Appendix D

Port Patterson Baseline Report by Aquenal Pty Ltd

AQUENAL PTY LTD

BASELINE ENVIRONMENTAL SURVEY

FOR THE MONITORING OF BIOLOGICAL IMPACT OF NUTRIENTS

RELEASED FROM A PROPOSED AQUACULTURE OPERATION NEAR

DOUG POINT, NORTHERN TERRITORY

OCTOBER 2005

REPORT TO

MARINE HARVEST

BY

AQUENAL PTY LTD

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1 Summary

Marine Harvest has proposed the establishment of a Barramundi Farm at Doug Point, in Geranium Channel, Port Patterson, Northern Territory. Aquenal Pty Ltd was commissioned to carry out a Baseline Environmental Survey to assess the baseline condition of several parameters expected to be sensitive to impact from elevated nutrient levels which may result from the proposed aquaculture operations.

The location of the proposed farm is in deep water in the channel to the east of Doug Point. The adjacent and estuary of Madford Inlet, 12 km to the west was selected as a control. Although not identical to the proposed farm location, it has sites with similar characteristics to the sites chosen to monitor impact near the proposed farm. Its proximity to Doug Point and ease of access combined with the lack of any nearby estuary more similar to the proposed farm site justified its selection. The environment of the farm and control sites is sheltered mangrove estuarine with great seasonal variation in fresh water inflow.

The main hydrological influences on these water bodies are the 6 to 7m tidal range, which results in large daily flushing of the mangroves with seawater, and run-off from heavy rains during the wet season. Towards the end of the dry season, when terrestrial run-off has ceased and hot temperatures prevail, negligible net flushing occurs through the estuary, and evaporation results in increased salinity and potentially a net inflow into the estuary. During this period, nutrients from the aquaculture facility are most likely to accumulate in the estuary on intertidal flats and in deeper channels. This survey was therefore planned to coincide with this period of peak nutrient stress in the late dry season and was undertaken during the first week of October 2005. Should the aquaculture facility be established, follow-up monitoring and surveys will be carried out over the next five years to assess changes over time.

To locate the areas where dissolved and suspended nutrients are most likely to accumulate at this time, a drogue survey was undertaken. The drogue survey indicated that water moving through the farm on the flood tide will carry farm-released nutrients through Geranium Channel and up into McKenzie Arm. On spring tides some nutrients will continue into Bynoe Harbour. On a single flood tide cycle nutrients will be washed more than 6 km up the estuary and some will be carried into the mangrove flats lining the channel and its tributaries. Waters passing through the farm on the ebb tide will primarily remain in the northern half of Geranium Channel with some dispersing out into Port Paterson. On slower moving ebb tides, particularly when a stiff sea breeze is blowing, floating and dissolved nutrients will be carried over the mud flats to the south-east of the farm site. It can be expected that the waters of Geranium Channel will wash back and forth past the farm with potential to accumulate nutrients during the dry season.

Six sample sites were selected in the vicinity of Doug Point at locations expected to be subject to heaviest influence from fish farm nutrients. Six similar sites were selected in Madford and Tahlee Inlets as control sites, corresponding as closely as possible to the monitoring sites at Doug Point. Sites for mangrove transects were selected near the shallow water sites at places where the mud banks at low tide were narrow enough to allow access, and where the mangrove flats were sufficiently wide to suggest evaporation may result in deposition of nutrients. Maps showing the location of Doug Point and sample sites are presented in Figure 2-1 and Figure 2-2, coordinates are listed in Table 8.1.1.

Sampling methodology involved the collection of triplicate or duplicate samples from each of the sample sites. For most parameters (sediment description, redox, particle size, photography of mangrove root assemblages and benthic infauna) three samples were collected – one from the

specified GPS position, one from 20m upstream in the same depth and one from 20m downstream in the same depth. Where cost of analysis compared to additional information gained was considered too high – for water-borne nutrients and chlorophyll – duplicate samples were collected. Water quality parameters were measured and sampled twice at five minute intervals at the site GPS position. Mangrove stand structure and composition was recorded at 4 sweep sites along one transect near each of the three intertidal monitoring sites and two intertidal control sites.

Soft, brown-grey mud was present in most cores, indicative of material currently being deposited in depositional zones of the estuary. Black streaking and mottling indicated moderately high organic loading and low permeability to oxygen. Coarser sediments at the faster flowing deep water sites are indicative of rapid water flow washing out a high percentage of fine sediments from the surface sediments. However the stratification noted showed that some of the fine material deposited during low flow periods is retained in the interstitial spaces of deeper sediments. The numerous burrows present indicated prolific animal life, as was also found in the benthic grab samples. A lack of burrows in coarse sediments reflects disturbance due to coring rather than a lack of benthic infauna. Macroscopic plants were absent due to the high attenuation of light in the muddy estuarine waters. A lack of gas bubbles and smell from the cores indicated the natural organic loading is moderate rather than high, and reduction of organic matter is proceeding apace with its deposition. In brief sediments were typical of largely undisturbed mangrove estuarine environments.

Redox potential results from this survey show sediments at most of the study sites were poorly to moderately oxygenated indicating that reduction of organic matter was proceeding only slightly slower than penetration of oxygen through the sediments. Control site C3 appeared to be in an area of slightly higher than average organic loading indicating that such loading can result in anoxic sediments. This is typical of impermeable sediments subjected to moderate organic loading. Redox values at the intertidal control site C1 was atypically high since this site was dominated by fine silt. Redox values found at the remaining sites are typical of those expected in a healthy, undisturbed mangrove estuarine environment.

Particle size analysis found a preponderance of fines at intertidal sites indicating a lack of high energy water movement. The occurrence of shell grit and pebbles in sediments from some deep-water sites reflected the trend to coarser sediments with greater water movement. That trend was masked to some degree by the occurrence of decayed plant material in the sediments. There was no clear division between intertidal sheltered sites and deep water mid-channel sites on particle size analysis alone, however sediments from most sheltered shallow water sites were finer than those from faster flowing deepwater sites. The main use of these results is to characterise the environment of the benthic infauna to assist in explaining similarities and differences between sites.

Water in both estuaries was warm with a salinity higher than that of seawater indicating there is minimal fresh water input at this time of year. As the shallow and deep readings were taken at different locations no evidence of stratification was noted. Water temperature and salinity readings present only a snapshot, being useful primarily as part of a long term monitoring program.

Nitrite and nitrate levels were at the low end of values recorded during baseline studies at Marine Harvest's four study sites (Port Hurd, Snake Bay, Channel Island and Doug Point). They were also lower than those found in studies in Darwin Harbour (Pardovan 1997, Parry and Munksgaard 1999, Pardovan 2002) where levels ranged between 0.005 mg/L and 0.030 mg/L

with the higher levels occurring in the wet season. Ammonia levels were consistent with the above studies with the exception that the levels recorded at F1, F3 and F4 compare with the highest wet season level of 40 mg/L measured in sites subject to run-off from urban areas (Parry and Munksgaard 1999). NOX levels were below draft ANZEC Interim Trigger Levels (ITL) for estuaries at all but one site and below ITL for coastal waters at all sites. NH_4 levels were below ITL for estuaries at 7 of the 12 sites and below ITL for coastal waters at all but one site.

Phytoplankton abundance was assessed through analysis of Chlorophyll α concentration in the water. Chlorophyll α levels found were at the low end of the range of those recorded during the initial stages of monitoring at Port Hurd (1.1 to 4.6 μg/L) and Channel Island (<2 μg/L) and lower than those recorded at Snake Bay (2 to 4 μg/L), so may be considered typical of mangrove estuaries. The results were consistent with but at the low end of results of studies within Darwin Harbour which found values of 1 – 2 μg/L in the main harbour and 1 – 199 μg/L in the tidal creeks (Wrigley *et al*. 1990, Pardovan 1997, Parry and Munksgaard 1999, Pardovan 2002, Sly *et al*. 2002). They were at or below draft ANZECC Interim Trigger Levels (ITLs) of 2 mg/L for slightly to moderately disturbed ecosystems for estuaries (Table 3.3.2, ANZECC 1999).

Macroscopic epiphytic algal growth was not detected on intertidal mangrove root and rhizome assemblages, which appeared in excellent health.

Mangrove communities assessed in the vicinity of Doug Point and Madford Inlet were typical for similar mangrove estuaries (see Brocklehurst and Edmeades, 2003). They were composed mainly of *Rhizophora* sp. and *Ceriops* sp. and were healthy and vibrant. A prevalence of dead branches on transect F2 was associated with shorter than normal *Rhizophora* sp. forest with the canopy height being about 4m compared to the more common 10 to 14m. This presumably indicates these trees are stressed by the conditions on Indian Island where shallow soil overlies rock.

Benthic infaunal communities were diverse however abundance was about half that found at Port Hurd, Snake Bay and Channel Island. Analysis found no obvious signs of existing impacts on macrobenthic communities at the Doug Point farm sites or adjacent control sites in the Madford and Tahlee Inlets. Some habitat-related variation was observed, with intertidal communities distinct from the subtidal communities. Within the intertidal and subtidal groupings, some differentiation was also observed between farm and control sites, although overlap was observed between these localities, particularly in the subtidal samples. There were no consistent trends in biodiversity or dominance on the basis of habitat, depth or inlet. Communities were generally diverse and exhibited low levels of faunal dominance. The value of the information gathered in this survey is primarily to provide baseline information with which to compare future changes

This survey presents the results of a baseline study which can be used to asses the biological impact of nutrients released from Marine Harvest's proposed aquaculture facility near Doug Point if it becomes operational. Follow-up monitoring over subsequent years is required at control sites and sites most likely to show impact to gain an understanding of natural variation and assess impact.

2 Operational Summary

2.1 Operational details

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Client:	Marine Harvest Barramundi Farms PO Box 117 Rosny Park Tasmania 7018 Phone: Darwin (08) 8941 5651 Fax: Darwin (08) 8941 5254
Field work:	Field work by Aquenal with assistance from Marine Harvest personnel
Date of fieldwork:	Drogue survey: 4th and 5th August 2005 Sampling: 2nd to 5th October 2005
Weather:	Hot, with clear skies, calm mornings followed by afternoon sea breezes from the north-west. No significant rain for several months prior to the survey.

2.2 Sampling rationale and nomenclature

After consideration of potential indicators of excessive organic loading and potential impacts of excessive organic loading on nearby habitats we propose that the variables included in our Barramundi Monitoring Proposal (Aquenal 2005) are those most likely to detect significant impacts from increased organic loading. These are benthic infauna community structure, redox levels in sediments, water-borne nutrients and chlorophyll, epiphytic algal growth on intertidal mangrove structures and mangrove stand structure. Parameters evaluated and rejected for this survey are discussed below.

Coral communities

These are likely to be of high conservation value being limited in extent and relatively rare in occurrence in mangrove estuarine habitats. However little is known of their extent, biology, natural variability and reaction to organic loading. There are no known coral reefs within Geranium Channel and it is expected that the distribution of any reef communities in the vicinity will be such that it would be difficult to find suitable control sites. Coral reefs are known to be patchy in the waters to the west of Indian Island and reefs surround the off-shore islands, however it is considered that these reefs are unlikely to be sites for nutrient concentration or deposition as the closest are more than 6 km to seaward and they are predominantly washed by oceanic waters. Given these factors, the presence of crocodiles and difficulties associated with underwater visibility, it would be expensive and time consuming to locate suitable reef communities in Geranium Channel if they exist. It would then be problematic to design a monitoring program which will have the statistical strength to indicate with a sufficient degree of certainty that changes in community structure are due to impacts from fish farming.

Seagrass beds

Seagrass is an important habitat as a fish nursery and as feeding grounds for dugong. Seagrass is known to exist along the seaward end of Indian Island and in Bynoe Harbour in some bays on the eastern shore of Indian Island. However these seagrass beds are sparse and patchy in nature and only visible to a diver or camera during neap tides at certain times of year. Typically seagrass beds undergo marked changes in extent from year to year due to various climate related stresses. Additionally crocodiles are known to frequent these waters endangering divers. Therefore mapping the extent of the seagrass beds is not a practical tool with which to monitor possible impacts of fish farming. It appears the most applicable tool for this is to monitor the growth of epiphytic algae on the seagrass blades. This could either be done by collecting seagrass samples and measuring the ratio of epiphytes to seagrass by dry weight or by a form of photographic analysis. A more practicable method to monitor epiphytic algal growth is to monitor it on mangrove root structures in the lower intertidal zones in the vicinity of the farm and backwaters inland of the farm as in the proposed program. This should give early warning of nutrient related problems and be able to show the source of the nutrients.

Turtle and Dugong populations

These are the subject of expensive and extensive ongoing monitoring programs across northern Australia but too little is known at this stage to develop a practical monitoring program to determine fish farm impacts.

Crocodile populations

It is possible to monitor crocodile population density using for example a system of timed observations. However such a program will require frequent observations over long periods of time. This could best be instigated at the commencement of farming operations and incorporated in the farm's routine environmental monitoring program. It was considered that it would be too

time consuming and of low cost effectiveness to collect meaningful data for inclusion in a baseline survey.

Thus it was decided that the most efficient and scientifically rigorous impact monitoring program was to monitor the potential impact of organic and nutrient related pollution from farming operations. Organic output from fish farming occurs as either dissolved nutrients or suspended organic material so drogues studies were carried out and sample sites chosen to best represent the locations where the two different fractions accumulate. To assist in differentiating between natural variation and impacts of organic enrichment from farming activities, a similar estuary, Madford Inlet, 12 km to the west of Doug Point (Figure 2-1) was also sampled. Sample sites were labelled F1 to F6 at Doug Point, with F1 to F3 being intertidal sites in small creeks or on mud flats where dissolved and buoyant nutrients are likely to accumulate due to precipitation and evaporation, and F4 to F6 being deep water sites where suspended material was likely to be deposited when tidal flows slowed at the turn of the tides. F1 was chosen in Phoenix Inlet as it was the most proximal shallow mangrove creek to the proposed farm site and although no drogues went up it, much of the water flowing into it on a rising tide will contain waters which have recently passed through the farm on the preceding ebb tide. Additionally the mangroves here were wide and on a gently sloping bank. F2 was located on mudflats near the farm site where they were narrow enough to allow access to the shore for surveying a mangrove transect. F3 was located in McKenzie Arm in a small side creek draining a wide area of mangroves. This site was chosen in preference to the banks of the southern portion of Geranium Channel as the later possessed no shallow mud banks or wide mangrove areas and all water entering McKenzie Arm will pass the farm location. F4 was selected to detect whether any significant amount of nutrients were being carried through the southern end of Geranium Channel and in to Bynoe Harbour. F5 and F6 were located 100m from either end of the proposed lease as, due to the fairly uniform depth profile in Geranium Channel, no more suitable deep water sites were found. These sites should therefore be the best indicators of deep water deposition throughout the channel. Sample sites in Madford Inlet and Tahlee Inlet were selected to reflect as closely as possible, based on visual assessment, sample sites at Doug Point (labelled with similar site numbers; C1 to C3 for intertidal sites and C4 to C6 for deep water sites). Maps showing the locations of these sites are presented in Figure 2-1 and Figure 2-2.

Mangrove transects were surveyed near the shallow water sites to enable any changes noted to be correlated to nutrient and benthic data. The mangrove sites are labelled F1, F2 and F3 for the farm transects in the Doug Point vicinity and C1 and C2 for the control transects in Madford Inlet.

2.3 Maps

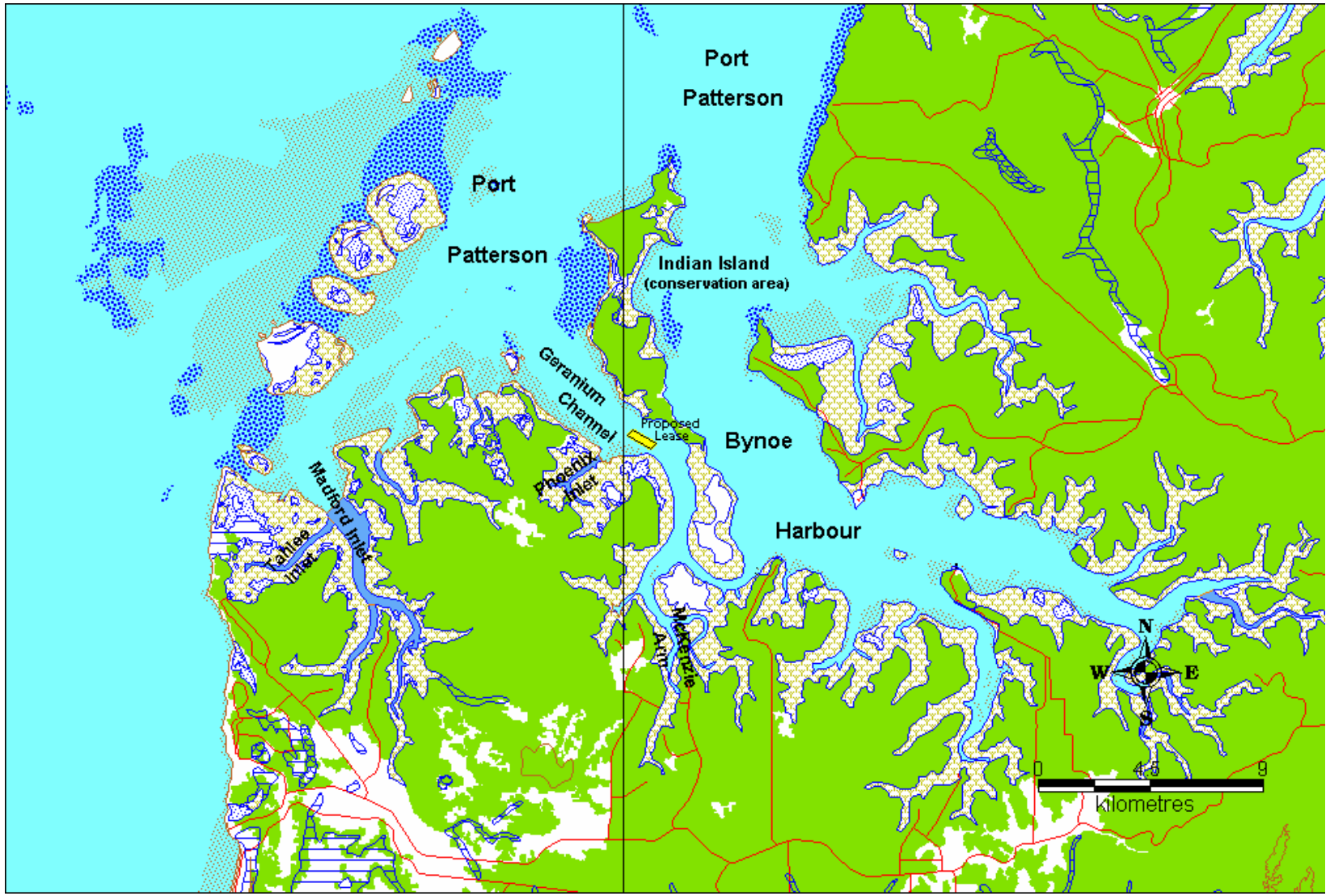

Figure 2-1 Broad-scale map of the study area. Refer to Figure 2-2 for detailed maps of survey sites in the vicinity of Doug Point/Geranium Channel and Madford Inlet.

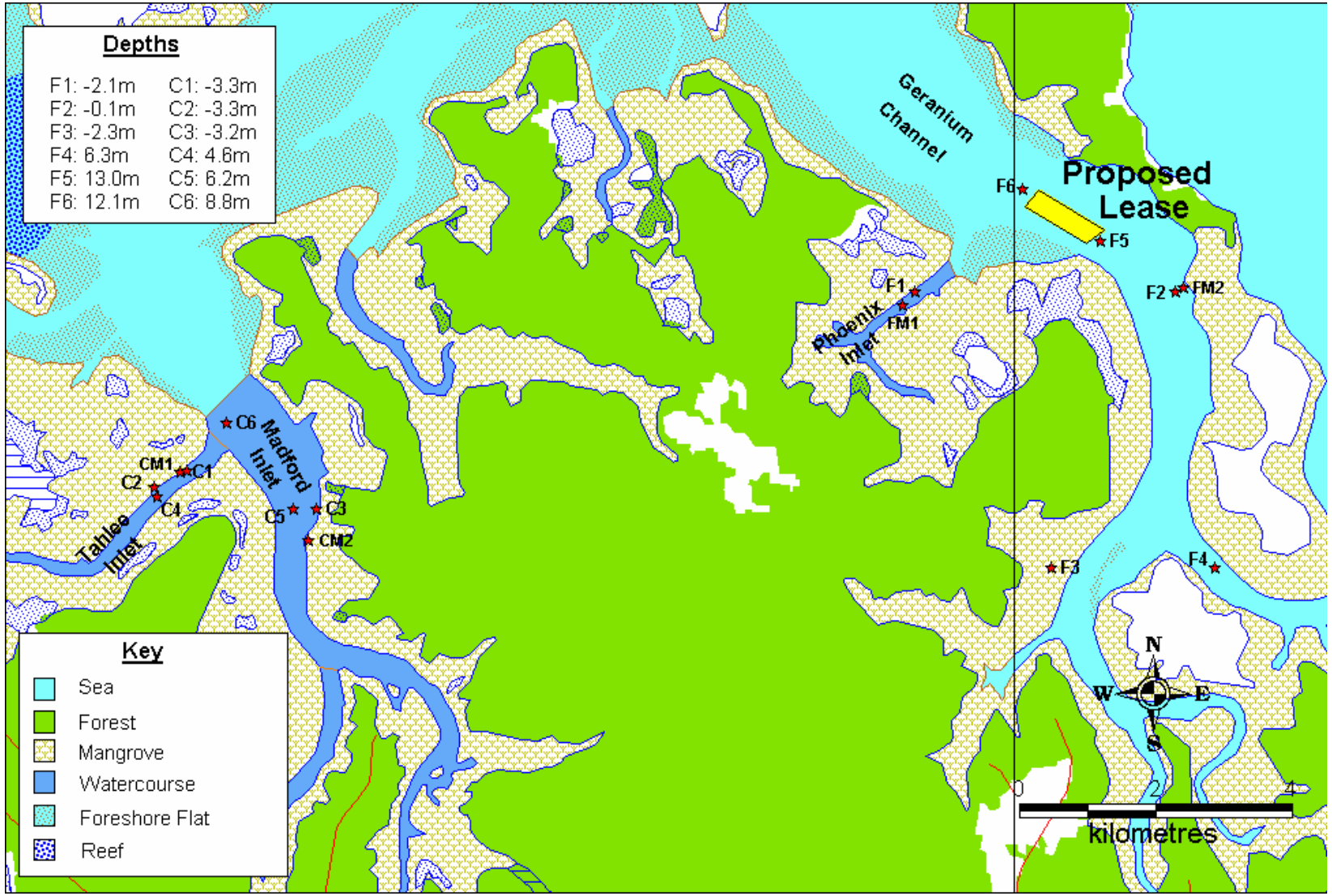

Figure 2-2 Survey map showing farm and control sample sites.

3 Nutrient Dispersion and Deposition

3.1 Drogue survey

Method

Pairs of drogues were released at two hourly intervals from the proposed farm site at Doug Point and at various locations within Geranium Channel during the spring tides of the 4th and 5th of August 2005. Positions of the drogues were plotted at approximately two hour intervals by GPS. All drogues were tracked as closely as possible and any that became grounded were shortened and re-released. Several drogues were released in the narrow southern end of Geranium Channel to confirm the direction of flow on both incoming and outgoing tides and to investigate the direction outgoing waters at the eastern end of the channel take. The purpose of the latter was to gather information on the likelihood of the proposed farm impacting on the established pearl oyster farms in Bynoe Harbour. Drogues were also released near the northern entrance to Geranium Channel to find which way they travelled on the outgoing tide. All drogues were pulled by 17:30 to enable the boats to return to shore before dark.

Drogues were constructed of 200 mm Styrofoam floats with a small orange flag on top and a cylinder of plastic mesh suspended below them at a depth of either 1 m or 5 m. A weight was attached to the plastic mesh to ensure it hung straight down from the float and to keep the flag upright so it could be seen. The plastic mesh caught the tide and dragged the float with the water flow at the set depth, regardless of wind and surface water movement. Eight drogues were built for the survey, four 1m drogues and four 5m drogues. On the maps following, the codes read 1 or 5 for the depth of the drogue then 1 to 4 for the number on the drogue

Results

Drogues released from the farm site at high tide travelled through Geranium Passage and out into Port Patterson but those released 2 hours later remained within Geranium Channel and returned past the farm on the following incoming tide. Those released at the farm site at half tide on the ebb travelled 3 km seawards then back past the southern side of the release point on the incoming tide, passing close to the entrance to Phoenix Inlet. Those released at the entrance to the channel were washed northwards into Port Paterson.

Drogues released at low tide travelled through Geranium Channel to the entrance of the narrow channel turning east to join Bynoe Harbour. Drogues released in the narrow southern section of the channel travelled to the east with the incoming tide and west with the ebb tide. Shallow sandbanks with a narrow navigation channel prevented drogues from passing out into Bynoe Harbour.

The 5m drogues moved similarly to the 1m drogues, moving at similar speeds, keeping within the well defined channels and only becoming stranded at the eastern end of Geranium Channel. Wind affected the shallow water driving it to windward and into the mudflats on the sides of the channels. Maps showing the logged positions of the 1m and 5m drogues are presented in Figure 3-1 and Figure 3-2 respectively.

Interpretation

Movements of drogues gives a simplistic but reliable indication of the immediate fate of nutrient output from a point source without resorting to costly computer modelling of estuarine flows.

The drogue survey indicated that water moving through the farm on the flood tide will carry farm released nutrients through Geranium Channel and up into McKenzie Arm. On spring tides some nutrients will continue into Bynoe Harbour. On a single flood tide cycle nutrients will be washed more than 6 km up the estuary and some will be carried into the mangrove flats lining the channel and its tributaries. Waters passing through the farm on the ebb tide will primarily remain in the northern half of Geranium Channel with some dispersing out into Port Paterson. On slower moving ebb tides, particularly when a stiff sea breeze is blowing, floating and dissolved nutrients will be carried over the mud flats to the south-east of the farm site. It can be expected that the waters of Geranium Channel will wash back and forth past the farm with potential to accumulate nutrients during the dry season.

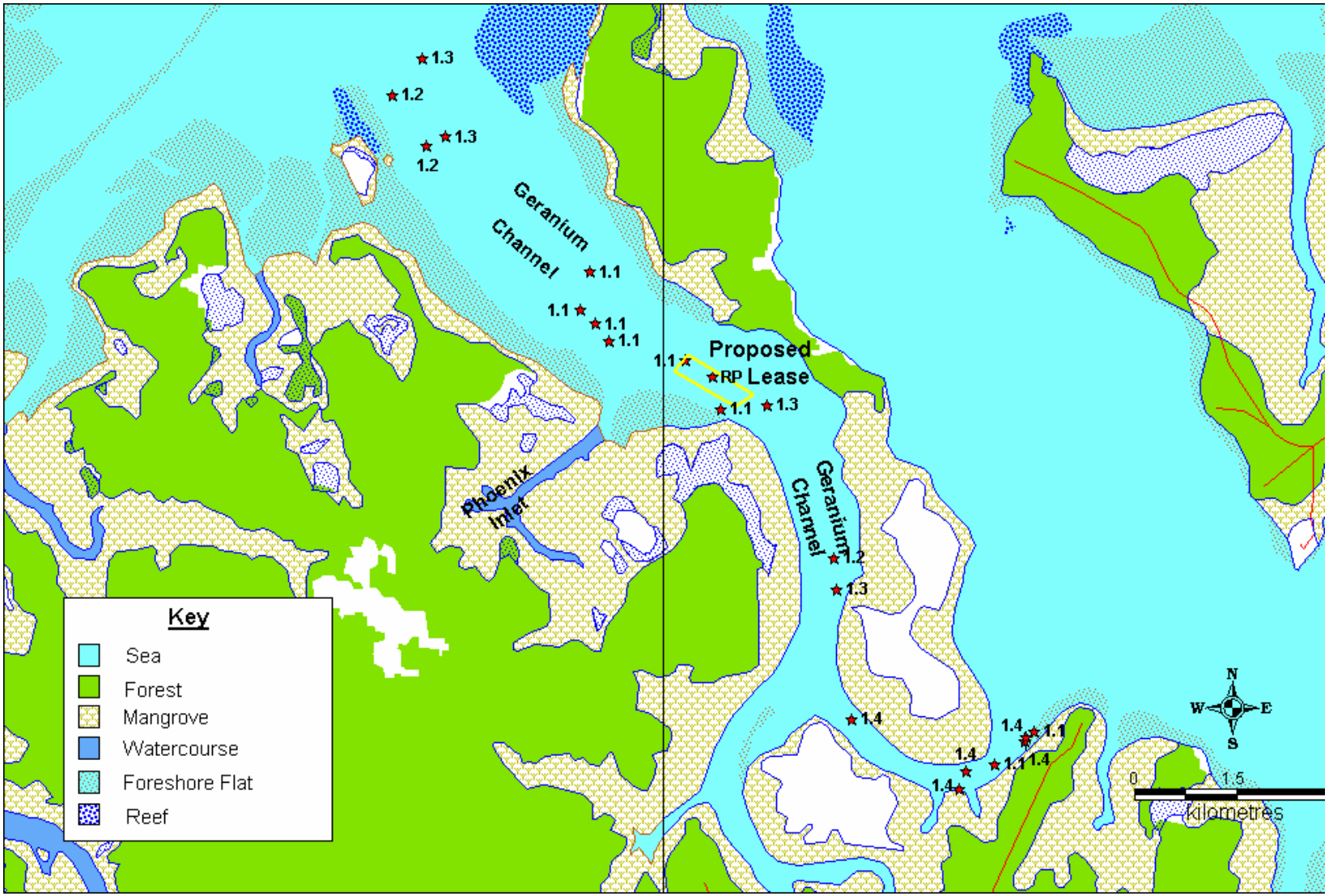

Figure 3-1 One metre drogue survey showing positions of drogues each two hours during one spring tide cycle.

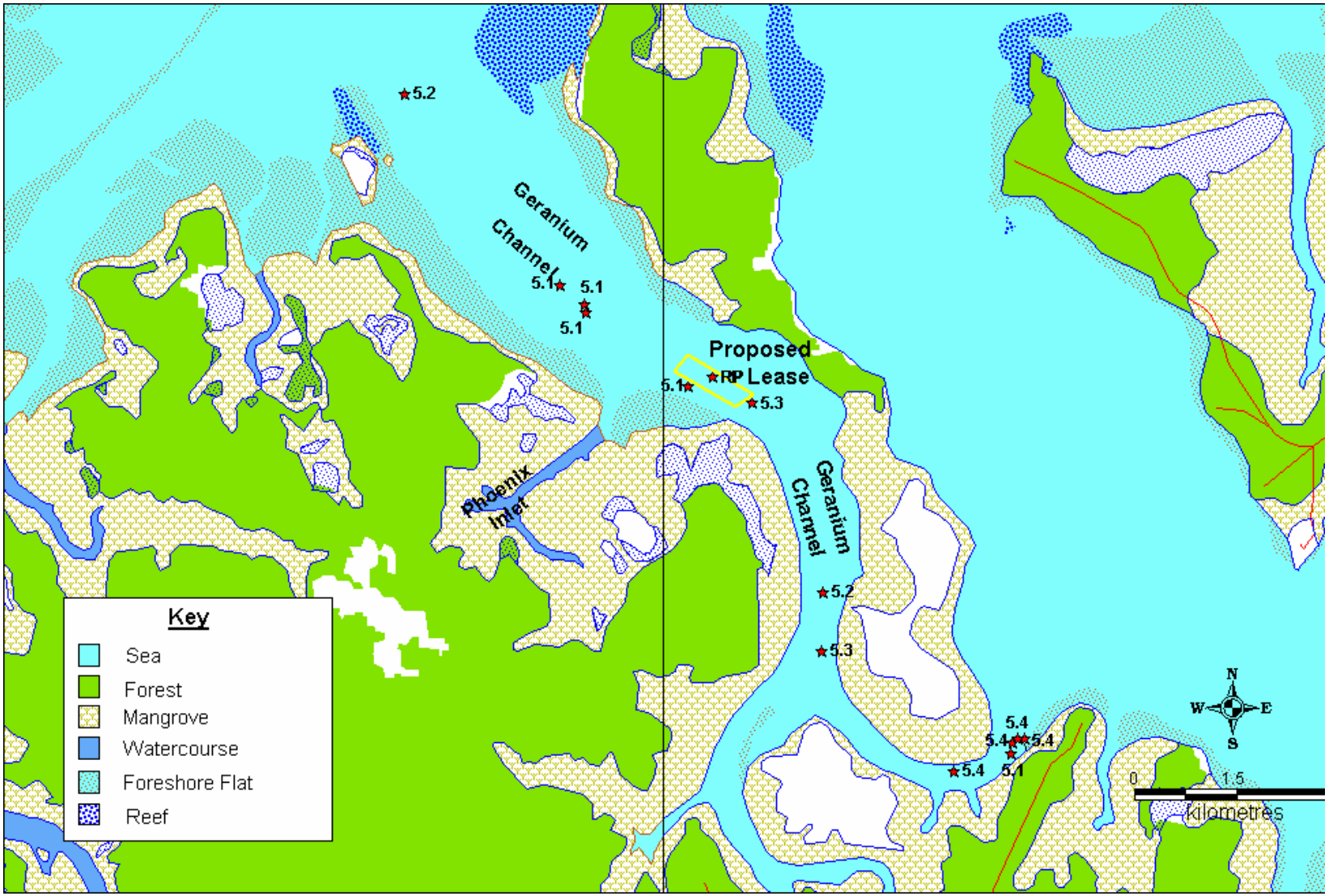

Figure 3-2 Five metre drogue survey showing positions of drogues each two hours during one spring tide cycle.

4 Sediment Analysis

4.1 Visual assessment

Method

At the intertidal sites, F1 to F3 and C1 to C3, sediment cores were collected by hand in 20 cm long, 43 mm internal diameter transparent Perspex tubes. These were collected with the water level below mid tide, on an outgoing tide, from undisturbed sediments. Triplicate samples were collected: one from the specified GPS position, one from 20 m upstream in the same depth and one from 20 m downstream in the same depth. Using the same core barrels, a Craib corer was used to collect triplicate sediment cores at the deep water sample sites, F4 to F6 and C4 to C6.

Cores were handled carefully and retained in a vertical orientation to minimise disturbance of the sediment surface until they were described and redox readings taken. Their length, colour, plant and animal life, gas vesicles, and smell were described. The visual description was partially obstructed in the more muddy sediments by sediments adhering to the outside of the core barrel. Smell was noted after the water was removed from the core barrels.

Results

Core length ranged from 80-190 mm, with shorter cores (<100 mm) coming from sediments containing gravel or sand. Sediments consisted largely of brown-grey mud, with organic material present in cores from intertidal sites only (Table 4.1.1). Sediment stratification was seen in most deep-water cores, with the bottom layers largely characterised by grey mud and a lack of organic matter. Shallow water cores displayed less stratification. Many of the cores contained black streaks or mottling. Animal burrows were observed in cores from all sites with the exception of F4 and C6, which had no burrows. There was no plant material, gas bubbles or strong smell recorded from any of the cores.

Interpretation

The soft, brown-grey mud present in most cores is material currently being deposited in the slower flowing depositional zones of the estuary. The black streaking and mottling indicates moderately high organic loading and low permeability to oxygen. The coarser sediments at the faster flowing deep water sites are indicative of rapid water flow washing out a high percentage of fine sediments from the surface sediments. However the stratification noted shows that some of the fine material deposited during low flow periods is retained in the interstitial spaces of deeper sediments. The numerous burrows present indicate abundant animal life, as was also found in the benthic grab samples. A lack of burrows in coarse sediments reflects disturbance due to coring rather than a lack of benthic infauna. Macroscopic plants were absent due to the high attenuation of light in the muddy estuarine waters. A lack of gas bubbles and smell from the cores indicates the natural organic loading is moderate rather than high, and reduction of organic matter is proceeding apace with its deposition. In brief sediments were typical of largely undisturbed mangrove estuarine environments.

Table 4.1.1 Visual description of sediment cores at farm and control sites. Abbreviations used in the table are: brn=brown, gy=grey md=mud, blk=black, lt=light, org=organic, matt=matter, mott=mottled, ptchy=patchy, sd=sand, sg=shell grit, spk=speckled, stks=streaks

Core No.	Length mm	Colour 1	Depth 1 mm	Colour 2	Depth 2 mm	Colour 3	Plants	Animals	Gas Bubbles	Smell
F1-1	150	Brn md spkd org matt, blk stks	150				Nil	Burrs to 60mm	Nil	Nil
F1-2	170	Brn md spkd org matt, ptchy gy	90	Brn md, gy stks	170		Nil	Burrs to 80mm	Nil	Nil
F1-3	180	Brn md spkd org matt	100	Gy/brn md	180		Nil	Nil	Nil	Nil
F2-1	110	Brn md spkd org matt & sg	110				Nil	Burrs to 50mm	Nil	Nil
F2-2	130	Brn md spkd org matt & sg	130				Nil	Burrs to 70mm	Nil	Nil
F2-3	100	Brn md spkd org matt & sg	50	Ptchy blk/brn md	100		Nil	Nil	Nil	Nil
F3-1	120	Brn md spkd org matt	60	Brn/gy md, blk stks	120		Nil	Burrs to 30mm	Nil	Nil
F3-2	100	Brn/gy md spkd org matt					Nil	Burrs to 100mm	Nil	Nil
F3-3	110	Brn md spkd sg		Gy md, blk stks	110		Nil	Burrs to 40mm	Nil	Nil
F4-1	135	Brn sd	10	Gy sd & md	135		Nil	Nil	Nil	Nil
F4-2	80	Gy sd & md	80				Nil	Nil	Nil	Nil
F4-3	190	Brn sd & md	30	Gy sd & md	190		Nil	Nil	Nil	Nil
F5-1	160	Gy/brn spkd md & sd	30	Gy md	160		Nil	Sev sm burrs to 60mm	Nil	Nil
F5-2	160	Gy/brn spkd md & sd	30	Gy md	160		Nil	Nil	Nil	Nil
F5-3	110	Gy/brn md	15	Gy md	110		Nil	Nil	Nil	Nil
F6-1	110	Gy/brn sd & md	40	Gy/brn md	110		Nil	Sev burrs to 40mm	Nil	Nil
F6-2	140	Gy/brn sd & md	40	Gy/brn md	140		Nil	Nil	Nil	Nil
F6-3	180	Gy/brn sd & md	30	Gy/brn md	180		Nil	Nil	Nil	Nil
C1-1	130	Brn md spkd org matt	130				Nil	Burrs to 100mm	Nil	Nil
C1-2	150	Brn md spkd org matt	150				Nil	Burrs to 90mm	Nil	Nil
C1-3	120	Brn md spkd org matt	120				Nil	Burrs to 60mm	Nil	Nil
C2-1	150	Brn/gy md spkd org matt, gy/blk stks	150				Nil	Nil	Nil	Nil
C2-2	170	Brn/gy md spkd org matt	170				Nil	Burrs to 50mm	Nil	Nil
C2-3	110	Brn/gy md, blk stks	110				Nil	Nil	Nil	Nil
C3-1	100	Brn/gy mud spkd org matt, blk stks	100				Nil	Burrs to 40mm	Nil	Nil
C3-2	140	Brn/gy mud spkd org matt, gy stks	140				Nil	Burrs to 100mm	Nil	Nil
C3-3	150	Brn/gy md spkd org matt	50	Blk md	110	Brn/gy md, blk stks	Nil	Burrs to 50mm	Nil	Nil
C4-1	130	Brn/gy slt & md	5	Gy spkd md & sg	130	Gy spk blk md	Nil	Burrs to 50mm	Nil	Nil
C4-2	130	Brn/gy slt & md	3	Gy spkd md	130		Nil	Burrs to 30mm	Nil	Nil
C4-3	120	Brn/gy slt & md	20	Gy md	120		Nil	One burr to 40mm	Nil	Nil
C5-1	145	Brn spkd sd	15	Gy spkd blk md	145	Gy mott blk md	Nil	Burrs to 60mm	Nil	Nil
C5-2	170	Lt gy sd & md	30	Gy mott blk md	170		Nil	Nil	Nil	Nil
C5-3	140	Brn spkd sd	15	Gy/brn md	140	Gy mott blk md	Nil	Burrs to 60mm	Nil	Nil
C6-1	80	Gy/brn spk md & gvl	25	Gy md, blk stks	80		Nil	Nil	Nil	Nil
C6-2	130	Gy/brn spk md & gvl	40	Gy md, blk stks	130		Nil	Nil	Nil	Nil
C6-3	80	Gy/brn spk md & gvl	50	Gy md, blk stks	80		Nil	Nil	Nil	Nil

4.2 Redox potential

Method

Redox potential was measured in millivolts (mV) at the surface of the sediment and at 1 and 4 cm below the sediment surface using a WTW pH 320 meter with a Mettler Toledo Ag/AgCl combination pH / Redox probe. The standard potential of the Ag/AgCl reference cell of the probe is 207 mV at 25°C, the approximate temperature of the samples during measurement. Calibration and functionality of the meter were checked before each test using a Redox Buffer Solution (220 mV at 25 °C). Measurements were made within three hours of the samples being collected. Corrected redox potential values were calculated by adding the standard potential of the reference cell to the measured redox potential and are reported in millivolts.

In all cases the lowest reading observed is recorded as the redox value. In low permeability, muddy sediments this is recorded when the reading is stable or dropping at less than 1 mV per second. In permeable, sandy sediments the lowest reading is often observed while the probe is being worked to the measurement depth. As soon as the probe stops moving in sandy sediments with low redox values, the readings normally start to increase due to water drawn down by the probe diluting the interstitial fluids.

Results

Corrected surface redox values ranged considerably, from 74 mV at F2 to 412 mV at C5 (Table 4.2.1). Redox values at 4cm were above 0 mV for all sites with the exception of C3 which had a corrected mean of -37 mV, indicating sediments were slightly anoxic at this site. High standard deviations were calculated for a number for sites, particularly C1 and C6 (Table 4.2.1, Figure 4-2). In the case of C1, readings taken from the redox probe at the time of sampling are considered unreliable, whereas the high standard deviation recorded at C6 is due to one sample returning significantly different results to the other replicates (Table 8.2.1).

Interpretation

Redox values at 0 cm and 1 cm are typically above 100 mV and widely variable due to spatial variation of sediment composition and animal bioturbation activity. The main value in these readings is to detect major pollution resulting in the deposition of a blanket of organic material which will deplete these sediments of oxygen and destroy animal life.

The redox potential at 4 cm is considered to be the most reliable indicator of sediment redox condition in soft or poorly consolidated sediments (Pearson and Stanley, 1979). Results from this survey show sediments at most of the study sites to be poorly to moderately oxygenated indicating that reduction of organic matter is proceeding only slightly slower than penetration of oxygen through the sediments. Control site C3 appears to be in an area of slightly higher than average organic loading indicating that such loading can result in anoxic sediments. This is typical of impermeable sediments subjected to moderate organic loading. Redox values at the intertidal control site C1 was atypically high since this site was dominated by fine silt, with more than 70% of particles <63 µm (Table 8.3.1). This indicates either some unusual condition in the sediments or malfunction of the measuring equipment. Redox values found at the remaining sites are typical of those expected in a healthy, undisturbed mangrove estuarine environment.

Table 4.2.1 Corrected redox potential of sediments at farm and control sites.

Site No.		Depth (cm) 0	1	4
F1	Corrected Mean	159	104	59
	Standard Deviation	18	39	32
F2	Corrected Mean	74	51	28
	Standard Deviation	34	19	6
F3	Corrected Mean	99	43	19
	Standard Deviation	60	41	62
F4	Corrected Mean	152	116	64
	Standard Deviation	14	6	27
F5	Corrected Mean	135	87	45
	Standard Deviation	62	54	39
F6	Corrected Mean	83	54	29
	Standard Deviation	17	13	6
C1	Corrected Mean	290	269	253
	Standard Deviation	117	108	89
C2	Corrected Mean	83	54	35
	Standard Deviation	35	26	19
C3	Corrected Mean	81	36	-37
	Standard Deviation	34	64	54
C4	Corrected Mean	98	76	48
	Standard Deviation	27	32	8
C5	Corrected Mean	415	81	62
	Standard Deviation	41	44	34
C6	Corrected Mean	250	169	63
	Standard Deviation	143	149	19

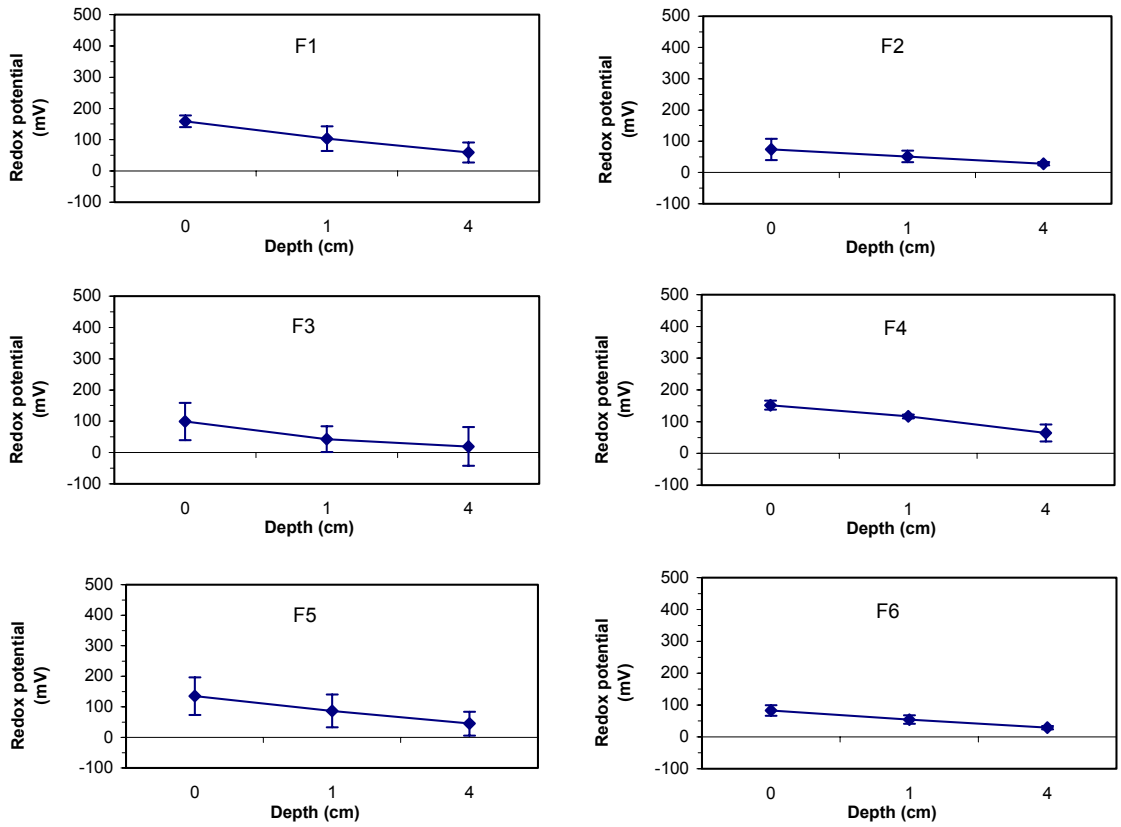

Figure 4-1 Redox potential in the top 4 cm of sediment cores at farm sites.

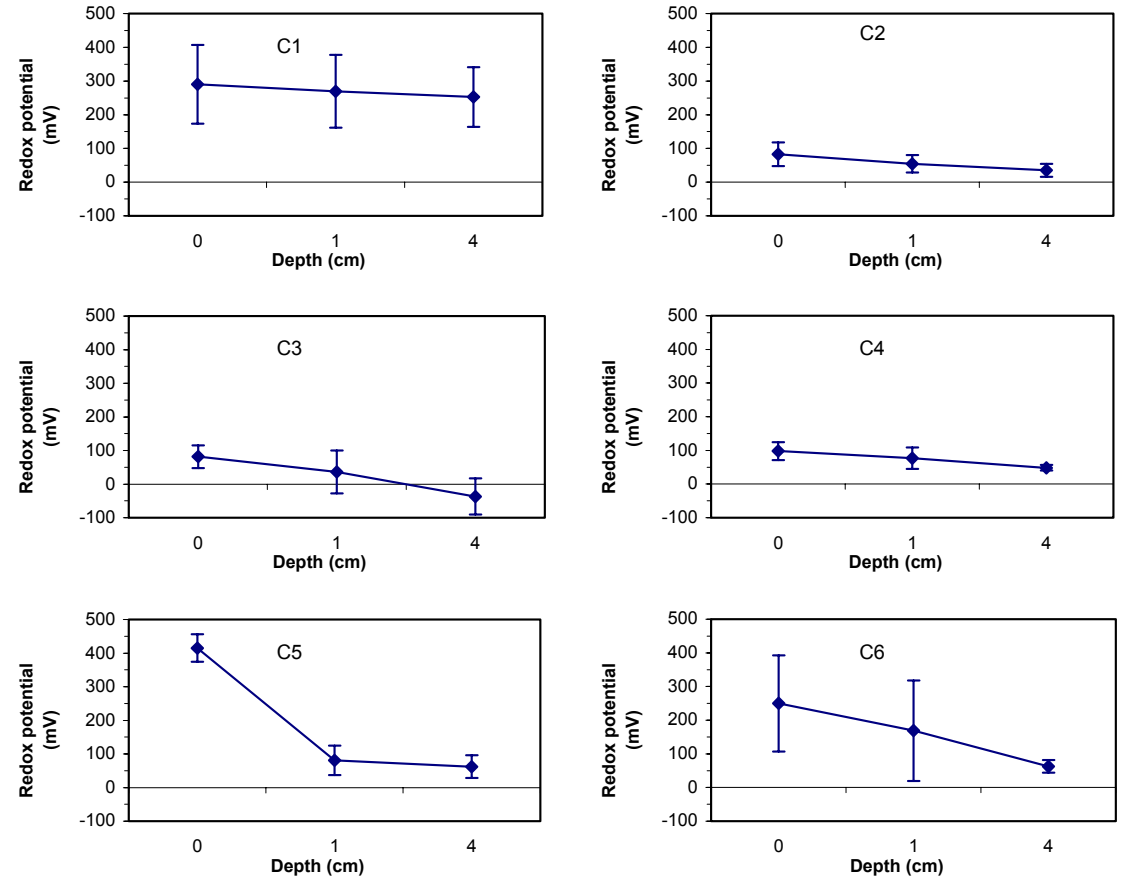

Figure 4-2 Redox potential in the top 4 cm of sediment cores at control sites.

4.3 Particle size analysis

Method

The top 100 mm of each sediment core was extruded from the core barrel and homogenised. To obtain an accurate and consistent volume of sample, a container of known volume (77 ml) was filled with the sample material which was then packed down and scraped level with a ruler. This was washed through a stack of sieves by shaking them under a moderate water spray. The sieve aperture sizes were 4 mm, 2 mm, 1 mm, 500 μm, 250 μm, 125 μm and 63 μm. The contents of each sieve were drained then transferred to a 100 ml measuring cylinder containing 20 ml of water, starting with the coarsest fraction and working through to the finest. The cumulative volume in the measuring cylinder was recorded after each sieve's contents were transferred. These volumes were entered into a spreadsheet and the fraction's percentage by volume of the original sample calculated. The percentage by volume of the sediment of less than 63 μm diameter was calculated to make the total up to 100%.

Results

Intertidal sites clearly contained more fine material than deep-water sites, although C4 and C5 were noticeably finer than other deep-water sites (Figure 4-3 Figure 4-4). All intertidal sites were comprised of more than 59% fines (i.e. material less than 63 μm, being silt, clay and organic matter), and consisted largely of mud, woody material and silt (Table 4.3.1, Table 8.3.1). The finest sediment was found at F1 where only 11.5% of sediment was coarser than 63 μm. Woody plant material was present at many sites which masks the true nature of the sediments and the correlation of sediment particle size with water speed. Sediments from all deep-water sites contained coarse material including shell and pebbles, with the coarsest sediments at F4, F5 and C6 where more than 61% of particles were larger than 63 μm (Table 4.3.1).

Table 4.3.1 Description of sediments retained in sieves during particle size analysis

Site	Description of sediment remaining in sieves
F1	Mud, clay, woody material and silt
F2	Mud, shell, woody material and silt
F3	Mud, clay, woody material and silt
F4	Mud, shell, pebbles and sand
F5	Mud, shell, pebbles and sand
F6	Mud, shell, pebbles and sand
C1	Clay, silt, sand and woody material
C2	Mud, clay, shell, silt and woody material
C3	Mud, woody material and silt
C4	Mud, woody material, pebbles, silt and sand
C5	Mud, clay, shell, woody material, silt and sand
C6	Mud, woody material, pebbles, silt and sand

Interpretation

The normal trend to coarser sediments with greater water movement is masked to some degree here by the occurrence of decayed plant material in the sediments. In sites more remote from mangroves, sediments are transported either in from the ocean or down

rivers and deposited. In these cases the size of the particles reflects the energy of normal ambient water movement with fine sediments indicating low energy movement and coarse indicating high. The more mixed the particle size distribution the greater the range of water movement from calm to rough. The preponderance of fines at intertidal sites reflects this trend overall, indicating a lack of high energy water movement such as swell or wave action. The occurrence of shell and pebbles in sediments from some deep-water sites also reflects this trend. There is no clear division between intertidal sheltered sites and deep water mid-channel sites on particle size analysis alone, however sediments from most sheltered shallow water sites were finer than those from faster flowing deepwater sites. The main use of these results will be in characterising the environment of the benthic infauna to assist in explaining similarities and differences between sites.

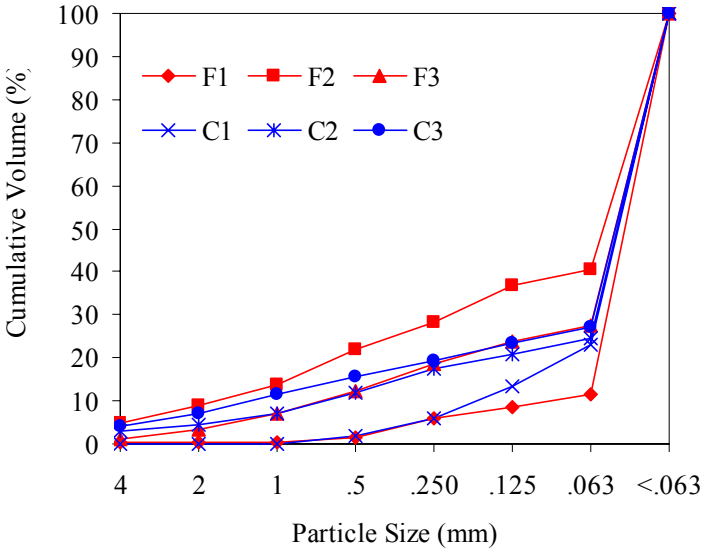

Figure 4-3 Particle size analysis of the top 100 mm of sediment cores from the intertidal farm and control sites.

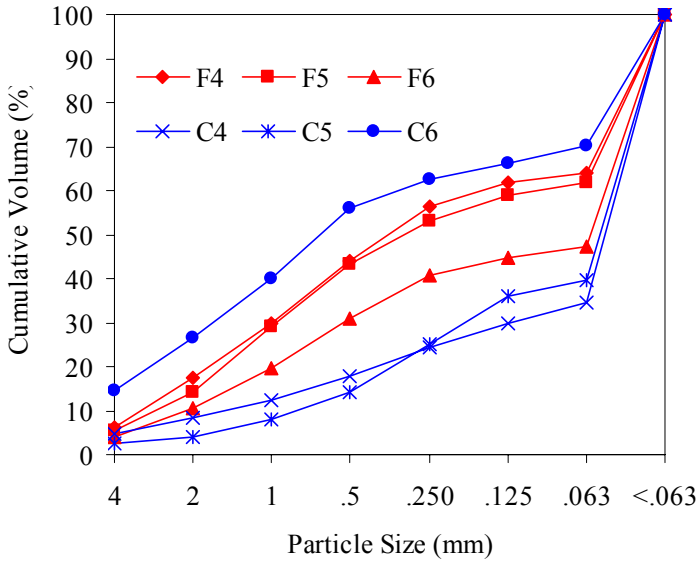

Figure 4-4 Particle size analysis of the top 100 mm of sediment cores from the subtidal farm and control sites.

5 Water Quality Analysis

5.1 Physico-chemical properties

Method

A number of physico-chemical properties were measured to enable detection of significant run-off during on-going monitoring, particularly as the wet season set in and also changes during the dry season. Parameters measured were temperature, salinity, pH and dissolved oxygen (DO). Measurements were made using an electronic data logger (Yeo-Kal YK-611 Water Quality Analyser) mid way through the ebbing tide at 0.3 m depth at sheltered shallow waters sites and 0.5 m above the seabed near the turn of the tide at deep water sites. Three series of readings were taken within 5 minutes of each other at each site to assess in-site variability.

Results

Surface water temperatures were consistent between sites, ranging from 29.3 - 31.3 °C. At the majority of sites, salinity was between 38 and 39 ppt, but reached 40.7 ppt at F3 (Figure 5-1, Table 5.1.1 and Table 8.4.1). Measurements of pH ranged from 6.9 to 7.6 with the lowest readings taken from farm sites F1 and F3. The recorded dissolved oxygen (DO) covered a large range, from 64.2% at F1 to 91.2% at F2. There was no clear difference in parameter measurements between farm and control sites, or between intertidal and deep-water sites. The data are consistent between replicate readings, as indicated by the low standard deviations (Table 5.1.1).

Interpretation

These readings provide only a snapshot view and little should be drawn from them without additional information. Their main use will be as part of a long term monitoring program. No significance can be placed on the small differences between estuaries based on this one set of data alone. However it is evident that the water in both estuaries is very warm and has a salinity higher than that of seawater (~35 ppt) indicating there is minimal, fresh water input and high evaporation in the catchments. The particularly high salinity at F3 indicates these factors are more accentuated there so it is a particularly susceptible site for accumulation of nutrients due to evaporation. As the shallow and deep readings were taken at different locations no evidence of stratification was noted.

Table 5.1.1 Physico-chemical data from surface waters at intertidal and subtidal farm and control sites.

Site	Temperature °C	Salinity ppt	DO % sat	DO mg/L	pH
F1	31.3 ± 0.1	39.2 ± 0.2	64.2 ± 3.0	3.7 ± 0.2	7.0 ± 0.1
F2	30.9 ± 0.1	38.0 ± 0.0	91.2 ± 0.4	5.4 ± 0.0	7.4 ± 0.0
F3	29.3 ± 0.0	40.7 ± 0.0	64.6 ± 0.3	3.8 ± 0.0	6.9 ± 0.0
F4	30.5 ± 0.0	38.4 ± 0.0	88.2 ± 0.7	5.2 ± 0.1	7.5 ± 0.0
F5	30.6 ± 0.0	38.3 ± 0.0	83.3 ± 0.3	4.9 ± 0.0	7.5 ± 0.0
F6	30.6 ± 0.0	38.2 ± 0.0	84.4 ± 0.2	5.0 ± 0.0	7.5 ± 0.0
C1	30.0 ± 0.0	38.2 ± 0.0	70.4 ± 1.6	4.2 ± 0.1	7.5 ± 0.0
C2	29.5 ± 0.0	38.6 ± 0.0	75.0 ± 0.1	4.5 ± 0.0	7.5 ± 0.0
C3	30.2 ± 0.0	38.0 ± 0.0	81.7 ± 0.8	4.9 ± 0.1	7.6 ± 0.0
C4	30.1 ± 0.0	39.1 ± 0.0	69.3 ± 0.3	4.1 ± 0.0	7.4 ± 0.0
C5	30.4 ± 0.0	38.7 ± 0.0	74.0 ± 0.2	4.4 ± 0.0	7.4 ± 0.0
C6	30.2 ± 0.0	38.8 ± 0.0	75.3 ± 0.2	4.5 ± 0.1	7.5 ± 0.0

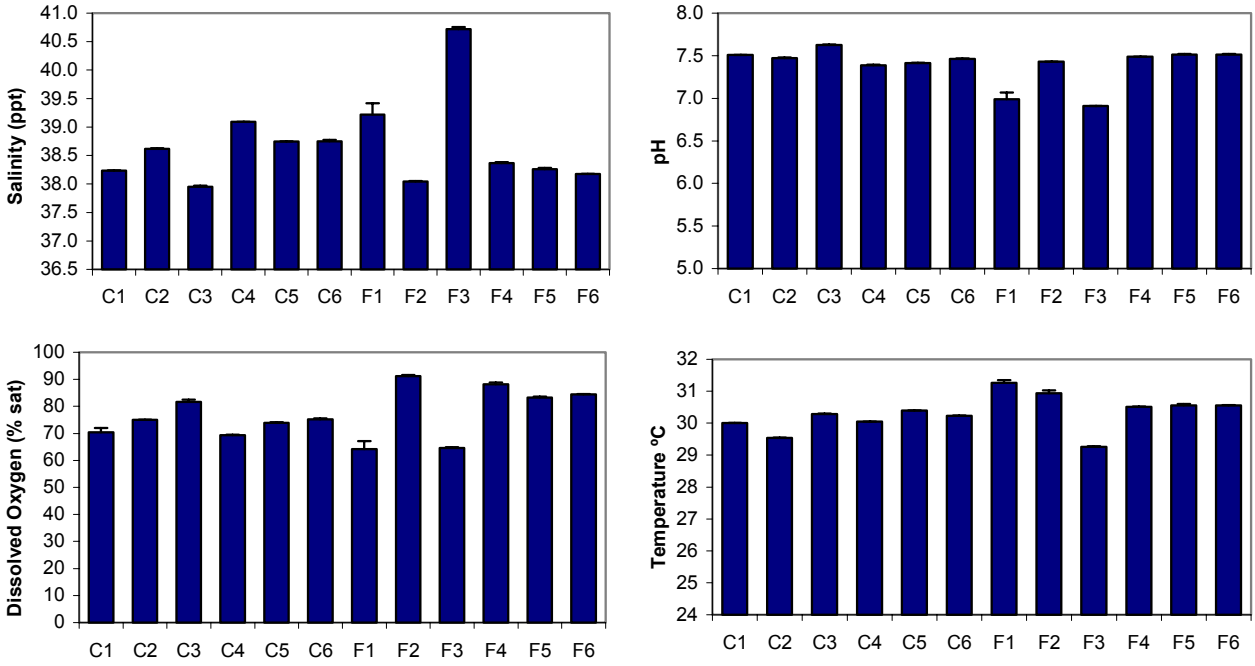

Figure 5-1 Physico-chemical data from surface waters at intertidal and deep waters at subtidal farm and control sites.

5.2 Nutrients

Method

Water samples were collected mid way through the ebbing tide from sheltered shallow waters sites, and near the turn of the tide at the deep water sites along with the other water quality parameters. Water samples were collected for laboratory analysis of chlorophyll and dissolved inorganic nitrogen from 0.3 m below the surface in clean plastic bottles at shallow water sites, and from 0.5 m above the seabed in a Nisken bottle. Water collected in the Nisken bottle was then transferred to clean plastic bottles. As soon as the water samples were collected they were sealed and placed in an esky on ice to stay chilled until they could be frozen at the shore base. They were delivered frozen to Northern Territory Environmental Analysis Laboratories for analysis.

Total dissolved inorganic nitrogen (DIN) consists of nitrates, nitrites and total ammonia nitrogen (TAN). The combined oxides of nitrogen (NOX) is measured by reducing all nitrates to nitrite and analysing the nitrite. To measure nitrate, NOX is analysed as described above, then nitrite is analysed and subtracted from NOX. The nitrate to nitrite ratio normally approximates 10:1. The occurrence of different forms of ammonia depends on pH. At the pH of average seawater (close to 8.2), ~95% of ammonia is in the cationic form of ammonium (NH_4^+) (Millero, 1996). It is NH_4^+ that is measured in the *APHA 4500 Ammonia Nitrogen* analysis, so effectively TAN and NH_4^+ are equivalent in seawater. DIN gives a better indication of bioavailable nutrient concentration than Total N which includes bound organic nitrogen, making DIN a better indicator of conditions conducive to algal blooms (Eyre, 2000; Harris, 1994). For further information see the footnotes and reference to bioavailable nutrient concentrations in the ANZECC guidelines Interim Trigger Levels in their Table 3.3.2.

Results

Nitrate and nitrite levels were below the detection threshold of 0.005 mg/L at all sites except F4-1 where nitrate was 0.010 mg/L. Ammonia levels ranged from 0.005 mg/L (detection threshold level) to 0.050 mg/L with values above 20 mg/L at F1, F3 and F4 sites. Summarised results can be found in Table 5.2.1 and full laboratory analysis reports in Table 8.5.1.

Interpretation

Nitrite and nitrate levels were at the low end of values recorded during baseline studies at Marine Harvest's four farm sites (Port Hurd, Snake Bay, Channel Island and Doug Point). They were also lower than those found in studies in Darwin Harbour (Pardovan 1997, Parry and Munksgaard 1999, Pardovan 2002) where levels ranged between 0.005 mg/L and 0.030 mg/L with the higher levels occurring in the wet season. Ammonia levels were consistent with the above studies with the exception that the levels recorded at F1, F3 and F4 compare with the highest wet season level of 40 mg/L measured in Ludmiller Creek and at East Point, sites subject to run-off from urban areas (Parry and Munksgaard 1999). However these studies were small and of short duration therefore little can be interpreted from the results at this stage. The main use for these data will be in gaining an understanding of normal levels for mangrove estuaries and in monitoring trends over time.

ANZECC draft guidelines for Interim Trigger Levels (ITL) for nutrients in slightly to moderately disturbed estuaries and coastal waters are given in Table 5.2.2. (ANZECC, 1999). Total N includes organic nitrogen which is not readily bio-available so was not measured in this survey. As Geranium Channel is inundated by 6 - 7 m tides twice per day during spring tides, salinities are close to marine and there is little or no freshwater input at this time of year, reference trigger levels should be somewhere between Estuarine and Coastal values, arguably nearer Coastal values. ANZECC guidelines are generalised for all of Australia and New Zealand and need to be verified against locally collected data. Ideally the reference condition would be defined using up to 3 to 5 years of at least monthly sampling data collected from at least 5 to 10 reference locations in well-functioning, unmodified ecosystems (ANZECC, 1999).

Given the above, NOX levels were below ITL for estuaries at all but one site and below ITL for coastal waters at all sites. NH_4 levels were below ITL for estuaries at 7 of the 12 sites and below ITL for coastal waters at all but one site.

Table 5.2.1 Dissolved inorganic nitrogen analysis

Site	Ammonia (mg/L)	Nitrite (mg/L)	Nitrate (mg/L)	NOX (mg/L)
F1-1	0.04	<0.005	<0.005	<0.010
F1-2	0.05	<0.005	<0.005	<0.010
F2-1	0.01	<0.005	<0.005	<0.010
F2-2	0.01	<0.005	<0.005	<0.010
F3-1	0.025	<0.005	<0.005	<0.010
F3-2	0.03	<0.005	<0.005	<0.010
F4-1	0.03	<0.005	0.01	<0.015
F4-2	0.01	<0.005	<0.005	<0.010
F5-1	0.01	<0.005	<0.005	<0.010
F5-2	0.01	<0.005	<0.005	<0.010
F6-1	0.015	<0.005	<0.005	<0.010
F6-2	0.01	<0.005	<0.005	<0.010
C1-1	0.010	<0.005	<0.005	<0.010
C1-2	0.020	<0.005	<0.005	<0.010
C2-1	0.010	<0.005	<0.005	<0.010
C2-2	0.010	<0.005	<0.005	<0.010
C3-1	0.005	<0.005	<0.005	<0.010
C3-2	0.010	<0.005	<0.005	<0.010
C4-1	0.015	<0.005	<0.005	<0.010
C4-2	0.015	<0.005	<0.005	<0.010
C5-1	0.01	<0.005	<0.005	<0.010
C5-2	0.01	<0.005	<0.005	<0.010
C6-1	0.02	<0.005	<0.005	<0.010
C6-2	0.02	<0.005	<0.005	<0.010

Table 5.2.2 ANZECC (1999) draft guidelines for interim trigger values for nutrients in estuaries and coastal waters.

Ecosystem type	Total N mg/L	NO_X mg/L	NH_4 mg/L
Estuaries	0.08	0.005	0.02
Coastal & marine	0.35	0.06	0.04

5.3 Phytoplankton - Chlorophyll α

Method

Abundance of phytoplankton in the water column was monitored through measurement of Chlorophyll α, the main light absorbing pigment used in photosynthesis, in the water column. Water samples were collected mid way through the ebbing tide from sheltered shallow waters sites and near the turn of the tide at the deep water sites at the same time as other water quality parameters. Water samples were collected for laboratory analysis of chlorophyll and organic nitrogen from 0.3 m below the surface at shallow water sites and 0.5 m above the seabed at deep water sites. As soon as the water samples were collected they were sealed and placed in an esky on ice to stay chilled until they were processed. The samples were filtered at the shore facility as soon as possible after collection using sterile techniques. 250 ml of sample was drawn through a 0.7 μm glass microfibre filter paper using a Buchner funnel. The filter paper was removed, rolled up and placed in a small glass vial using forceps. This was then chilled and kept on ice until it was analysed for Chlorophyll α at Northern Territory Berrimah Farm Water Laboratories.

Results

Chlorophyll α levels were uniformly low, with 2 μg/L or less recorded at all sites (Table 5.3.1). Levels of chlorophyll α at all sites were 1 μg/L or less, with the exception of the intertidal site F3, where 2 μg/L was recorded. There were no results for C4-2 or C5-1 as these samples were contaminated during transport to the laboratory. There was no noticeable difference in chlorophyll levels from deep and shallow water farm sites.

Summarised results can be found in Table 5.3.1and full laboratory analysis reports in Table 8.5.1.

Interpretation

Chlorophyll α levels found in this survey are at the low end of the range of those recorded during the initial stages of monitoring at Port Hurd (1.1 to 4.6 μg/L) and Channel Island (<2 μg/L) and lower than those recorded at Snake Bay (2 to 4 μg/L), so may be considered typical of mangrove estuaries. The value in this analysis will be in monitoring changes with time and assessing natural variation and gain an understanding of normally prevailing levels in mangrove estuaries.

The results of this study were consistent with but at the low end of results of studies within Darwin Harbour which found values of 1 – 2 μg/L in the main harbour and 1 – 199 μg/L in the tidal creeks (Wrigley *et al*. 1990, Pardovan 1997, Parry and Munksgaard 1999, Pardovan 2002, Sly *et al*. 2002). They were at or below draft ANZECC Interim Trigger Levels (ITLs) of 2 mg/L for slightly to moderately disturbed ecosystems for estuaries (Table 3.3.2, ANZECC 1999).

Table 5.3.1 Chlorophyll α data

Site	Chlorophyll α (µg/L)
F1-1	<1
F1-2	<1
F2-1	<1
F2-2	<1
F3-1	2
F3-2	2
F4-1	<1
F4-2	<1
F5-1	<1
F5-2	<1
F6-1	<1
F6-2	<1
C1-1	<1
C1-2	<1
C2-1	<1
C2-2	<1
C3-1	<1
C3-2	<1
C4-1	<1
C4-2	N.A.
C5-1	N.A.
C5-2	1
C6-1	<1
C6-2	<1

6 Biological Analysis

6.1 Mangrove stand structure and composition

Method

Mangrove stand structure and composition were recorded at three sites around Doug Point in areas considered most likely to be subject to impact by nutrients released from the proposed aquaculture facility. These sites were selected with regard to drogue movements and proximity to the proposed farm, and to cover a range of habitats from small creeks to the side of the main channel. A further consideration was access by boat at mid to low spring tide. For simplicity and to enable results to be better interpreted the shallow water sample sites and corresponding mangrove transects were positioned adjacent to each other. Two sites in similar locations were studied in the control estuary of Madford Inlet.

Methodology used was the Angle Count Cruising (ACC) method as described in Moritz-Zimmermann *et al* (2002) Section 4.4.1 and Brocklehurst and Edmeades (2003). This method involved using an aluminium basal wedge (Bitterlich gauge) to count trees in a 360° sweep from selected sites, in this case along 50 m transects. A gap in the wedge corresponding to a Basal Area Factor (BAF) of 1.0, 0.75, 0.5 or 0.25 was selected that counted 30 to 40 trees per sweep. All trees greater than or equal to the gap were counted, including borderline trees. Trees were identified to species level and their diameter at breast height (DBH), height, status (dead or alive) and condition was recorded. DBH was measured at 1.3m above ground or 20 cm above prop roots as described in Moritz-Zimmermann *et al* (2002). ACC counts are sub-samples compared to full plots but take much less time. The accuracy of ACC method is ± 10% for trees less than 400 mm DBH (Brocklehurst and Edmeades, 1995), so is applicable to this study where all trees were less than 400 mm DBH.

Using the formulae given below, these measurements enabled the calculation of:

- total basal area per ha;
- basal area per species per ha;
- basal area of dead trees per ha;
- dominance of species and dead trees;
- total stem density per ha;
- stem density per species per ha; and
- stem density of dead trees per ha.

For each sweep site:
Basal Area (m^2/ha) = count x BAF
Dominance = (BA of species/ Total BA) x 100
Stem Density (SD/ha) for each individual tree = $BAF/(0.00007854*(DBH)^2)$
SD/ha = the sum of SD of all trees counted

Stand structure and composition was surveyed at four sweep sites along a 50m transect perpendicular to the shore across the various vegetation zones at each site. The distance between sweep sites was such that few individual trees were counted in more than one sweep. Transects were located using GPS, a mangrove tree at the water's edge was marked with a labelled orange cattle tag and the direction of the transect from this tag was recorded. The first sweep site (the start of the transect) was selected so it was sufficiently distant from the water's edge that a full circle of mangroves could be measured to ensure the ACC results would be valid. This resulted in very few of the mangroves at the water's

edge being included in the count. At each sweep site each tree counted was identified to species level where possible and measured for diameter, height, status and condition. Only trees counted using the ACC method were identified and assessed. Five trees at each site were selected as typical of the site and tagged for future measurement. The distance of subsequent sweep sites was recorded using a 50m tape.

Results

Mangrove stand structure in the Doug Point and Madford Inlet study areas was dominated by *Rhizophora* sp. and *Ceriops* sp. (Table 6.1.2). Generally *Rhizophora* sp. dominated the sites nearest the water's edge and *Ceriops* sp. dominated the inland sites. The Rhizophora species were either *Rhizophora stylosa* or *Rhizophora apiculata*, the former of which has brown spots on its leaves and the later does not. However the two interbreed to form a hybrid, and various trees had spots on some leaves and not on others, apparently identical trees had spots on one but not the other and most trees were too tall to inspect their leaves so a distinction could not be made. With *Ceriops sp*., species can only be differentiated by their flowers and fruit. Since very few Ceriops were in flower or fruit no distinction could be made between these species either.

Another species occurring in significant numbers was *Avicennia marina* which was the second most dominant species at sites at F1 and F3. *Bruguiera exaristata* and *Bruguiera parviflora* were also among the dominating species at two farm and two control sites.

Mangrove condition was generally healthy with less than 10% dead trees per hectare at all but five sites. The high percentage of dead trees at C2-2 (38.4%) was the result of one small dead Ceriops standing adjacent to the measuring site. The calculations assume this to be typical of the stand structure of the site, i.e. that there is a dead small mangrove every few square metres.

Low numbers of trees with crown damage or dead branches were recorded except at F2-3, F2-4 and F3-1 where about half the trees surveyed had some dead branches. At several sites with older trees of *Rhizophora* sp. or *Avicennia marina* many of the trees were leaning to some degree but healthy.

A summary of results is given in Table 6.1.1. Field records are presented in Table 8.6.1 to Table 8.6.20.

Interpretation

Mangrove communities assessed in the vicinity of Doug Point and Madford Inlet were typical for similar mangrove estuaries (see Brocklehurst and Edmeades, 2003). They were composed mainly of *Rhizophora* sp. and *Ceriops* sp. and were healthy and vibrant. The prevalence of dead branches on transect F2 was associated with shorter than normal Rhizophora forest with the canopy height being about 4m compared to the more common 10 to 14m. This presumably indicates these trees are stressed by the conditions on Indian Island where shallow soil overlies rock. Although additional analysis can be done using this data its main use is to provide a baseline for monitoring future change.

Table 6.1.1 Mangrove stand structure and composition using ACC method at control and farm sites.

Transect	Distance m	Bearing	Date	TBA m2/ha	BA Sp1 m2/ha	BA Sp2 m2/ha	BA Dead m2/ha	Dom Sp1 %	Dom Sp2 %	Dom Dead %	TSD SD/ha	SD Sp1 SD/ha	SD Sp2 SD/ha	SD Dead SD/ha	Ratio Dead %	Mean Ht m
F1-1	0	330	3/10/2005	26.3	13.5	9.0	1.5	51.4	34.3	5.7	47910	8237	39599	6032	12.6	5.9
F1-2	10	31	3/10/2005	17.0	13.0	0.5	3.0	76.5	2.9	17.6	30412	26342	2.5	4015	13.2	4.9
F1-3	20	310	3/10/2005	22.5	20.0	1.0	1.5	88.9	4.4	6.7	27340	26410	9	921	3.4	4.9
F1-4	31	290	3/10/2005	27.0	23.0	1.5	2.0	85.2	5.6	7.4	72059	58262	212	13562	18.8	5.0
F2-1	0	50	3/10/2005	24.0	21.8	1.5	0.8	90.6	6.3	3.1	5534	5453	14	66	1.2	5.3
F2-2	14	60	3/10/2005	18.0	16.0	1.5	0.5	88.9	8.3	2.8	12463	10585	1778	99	0.8	3.8
F2-3	28	50	3/10/2005	9.0	10.3	0.0	0.3	113.9	0.0	2.8	3714	3679	0	35	0.9	3.7
F2-4	43	80	3/10/2005	20.5	16.0	1.5	2.0	78.0	7.3	9.8	19612	14789	3333	1031	5.3	3.3
F3-1	0	30	3/10/2005	31.5	22.5	6.0	0.0	71.4	19.0	0.0	9244	2961	2194	0	0.0	9.4
F3-2	14	60	3/10/2005	19.0	12.5	3.0	0.5	65.8	15.8	2.6	14078	12047	289	64	0.5	6.9
F3-3		40	3/10/2005	22.5	10.0	8.0	1.0	44.4	35.6	4.4	15035	13829	607	62	0.4	8.4
F3-4	42	50	3/10/2005	30.0	27.8	0.8	1.5	92.5	2.5	5.0	74712	63740	132	10839	14.5	4.5
C1-1	0	310	4/10/2005	27.0	17.3	4.5	0.8	63.9	16.7	2.8	19181	1844	17038	12	0.1	8.7
C1-2	8	320	4/10/2005	27.0	15.8	6.0	0.0	58.3	22.2	0.0	91941	60250	875	0	0.0	4.9
C1-3	15	310	4/10/2005	19.0	8.0	6.5	0.5	42.1	34.2	2.6	27184	14557	1457	5261	19.4	6.1
C1-4	29	310	4/10/2005	39.0	22.0	863.3	0.0	56.4	2213.5	0.0	7963	2309	863	0	0.0	11.0
C2-1	0	100	5/10/2005	32.3	30.0	0.0	2.3	93.0	0.0	7.0	7598	7262	0	336	4.4	6.3
C2-2	14	120	5/10/2005	23.3	18.8	2.3	2.3	80.6	9.7	9.7	34738	16379	5032	13327	38.4	4.1
C2-3	23	140	5/10/2005	24.8	15.8	7.5	2.3	63.6	30.3	9.1	47776	19497	24543	3736	7.8	3.8
C2-4	38	140	5/10/2005	24.0	17.3	5.3	0.8	71.9	21.9	3.1	16323	5300	10318	698	4.3	6.9

Table 6.1.2 Dominant species at control and farm sites.

Site	Dom sp. 1	Dom sp.2	Site	Dom sp. 1	Dom sp.2	Site	Dom sp. 1	Dom sp.2
F1-1	Rhizophora sp.	Ceriops sp.	F3-1	Rhizophora sp.	Avacennia marina	C1-1	Rhizophora sp.	Bruguiera exaristata
F1-2	Ceriops sp.	Avacennia marina	F3-2	Ceriops sp.	Rhizophora sp.	C1-2	Bruguiera parviflora	Rhizophora sp.
F1-3	Ceriops sp.	Avacennia marina	F3-3	Ceriops sp.	Rhizophora sp.	C1-3	Ceriops sp.	Rhizophora sp.
F1-4	Ceriops sp.	Bruguiera exaristata	F3-4	Ceriops sp.	Bruguiera parviflora	C1-4	Rhizophora sp.	Excoecaria agallocha
F2-1	Rhizophora sp.	Sonneratia alba				C2-1	Rhizophora sp.	-
F2-2	Rhizophora sp.	Ceriops sp.				C2-2	Rhizophora sp.	Ceriops sp.
F2-3	Rhizophora sp.	-				C2-3	Rhizophora sp.	Ceriops sp.
F2-4	Rhizophora sp.	Ceriops sp.				C2-4	Rhizophora sp.	Ceriops sp.

6.2 Epiphytic algal growth

Method

Epiphytic algal growth on mangrove roots was assessed qualitatively using digital camera photographs taken from set positions at each of the intertidal sites. Two photos were taken at three locations 20 m apart at each intertidal site, one from about 5 m distant showing general extent of growth and one from about 1 m showing root assemblages in detail. Both were taken when the roots were sufficiently exposed and light conditions adequate to enable algal growth to be clearly seen. Comparison of a time series of photographs will show any significant change. Comparison with photos of control sites will show differences from wider seasonal changes.

Results

Photos taken at the shallow water sample sites showed no visible epiphytic algal growth. Additionally, close inspection of mangrove roots and intertidal structures at those sites found no visible algal growth.

Two representative photos from each mangrove monitoring site are presented on the following pages.

Interpretation

All intertidal mangrove root and rhizome assemblages appear in good health with regard to epiphytic algal growth, indicating waterborne nutrient levels are too low for the establishment of epiphytic algal growth.

Figure 6-1 Mangrove root assemblages at site F1

Figure 6-2 Mangrove root assemblages at site F2

Figure 6-3 Mangrove root assemblages at site F3