	123	161	
Apr-97	126	128	171	151	138	109
Nov-97	145	148	209	186	164	124
Apr-98					116	76

Total abundance for sites 1 - 6

	1	2	3	4	5	6
Nov-95	2528	4801	10748	8873	16746	
Apr-96	1317	5414	22677	7435	13334	
Nov-96	2768	2554	9969	3622	7976	
Apr-97	1396	1569	6756	8009	8399	6515
Nov-97	2383	2043	2043	6584	7518	4667
Apr-98					5853	7811

Appendix 2. Abundant, common, and scarce species at Station 17-24.

Species Name	Species Code	Abundance across all stations	Category	Percentage of Total 78819
Family Rissoidae 1	BMGnR2nn001	12212	Abundant	15.5
Ringicula sp.	BMGnR1Rn001	11259	Abundant	14.3
Nassarius dorsatus	BMGnN1Nn001	4629	Common	5.87
Order Foraminifera	BPRFnnnn001	4437	Common	5.63
Family Collumbellidae 1	BMGnC3nn001	3609	Common	4.58
Syrnola sp.	BMGnP2Sn001	3528	Common	4.48
Cellanthus sp.	BPRFE1Cn001	2639	Common	3.35
Class Gastropoda	BMGnnnnn014	2366	Common	3.00
Family Collumbellidae 2	BMGnC3nn002	2153	Common	2.73
Dentalium sp.	BMSnD1Dn001	2048	Common	2.60
Cyclostremiscus sp.	BMGnV2Cn001	1796	Common	2.28
Family Rissoidae	BMGnR2nn002	1471	Common	1.87
Family Neritidae	BMGnN3nn001	1346	Common	1.71
Class Gastropoda 24	BMGnnnnn024	1332	Common	1.69
Epitonium sp. 4	BMGnE2En004	1281	Common	1.63
Epitonium sp. 3	BMGnE2En003	1159	Common	1.47
Atys cylindricus	BMGnA3AC001	1031	Common	1.31
Epitonium sp. 4	BMGnE2EE004	963	Common	1.22
Family Littorinidae 1	BMGnL1nn001	901	Common	1.14
Nassarius sp. 2	BMGnN1Nn002	815	Common	1.03
Class Gastropoda 37	BMGnnnnn037	814	Common	1.03
Class Gastropoda 10	BMGnnnnn010	747	Scarce	0.95
Plicarcularia burchardi	BMGnN1PB001	676	Scarce	0.86
Cardita sp.	BMBnC3Cn001	655	Scarce	0.83
Austrocochlea obtusa	BMGnT2AO001	615	Scarce	0.78
Class Gastropoda 25	BMGnnnnn025	510	Scarce	0.65
Class Gastropoda 38	BMGnnnnn038	496	Scarce	0.63
Family Vermetidae	BMGnV2nn001	493	Scarce	0.63
Epitonium sp. 2	BMGnE2En002	432	Scarce	0.55
Cyclostremiscus sp. 2	BMGnV2nn002	409	Scarce	0.52
Turritella sp. 1	BMGnT6Tn001	408	Scarce	0.52
Pyrene sp.	BMGnC3Pn001	387	Scarce	0.49
Family Pyramidellidae 4	BMGnP1nn004	369	Scarce	0.47
Class Gastropoda 116	BMGnnnnn116	353	Scarce	0.45
Cyclostremiscus sp. 2	BMGnV2Cn002	352	Scarce	0.45
Turitella sp. 6	BMGnT6Tn003	324	Scarce	0.41
Class Gastropoda 42	BMGnnnnn042	322	Scarce	0.41
Family Pyrmaidellidae 2	BMGnP1nn002	305	Scarce	0.39
Family Pyramidellidae 1	BMGnP1nn001	287	Scarce	0.36
Nassarius sp. 4	BMGnN1nn004	260	Scarce	0.33
Trigonosotma obliquata	BMGnT2TC001	255	Scarce	0.32
Family Myochamidae	BMBnM4nn001	245	Scarce	0.31
Mactra abbreviata	BMBnM1MA001	239	Scarce	0.30
Family Turridae 2	BMGnT5nn002	239	Scarce	0.30

Nassarius dorsatus	BMGnN1ND001	228	Scarce	0.29
Acteocina fusiformis	BMGnA1AF001	224	Scarce	0.28
Class Gastropoda 20	BMGnnnnn020	199	Scarce	0.25
Epitonium sp. 2	BMGnE2EE002	191	Scarce	0.24
Thalotia sp. 1	BMGnT2Tn001	191	Scarce	0.24
Class Gastropoda 3	BMGnnnnn003	190	Scarce	0.24
Class Gastropoda 46	BMGnnnnn046	177	Scarce	0.22
Cyclostremiscus sp. 4	BMGnV2nn004	176	Scarce	0.22
Lochyrma sulcifera	BMGnM1LS001	163	Scarce	0.21
Cyclostremiscus sp. 3	BMGnV2Cn003	152	Scarce	0.19
Class Gastropoda 15	BMGnnnnn015	141	Scarce	0.18
Semele sp.	BMBnS1Sn001	139	Scarce	0.18
Azorinus sp. 2	BMBnS2An002	125	Scarce	0.16
Bedeva hanleyi	BMGnM2BH001	119	Scarce	0.15
Soletellina sp.	BMBnP4Sn001	114	Scarce	0.14
Class Gastropoda 69	BMGnnnnn069	114	Scarce	0.14
Class Gastropoda 54	BMGnnnnn054	113	Scarce	0.14
Family Cuspidaridae	BMBnC4nn001	109	Scarce	0.14
Family Pyramidellidae 1	BMGnP2nn001	107	Scarce	0.14
Tellina sp. 7	BMBnT1Tn007	105	Scarce	0.13
Euchelus atratus	BMGnT2EA001	100	Scarce	0.13
Class Bivalvia 30	BMBnnnnn030	96	Scarce	0.12
Infra order Caridea	BCMDC1nn001	82	Scarce	0.10
Family Pyramidelidae 4	BMGnP2nn004	82	Scarce	0.10
Eunice sp.	BAPnE1En001	80	Scarce	0.10

Port Curtis Seagrass Monitoring and Research
May, 1999

Central Queensland
UNIVERSITY

Centre For Environmental Management
Central Queensland University
Gladstone Campus

Port Curtis Seagrass Monitoring and Research
May, 1999

Supervisor: Dr. Michael Walker BSc (Hons) (UTas), PhD (JCU)
Senior Research Fellow
Faculty of Applied Science
Central Queensland University

Authors: Samantha Lewis BSc (Hons) (UTas)
Kirsty M^c^Namara ADARM (CQU)

Table of Contents

1.0	**Executive Summary**	1
2.0	**Introduction**	2
3.0	**Methodology**	2
	Seagrass transects	3
	Benthic sampling	3
	Seagrass biomass	3
4.0	**Results**	4
	Seagrass transects	5
	Seagrass biomass	4
	Benthic sampling	5
5.0	**Discussion**	6
6.0	**References**	7

List of Figures

Figure 1 Percentage Coverage of seagrass species along transects at Friend Point and Flying Fox in August, 1998

Figure 2 Dry Weight of *Zostera capricorni* components at Friend Point and Flying Fox in August, 1998.

List of Appendices

Appendix 1 Biomass (wet and dry weights) of *Z. capricorni*, *H. ovalis* and algae in samples taken at Friend Point and Flying Fox in August 1998 and March 1999.

1.0 Executive Summary

The construction of the Stuart Oil Shale Plant, and its expansion to Stage 2 operations, has the capacity to have indirect and direct impacts on adjacent extensive seagrass/algal beds through increased sedimentation and changes in freshwater flows. The Stuart Oil Shale project has a responsibility to monitor and minimise any impacts on neighbouring seagrass/algal beds. Central Queensland University's Centre for Environmental Management has been commissioned by Stuart Oil Shale to undertake this task on its behalf.

The seagrass *Zostera capricorni* and *Halophila ovalis* dominate the mudflat adjacent to the Stuart Oil Shale site. Four permanent buoys were located during 1998 at the North, South, East and West extremes of each seagrass bed, with 1 buoy marking the centre. A series of six transects were surveyed using snorkeling equipment between the five established buoys twice a year with six quadrats assessed for seagrass coverage and composition every ten metres. Additionally, biomass sampling occurred twice a year in March and September at four stations at both Friend Point and Flying Fox using a van Veen grab. Seagrass found was firstly separated by species (*H. ovalis* and *Z.capricorni*) and then further separated into the various components (leaves, roots, shoots and rhizomes). Macrobenthic species greater than 1mm were also separated from biomass grabs and the diversity and abundance of species recorded.

Seagrass biomass in March 1999 was significantly lower than that found in August 1998. Also the biomass of *H. ovalis* was always less than that of *Z. capricorni*. *Z. capricorni* biomass was fairly consistent at Flying Fox stations, while biomass was more variable at Friend Point. *H. ovalis* was found to occur more frequently at Flying Fox than Friend Point. Algal biomass at all stations was consistently low, with no algae being found in March, 1999. *Z. capricorni* frequently exhibited reciprocal relationships to *H. ovalis* and algae. No correlation was found between seagrass biomass and benthic biomass. However, Shannon-Wiener diversity and equitability were low at some stations, suggesting disturbance is occurring.

Freshwater flows have the ability to alter seagrass species composition, particularly the abundance of less competitive species such as *H. ovalis*. It is very important to monitor these changes in order to determine the impacts on benthic fauna in the seagrass beds themselves and in the harbour as a whole.

2.0. Introduction

The construction of the Stuart Oil Shale Plant and expansion to Stage 2 has the capacity to have indirect and direct impacts on adjacent extensive seagrass/algal beds through increased sedimentation and changes in freshwater flows.

The project has a responsibility to minimise and monitor any impacts on neighbouring seagrass/algal beds. Central Queensland University's Centre for Environmental Management has been commissioned by the Oil Shale project partners to undertake this task on their behalf. This report outlines the seagrass monitoring program conducted since September 1998.

The seagrass *Zostera capricorni* and *Halophila ovalis* dominate the mudflat adjacent to the site. There are also 2 algal species that have been tentatively been identified as *Rhizoclonium sp* and *Monostroma sp.* Three broad habitat types have been identified for the mud flat as follows:

* outer channel margins containing a mixture of seagrass and algae, often with algae dominant

* inner, sheltered channel margins where large patches of extensive seagrass cover sometimes occurred

* an extensive mud/sandflat subject to regular tidal inundation and dominated by *Z.capricorni,* but never continuously in terms of cover.

3. 0 Methods

Condition of seagrasses in the past have been assessed by the Centre for Environmental Management in terms of detailed observations and comparisons of seagrass abundance, condition and physical changes over time for related areas adjacent to Gladstone Port Authority landfill sites and more distant control stations. Samples were taken at several stations on the seagrass bed, with transect lines running across the central area of the flat, in order to be representative of seagrass composition. Observations on the overall appearance and condition of the seagrasses were made, including the presence or absence of filamentous algal mats and the density of epiphytic algae on seagrass leaves.

Permanent buoys were established for the Stuart Oil Shale project over seagrass beds at Flying Fox and Friend Point in September 1998. Each buoy consisted of a triangular concrete block placed on the mudflat and linked to a 4 inch diameter polystyrene float via can of 6mm SS304 stainless steel chain and up to 7m of 10mm silver rope with a 12 inch diameter polystyrene float which was marked with the station number and CQU Marine Research. The chain was attached to stainless steel eye cemented into the concrete block with a 5/6" SS304 stainless steel shackle and the rope with a 10mm RF487 thimble and rope eye splice. Four buoys were located at the North, South, East and West extremes of each seagrass bed, with 1 buoy marking the centre.

Seagrass Transects

A series of six transects were surveyed by swimming with snorkeling equipment between the five established buoys twice a year with six quadrats assessed for seagrass coverage and composition every ten metres. The percentage coverage of each species of seagrass and algae in each 0.5 m^2 quadrat was recorded. Around each buoy, ten further quadrats were assessed using the same method.

Benthic Sampling

Biomass sampling occurred twice a year in March and September at both Friend Point and Flying Fox seagrass beds. Four stations for each bed were sampled at the North, South, East and West extremes of the beds (near the established buoys). A 0.1m^2 van Veen grab was used to collect 10 replicate benthic samples at each of the four stations and one sediment sample per station. The samples were sieved through a 1mm sieve, with the retained portion preserved in 5% formalin for 72 hours. Samples were then transferred to 70% ethanol for storage until sorting. All samples were sorted in the laboratory using a dissecting microscope, with species being identified to family level and where possible genus and species. Statistical analysis, including Shannon-Wiener and equitability, was undertaken using species composition and abundance measures.

Seagrass Biomass

Prior to preservation, seagrass was separated from benthic samples and set aside for sorting. This was firstly separated by species (*H. ovalis* and *Z.capricorni*) and then further separated into component parts (leaves, roots, shoots and rhizomes). Each of these components were weighed before (wet weight) and after (dry weight) drying at 40°C for 24hrs.

4.0 Results

Seagrass transects

Average percentage coverage for each species was calculated every ten metres along each transect from the six replicate quadrats assessed. These results have been presented graphically in Figure 1. The average percentage coverage of seagrass species at the five buoys was also calculated (below).

	% Coverage		
Flying Fox	*Z. capricorni*	*H. ovalis*	Algae
Buoy 1	3.4	0	0
Buoy 2	13.8	10.4	0
Buoy 3	8.8	13.2	0
Buoy 4	4	0	0
Buoy 5	16	10	0

	% Coverage		
Friend Point	*Z. capricorni*	*H. ovalis*	Algae
Buoy 1	46.4	0	0
Buoy 2	21.45	0	11.5
Buoy 3	60.8	0	0.08
Buoy 4	0	0	0
Buoy 5	22	10	10.8

Friend Point transects were dominated by *Z. capricorni* with very little *H. ovalis* present. Transects on the South-Western side of the bed from buoy 4 had higher percentages *H. ovalis* (4-3 up to 50% *H. ovalis* and 4-5 up to 30%). Algae occurred at 4/6 transects, particularly at the North West part of the bed. *H. ovalis* does not normally occur where algae is found, and a reciprocal relationship frequently occurred between *Z. capricorni* and algae or *H. ovalis*.

Flying Fox had both *H. ovalis* and *Z. capricorni* present, with a reciprocal relationship occurring. Algae was not present at Flying Fox.

Buoy data was fairly consistent with the transect data for areas near the buoys.

Seagrass Biomass

The wet and dry weights of components of *Z. capricorni* and *H. ovalis* and the total wet and dry weight of algae found at biomass stations in August 1998 and March 1999 are presented in Appendix 1. Dry weight of *Z. capricorni* components at Friend Point and Flying Fox stations are

also presented graphically in Figure 2. Data for *H. ovalis* and algae are not graphed due to low amounts found at the stations.

Seagrass biomass in March 1999 was significantly lower than that found in August 1998. Also the biomass of *H. ovalis* was always less than that of *Z. capricorni*. *Z. capricorni* biomass was fairly consistent at Flying Fox stations, while at Friend Point, biomass was more variable, with Station 3 having particularly high biomass. *H. ovalis* was found more frequently at Flying Fox than Friend Point. Biomass of algae at all stations was consistently low, with no algae found in March, 1999. Number of shoots correlated with biomass. Leaf length varied between 5.6cm and 10.42cm for *Z. capricorni* and 0.85cm and 1.95cm for *H. ovalis*. Leaf length in August 1998 was generally longer than that in March, 1999.

Transect results appear generally consistent with biomass results. The amount of *Z. capricorni* was more variable at Friend Point transects than Flying Fox transects, with *H. ovalis* being more common at Flying Fox. Generally buoy data was consistent with dry weight data, with exceptions.

Benthic Sampling

The number of species, abundance, Shannon-Wiener diversity, and equitability were calculated for each station at both seagrass sites for both sampling events. These are tabulated below.

Stations	Date	Abundance	Richness	Shannon-Wiener	Equitability
Flying Fox 1	Aug-98	284	54	3.36	0.84
	Mar-99	183	46	3.41	0.89
Flying Fox 2	Aug-98	232	56	3.49	0.87
	Mar-99	315	55	3.38	0.84
Flying Fox 3	Aug-98	1229	81	3.02	0.69
	Mar-99	319	52	3.17	0.80
Flying Fox 4	Aug-98	310	45	2.93	0.77
	Mar-99	1059	67	2.51	0.60
Friend Point 1	Aug-98	425	45	3.01	0.79
	Mar-99	783	58	2.98	0.73
Friend Point 2	Aug-98	241	43	3.10	0.82
	Mar-99	118	31	2.99	0.87
Friend Point 3	Aug-98	351	53	3.08	0.78
	Mar-99	578	53	3.10	0.78
Friend Point 4	Aug-98	548	65	3.18	0.76
	Mar-99	440	55	3.14	0.78

Diversity and equitability were low at Flying Fox Station 3 and 4 and Friend Point Stations 1 and 2. Communities at these sites may be undergoing disturbance of some kind, which requires further investigation. Changes to benthic biomass did not reflect changes in seagrass biomass. It can not be expected that this would be apparent from such short term data as seasonal effects can not be factored out at this stage.

5.0 Discussion

Seagrass ecosystems are important contributors to coastal ecosystems. Seagrass provides a major food source in detrital based food chains, and a direct food source for grazing animals including the dugong and the green turtle (Lanyon, 1986). Seagrass meadows support a rich and diverse range of flora and fauna and provide a nutrient rich shelter (Lanyon, 1986).

Topography, substrate type, tidal exposure, water clarity and salinity are all factors which are important in determining seagrass distribution (Lanyon, 1986). Seagrass biomass and cover varied between sites and within sites in this study. At Flying Fox, *Z. capricorni* distribution was more consistent than at Friend Point, perhaps due to less variation in the above factors. Algae at Friend Point was found to be more common at the North Western end of the bed, which is closer to land. This may reflect different sediment composition, or alternately increased nutrient runoff from the land. *H. ovalis* was more common at the South Western end of the bed at Friend Point (deeper water) and the South Eastern side of the bed at Flying Fox (near a deep channel). This may be indicative of a preference for deeper waters.

Trends in seagrass composition were apparent in the transect data. *Z. capricorni* frequently exhibited reciprocal relationships to *H. ovalis* and algae. This suggests that the species prefer different conditions and so are more prolific where those conditions prevail. It is not known whether the species are in direct competition with each other. Low percentage coverage overall suggest that the community is not at climax, such that spatial competition is not presently a factor limiting growth.

Z. capricorni belongs to a group of seagrasses called magnozosterids which have high tolerance to environmental variations, such that they are able to inhabit wide ranges (den Hartog, 1977). Halophilids (such as *H. ovalis*) have a low competitor capacity and occur in habitats where others

are absent (den Hartog, 1977). *H. ovalis* has been known to occur in habitats where freshwater runoff prevents other seagrasses growing. Changes in seagrass species composition may therefore occur with changes to freshwater flows.

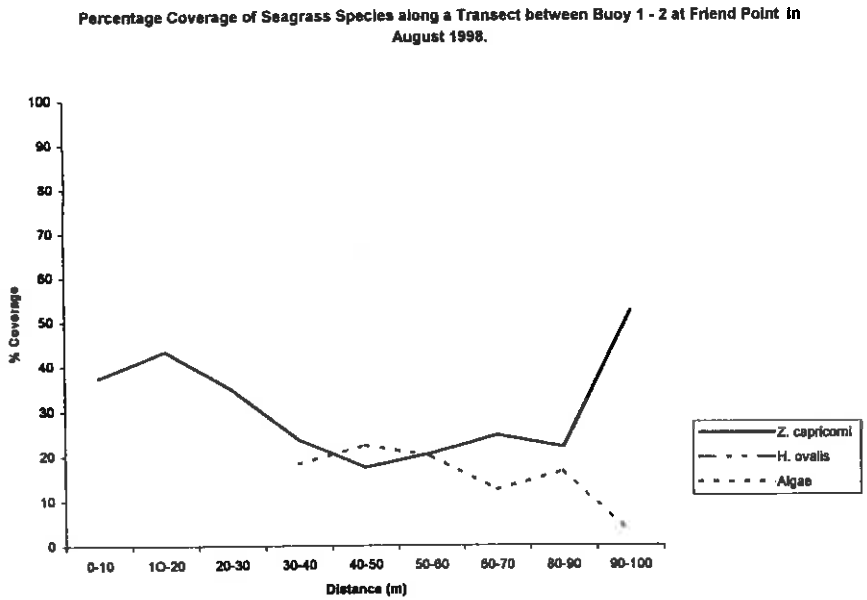
Sediment composition is currently being studied and will provide valuable insight into the distribution patterns of these seagrasses. Benthic biomass is expected to be influenced both by seagrass cover and sediment composition. At this stage, there is evidence that disturbance may be occurring at some stations, particularly Station 3 at Flying Fox, however correlation with seagrass biomass is not yet possible. The short term nature of this study precludes meaningful results from what is intended to be a long term indicator. Further analysis of benthic, seagrass and sediment data in the future will provide insight into the importance of these seagrass beds to the Port Curtis ecosystem.

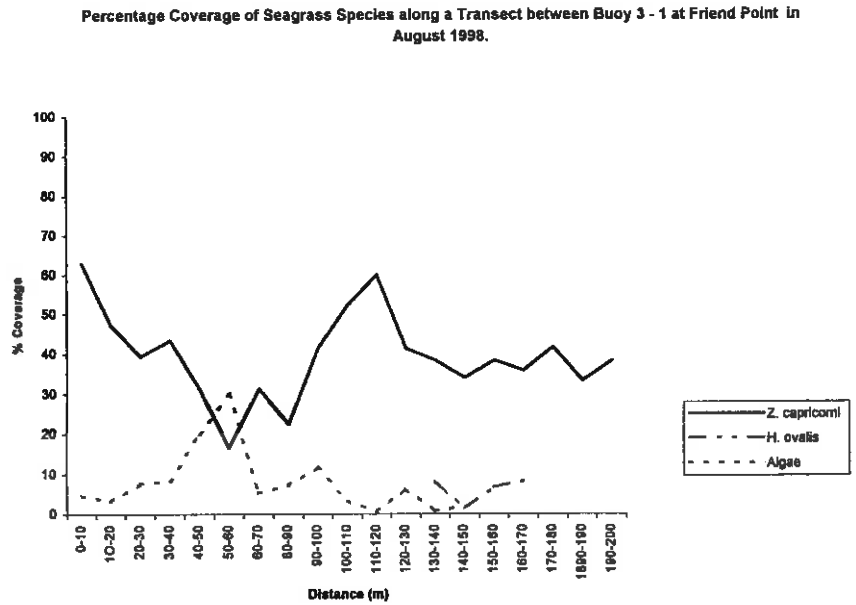
6.0 References

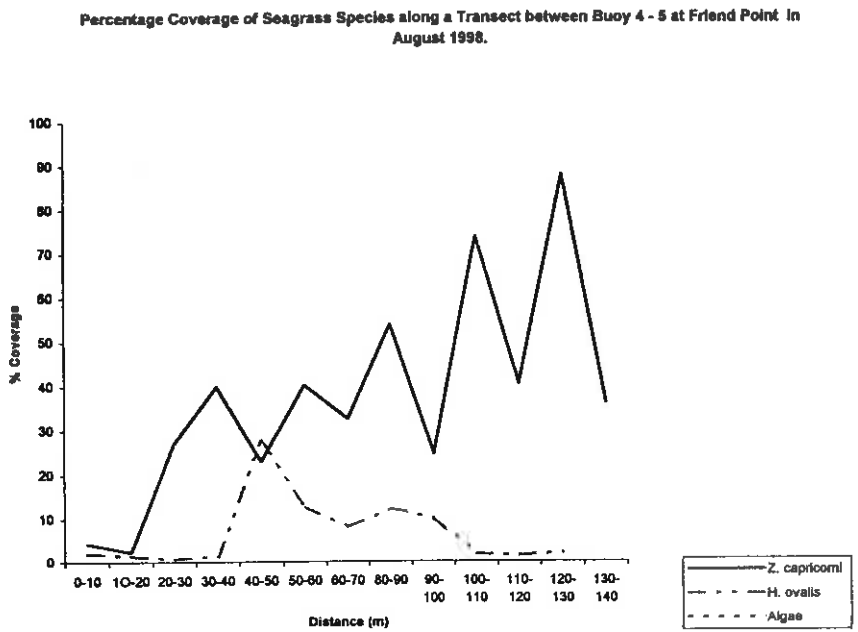
den Hartog, C., (1977). Structure, function and classification in seagrass communities. In *Seagrass Ecosystems. A scientific perspective.* (eds. C.P. McRoy and C. Helfferich). Marcel Dekker Inc: New York. p. 89-122.

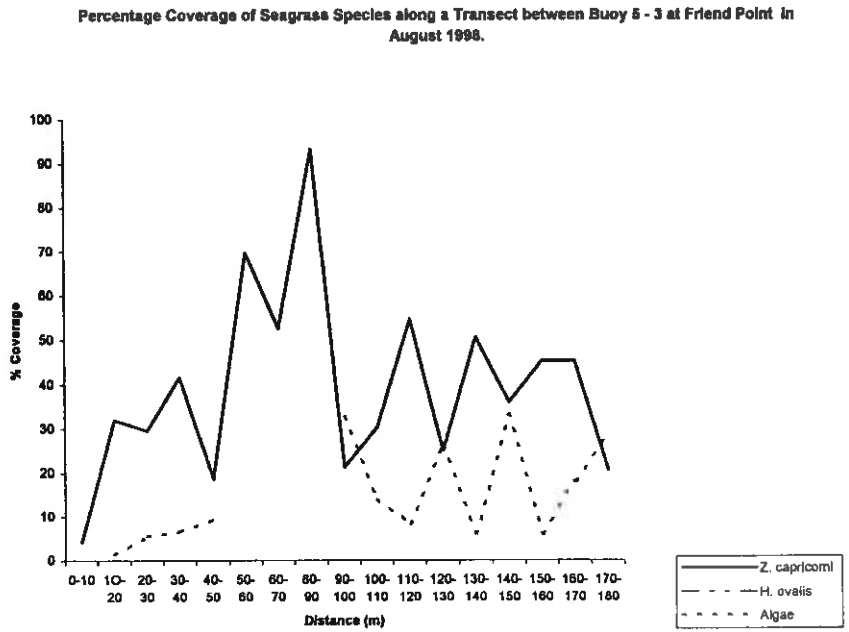
Lanyon, J. (1986). *Seagrasses of the Great Barrier Reef.* Great Barrier Reef Marine Park Authority Special Publication Series (3), QLD.

Figure 1a. Percentage coverage of seagrass species along transects at Friend Point in August, 1998.

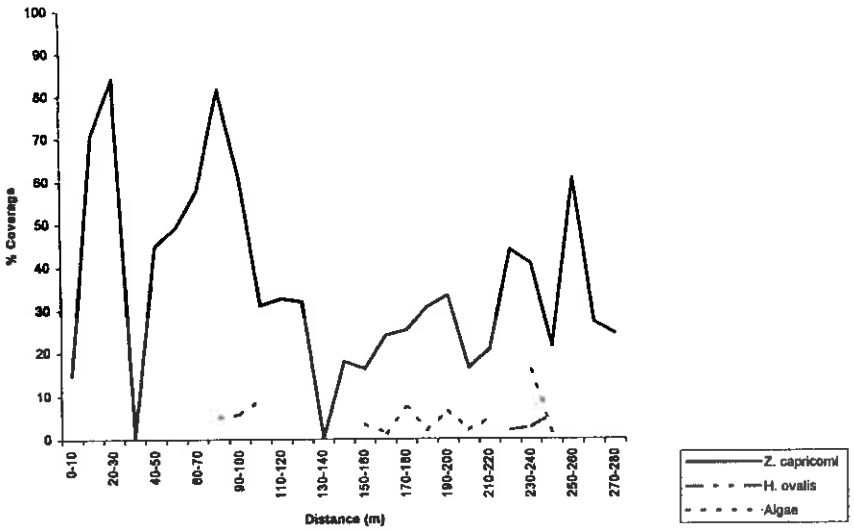








Percentage Coverage of Seagrass Species along a Transect between Buoy 2 - 3 at Friend Point in August 1998.



Percentage Coverage of Seagrass Species along a Transect between Buoy 4 - 3 at Friend Point in August 1998.

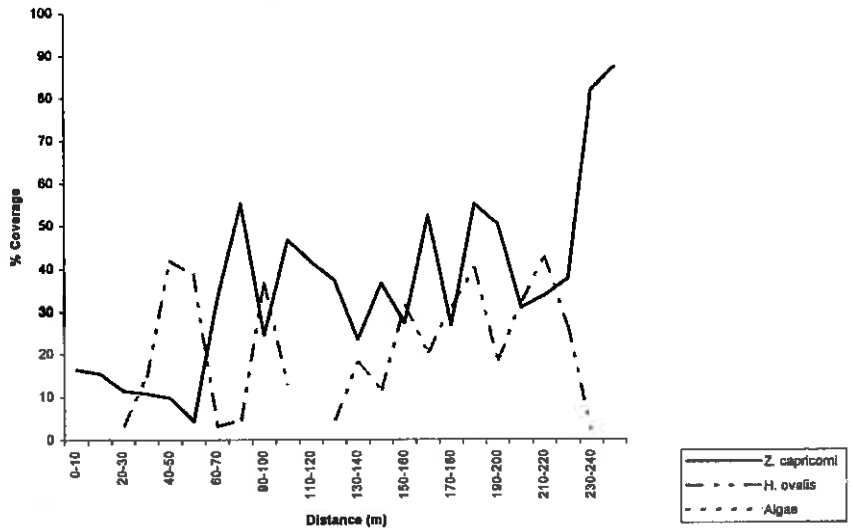
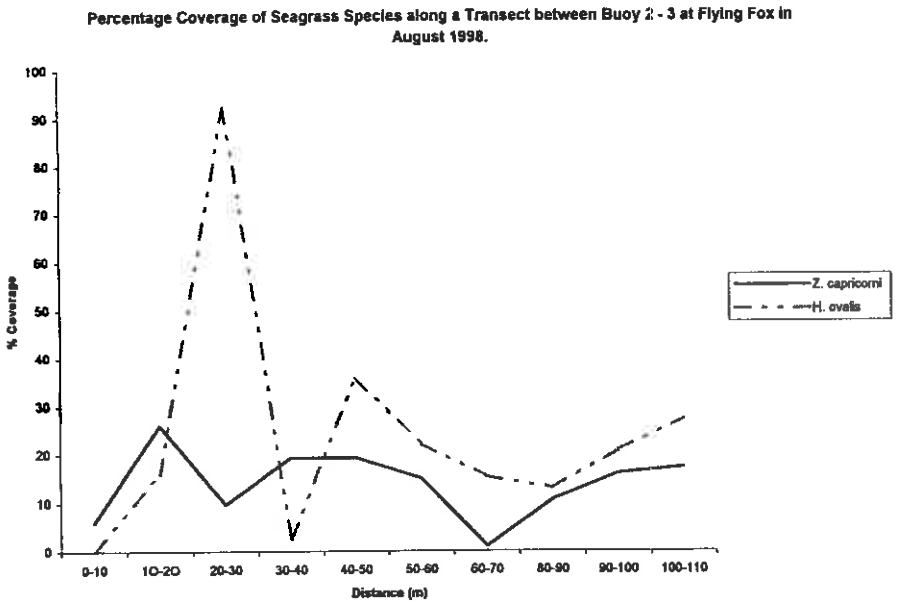
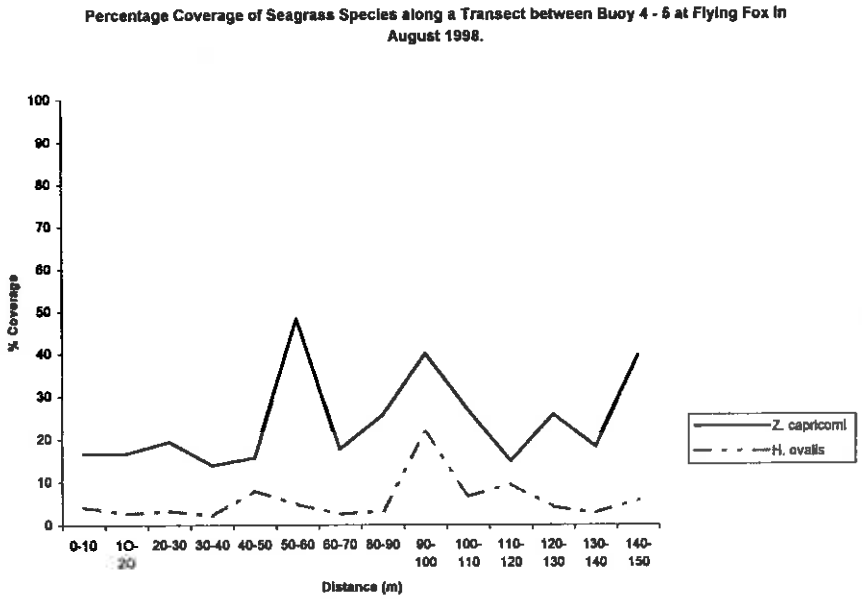
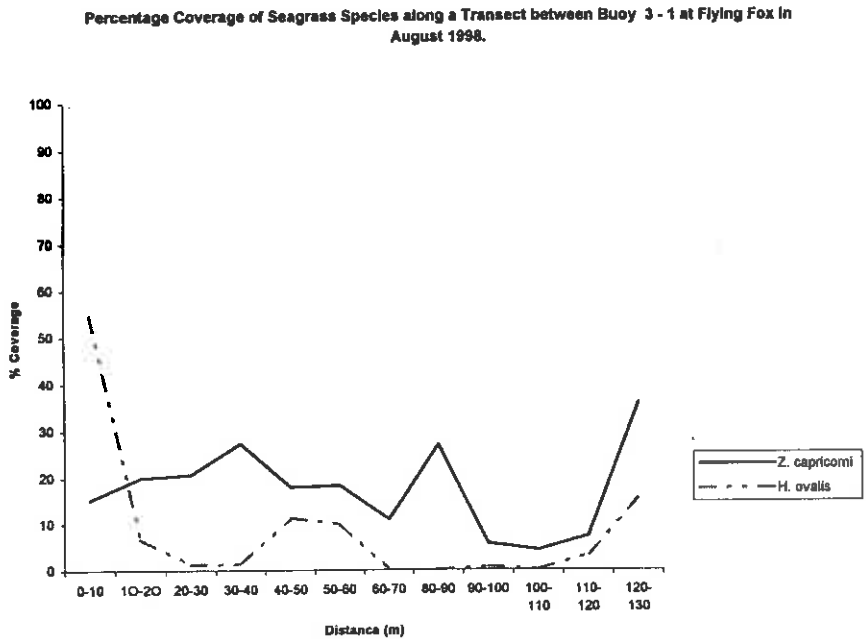
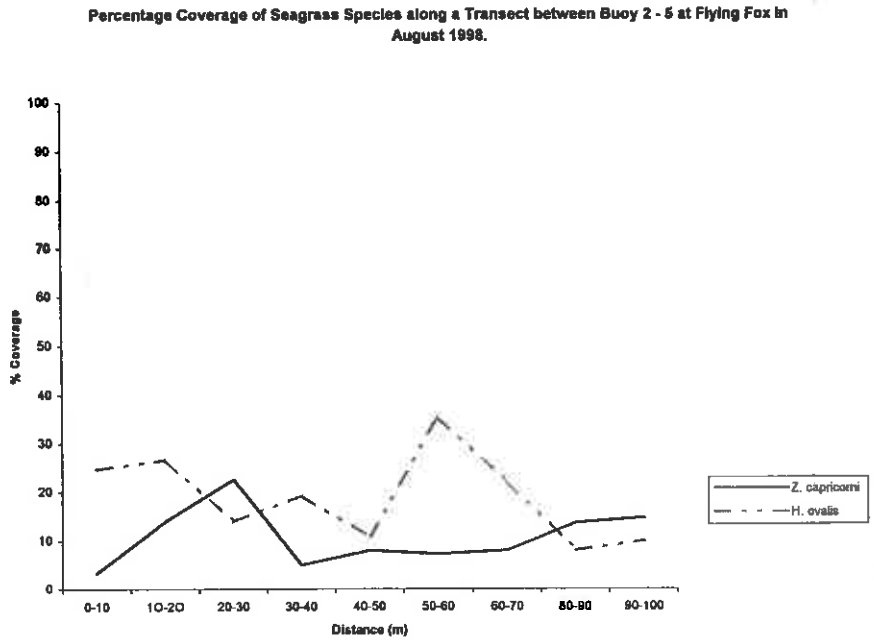


Figure 1b. Percentage coverage of seagrass species along transects at Flying Fox in August, 1998.

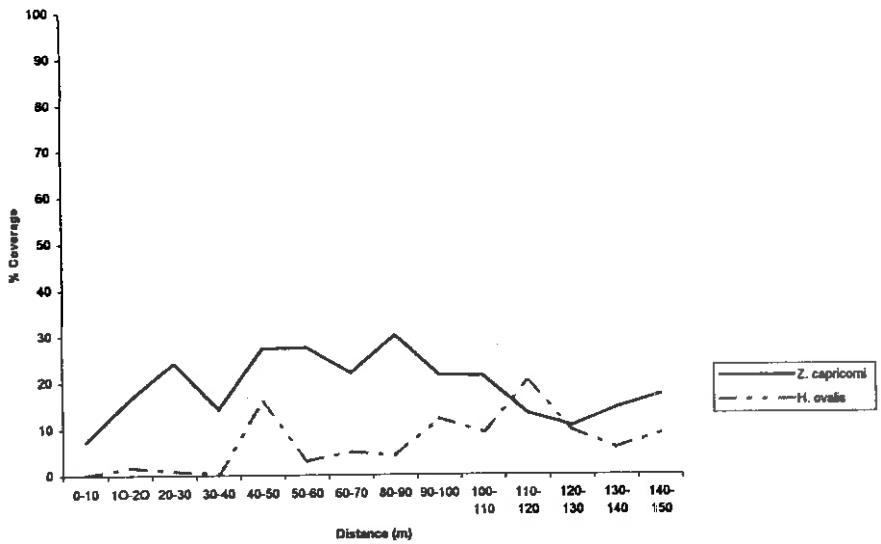








Percentage Coverage of Seagrass Species along a Transect between Buoy 4 - 3 at Flying Fox in August 1998.



Percentage Coverage of Seagrass Species along a Transect between Buoy 1 - 2 at Flying Fox in August 1998.

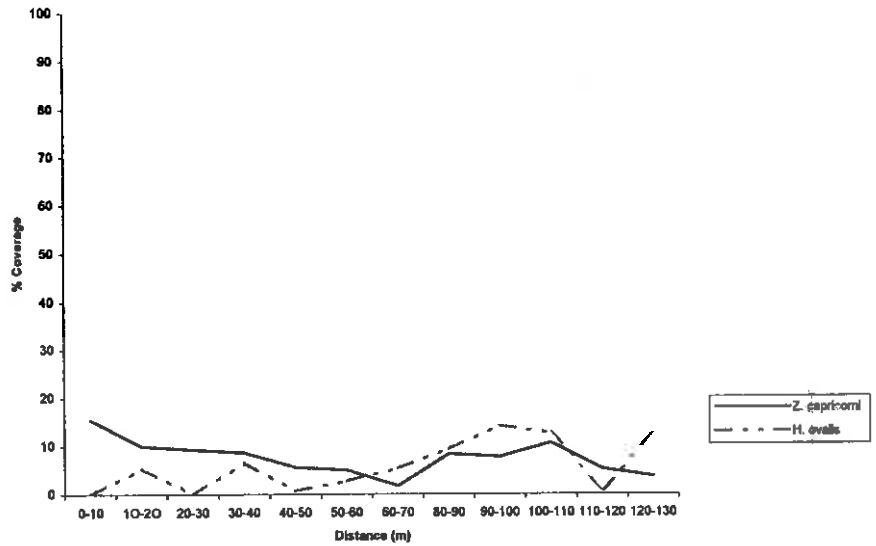


Figure 2a. Dry Weight of *Zostera capricorni* components at Friend Point and Flying Fox in August 1998.

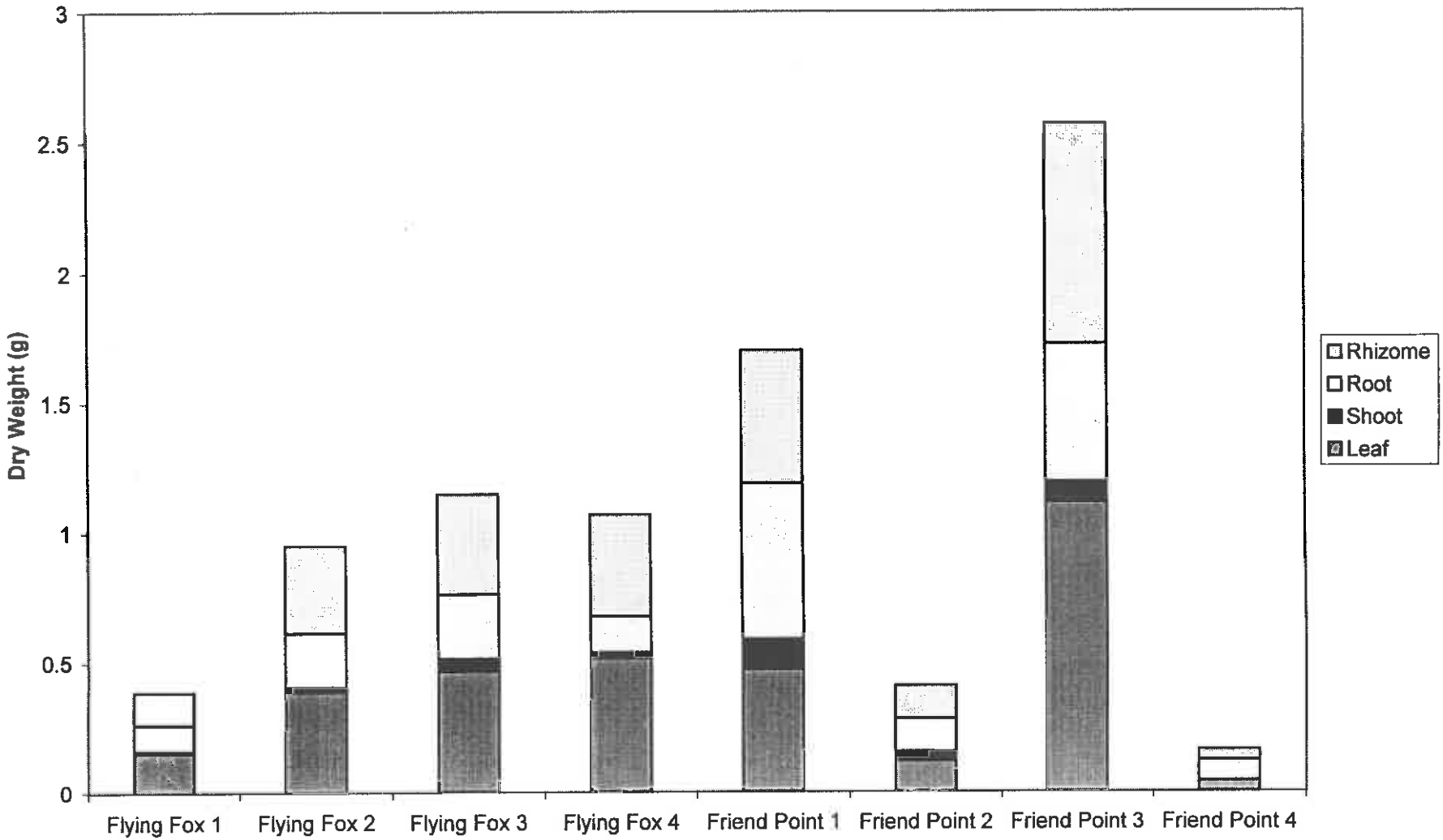
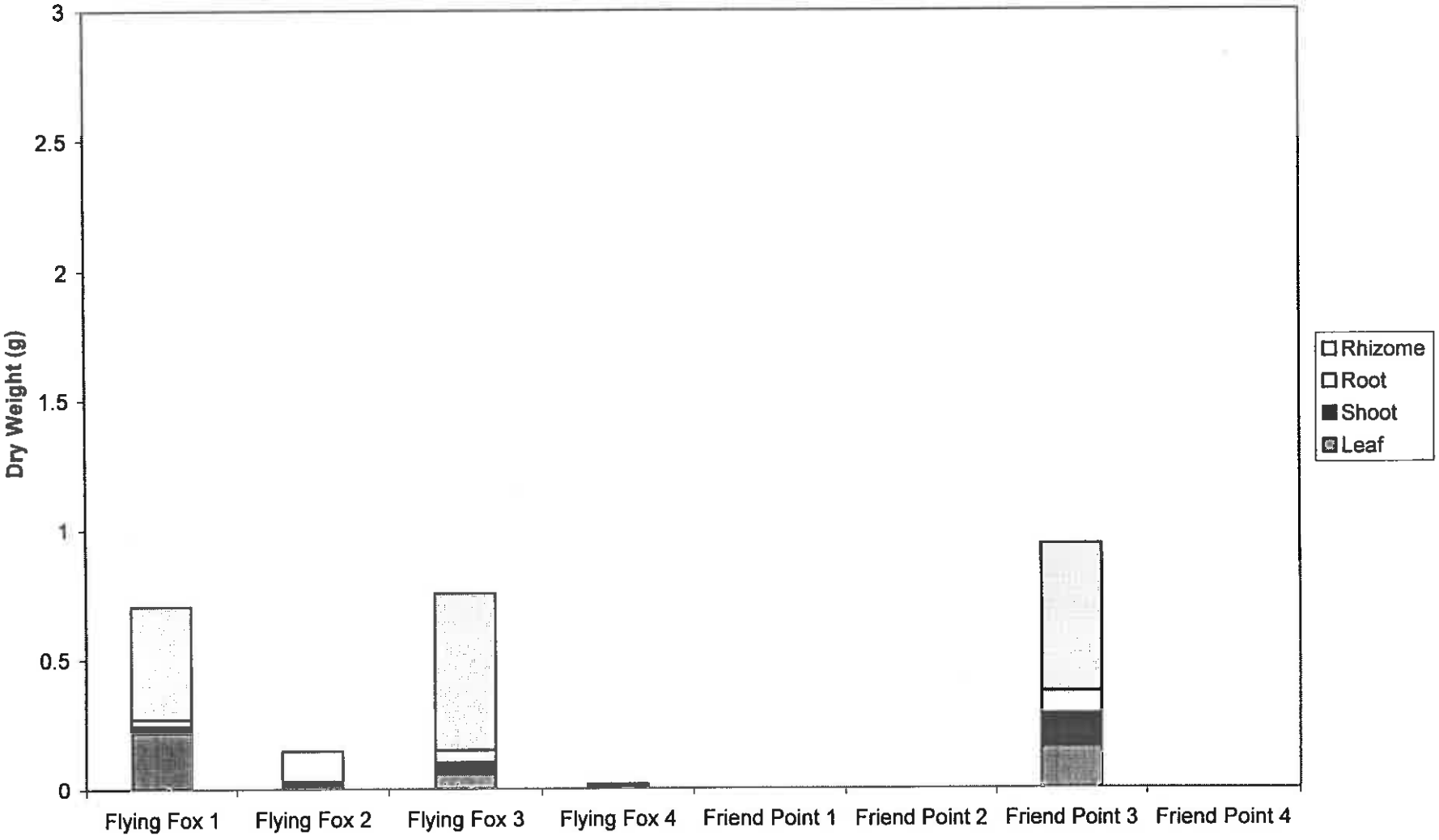


Figure 2b. Dry Weight of *Zostera capricorni* components at Friend Point and Flying Fox in March 1999.



ɔendix 1. Biomass (wet and dry weights) of *Z. capricorni*, *H. ovalis* and algae at Friend Point and Flying Fox in August, 1998 and March 1999.

ıd Point Seagrass Biomass in August 1998

		Wet weight				Dry weight				No Shoots	Leaf Length
		Leaf	Shoot	Root	Rhiz.	Leaf	Shoot	Root	Rhiz		
ation 1	*Z. capricorni*	2.168	0.573	2.71	3.814	0.469	0.117	0.602	0.514	74	8.16
ation 2	*Z. capricorni*	0.597	0.13	0.561	0.899	0.117	0.037	0.128	0.127	16	7.43
ation 3	*Z. capricorni*	10.721	1.03	6.966	6.013	1.114	0.077	0.535	0.845	75	10.42
ation 4	*Z. capricorni*	0.275	0	0.522	0.318	0.04	0	0.081	0.04	16	5.6

ıg Fox Seagrass Biomass for August 1998

		Wet weight				Dry weight				No Shoots	Leaf Length
		Leaf	Shoot	Root	Rhiz.	Leaf	Shoot	Root	Rhiz		
ation 1	*Z.capricorni*	1.153	0.040	1.166	1.203	0.153	0.007	0.101	0.126	68	8.38
	H.ovalis	0.068	0.000	0.027	0.058	0.001	0.000	0.001	0.001	0	0.85
ation 2	*Z.capricorni*	3.147	0.272	2.284	3.812	0.386	0.018	0.207	0.338	82	6.16
	H.ovalis	1.048	0.286	0.887	1.350	0.172	0.024	0.071	0.117	52	1.95
ation 3	*Z.capricorni*	3.611	0.437	2.316	3.343	0.464	0.050	0.246	0.387	74	6.44
ation 4	*Z.capricorni*	4.998	0.260	2.501	3.696	0.514	0.022	0.140	0.392	82	7.12
	H.ovalis	0.484	0.048	0.217	0.567	0.035	0.006	0.009	0.044	33	1.62

ıd Point Seagrass Biomass in March 1999

		Wet weight				Dry weight				No Shoots	Leaf Length
		Leaf	Shoot	Root	Rhiz.	Leaf	Shoot	Root	Rhiz		
ation 3	*Z. capricorni*	0.55	0.355	0.943	3.391	0.157	0.126	0.09	0.57	23	5.65
	H. ovalis	0.108	0.217	0.069	0.393	0.026	0.004	0.008	0.009	6	1.59

ıg Fox Seagrass Biomass for March 1999

		Wet weight				Dry weight				No Shoots	Leaf Length
		Leaf	Shoot	Root	Rhiz.	Leaf	Shoot	Root	Rhiz		
ation 1	*Z.capricorni*	0.508	0.113	0.316	3.491	0.218	0.026	0.026	0.432	43	4.35
ation 2	*Z.capricorni*	0.125	0.056	0.107	1.006	0.014	0.003	0.011	0.119	9	4.25
	H.ovalis	0.281	0.070	0.063	0.242	0.039	0.006	0.006	0.039	18	1.77
ation 3	*Z.capricorni*	0.450	0.198	0.323	3.313	0.058	0.044	0.047	0.601	26	5.09
	H.ovalis	0.034	0.007	0.011	0.034	0.002	0.001	0.001	0.001	3	1.44
ation 4	*Z.capricorni*	0.011	0.000	0.034	0.083	0.001	0.000	0.006	0.011	2	3.15

mass of algae (wet and dry weights) found at Friend Point and Flying Fox in August 1998.

		Wet	Dry
ying Fox	Station 1	1.24	0.09
	Station 2	0.01	0.01
	Station 3	1.38	0.48
	Station 4	1.86	0.18
ɜnd Point	Station 2	2.6	0.4

Port Curtis Fish and Fisheries Report
May, 1999

Table of Contents

1	**Introduction**	1
2	**Methodology**	2
3	**Results**	2
4	**Discussion**	3
5	**References**	5

List of Tables

Table 1 Marine Fishes collected from Port Curtis adjacent to Stuart Oil Project 1998-1999

Table 2 Summary fish species caught Port Curtis adjacent to Stuart Oil Shale Project May – June 1998

FISHES OF PORT CURTIS ADJACENT TO THE STUART OIL PROJECT

1. Introduction

Stage 1 of the Stuart Project Oil Shale comprises the mining and on site processing of oil shale from the Kerosene Creek member of the Stuart Oil Shale Deposit. Stage 1 is a research and development project and involves the construction and operation of a mine and demonstration plant capable of producing 4500 barrels of oil per day. The environmental approval of Stage 1 followed the completion of a rigorous Environmental Impact Assessment Study in 1992. The construction stage of the project commenced in 1998.

The project site is located on the coastal lowlands of Port Curtis, Central Queensland; to the east of the Mt Larcom range approximately 15km north of Gladstone. The Kerosene Creek member is the uppermost oil shale unit of the larger Stuart Oil Shale Deposit which is approximately 5km wide and 40km in length, extending in a northwesterly direction from South of Boat Creek.

Stage 2 of the project involves the extension of the Stage 1 oil shale mine to include the full Kerosene Creek member and the construction of the Stage 2 process plant which includes a single commercial scale oil shale processing module and associated oil recovery (processing) facilities.

Stage 2 of the Stuart Oil Shale Project will involve progressive open cut mining of the Kerosene Creek member over a 10 km strike length. The mine path will intersect a number of creeks and gullies which convey runoff from catchment areas lying between the Mount Larcom range and Port Curtis. Mining will necessitate the progressive diversion of creeks and gullies around the mine in a series of staged diversions. These diversions will, at times, alter the freshwater flow regime into Port Curtis temporarily and spatially. This has the capacity to alter movements and distributions of migratory and resident fishes within Port Curtis either by changes of habitat or salinity. This report documents the fish species for the area adjacent to the Stuart Oil Shale Project between Fisherman's Landing and Friend Point/Graham Creek. This work was undertaken by the Fisheries Consultants, Curtis Coast Consulting Pty Ltd on behalf of the proponents SPPD.

Port Curtis has not been extensively studies in terms of its fish/fisheries particularly the area from Fisherman's Landing to Friend Point and Graham Creek. Previous biological surveys of the area have mostly sampled fishes as a bycatch or as part of IAS survey work (WBM, 1990, Dames and Moore, 1998). A checklist of fishes recorded for the Curtis Coast is given in the Curtis Coast Study Report (QDEH, 1994). It is assumed that the species list had the assistance of or was compiled by the Queensland Museum.

2. Methodology

Net fishing was undertaken during May 1998. Net specifications were as follows:

- 0.5in x 15m monofilament net
- 0.5in x 15m cotton net
- 2.25in x 66m monofilament net
- 4.5in x 100m monofilament net
- 8in x 30m monofilament net
- 9in x 45m monofilament net

Nets were set prior to high tide and hauled 3 to 4 hours later before they and their catch were exposed. The area investigated was relatively shallow and was mostly exposed during low tides. Setting times were selected for suitability of tides in terms of both size, current intensity and timing. The techniques employed attempted to replicate a commercial net fishing exercise.

All fishes caught were photographed, identified using Marshall (1964) and Grant (1985), and measured. Fish in good condition, where possible, were released alive after capture under the terms of a QFMA General Fisheries Permit PRM00358A.

3. Results

In excess of 650 fishes from 44 fish species and representative of 30 families were caught, measured and identified (Table 1).

Species caught and measured are summarised (Table 2) in terms of number, length and weight.

Two species, the triple tail and the brown banded catshark were the first scientifically documented records for the Curtis Coast.

It was noted that during the May survey that:

- blue salmon were feeding on banana prawns and small bait fishes 10.5.98, 24.5.98
- flat salmon were feeding on banana prawns and fish (mullet, mudskipper and an eel) 24.5.98, 10.5.98
- 1 sea mullet was in spawning condition 24.5.98
- King salmon were feeding on prawns and small mullet 9.5.98
- grunter were feeding on sesarmid crabs and pistol shrimps 9.5.98
- the barramundi caught had been feeding on fish 9.5.98
- catfish were feeding on sesarmid crabs and fish 22.5.98
- black bream had been feeding on sesarmid and *Thalamita* sp. crabs and small molluscs 22.5.98 and one was in spawning condition
- a yellow fin bream was in spawning condition 24.5.98
- the hammerhead shark had been feeding on prawns 22.5.98
- the large bronze whaler caught had an empty stomach 9.5.98
- the black tip shark caught had been feeding on fish 9.5.98

4. Discussion

WBM (1990), conducted 30 gill net sets during September and November 1989 along the foreshore of the Targinnie Wetland (assumed to be between Fisherman's Landing and the Calliope River mouth). They caught 68 specimens composed of 13 species. Two of these species, the blind shark *Brachaelurus waddi* and the striped butterfish *Selenotoca nultirodiatus* were not encountered during this study. WBM (1990) also conducted four seine hauls and captured approximately 250 specimens representative of 18 species, some of which were encountered during this study. As seines have smaller mesh and the technique is different to set gill netting, different and smaller fishes are expected to be caught. The opportunity for seining

along the foreshore of Port Curtis adjacent to the Stuart Oil Shale plant is limited because of the soft muddy bottom, shallow depths, snags and oyster covered rocks located on harder bottoms, the limited number of hard banks on which to haul and the strong currents associated with tidal movements. Thus it is believed that utilising only set gill netting, of a variety of mesh sizes, is justified.

This study represents one of the first attempts to sample fishes of commercial and recreational importance in a similar manner to a commercial fishing operation. Professional fishers operate in the study area irregularly seeking mullet for bait, salmon and barramundi in season. Catches are generally small and are recorded on the QFISH database for Port Curtis. They cannot be separated according to specific areas. The foreshore area of study and associated tidal creeks receive a relatively high fishing pressure from professional and recreational fishers seeking the highly valued mud crab.

The Gladstone region supports one of the most productive mud crab fisheries in Queensland, second only to Moreton Bay. Mud crabs have a strong relationship with mangrove communities and may well be a keystone species of these communities. Females spawn offshore in winter and recruitment of small crabs occurs in spring. Juveniles are found in sheltered waters, especially in the upper reaches of mangrove creeks. A new shell disease of mud crabs was encountered in the area of study adjacent to Fisherman's Landing. The phenomena is currently the topic of a Fisheries Research Grant. To date the phenomena can not be related to industrial sources.

Of the more numerous fishes caught during this study, migratory fish predominate eg mullet, bony bream, blue salmon, flat salmon and blue herring. Detritus and plankton feeding fishes utilise the foreshores and tidal creeks of Port Curtis (eg mullet, bony bream, blue herring or other clupeids). The larger predatory fishes (eg blue salmon, blue catfish, flat salmon, grunter, King salmon, barramundi and sharks) seek out these bait fishes for food as well as prawns and sesarmid crabs which reside in the tidal creeks or sheltered foreshore areas. Other omnivorous fishes such as the black and silver bream feed on smaller fishes as well as on molluscs and small crustaceans located in seagrass beds and elsewhere.

Of the other 30 species recorded in Table 2, 15 species are assessed as being of commercial value to either recreational or commercial fishers. These species are mullet, flat salmon, blue salmon,

black and silver bream, flathead, whiting, King salmon, narrow barred mackeral, barramundi, garfish, cod and jewfish.

No fish species encountered in the area of study could be regarded as endangered. The fish fauna is typical of a sheltered marine embayment or estuary. The recreationally and commercially important fish fauna relies upon the bait fishes, prawns, crabs and other small benthic animals present in the area as a food resource and is very much part of the Port Curtis ecosystem of saltflats, mangroves, seagrasses, tidal creeks and benthic communities. The continued existence of the Port Curtis fish fauna in adequate abundance to satisfy commercial and recreational fishers is dependant upon fish habitat protection and the maintenance of good water quality. The Stuart Oil Shale project has a responsibility to preserve fish habitat and good water quality. Its future operation at Stage 2, with good environmental management and monitoring, does not threaten this resource.

5. References

Dames & Moore. (1998). *Comalco Alumina Project Gladstone - Impact Assessment Study Environmental Impact Statement, Vol 1& 2*. Brisbane.

Grant, E.M. (1985). *Guide to Fishes*. The Department of Harbours and Marine, Brisbane.

Marshall, T.C. (1964). *Fishes of the Great Barrier Reef and Coastal Waters of Queensland.* Angus and Robertson Ltd., Sydney.

Queensland Department of Environment and Heritage. (1994). *Curtis Coast Study - Resource Report.* Queensland Department of Environment and Heritage, Rockhampton.

WBM Oceanics Australia. (1990). *Impact Assessment Study Reclamation of Land West of Calliope River.* Report prepared for Gladstone Port Authority, WBM Oceanics, Spring Hill.

TABLE 1: Marine Fishes collected from Port Curtis adjacent to Stuart Oil Shale Project 1998 -1999

FAMILY NAME	GENUS SPECIES	COMMON NAME
ARIIDAE	*Arius graeffei*	Blue catfish
BELONIDAE	*Strongylura strongylura*	Black spot longtom
CARANGIDAE	*Caranx kalla*	Herring trevally
	Scomberoides commersonianus	Queenfish/Leatherskin
CARCHARHINIDAE	*Carcharhinus leucas*	Estuary whaler
	Carcharhinus spallanzani	Blacktip shark
CLUPEIDAE	*Harengula abbreviata*	Southern herring
	Chirocentrus dorab	Wolf herring
	Nematalosa come	Bony bream/ hairbacked herring
	Pellona ditchela	Ditchelee herring
	Harengula koningsbergeri	Spotted herring
	Megalops cyprinoides	Oxeye herring
ECHENEIDAE	*Echeneis neucrates*	Slender suckerfish
ELEUTHERONEMA	*Eleutheronema tetradactylum*	Blue salmon
ENGRAULIDAE	*Thrissocles setirostris*	Hamilton's anchovy
EPINEPHELINIDAE	*Epinephelus tauvina*	Estuary rock cod
GERRIDAE	*Gerres ovatus*	Silver belly
HEMIRAMPHIDAE	*Arrhamphus scierolepis*	Snub-nosed garfish
	Hyporhamphus australis	Sea garfish
* HEMISCYLLIDAE	*Chiloscyllium punctatum*	Brown banded catshark
LATIDAE	*Lates calcarifer*	Barramundi
LEIOGNATHIDAE	*Leiognathus bindus*	Orange tipped ponyfish
	Leiognathus equula	Common ponyfish
* LOBOTIDAE	*Lobotes surinamensis*	Triple tail
MUGILIDAE	*Mugil cephalus*	Sea mullet
	Mugil vaigiensis	Diamond scale mullet
MURAENESOCIDAE	*Muraenesox arabicus*	Pike eel
MYLIOBATIDAE	*Himantura granulata*	Mangrove ray
PEMPHERIDAE	*Leptobrama mulleri*	Flat salmon/ steelback
PLATYCEPHALIDAE	*Platycephalus fuscus*	Dusky flathead
	Platycephalus indicus	Bar tailed flathead
POLYNEMIDAE	*Polydactylus sheridani*	King salmon
POMADASYIDAE	*Pomadasys hasta*	Grunter
	Plectorhynchus nigrus	Brown morwong/ Blubber lip
RHINOBATIDAE	*Rhinobatos typus*	Giant shovelnose ray
SCIAENIDAE	*Johnius soldado*	Silver jewfish
SCOMBRIDAE	*Scomberomorus semifasciatus*	Broad barred mackerel
SILLAGINIDAE	*Sillago analis*	Golden lined whiting
	Sillage maculata	Trumpeter whiting
SPARIDAE	*Mylio australis*	Yellow fin bream
	Mylio berda	Black bream
SPHYRAENA	*Sphyraenella obtusata*	Striped seapike
SPHYRNIDAE	*Sphyrna lewini*	Scalloped hammerhead
TRICANTHIDAE	*Tripodichthys angustifrons*	Tripod fish

* New scientific record Port Curtis

Table 2

Summary fish species caught Port Curtis adjacent to Stuart Oil Shale Project - May - June 1998

627 specimens 30 species

Description	Specimens	Length	Weight
Sea mullet	166	180-330mm TL	100-500gm
Bony bream	80	112-197mm LCF	25-175gm
Blue salmon	79	208-505mm LCF	100-200gm
Flat salmon	66	180-374mm LCF	100-750gm
Spotted herring	61	71-137mm LCF	
Blue herring	52	77-92mm LCF	
Blue catfish	20	212-445mmLCF	150-1600gm
Hamilton's anchovy	16	108-210mm LCF	
Grunter	17	320-438mm LCF	300-1300gm
Yellow fin bream	14	235-300mm LCF	300-750gm
Diamond scale mullet	9	495-585mm LCF	2200-2900gm
Bigeye herring	8	152-180mm LCF	50-75gm
Black bream	6	246-308mm LCF	500-750gm
Pony fish	6	60-140mm LCF	up to 50gm
Flathead	4	353-505mm TL	300-800gm
Whiting	4	222-255mm LCF	100-150gm
King salmon	2	525-595mm LCF	1900-3000gm
Wolf herring	2	358-465mm LCF	
Broad barred mackerel	2	215-218mm LCF	125gm
Hammerhead shark	2	580-685mm TL	700-800gm
Banjo ray	2	400mm TL	200gm
Barramundi	1	605mm TL	2500gm
Bronze whaler shark	1	1480mm TL	>40kg
Herring trevally	1	185mm TL	
Garfish	1	158mm TL	less 50gm
Silver jewfish	1	211mm TL	175gm
Pike eel	1	1340mm TL	2600gm
Cod	1	352mm TL	600gm
Longtom	1	321mm LCF	50gm
Blacktip shark	1	950mm TL	6600gm

VEGETATION SURVEY :
MANGROVE COMMUNITIES FROM FISHERMANS LANDING WHARF TO FRIEND POINT

Authors

Dr Michael Walker Bsc (Hons) (Tas), PhD (JCU)
Senior Research Fellow
Faculty of Applied Science
Central Queensland University

Roland Rupp B. App Sc (Hons)(CQU)

Damon Shearer (ADBLT) CQU

Research Team

Roland Rupp (CQU-CEM)
Roderick Johnson (CQU-CEM)
Damon Shearer (CQU-CEM)

Photography

Roland Rupp
Roderick Johnson
Dr Michael Walker

TABLE OF CONTENTS

EXECUTIVE SUMMARY

1.0 INTRODUCTION **6**

1.1 Background information 6
1.2 Vegetation survey 7
1.3 Permanent mangrove monitoring sites 8

2.0 MATERIALS AND METHODS **8**

2.1 Aerial photography 8
2.2 Ground truthing 9
2.3 Permanent plots 10

3.0 RESULTS **12**

3.1 Aerial photography (map) 12
3.2 Specific observations from transects 13
3.3 Permanent plots 23
3.3.1 Data from permanent plots 23
3.3.2 Leaf litter data 31

4.0 GENERAL DISCUSSION **32**

5.0 COLOUR PLATES **34**

6.0 REFERENCES **41**

LIST OF FIGURES

Figure 1. Map of Port Curtis showing location of the Stuart Oil Shale Plant site in relation to the survey area.

Figure 2. Map of survey area with transect locations indicated.

Figure 3. Table showing the distance (m) of each transect from the northern bundwall, the distances between transects and the bearings of each transect.

Figure 4. Mangrove data sheet for permanent plot D1.

Figure 5. Mangrove data sheet for permanent plot Gully C.

Figure 6. Mangrove data sheet for permanent plot North Friend Point.

Figure 7. Leaf litter data for D1, Gully C and North Friend Point for January/ February 1999.

COLOUR PLATES

Plate 1. Mature *Rhizophora stylosa* forest (8-12m in height) dominating mid-intertidal region.

Plate 2. Reed bed adjacent to roadway under construction.

Plate 3. Saltmarsh communites encountered along survey area.

Plate 4. Change in mangrove communities at Transect 8.

Plate 5. Discontinious band of *R. stylosa* near Transect 8.

Plate 6. Mangrove communities surrounding Gully C.

Plate 7. Swamp region showing remains of former *C. tagal* forest.

Plate 8. Mature open forest of *R. stylosa* near Gully C permanent plot.

Plate 9. Brahminy Kite nest found along Transect 10.

Plate 10. Beach ridge lined with mangrove debris near Transect 13.

Plate 11. *O. octodonta* lining a gravel band near Transect 17.

Plate 12. Mature *A. marina* tree with pneumatophore root mat clearly visible.

Plate 13. Mangrove communities along survey area with Friend Point in bottom left corner.

Executive Summary

A survey of mangrove communities to receive mine water run-off was conducted by the Centre for Environmental Management of the Central Queensland University in December 1998. The current (pre-mining) status of mangroves is provided for the region between the northern bundwall situated at the rear of the Queensland Cement and Lime (QCL) plant and Friend Point. Mangrove communities were assessed by examination of aerial photography from two sources and confirmed by ground truthing. The entire fringe from both a seaward and landward aspect was examined and described. Transects from the beach ridge or high water mark were run to the seaward extent of the mangroves where distinct changes in forest structure were observed. Mangrove zonation, species distribution, canopy height, sediment topography and other notable features including the presence and location of drainage channels, gravel banks, areas subject to shoreline erosion and isolated stands of dead mangroves were recorded.

The mangrove fringe ranges from 5m to over 230m in width with 7 of the 12 species of mangroves found in Port Curtis sited along the survey area. The mangrove communities along the survey area conform to the following generalised zonation pattern. The low intertidal region on the seaward side of the *Rhizophora stylosa* zone is sporadically dotted with mature *Avicennia marina* trees. *A. marina* exist in this zone as solitary trees or in small groupings, but not as a consolidated stand. The mid-intertidal zone, largely dominated by *R. stylosa,* has an open or semi-closed forest structure for much of the surveyed area with the majority of trees having one primary stem and ranging in height from 4-12m. Sections of forest with trees from 3-5m in height with multiple stems and a fused or shared arrangement of prop roots were also observed.

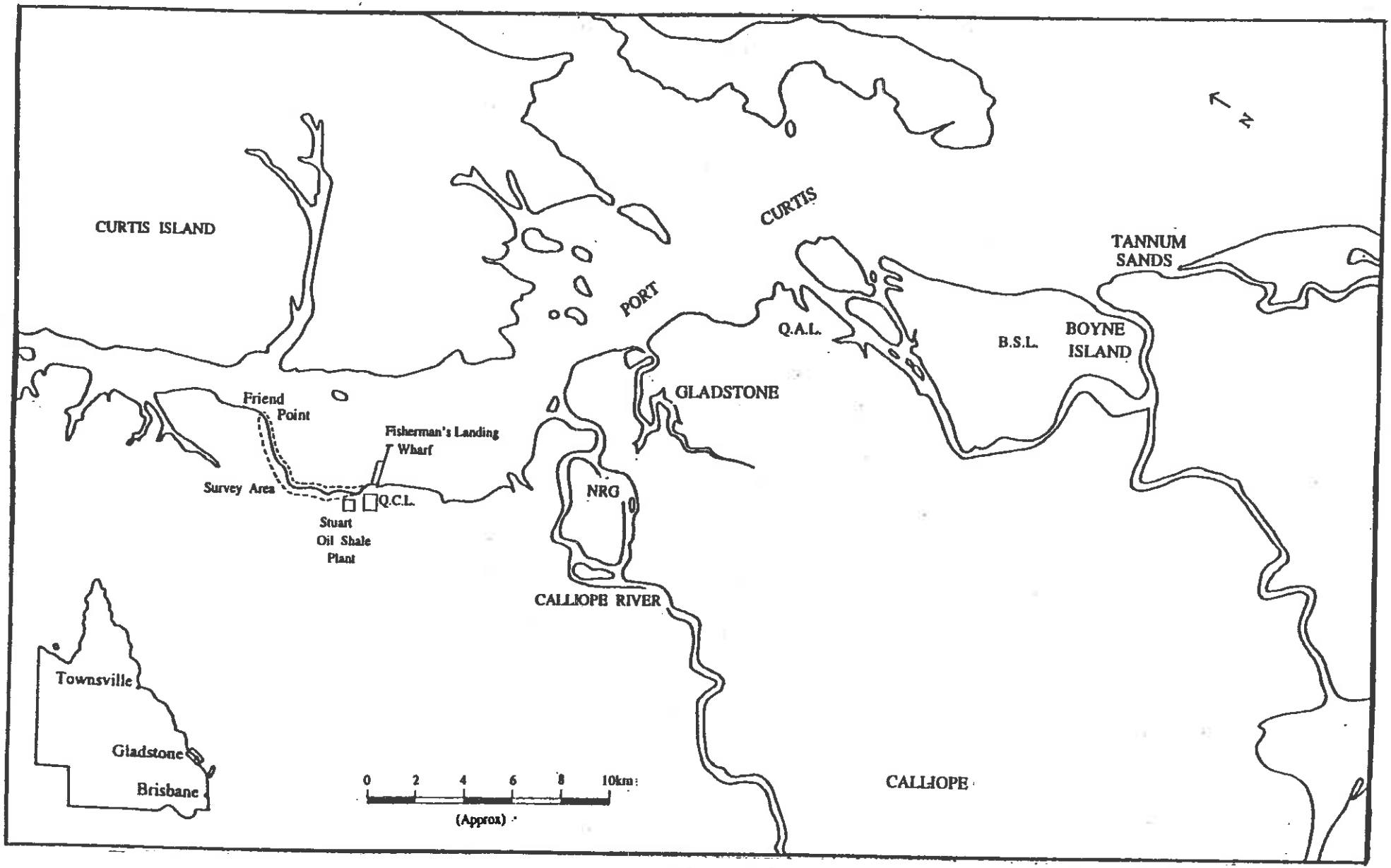
The number of established seedlings within the forest proper is generally related to the amount of available light. Hence, even established seedlings often fail to reach maturity due to competition for light or from herbivory by sesarmid crabs (pers.com, Duke, N.C. 1996). There was notable herbivory of leaves in the canopy of *R. stylosa* trees along the surveyed area. Based on data collected for mangroves throughout Port Curtis the

amount ranges from very little (<5%) to high (≥50%) (Dobbie, R., 1998 unpublished). Larvae of the cup moth *Doratifera* sp. are believed to be largely responsible for this damage.

Moving landward out of the mature *R. stylosa* zone into the higher mid-intertidal region, tree height decreases and the forest gives way to a *R. stylosa* thicket with trees 4m or less in height. With the progression landward the number of *R. stylosa* trees decreases until *R. stylosa* drop from the zonation almost entirely with *Ceriops tagal* and *A. marina* increasing in number. *Aegiceras corniculatum*, *Aegialitis annulata, Osbornia octodonta* and *Lumnitzera racemosa* can also be found in this zone. Plant height decreases to 1m or less and then rather abruptly the mangrove zone gives way to saltflats. Depending on the elevation of the land with respect to sea-level and the presence of drainage channels, the mangrove zone can continue to and beyond the mark of highest astronomical tide.

The mangroves are a dynamic environment under the influence of tide, current, wind and wave action with forest structure varying according to the combined effect of these factors. Furthermore, influences from the landward margin including erosion, sedimentation, land reclamation, industrial out-flows, run-off from agriculture in addition to fresh water flows from creeks and drainage channels impact on mangrove communities. Although an observable trend in the zonation of mangroves in the survey area is apparent, it does vary considerably depending on hydrodynamic and other influences. Thus, ongoing monitoring prior to and following the alteration of fresh water flows to Gullies C, D and E is necessary to detect any changes to mangrove communities and to develop strategies to alleviate potential loss of mangrove habitat.

Figure 1: Map of Port Curtis showing the location of the Stuart Oil Shale plant site in relation to the survey area.



1.0 GENERAL INTRODUCTION

1.1 Background information

Stage 1 of the Stuart Oil Shale Project comprises the mining and on site processing of oil shale from the Kerosene Creek member of the Stuart Oil Shale Deposit. Stage 1 is a research and development project and involves the construction and operation of a mine and demonstration plant capable of producing 4500 barrels of oil per day. The environmental approval of Stage 1 followed the completion of a rigorous Environmental Impact Assessment Study in 1992. The construction stage of the project commenced in 1998.

The project site is located on the coastal lowlands of Port Curtis, Central Queensland; to the east of the Mt Larcom range approximately 15km north of Gladstone. The Kerosene Creek member is the uppermost oil shale unit of the larger Stuart Oil Shale Deposit which is approximately 5km wide and 40km in length, extending in a north-westerly direction from South of Boat Creek.

Stage 2 of the project involves the extension of the Stage 1 oil shale mine to include the full Kerosene Creek member and the construction of the Stage 2 process plant which includes a single commercial scale oil shale processing module and associated oil recovery (processing) facilities.

Stage 2 will not proceed until the proponents of the project have determined the success of Stage 1. No decision has been made whether to proceed or not. It was necessary, however, to undertake the impact assessment process for Stage 2 as part of Stage 1 of the project because of the long lead times required to undertake such a study. A small portion of the Stuart Oil Stage 2 IAS was to survey mangrove communities that are to receive altered water flows as part of the second stage

development. These mangrove communities have been sampled in the past by the consultants WBM Oceanics (1989) in the Impact Assessment Study of Reclamation of Land West of Calliope River. Flows to three existing gullies (C, D and E) which occur along the survey area will be diverted to an engineered channel where the flow velocity will be limited to 2m/s. Increased runoff and sedimentation to these gullies during flood events is likely to adversely effect mangrove communities at gully mouths. In order to properly monitor the potential effects of mine operations on adjacent mangrove communities the current survey was conducted by the Centre for Environmental Management of Central Queensland University.

1.2 Vegetation survey

Aerial photographs from two sources were used to clarify the zonation patterns of mangrove communities in the survey area. The first were 1:5 000 photos taken in March 1999 taken by Airesearch Mapping on behalf of the Gladstone Port Authority. The second were photographs taken at 500 hundred feet in a chartered plane by Dr Michael Walker in March 1999. Used in conjunction with ground truthing a detailed description of the mangrove communities and their zonation patterns was obtained.

Ground truthing involved a thorough examination of the survey area on foot. Transects were run each time there was an observable change in forest structure or zonation. For the purposes of this report a transect was defined as a line running perpendicular to the shore extending from the high water mark to the seaward extent of the mangroves along which changes regarding zonation and species distribution were recorded. Other notable features including the location of drainage channels, gravel banks, areas effected by shoreline erosion and the presence of isolated stands of dead mangroves were also recorded. The following report outlines the status of shoreline mangroves with reference to salt-marsh species within the region between the northern bund-wall situated to the rear of Queenlsand Cement Limited and Friend Point as at April 1999 (Fig. 1).

1.3 Permanent Mangrove Monitoring Sites

The Centre for Environmental Management of the Central Queensland University on behalf of local industry has established 34 permanent mangrove monitoring sites throughout Port Curtis. Three of these sites (D1, Gully C and Northern Friend Point) are situated within the survey area. These sites are monitored half yearly with aspects of growth, reproduction, leaf litter fall and sedimentology being considered. Data and descriptions are provided for these three sites to support and complement the survey data.

2.0 METHODS AND MATERIALS

2.1 Aerial photography

Aerial photographs (scale 1:5 000) were taken in March 1999 by Airesearch Mapping. The photographs were examined with a Sokkisha MS - 27 stereoviewer. Resolution was sufficient to approximate forest zonation and structure but differientation of species was difficult and sometimes not possible. Nonetheless the photos accurately display the extent of mangrove habitat as well as prominent geomorphic and hydrodynamic features of the study area.

A complimentary set of aerial photographs were taken by Dr Michael Walker at an altitude of 500 feet in March 1999. A Pentax MZ-50 with a wide angle lens was used for these shots providing the resolution required to more accurately determine zonation patterns. Used in conjunction the two sets of photographs provide sufficient detail to determine zonation patterns and species distribution accurately when supported by ground truthing data. It should be noted that the latter set of photographs were taken as panoramas at various angles to the study area due to the limitations of the aircraft and thus are not to scale.

2.2 Ground truthing

A preliminary survey of the study area from a seaward aspect was conducted from a university vessel at high tide on the 26.11.98. The boat was motored close to the mangroves at low speed allowing qualitative data regarding zonation patterns and forest structure to be collected by an observer familiar with mangroves of Port Curtis. The approximate location of gravel banks, drainage channels, and other notable features were also recorded.

The land based survey was conducted between 2.12.98 and 8.12.98 and again on 27.04. 99. A team of three field personnel was used. Two workers were required to operate field equipment and the third to record data and describe the study area. The methods used to describe the mangrove communities were based on Macnae (1968); English *et al.* (1994) and Hegerl, *et al.* (1981). Transects were run each time a change in forest structure or zonation was observed by the research team with additional transects being run in areas where the forest had the same structure for several hundred metres. Each transect was marked and numbered at several points along its course. A compass bearing was taken at the commencement of each transect and maintained for the entire transect. Sighter bearings and back bearings along the transect ensured linearity. The researchers discretion was used to discern zonation changes. All distance measurements were taken with a Sonin Combo Pro Electronic Distance Measuring Tool and Sonin Combo Pro Reciever.

Changes in zonation were recorded according to the dominant genus. Additional descriptions based on there tidal zonation i.e (low, mid or high intertidal zone) were also made. Descriptions of forest structure were based on techniques for assessing terrestrial vegetation adapted to mangroves (Hegerl *et al*, 1981). Any additional features or observations including the presence and location of drainage channels, gravel banks, sediment description, isolated stands of dead mangroves, leaf herbivory, faunal activity and eroded areas were recorded. Any prominent features occurring in

areas where transects were not run were also recorded. Any species that were not readily identified in the field were taken back to the laboratory for later verification by a botanist. The presence of salt-marsh species was noted.

2.3 Permanent Plots

Three sites (D1, Gully C and Northern Friend Point) are fixed 10x10m square quadrats monitored quarterly. The plots are marked by corner pegs, (1.5m tomato stakes with painted white tops) with the perimeter marked by surveyors tape. Quantitative data was obtained on the condition of the plots by the record of the following variables:

- One corner of the plot was marked as the origin co-ordinate (0,0) from which the location of each plant was recorded in terms of its XY co-ordinates.

- Canopy height and foliage cover were estimated (adopted from techniques by Hegerl *et al.*,(1981) to provide the structural information for the plot. Records were taken of any emergent trees or gaps in the forest canopy.

- A FPC (foliage projected cover) tube was used to estimate the canopy density. 25 readings are taken along each of the four sides of the plot perimeter giving a total of 100 readings per plot. The viewer records what is seen through the tube as Sky, Branch or Leaf.

- Stainless steel screws and tags are used for identification of individual plants and as a reference point from which measurements of girth and sedimentation/erosion are taken. Measurements of girth were taken with a tailors tape and veneer callipers are used to record basal diameters and diameters at breast height. Sedimentation/erosion is recorded by taking the vertical distance from the screw to the sediment surface with a measuring pole (1cm graduations).

- Individual plants are classified as trees, shrubs (>25mm DBH - if <1.3m high must be multi-stemmed eg. ceriops), saplings (<24mm DBH or >10mm basal diameter - if it is in a scrub plot then it must be clearly distinguishable as an individual plant), or seedlings (<130cm high and <10mm Basal Diameter).

- Leaf and bark were given a health rating according to the following:

  0 = Dead, 1 = Poor, 2 = Moderate, 3 = Good.

- Seedlings were tagged and dated, with height, basal diameter, a health rating and number of nodes recorded.

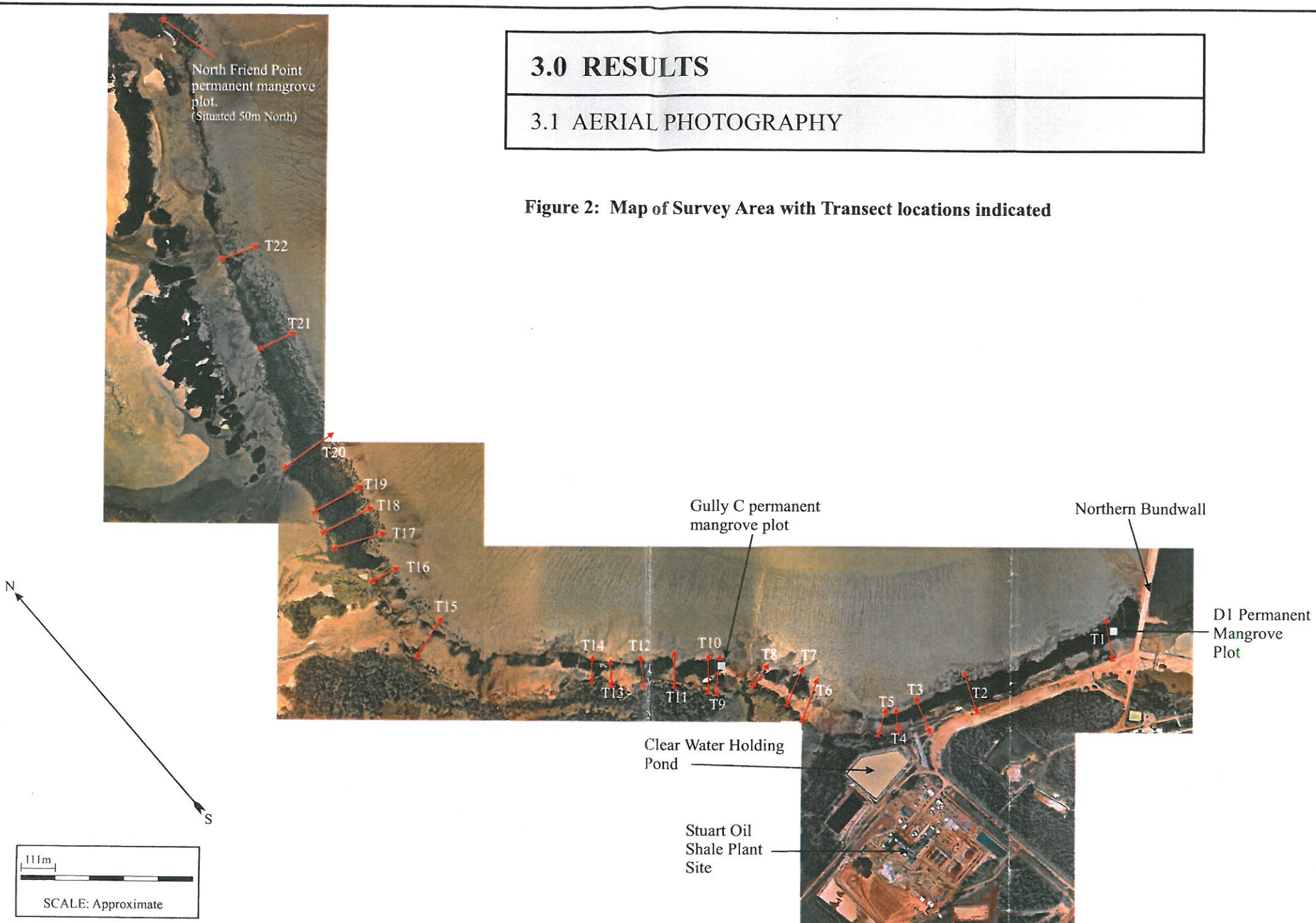
- A sediment corer was used to obtain sediment samples at 0-5cm and 15-20cm in depth. These samples are then processed to determine particle size distribution and combustible matter. The basic colour and surface tint and texture of the sediment was recorded.

- Rates of leaf fall in each experimental plot are measured quarterly using 3 litter catchers (1m x1m square with tubular PVC frames to which tapering bags of shade cloth were attached; see Duke *et* al., 1981) suspended in the canopy (above the high water mark) within close proximity to the plot. Litter collected in these traps is separated into components (leaves, stipules, reproductive parts, dead wood and herbivory classes).

3.0 RESULTS

3.1 AERIAL PHOTOGRAPHY

Figure 2: Map of Survey Area with Transect locations indicated



3.2 Descriptions of mangrove communities from transect data

Provided below are descriptions of the mangrove communities encountered along and between transects.

Transects 1, 2, 3.

Extending north from the northern bundwall for ~1km the mangroves are dominated by a mature mid-intertidal *Rhizophora stylosa* (var. Griff) forest with trees from 8-12m in height (Plate 1). Within the forest proper there is a sparse understory of *R. stylosa* seedlings to 1m in height. Tree height decreases to ~4m as you progress landward from the mid-high intertidal zone with *Ceriops tagal* and *Avicennia marina* appearing in higher numbers forming a mixed stand before giving way to salt flat communities. There are pockets of mangroves in the higher intertidal region along this stretch consisting of mixed associations of *A. marina*, *L. racemosa* and *C. tagal*.

A reed bed covering an area of about ~500m^2 exists in the high intertidal region ~500m north of the bundwall. The reeds are in poor condition and may have been impacted by the construction of a nearby roadway (Plate 2). The roadway runs parallel to the mangroves for approximately 600m before veering northwest towards the refinery. Erosion from the roadway onto the adjacent saltflat is occurring as the road is not armored. The low-intertidal region is dotted with *A. marina* trees up to 4m in height. There are generally very few *R. stylosa* present in the low-intertidal zone beyond the seaward extent of the consolidated Rhizophora stand.

Transect 4.

A patchy community of *C. tagal* (1-2m) with an occasional *R. stylosa* exists in the high intertidal zone. Moving seaward there is an abrupt species change with *R. stylosa* becoming dominant with trees to 3m in height marking the beginning of the mid-intertidal region. Progressing through the mid-intertidal region trees reach a

maximum height of ~7m. The understorey is relatively bare indicating high tidal export and/or herbivory of senescent leaves by mangrove crabs (F. Sesarminae). The topography of the sediment has been altered by the mud lobster (*Thalassina squamifera*) and the Alpheid shrimps (*Athanus japonicus* and *Alpheus nr. pacificus*) which leave characteristic mounds of mud (up to 40cm) high on the surface. The forest canopy has been heavily impacted by insect herbivory predominantly by the larvae of the cup moth *Doratifera* sp.

Transect 5

A beach ridge approximately 8m wide exists on the landward edge and is colonised by *C. tagal* and *L. racemosa*. Moving seaward there is a saltflat approximately 21 m wide followed by a mixed thicket of *C. tagal, R. stylosa* and *A. marina* with *R. stylosa* seedlings in light gaps for 14m. *R. stylosa* then becomes predominant with tree height increasing gradually to about 7m at the seaward edge with an open forest structure. The forest floor is relatively bare of leaf material and seedlings. In contrast to transect 4 the sediment topography is flatter with fewer Thalassinid and shrimp mounds. Some solitary *A.marina* trees dot the low-intertidal zone beyond the consolidated *R. stylosa* stand.

A levee bank approximately 1m high extending into the high intertidal zone coincides with a change in forest structure. The levee situated some 150-200m behind the Stuart Oil Shale clear water holding pond has a fence line running along it and forms the southern edge of a drainage channel. North of the drainage channel the mangrove zone decreases in width and the mangroves are represented by a thin band of mature *R. stylosa* 6-7m tall with low numbers of *C. tagal*. A saltflat ~30m wide is colonised by the common saltmarsh species *Suaeda australis* (Austral Seabite), *Sarcocornia quinqueflora* (beaded grasswort), *Halosarcia indica* (Samphire) and *Sporobolus viginicus* (salt couch) (Plate 3). The high intertidal region is dotted with *C. tagal, L. racemosa, A. marina*. A beach ridge marks the upper boundary of the high intertidal

region. Just south of transect 6 there is an isolated stand of dead *R. stylosa* trees 1.5-2.5m tall.

Transect 6

There is a beach ridge on the landward margin with stunted *Aegicerus annulata* (25cm tall) and saltmarsh species as in transect 5. This leads onto a saltflat colonised by low numbers of *A. marina* and *C. tagal* 1-2m in height. A Rhizophora thicket marks the beginning of the mid-intertidal zone and leads into an open forest of *R. stylosa* trees ~5m tall. Sediment in the mid-intertidal region is sandy with small pebbles in contrast to the clay/silt mangrove mud characteristic of the mid-intertidal region elsewhere in Port Curtis. *R. stylosa* seedlings 50cm-80cm tall are numerous where light gaps are present. Beyond the seaward edge of the Rhizophora zone in the low-intertidal zone there is a rocky oyster band extending seaward for about 50m. Just north of transect 6 a gravel bank runs parallel to the shoreline through the mangrove forest.

Transect 7

Transect 7 situated 50 north of transect 6 has a beach ridge colonised by *A. annulata* followed by 44m of saltflat with no vegetation. At the landward edge of the mid-intertidal zone there is a small fringe of stunted *A. annulata* 20-50cm tall. The transect passes through an isolated patch of dead Rhizophora about 1.5m in height in the mid-intertidal region. There is some re-vegetation of this area by *L. racemosa* and *A. marina*.

Transect 8

Transect 8 situated 116m north of transect 7 marks an abrupt decrease in tree height from 7m to 5m in the mid intertidal region coinciding with a decrease in the width of the Rhizophora fringe (Plate 4). 10m north of transect 8 the mangroves become discontinious and are represented by a thin band of stunted Rhizophora and a few

avicennia for roughly 50 m (Plate 5). *A. annulata* about 50cm tall with a round, bushy habit extend from the rear of the mid-intertidal back to the beach ridge.

Gully C, 30m north of transect 8 which meanders through farmland to the shoreline. *A. annulata* dot the edges of the gully above the level of the beach ridge. Where the channel runs through the mid-intertidal zone there are dense clumps of *R. stylosa* seedlings 30cm-1m tall as well as some *R. stylosa* saplings on the seaward margin (Plate 6). Small numbers of *A. marina* trees occur intermittently along the banks of the channel in the high intertidal zone. Heading north from Gully C there is a rocky flat for 30m with no mangroves then low numbers of *A. annulata* and *R. stylosa.*

Transect 9

Transect 9 crosses through one of the permanent monitoring plots (Gully C). In the high intertidal zone the transect crosses through a mangrove swamp which exists in a depression landward of a rocky beach ridge. *C. tagal* dominate the swamp with low numbers of *R. stylosa, L. racemosa* and *A. marina* also present. There are remnants of a former Ceriops stand at the southern end of the swamp (Plate 7), with thick healthy communities at the northern end. Moving seaward from the beach ridge, the *R. stylosa* forest is open with trees increasing from 4-8m. The trees are widely spaced allowing enough light for mature *A. marina* and *A. annulata* shrubs to exist in the mid-intertidal region which is normally dominated by *R. stylosa* (Plate 8). There are numerous *A. marina* seedlings in the high mid-intertidal zone with Rhizophora seedlings scattered throughout the forest. The sediment is firm and sandy with few sesarmid burrows.

Transect 10

Situated 41m north of transect 9, this transect has the same forest structure in the mid-intertidal zone with trees to 8m tall. In the high mid-intertidal zone the sediment is mangrove mud with scattered Rhizpohora and Avicennia seedlings. An active

Brahminy Kite nest occurs in the mid-intertidal zone along this transect (Plate 9). Moving north from transect 10 zonation returns to a more defined pattern ie. Moving landward to seaward there is a beachridge followed by a saltflat then a low growing mixed scrubby thicket leading into a mature Rhizophora forest.

Transect 11

The mangroves start at the base of the beach ridge with *C. tagal* 50cm-1m tall leading into scattered associations of *L. racemosa, A. marina, Osbornia octodonta* and *R. stylosa* to the landward edge mid-intertidal zone. At the landward edge of the mid-intertidal zone there is a stand of *R. stylosa* saplings and trees to 2.5m with the occasional Avicennia and Ceriops. In the mid-intertidal Rhizophora zone the forest begins to open up with average tree height increasing to 5m at the seaward edge.

Transect 12

On the landward fringe there is a mixed stand of *R. stylosa* (to 4m in height), *C. tagal* and *A. marina* shrubs to 1m tall. Between this high intertidal fringe and the mid-intertidal zone there is a thin band of Rhizophora seedlings. At the landward edge of the mid-intertidal zone there are Rhizophora trees 3-4m tall and some Ceriops 2-3m tall. Moving seaward the forest is predominantly *R. stylosa* 3-4m tall. There is a gravel bank 40m into the mid-intertidal zone. Rhizophora seedlings occur throughout the forest as do Thalassinid mounds and sesarmid burrows. Beyond the extent of the Rhizophora zone in the low-intertidal region there are a few Avicennia trees ~3m tall.

Transect 13

The beach ridge is covered with leaf and tree debris (Plate 10). The landward mangrove fringe is made up of *L. racemosa* (2.5m in height) and *C. tagal* (2.5m high). Then there is a shrubby zone of Avicennia (0.2-0.7m high). The Rhizophora fringe is 8m wide with trees to 4m in height.

Transect 14

The forest abuts the beach ridge with an intermingled stand of *L. racemosa, C. tagal, R. stylosa* and *A. marina* to 3m tall. This continues to the mid-intertidal zone with Rhizophora trees to 4m in height. There is a sandy ridge within the forest colonised by saltmarsh species as well as *C. tagal* and *A. annulata.* The ridge extends northward for approximately 100m before turning landward and joining the saltflat. There are some Rhizophora trees knocked over on the seaward margin. Approximately 214m north of transect 14 there is a drainage channel (Gully E) with shrubby Avicennia and Aegicerus trees to 2m along its banks in the landward reaches. Where the gully drains in the high to mid-intertidal region there is a wide band of *A. annulata, C. tagal* and *A. marina* to 2m tall. 300 north of Gully E there is an intact fence line beyond which the forest returns to a typical zonation pattern. Beyond the fence line the saltmarsh widens to ~150m wide with sparse vegetation. The forest has a clear zonation with a distinct *R. stylosa* band in the mid-intertidal region. There is a distinct beach ridge at the rear of the saltflat marking the landward margin of the mangrove zone.

Transect 15

On the landward edge a few *C.tagal* trees are present and in the high-intertidal zone there are a few shrubby *A. annulata.* There is a cobbled saltflat extending to the back of the Rhizophora zone. A low growing Rhizophora thicket (3-4m tall) dominates the mid-intertidal zone. In the low-intertidal region there are a few Avicennia and Rhizophora trees. Just north of transect 15 there is a drainage channel lined with shrubby Aegicerus and Ceriops trees about 2m tall, beyond which the saltflat widens substantially. On very high tides water moves from the saltflat back to the sea via this and other channels further north. The channel is ~2m wide with steep banks. Rhizophora trees line the banks with prop roots extending down towards the water. *Osbornia octodonta* appear along the banks of the channel with *A. corniculatum* and *A. marina.*

Transect 16

This transect crosses of one of the deeper drainage channels formed by water running off the saltflat. The banks of the channel are lined with *A. corniculatum*, *R. stylosa* seedlings and saplings and Ceriops saplings. Heading seaward there are scattered mangroves (*A. corniculatum, O. octodonta, A. marina*) growing through the cobbled surface rock.

Transect 17

Located 210m north of Transect 16. There is a marked beach ridge on the landward margin. 15m south of Transect 17 there is a rocky bank lined with Osbornia running perpendicular to the shoreline (Plate 11). The mangroves begin at the base of the beach ridge with a band of Rhizophora and shrubby Avicennia ~2m tall. Then there is a Rhizophora thicket with very dense prop roots and trees to 3.5m tall in the mid-intertidal zone. The low intertidal zone is comprised of scattered Avicennia trees 3.5m high with dense pneumatophore coverage around the base of the trees and a high abundance of mud whelks (*Telescopium telescopium*).

Transect 18

A Rhizophora thicket with intermingled ceriops trees abuts the beach ridge. Moving seaward the Ceriops drop from the zonation and there is a dense Rhizophora thicket with tree to 2.5m tall for 55m. The forest then opens slightly but canopy height remains the same to the seaward edge. At the seaward fringe the roots of Rhizophora trees have been undermined and are exposed due to erosion resulting from water flooding out through the mangroves from the extensive saltpans on large tides (R. Rupp., 1998 pers obs). The seagrass *Zostera capricornii* grows right to the seaward extent of the mangroves in this area. A band of scattered Avicennia trees to 5m in height occupy the lower mid-intertidal zone (Plate 12). From Transect 18 north to

Friend Point there is a defined zone of mature Avicennia trees in the low-intertidal region. The trees are well spaced with dense pneumatophore coverage.

Transect 19

Situated 90m from transect 18, transect 19 has a seaward fringe similar to transect 18. Moving landward into the Rhizophora zone there are numerous Rhizophora and some Avicennia seedlings. The forest is 4-5m tall with thick, dense prop roots. This zone extends landward for 55m and then the forest becomes more dense. Prop roots overlap and intermingle in this area with a thick dense canopy cover. The zonation changes to a Rhizophora thicket with light gaps for 15m. Avicennia trees have colonised the light gaps. The thicket gives way to a more open area colonised by scattered Avicennia trees to 4m in height and Rhizophora and Ceriops trees to 2m tall. This zone continues for 28m with tree height decreasing to 1m and Rhizophora drops from the zonation as you progress landward. This gives way to 20m of saltflat with a beachridge on the landward margin.

Transect 20

Transect 20 is 175m from Transect 19. There is an expansive saltflat to the rear of transect 20. The first mangrove zone is a mixed shrubby band of Rhizophora, Avicennia and Ceriops with Rhizophora dominating. This leads into a Rhizophora thicket (trees to 3.5m) with dense awkwardly branching prop roots and trunks with highly variable girths. The zonation changes to an open Rhizophora forest (to 6m tall) mixed with areas of Rhizophora thicket. Zonation changes again with tree height decreasing to 4m and tree and root density increasing for 60m. The forest then begins to open with Avicennia and Ceriops trees scattered throughout the still predominantly Rhizophora zone. Rhizophora and Avicennia seedlings have colonised light gaps. This leads into the low-intertidal Avicennia zone with trees to 5m scattered over the mud flat extending seaward for 70m beyond the end of the

Rhizophora zone. There are also a few mature Rhizophora trees in the low intertidal zone.

Transect 21

The seaward zone of Transect 21 is the same as in Transect 20. Moving landward there is a zone of Rhizophora (2.5m tall) with scattered Rhizophora seedlings. The sediment is sandy with few crab burrows for 30m followed by a change in zonation to larger trees 5-6m tall with dense prop roots for 35m. The forest height then decreases gradually over the next 15m to a height of 3m and zonation changes to a Rhizophora thicket for 40m. In this zone there are isolated areas of larger trees with an open forest structure. In the higher intertidal there is a Ceriops thicket for 35m and on the landward edge there are mixed associations of Rhizophora and Avicennia (2-3m in height) for 15m.

Transect 22

Transect 22 is situated 310m north along the landward fringe from transect 21. There is an initial landward zone approximately 30m wide with open Rhizophora forest (trees to 7m) and some seedlings in light gaps. Zonation then changes to an Avicennia zone (trees 2-3m in height) with Rhizophora and Avicennia seedlings throughout for 15m. Then there is a Rhizophora zone with some Avicennia trees to 3m in height for 60m. This extends through to the seaward mangrove fringe with very little understorey except Rhizophora seedlings. The seaward fringe is predominantly Avicennia (to 5m) and some Rhizophora (to 6m). Looking north from Transect 22 there is a break in mangrove zonation for approximately ~450 metres the with remains of dead trees (Plate 13). Mangrove communities begin again at Friend Point.

Figure 3: Shown are the distances (m) of each transect from the northern bundwall, the distances between transects and the bearings of each transect.

Transect Number	Distance (m) from bundwall	Distance (m) b/w transects	Bearings (degrees)	Transect number	Distance (m) From bundwall	Distance (m) b/w transects	Bearings (degrees)
1	80	430	27	12	2110	95	30
2	510	170	27	13	2205	138	50
3	680	98	29	14	2343	600	40
4	778	100	35	15	2943	347	90
5	878	630	70	16	3290	210	50
6	1508	50	70	17	3500	60	50
7	1558	116	60	18	3560	90	60
8	1674	152	70	19	3650	175	70
9	1826	41	20	20	3825	370	110
10	1867	123	40	21	4195	310	130
11	1990	120	56	22	4505	-	110

3.3 Permanent Plots

3.3.1 Data from permanent plots

Figures 5-7: Display data collected in January/February of 1999 for three permanent mangrove plots located along or in close proximity to the survey area.

Figure 5: Mangrove data sheet

Plot No: **D1** Date 29/1/99

Quad No.	Tag No.	Spec-ies	Plant Class	Girth Type	Girth (mm)	Trunk Type/No nodes	Plant Ht (cm)	Nail Ht (cm)	Leaf Health	Bark Health	Mistletoe	Lichens L1	Lichens L2	Lichens L3	Notes
Q1	1	Rhz	T	C	445			113	2	2			y		
	2	Rhz	T	C	280			118	3	3			y		
	4	Rhz	Se	B	5		62		3						
	5	Rhz	T	C	570			118	3	3			y		
	5;2	Rhz	B	C	220				3	3			y		
	5;3	Rhz	B	C	220				3	3			y		
	6	Rhz	T	C	210			120	2	3					
	7	Rhz	Sa	D	18		100		3	3					
	8	Rhz	Se	B	5		66		3						
	16	Rhz	Se	B	9		70		2						
	17	Rhz	Se	B	6		50		3						
	11	Rhz	Se	B	9		80		3						
	9	Rhz	Se	B	6		64		2						
	12	Rhz	Se	B	8		82		2						
	14	Rhz	T	C	160			17	3	3			y		
	98-4-1	Rhz	DSe						0						
Q2	65	Rhz	Se	B	5		56		1						
	98-4-6	Rhz	DSe						0						
	70	Rhz	Se	B	14		98		2						
	72	Rhz	T	C	590			120	3	3			y		
	87	Rhz	T	C	200			123	2	3			y		
	76	Rhz	DT					120							
	74	Rhz	T	C				114	3	3			y		
	75	Rhz	Se	B			72		3						
	98-4-5	Rhz	DSe						0						
	81	Rhz	T	C	295			119	3	3			y		
	91	Rhz	DSe						0						
	59	Rhz	DSe						0						
	58	Rhz	Se	B	6	10nodes	82		3						
	82	Rhz	T	C	610		112		3	3			y		
Q3	82-2	Rhz	Db	C	265		110								
	57	Rhz	Se	B	6	13nodes	70		3						
	56	Rhz	T	C	250		124		2	3					
	55	Rhz	Se	B	8		100		2						
	50	Rhz	Se	B	6	9nodes	58		3						
	51	Rhz	T	C	650		124		3	3					
	53	Rhz	Se	B	7	13nodes	68		3						

Propogules Checked [3] Untagged Seedlings [ ]

1. D = Diameter at Breast Height C = Circumference at Breast Height B = Basal Diameter (0.3m)
2. **T=Tree; Sh=Shrub** (>25mm DBH-if <1.3m high must be multistemmed e.g. Ceriops); **Sa=Sapling**(<24mm DBH or >10mm Basal Diameter--if it is in a scrub plot then it must be clearly distinguishable as an individual plant); **Se=Seedling** (<130cm high and <10mm Basal Diameter)
3. If plant has multiple stems branching below 1.3m then record the main trunk as "T, SH or SA" and indicate secorndary trunks/branches as "2". Only record trunks or branches >25mm diameter
4. **Leaf & Bark Health:** 0=Dead, 1=Poor, 2=Moderate, 3=Good; **Mistletoe & Lichens:** Tick if present

Figure 5 cont.
Mangrove Data Sheet:

Plot No. D1:

Date: 29/1/99

Quad No.	Tag No.	Spec-ies	Plant Class	Girth Type	Girth (mm)	Trunk Type/No Nodes	Plant Ht (cm)	Nail Ht (cm)	Leaf Health	Bark Health	Mistletoe	Lichens			Notes
												L1	L2	L3	
Q3	54	Rhz	Se	B	7		75		3						
	98-4-4	Rhz	DSe						0						
	61	Rhz	T	C	610			119	2	3			y		
	43	Rhz	Se	B	7	8nodes	60		2						
	98-4-3	Rhz	DSe						0						
	64	Rhz	T	C	320			120	2	1			y		
	63	Rhz	DSe						0						
	62	Rhz	Se	B	64	13nodes			3						
	38	Rhz	Se	B	5	8nodes	60		2						
	46	Rhz	Se	B	5		70		2						
Q4	30	Rhz	T	C	590			116	3	3			y		
	36	Rhz	Se	B	6	14nodes	67		3						
	35	Rhz	Se	B	6	13nodes	60		2						
	23	Rhz	Sa	D	8		92		3						
	28	Rhz	Se	B	5	9nodes	50		2						
	24	Rhz	Sa	D	12		110		2						
	22	Rhz	Se	B	8	20nodes	70		3						
	21	Rhz	Se	B	7		90		3						
	98-4-2	Rhz	DSe						0						

Propogules Checked ☐ Untagged Seedlings ☐

1. D = Diameter at Breast Height C = Circumference at Breast Height B = Basal Diameter (0.3m)
2. T=Tree; Sh=Shrub (>25mm DBH-if <1.3m high must be multistemmed e.g. Cerlops); Sa=Sapling(<24mm DBH or >10mm Basal Diameter--if it is in a scrub plot then it must be clearly-distinguishable as an individual plant); Se=Seedling (<130cm high and <10mm Basal Diameter)
3. If plant has multiple stems branching below 1.3m then record the main trunk as "T, SH or SA" and indicate secorndary trunks/branches as "2". Only record trunks or branches >25mm diameter
4. Leaf & Bark Health: 0=Dead, 1=Poor, 2=Moderate, 3=Good; Mistletoe & Lichens: Tick if present

Figure 5 cont.
Mangrove Data Sheet
Plot: D1

Foliage Projective Cover

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
S	S	S	L	L	L	L	L	L	L	B	L	L	L	B	L	B	B	B	L	B	L	S	B	S
S	B	L	L	L	B	B	L	L	B	S	B	B	L	L	L	B	B	S	L	S	B	B	S	S
S	L	L	S	B	B	L	B	L	L	S	L	L	L	S	L	S	L	S	S	B	S	S	L	B
L	S	B	L	S	B	B	L	S	B	L	S	L	B	B	L	L	L	S	S	S	B	S	B	B

Leaf 42 Branch: 31 Sky: 27

Sediment RESULTS PENDING

Measurements:

Sample Depth cm	pH	Redox Potential (mV)	Temperature (°C)	Salinity (ppK)	Conductivity (mS/cm)

Colour:

basic colour: black grey yellow brown red

surface tint: NONE white greyish yellowish reddish greenish

Organic matter/fibrous root material at the surface? yes no
Salt deposits on surface? yes no

Texture:

Very Firm Firm Soft Sloppy

Sand Sandy/Loam Loam (silt) Clay Loam Light Clay Medium-Heavy Clay

Canopy:

Average Canopy Height (m): 7 Visual FPC Estimate (%): 70

Description:

Even Small gaps Large gaps Scattered Trees Open

Emergent Trees Present yes no
Gaps in Canopy: yes no

Other Comments:

.....
.....
.....
.....

Figure 6
Mangrove Data Sheet:

Plot No: **Gully C**

Date: 20-1-99

Quad No.	Tag No.	Spec-ies	Plant Class	Girth Type	Girth (mm)	Trunk Type/No Nodes	Plant Ht (cm)	Nail Ht (cm)	Leaf Health	Bark Health	Mistletoe	Lichens L1	Lichens L2	Lichens L3	Notes
1	1	Rhz	T	C	435			130	3	3			y		
	2	Rhz	T	C	480			158	3	3			y		
	3	Rhz	T	C	260			109	1	3			y		
	4	Rhz	T	C	220			110	1	3			y		
	36	Rhz	Se	B	6		62		2						
	99-1-1	Rhz	Se	B	5		46		3						
	39	Rhz	Se	B	7		74		3						
	37	Rhz	Se	B	6	3 nodes	50		3						
	99-1-2	Rhz	Se	B	3	4 nodes	39		3						
	38	Rhz	Se	B	5		34		3						
	5	Rhz	T	C	350			118	3	3			y		
	41	Rhz	Sa	B	11		80		2						
2	29	Rhz	T	C	255			110	3	3			y		
	31	Rhz	T	C	315			109	3	3			y		
	32	Rhz	T	C	380			105	3	3			y		
	33	Rhz	T	C	275			128	2	3			y		
	30	Rhz	T	C	275			128	3	3			y		
	42	Rhz	Se	B	6	8 nodes	52		3						
	34	Rhz	T	C	260			106	3	3			y		
	99-1-3	Rhz	Se	B	5	4 nodes	40		2						
	46	Rhz	Se	B	6		54		3						
	45	Rhz	Se	B	7		50		3						
	43	Rhz	Se	B	6		52		3						
	99-1-4	Rhz	Se	B	5	4 nodes	40		3						
	35	Rhz	T	C	185			108	3	3			y		
	48	Rhz	Se	B	6	8 nodes	52		3						
	47	Rhz	Se	B	7	9 nodes	68		3						
	49	Avi	Sa	B	22		70		3						
	23	Rhz	T	C	280			110	3	2			y		
	22	Rhz	T	C	335			109	3	3			y		
	25	Rhz	T	C	305			106	3	3			y		
	24	Rhz	T	C	235			108	3	3			y		
	26	Rhz	T	C	370			107	3	2			y		
	27	Rhz	T	C	280			107	2	3			y		
	28	Rhz	T	C	420			109	2	2			y		
	21	Rhz	T	C	355			110	3	2			y		
	50	Rhz	Se	B	6	8 nodes	58		3						

Propogules Checked ☐ Untagged Seedlings ☐

1. **D** = Diameter at Breast Height **C** = Circumference at Breast Height **B** = Basal Diameter (0.3m)
2. **T=Tree; Sh=Shrub** (>25mm DBH-if <1.3m high must be multistemmed e.g. Ceriops); **Sa=Sapling**(<24mm DBH or >10mm Basal Diameter--if it is in a scrub plot then it must be clearly distinguishable as an individual plant); **Se=Seedling** (<130cm high and <10mm Basal Diameter)
3. If plant has multiple stems branching below 1.3m then record the main trunk as "T, SH or SA" and indicate secorndary trunks/branches as "2". Only record trunks or branches >25mm diameter
4. **Leaf & Bark Health: 0**=Dead, **1**=Poor, **2**=Moderate, **3**=Good; **Mistletoe & Lichens:** Tick if present

'igure 6 cont.
Mangrove Data Sheet:

'lot No: **Gully C**

'ate: 20-1-99

Quad No.	Tag No.	Spec-ies	Plant Class	Girth Type	Girth (mm)	Trunk Type/No Nodes	Plant Ht (cm)	Nail Ht (cm)	Leaf Health	Bark Health	Mistletoe	Lichens L1	Lichens L2	Lichens L3	Notes
	18	Rhz	T	C	380			110	3	3			y		
	18-2	Rhz	B	C	355			130	2	2			y		
	17	Rhz	T	C	365			110	2	3			y		
	16	Rhz	T	C	210			109	2	3			y		
	51	Avi	T	B	19		110		2						
3	14	Rhz	T	C	345			110	2	3			y		
	15	Rhz	T	C	470			110	2	3			y		
	14-2	Rhz	B	C	220			130	2	3			y		
	12	Rhz	T	C	385			110	2	3			y		
	11	Rhz	T	C	450			108	3	2			y		
	13	Rhz	T	C	235			108	2	2			y		
	20	Rhz	T	C	415			109	2	3			y		
	19	Rhz	T	C	440			108	3	3			y		
4	10	Rhz	T	C	450			165	2	2			y		
	7	Rhz	T	C	310			109	2	3			y		
	6	Rhz	T	C	300			110	2	3			y		
	99-1-5	Rhz	Se	B	6	4nodes	50		3						
	9	Rhz	T	C	345			110	2	2			y		
	8	Rhz	T	C	300			108	1	2			y		

ropogules Checked ☐ Untagged Seedlings ☐

D = Diameter at Breast Height C = Circumference at Breast Height B = Basal Diameter (0.3m)

T=Tree; Sh=Shrub (>25mm DBH-if <1.3m high must be multistemmed e.g. Ceriops); Sa=Sapling(<24mm DBH or >10mm Basal Diameter-if it is in a scrub plot then it must be clearly distinguishable as an individual plant); Se=Seedling (<130cm high and <10mm Basal Diameter)

If plant has multiple stems branching below 1.3m then record the main trunk as "T, SH or SA" and indicate secorndary trunks/branches as "2".

Only record trunks or branches >25mm diameter

Leaf & Bark Health: 0=Dead, 1=Poor, 2=Moderate, 3=Good; **Mistletoe & Lichens:** Tick if present

Figure 6 cont.
Mangrove Data Sheet
Plot: Gully C

Foliage Projective Cover

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
L	L	L	L	B	L	B	L	B	S	S	L	L	S	S	S	S	L	B	S	L	S	S	B	L
B	S	L	L	B	S	S	L	L	L	B	L	L	B	L	S	B	L	S	S	B	B	S	B	S
S	L	L	S	L	L	S	B	L	L	S	L	L	B	S	L	S	S	S	S	L	L	S	L	S
S	S	B	B	S	L	L	B	S	S	B	B	L	B	S	L	L	L	L	S	B	L	B	B	L

Leaf 42 Branch: 23 Sky: 35

Sediment RESULTS PENDING

Measurements:

Sample Depth cm	pH	Redox Potential (mV)	Temperature (°C)	Salinity (ppK)	Conductivity (mS/cm)

Colour:

basic colour: black grey yellow brown red

surface tint: NONE white greyish yellowish reddish greenish

Organic matter/fibrous root material at the surface? YES NO
Salt deposits on surface? YES NO

Texture:

Very Firm Firm Soft Sloppy

Sand Sandy/Loam Loam (silt) Clay Loam Light Clay Medium-Heavy Clay

Canopy:

Average Canopy Height (m): 6 Visual FPC Estimate (%): 40

Description:

Even Small gaps Large gaps Scattered Trees Open

Emergent Trees Present YES NO Gaps in Canopy: YES NO

Other Comments:

.....

.....

.....

.....

.....

Figure 7
Mangrove Data Sheet:

Plot No: **Nth Friend Point**

Date: 16/2/99

Quad No.	Tag No.	Spec-ies	Plant Class	Girth Type	Girth (mm)	Trunk Type/No Nodes	Plant Ht (cm)	Nail Ht (cm)	Leaf Health	Bark Health	Mistletoe	Lichens L1	Lichens L2	Lichens L3	Notes
	10	Rhz	T	C	487			137	3	3			y		
	11	Rhz	T	C	265			137	3	2			y		
	18	Rhz	T	C	237			197	3	3			y		
	17	Rhz	T	C	480			224	3	3			y		
	16	Rhz	T	C	412			149	2	3			y		
	26	Rhz	T	C	375			176	3	3			y		
	20	Rhz	T	C	382			174	2	3			y		
	19	Rhz	T	C	395			195	3	3			y		
	35	Rhz	Sa	D	10		150		3	3					
	21	Rhz	T	C	370			200	2	3			y		
	22	Rhz	T	C	407	1		200	3	3			y		
	23	Rhz	T	C	240	2		210	3	3			y		
	24	Rhz	T	C	300			180	3	2			y		
	25	Rhz	T	C	305			174	3	2			y		
	27	Rhz	T	C	422			174	2	2			y		
	29	Rhz	T	C	350			232	3	3			y		
	28	Rhz	T	C	420			248	2	2			y		
	30	Rhz	T	C	285			170	2	2			y		
	31	Rhz	T	C	380			250	2	2			y		
	33	Rhz	T	C	555			160	1	3			y		
	32	Rhz	T	C	225			150	2	3			y		
	34	Rhz	T	C	425			194	3	2			y		
	15	Rhz	T	C	378			163	3	3			y		
	12	Rhz	T	C	345			160	3	3			y		
	13	Rhz	T	C	257			161	2	3			y		
	14	Rhz	T	C	318			170	3	3			y		

Propogules Checked ☐ Untagged Seedlings ☐

1. **D** = Diameter at Breast Height **C** = Circumference at Breast Height **B** = Basal Diameter (0.3m)
2. **T=Tree; Sh=Shrub** (>25mm DBH-if <1.3m high must be multistemmed e.g. Ceriops); **Sa=Sapling**(<24mm DBH or >10mm Basal Diameter--if it is in a scrub plot then it must be clearly distinguishable as an individual plant); **Se=Seedling** (<130cm high and <10mm Basal Diameter)
3. If plant has multiple stems branching below 1.3m then record the main trunk as "T, SH or SA" and indicate secondary trunks/branches as "2". Only record trunks or branches >25mm diameter
4. **Leaf & Bark Health:** 0=Dead, 1=Poor, 2=Moderate, 3=Good; **Mistletoe & Lichens:** Tick if present

Figure 7 cont.
Mangrove Data Sheet
Plot: Nth Friend Point

Foliage Projective Cover

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
L	L	L	L	L	B	S	S	S	L	L	L	B	S	S	S	L	S	L	B	S	S	L	S	L
L	S	S	S	S	L	L	S	L	L	B	B	B	S	L	L	S	L	L	S	S	S	S	S	S
S	L	S	B	B	B	S	B	L	L	B	B	L	B	L	L	S	L	L	S	L	L	L	L	L
L	L	L	B	B	B	B	L	L	B	L	B	L	B	L	L	L	L	B	L	B	L	S	S	B

Leaf: 48 Branch: 23 Sky: 29

Sediment

Measurements: **RESULTS PENDING**

Sample Depth cm	pH	Redox Potential (mV)	Temperature (°C)	Salinity (ppK)	Conductivity (mS/cm)

Colour:

basic colour: black grey yellow brown red

surface tint: NONE white greyish yellowish reddish greenish

Organic matter/fibrous root material at the surface? YES NO
Salt deposits on surface? YES NO

Texture:

Very Firm Firm Soft Sloppy

Sand Sandy/Loam Loam (silt) Clay Loam Light Clay Medium-Heavy Clay

Canopy:

Average Canopy Height (m): 4 Visual FPC Estimate (%): 40

Description:

Even Small gaps Large gaps Scattered Trees Open

Emergent Trees Present YES NO Gaps in Canopy: YES NO

Other Comments:

.....

.....

.....

.....

.....

3.3.2 Leaf Litter Data

Figure 8. Provides the average leaf litter fall totals for a collection period of two months for the three sites occurring along the survey area. The amount of insect herbivory for each site as well as component totals are given.

Sites	North Friend Point	Gully C	D1
Collection Date	16/2/99	20/1/99	29/1/99
Components/Herbivory classes.			
0% herbivory	99	82	88
25% herbivory	64	38	74
50% herbivory	3	6	18
75% herbivory	6	5	13
100% herbivory	A	a	9
Apical leaves	1	4	4
Broklen leaves	A	3	a
Total leaves	173	138	206
Stipules	142	145	144
Flowers	33	18	7
Fruit	3	39	3
Propagules	4	1	1
Stems	p	p	a
Wood	p	p	p
Cup Moth cocoons	a	a	a
Frass	p	p	p
Lichen	a	a	a
Mistletoe leaf	a	a	a
Mistletoe flower	a	a	a
Mistletoe seed	a	a	a
Mistletoe wood	a	a	a

Note: p = present, a = absent

4.0 GENERAL DISCUSSION

The mangrove zone along the survey area ranged in width from 5m to over 230m. Seven of the 12 mangrove species found in Port Curtis (*A. marina, R. stylosa, C. tagal, O. octodonta, A. annulata, L. racemosa* and *A.corniculatum*) were sited along the survey area. WBM Oceanics (1989) cited one extra species *Bruguiera gymnorhiza* in a survey of the same area.

The mangroves within the survey in large part conformed to a generalized zonation pattern. The saltflat and high intertidal region was commonly colonised by the species *C. tagal, A. marina, O. octodonta, A. annulata, L. racemosa* and *A.corniculatum.* The latter four species rarely formed a consolidated stand and rather existed as mixed associations of shrubby plants with an occasional emergent tree. Moving into the mid-intertidal region there was commonly a Rhizophora thicket with Ceriops or Avicennia trees intermingled with the Rhizophora. With progression into the mid-intertidal region Rhizophora dominated and forest height increased to a maximum of ~12m. The Rhizophora forest for much of the surveyed area had an open or semi-closed forest structure with individual trees distinguishable by an obvious primary trunk. Sections of forest towards the northern end of the survey area were quite different with a dense intertwined arrangement of prop roots and a thick canopy cover. Moving into the low-intertidal region Rhizophora dropped from the zonation and Avicennia was the dominant species. The Avicennia rarely formed a consolidated stand but existed as a scattering of trees with a wide reaching pneumatophore root mat.

Notable features along the survey area included the presence of isolated stands of dead and fallen mangroves possibly resulting from storm events (WBM Oceanics, 1992 in Envirosciences 1993). Additionally there were isolated sections of shoreline erosion. Sediment had been undermined from mangrove fringes as a result of tidal surges receding rapidly through the forest from the extensive Targinie saltflats during king tides.

Sediment characteristics varied considerably along the survey area ranging from firm sandy substrate to sloppy mud. This has led to a noticeable variation in faunal and Floral communities between contrasting sediment environments. In firmer sediments crab burrow numbers appeared low in comparison to softer mud. Additionally, seedling numbers for species such as Rhizophora and Ceriops also appeared to be lower in the firmer sediments. This may reflect a reduced ability of propagules to penetrate the firmer sediment, a requirement for seedling establishment. Insect herbivory ranged from low (<5%) to high (>50%) along the survey area and in general, herbivory appeared higher at the southern end of the survey area.

In summary mangroves are a dynamic environment under the influence of many factors both anthropogenic and natural and they are subject to continuous change. Thus, ongoing monitoring prior to and following the alteration of fresh water flows to the survey area (via gullies C, D and E) is essential in the detection of mangrove stress and in the development of strategies to alleviate potential mangrove habitat loss.

5.0 COLOUR PLATES

Plate 1. Mature *Rhizophora stylosa* forest (8-12m in height) dominating mid-intertidal region.

Plate 2. Reed bed adjacent to roadway under construction.

Plate 3. Saltmarsh communites encountered along survey area.

Plate 4. Change in mangrove communities at Transect 8

Plate 5. Discontinious band of *R. stylosa* near Transect 8.

Plate 6. Mangrove communities surrounding Gully C.

Plate 7. Swamp region showing remains of former *C. tagal* forest

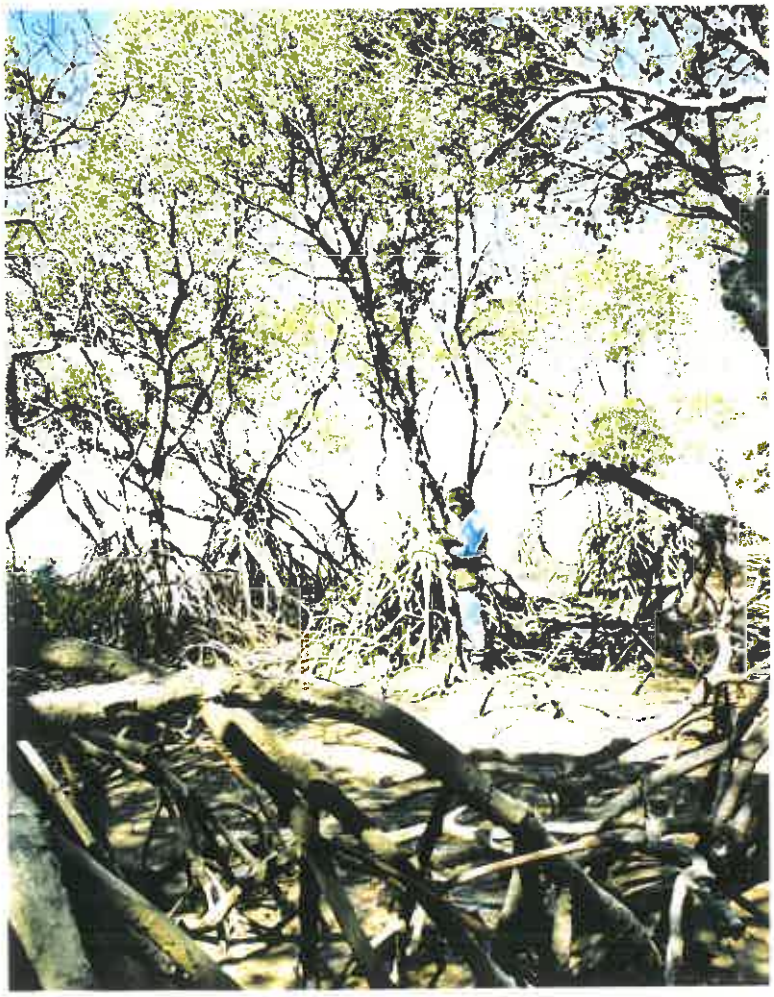


Plate 8.

Mature open forest of *R. stylosa* near Gully C permanent plot

Plate 9 Brahminy Kite nest found along Transect 10.

Plate 10 Beach ridge lined with mangrove debris near Transect 13.

Plate 11 *O. octodonta* lining a gravel band near Transect 17

Plate 12 Mature *A. marina* tree with pneumatophore root mat clearly visible.

Plate 13 Mangrove communities along survey area with Friend Point seen in the bottom left corner.

5.0 REFERENCES

Dobbie, R. 1998. Mangrove Leaf Litter Report. (Unpublished)

Duke, N.C., Bunt, J.S., Williams, W.T. 1981. Mangrove leaf litter in north-eastern Australia I. Annual totals by components in selected species. *Aust. J. Bot.* **29**: 547-553.

English, S., Wilkinson, C., Baker, V. 1994. Survey manual for tropical marine resources. *Australian Institute of Marine Science,* Townsville.

Envirosciences. 1993. Draft Environmental Impact Assessment Study of the Proposed Stuart Oil Shale Project. Prepared for Southern Pacific Petroleum N.L. and Central Pacific Minerals.

Hegerl, E.J., Davie, J.D.S., Davie, P.J.F., Outridge, P.M., Shanko, P., Stock, E.C., Claridge, G.G., 1981. The research program for tidal wetlands survey, Kakadu National Park mangrove forests and tidal marshes. Vol **3.** Australian Littoral Society report to the Australian National Parks and Wildlife Service.

Macnae, W. 1968. A general account of the fauna and flora of mangrove swamps and forest in the Indo-west Pacific region. *Adv. Mar. Biol.* **6**: 73-270.

WBM Oceanics. 1989. Impact Assessment Study of Reclamation of Land West of Calliope River. Report prepared in association with Murchill, Bate Parker and Partners Pty Ltd and Ken Todd Town Planning Pty Ltd for Gladstone Port Authority.