Appendix E

Channel Island 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

CHANNEL ISLAND, DARWIN HARBOUR

AUGUST 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 Channel Island in Darwin Harbour, 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 Channel Island. The adjacent and estuary of Little West Arm, which discharges into Darwin Harbour just over 6 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 Channel Island 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 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 last week of August 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. Six sample sites were selected in the vicinity of Channel Island at locations expected to be subject to heaviest influence from fish farm nutrients. Six similar sites were selected in Little West Arm as control sites, corresponding as closely as possible to the monitoring sites at Channel Island. 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.

The drogue survey indicated that water moving through the farm on the flood tide will carry farm released nutrients both out into the main channel and up into Jones Creek. On a single flood tide cycle nutrients will be washed more than 3 km up Jones Creek and eventually be carried into the mangrove flats lining the creek and its tributaries. It can be expected that the waters of Jones Creek will wash back and forth past the farm with some potential to accumulate nutrients during the dry season. However the waters which flow back to the main channel on the flood can be expected to mix with the larger volume of water there and become dispersed. Thus the sites where nutrients may be expected to accumulate in the incoming tide are within Jones Creek.

Nutrients carried on the ebb tide will be primarily washed through the back channel in which the farm site is to be situated and out into the main channel. A significant portion of those washed into the main channel will not return on the subsequent tide but be dispersed in the main channel. On slower moving ebb tides, particularly when a stiff sea breeze is blowing, floating and dissolved nutrients will also be cried over the mud flats to the north-east of the farm site.

Maps showing the location of Channel Island 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 representing material currently being deposited in the slower flowing depositional zones of the estuary. Black streaking and mottling indicated moderately high organic loading and low permeability to oxygen. The coarser sediments at C5 and C6 are indicative of rapid water flow washing out fine sediments, as expected in the faster flowing channel sites. Coarse material in samples from F5 and F6 seems to have been disguised by the muddier fraction. Numerous burrows present indicate prolific animal life, as was also found in the benthic grab samples. 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 values at 0 cm and 1 cm were typically above 100 mV and widely variable due to spatial variation of sediment composition and animal bioturbation activity. The redox potential at 4 cm show sediments at many of the study sites to be poorly to moderately oxygenated indicating that reduction of organic matter is proceeding only slightly lower than penetration of oxygen through the sediments. This is typical of impermeable sediments subjected to moderate organic loading. Redox values at the intertidal control sites C2 and C3 were atypically high indicating 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.

The normal trend to coarser sediments with greater water movement is masked here by the occurrence of decayed plant material in the sediments at the sheltered backwater sites and consolidated clay at the deep site, C6. The preponderance of fines reflects this trend overall, indicating a lack of high energy water movement such as swell or wave action. The occurrence of shell grit and coarse sand in sediments from some deep-water sites also reflects this trend; however there is no clear division between intertidal sheltered sites and deep water mid-channel sites on particle size analysis alone. 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.

Water in both estuaries was warm with a salinity close to 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 (NOX) levels were consistent with those found in earlier studies (Pardovan 1997, Parry and Munksgaard 1999, Pardovan 2002). Ammonia (TAN) levels were also consistent with the exception that the 35 mg/L concentrations were approaching the highest wet season level of 40 mg/L measured in Ludmiller Creek (Parry and Munksgaard 1999). NOX and TAN levels were above ANZECC draft guidelines for Interim Trigger Levels (ITL) for nutrients in slightly to moderately disturbed estuaries at several sites at both farm and control sites but below ITL for coastal waters at all sites.

Chlorophyll α levels found in this study were consistent with results of earlier studies within Darwin Harbour (Wrigley *et al*. 1990, Pardovan 1997, Parry and Munksgaard 1999, Pardovan 2002, Sly *et al*. 2002). They were equal to or below draft ANZECC Interim Trigger Levels (ITLs) of 2 mg/L for slightly to moderately disturbed ecosystems forestuaries (Table 3.3.2, ANZECC 1999). The results are within the range of those recorded during the initial stages of monitoring at Port Hurd (<2 μg/L) and Doug Point (<2 μg/L) and lower than those recorded at Snake Bay (generally 3 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.

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 Channel Island and Little West Arm were typical for similar Darwin Harbour (see Brocklehurst and Edmeades, 2003). They were composed mainly of *Rhizophora* sp. and *Ceriops* sp. and were healthy and vibrant.

Benthic infaunal analysis found no obvious signs of existing impacts on macrobenthic communities at Channel Island or the adjacent Little West Arm. Some habitat-related variation was observed, with intertidal communities distinct from the majority of the subtidal communities. There were no consistent trends in biodiversity or dominance on the basis of habitat 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 Channel Island 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 potential impact.

2 Operational Summary

2.1 Operational details

Contractor:	Aquenal Pty Ltd ABN 86 081 689 910 G.P.O. Box 828 Hobart Tasmania 7001 Phone: 03 6234 3403 Fax: 03 6234 3539 E-mail: admin@aquenal.com.au
Aquenal Personnel:	Derek Shields, Jeremy Dudding
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: 2nd-3rd August 2005 Sampling: 21st-23rd & 30th August 2005
Weather:	Hot, with clear skies, calm mornings followed by afternoon sea breezes from the 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. The distribution of reef communities is such that it is difficult to find suitable control sites that are not being influenced by other potentially modifying pressures. Given these factors it will be expensive and time consuming to do sufficient background studies 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. However there are no known areas of seagrass in the vicinity of a proposed farm. Additionally seagrass beds in the entrances to similar muddy mangrove estuaries are typically sparse and patchy in nature and only visible to a diver or camera during neap tides at certain times of year. 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. Also dugong are rarely sighted in the Channel Island vicinity.

Crocodile populations

It is possible to monitor crocodile population density using for example a system of timed observations. However the crocodile population in the vicinity of Darwin is presently undergoing rapid change so it would be difficult to differentiate effects of the farm from this. Additionally there is a widespread trapping program in the vicinity which will have a sporadic and confusing impact on survey results.

Thus it was decided that the purpose of this survey 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 were released 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, Little West Arm, 6 km to the west of Channel Island (Figure 2-1) was also sampled. Sample sites were labelled F1 to F6 at Channel Island, with F1 to F3 being intertidal sites in small creeks or on mud flats, 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. Sample sites in Little West Arm were selected to reflect as closely as possible, based on visual assessment, sample sites at Channel Island (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 Channel Island estuary and C1 and C2 for the control transects in Little West Arm.

2.3 Maps

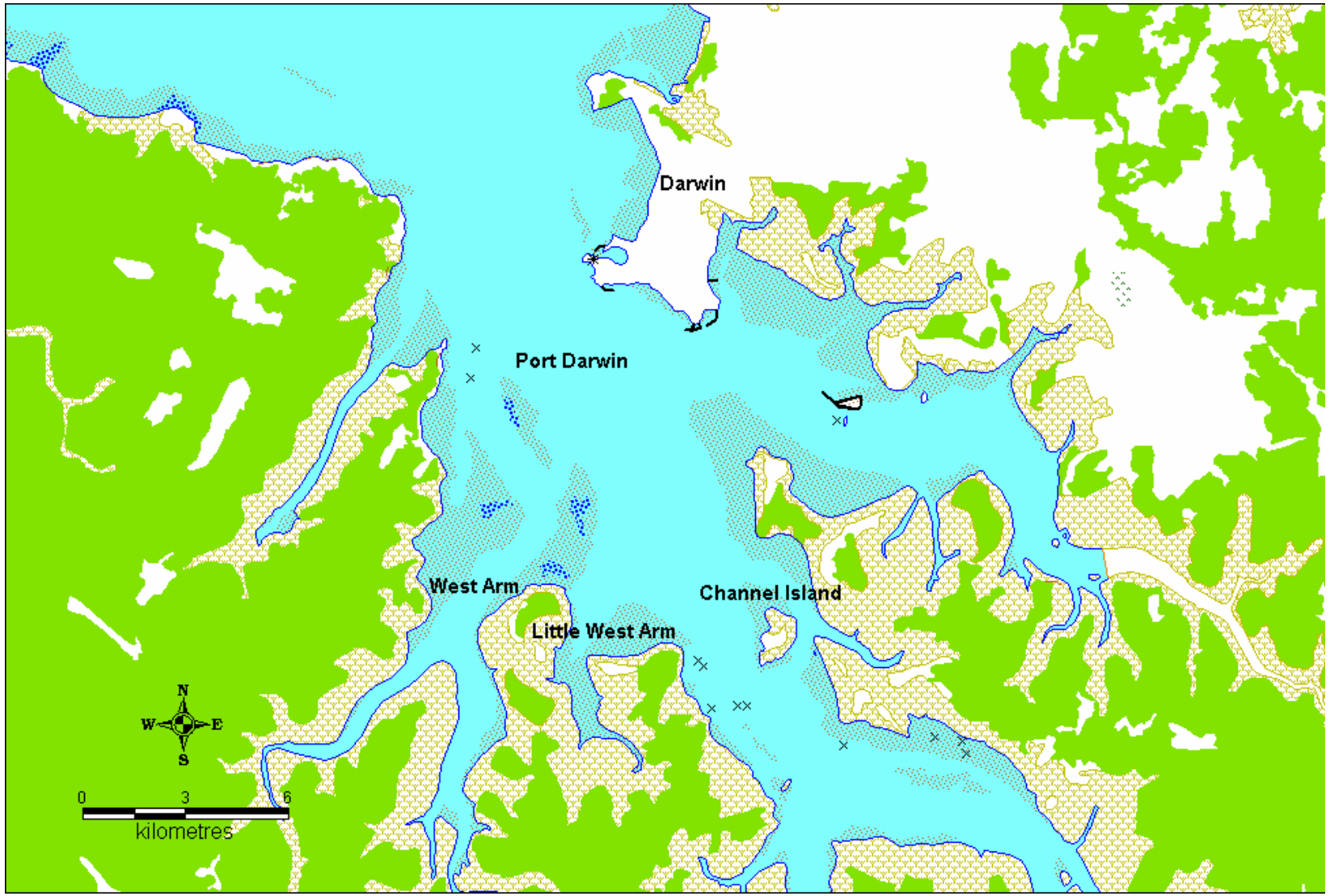

Figure 2-1 Broad-scale map of the study area in Port Darwin. Refer to Figure 2-2 for detailed maps of survey sites in the vicinity of Channel Island Little West Arm respectively.

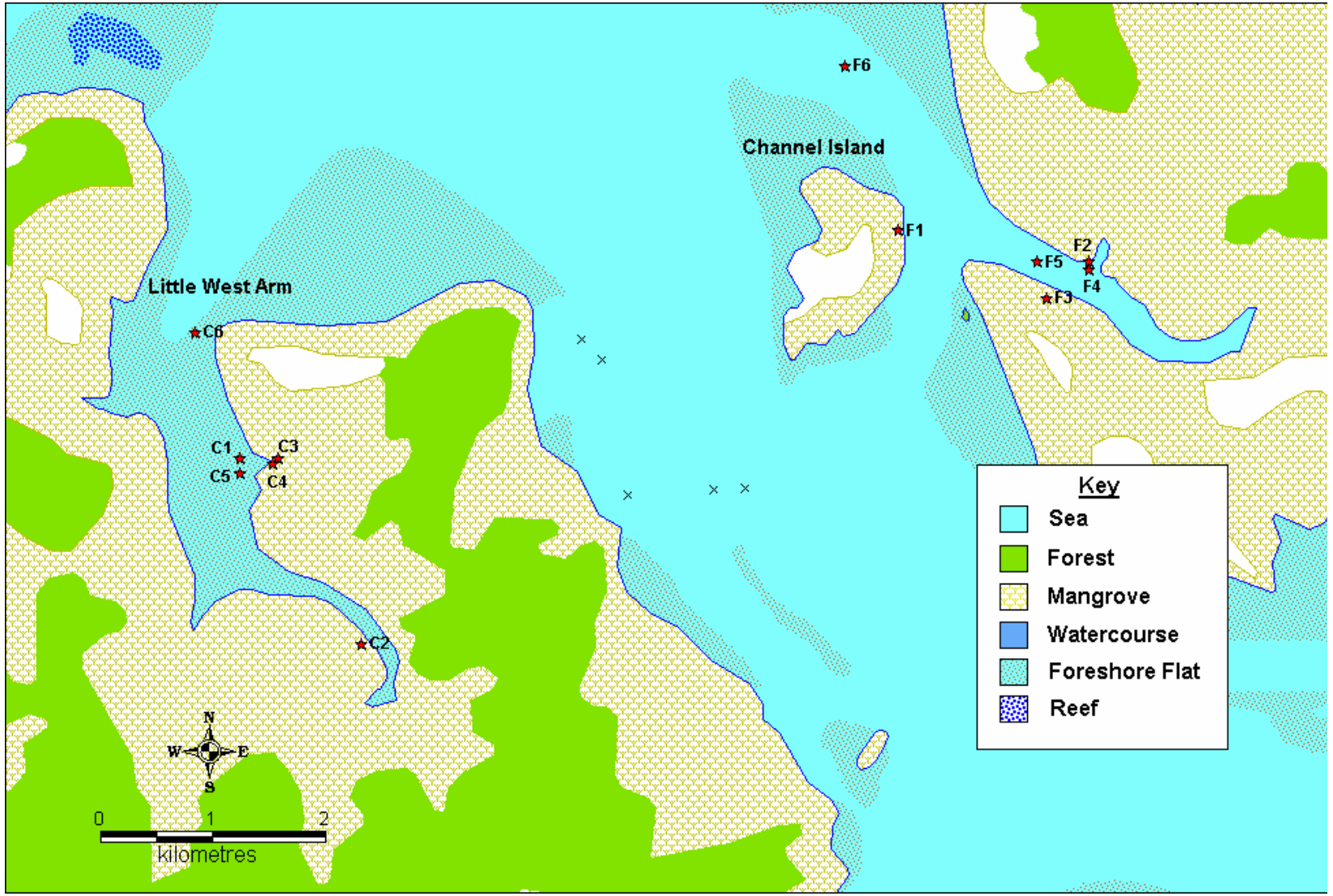

Figure 2-2 Survey map showing farm and control sample sites.

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 Channel Island during the spring tides of the 2nd and 3rd 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. All drogues were pulled at 18:00 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

The 1m drogues released on the flood tide moved up the estuary to the confluence with Jones Creek. Here they divided equally, with half heading southwards under the bridge and back into the main channel, and half travelling south-eastwards up Jones Creek. Both drogues travelling up Jones Creek were eventually washed into the mangroves on the southern bank. On the ebb tide the early released drogues followed the route of the back channel out into the main channel with the first released drogue, 1.1, travelling back past the western side of Channel Island on the subsequent flood tide. The 1m drogue released late in the ebb after the sea breeze was up was washed into the mud flats to the north-east of the farm. A map showing the logged positions of the 1m drogues is presented in Figure 3-1.

The 5m drogues moved similarly to the 1m drogues but those heading up Jones Creek on the flood became grounded on a mud bank at its entrance. The first 5m drogue released on the ebb became grounded several times but the second, 5.2, travelled out into the main channel and, like drogue 1.1, was carried back past the western side of Channel Island on the subsequent flood tide. A map showing the logged positions of the 5m drogues is presented in Figure 3-2.

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.

In this case the drogues indicated that water moving through the farm on the flood tide will carry farm released nutrients both out into the main channel and up into Jones Creek.

On a single flood tide cycle nutrients will be washed more than 3 km up Jones Creek and eventually be carried into the mangrove flats lining the creek and its tributaries. It can be expected that the waters of Jones Creek will wash back and forth past the farm with some potential to accumulate nutrients during the dry season. However the waters which flow back to the main channel on the flood can be expected to mix with the larger volume of water there and become dispersed. Thus the sites where nutrients may be expected to accumulate in the incoming tide are within Jones Creek.

Nutrients carried on the ebb tide will be primarily washed through the back channel in which the farm site is situated and out into the main channel. A significant portion of those washed into the main channel will not return on the subsequent tide but be dispersed in the main channel. On slower moving ebb tides, particularly when a stiff sea breeze is blowing, floating and dissolved nutrients will also be cried over the mud flats to the north-east of the farm site.

Two shallow water sample and mangrove monitoring sites (F1 and F2) and two deep water sample sites (F4 and F5) were selected in Jones Creek as sites most likely to show possible nutrient related impact. One shallow water and mangrove monitoring site (F3) was selected on Channel Island adjacent to the farm site for its proximity to the farm. The wide mud flats to the north-east of the farm prevented access to suitable shallow water sites in that area. A third deep water site (F6) was selected in the back water channel north of the farm site as a likely location for deposition of sedimentary nutrients on the outgoing tide.

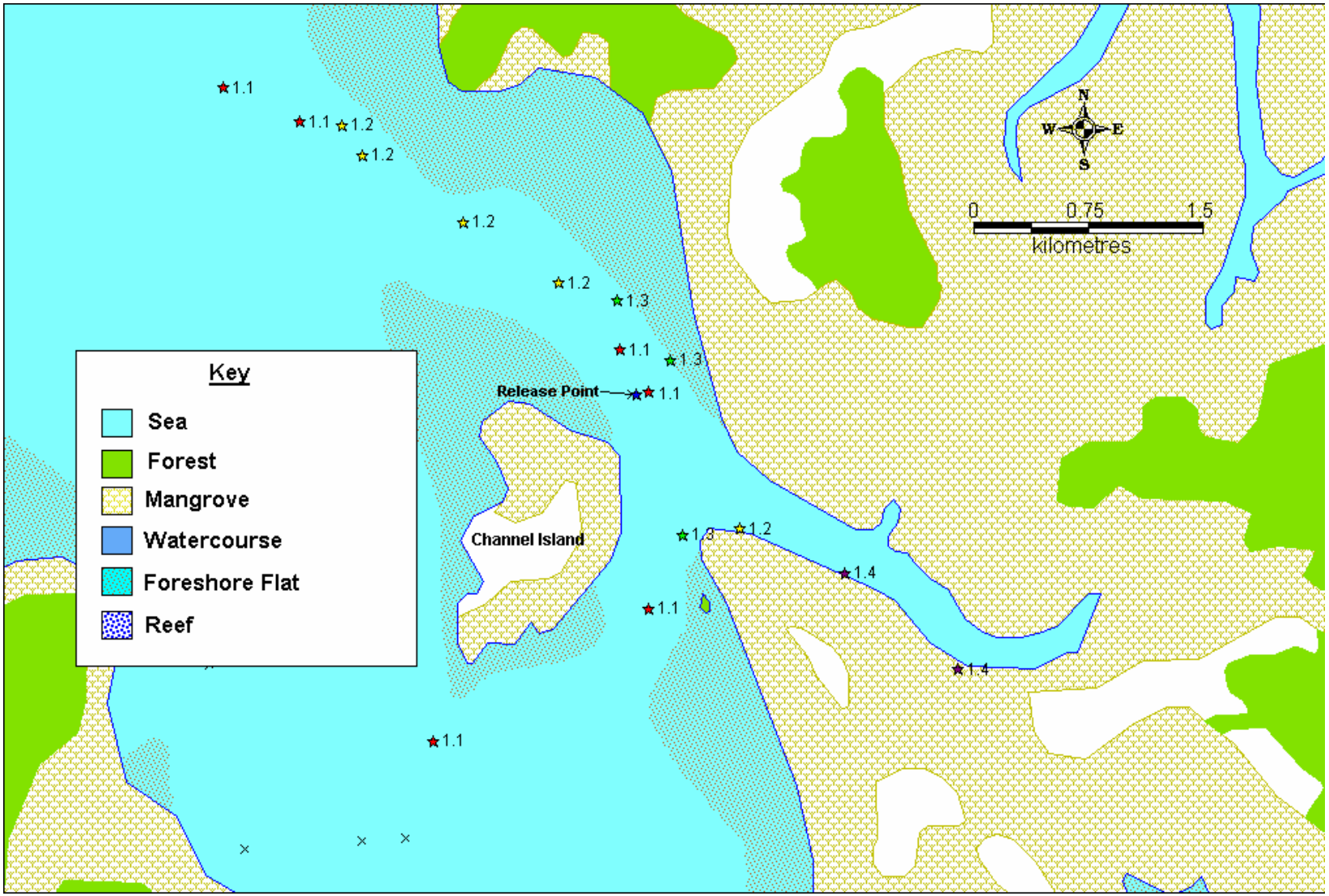

Figure 3-1 One metre drogue survey showing positions of drogues each two hours during one spring tide cycle.

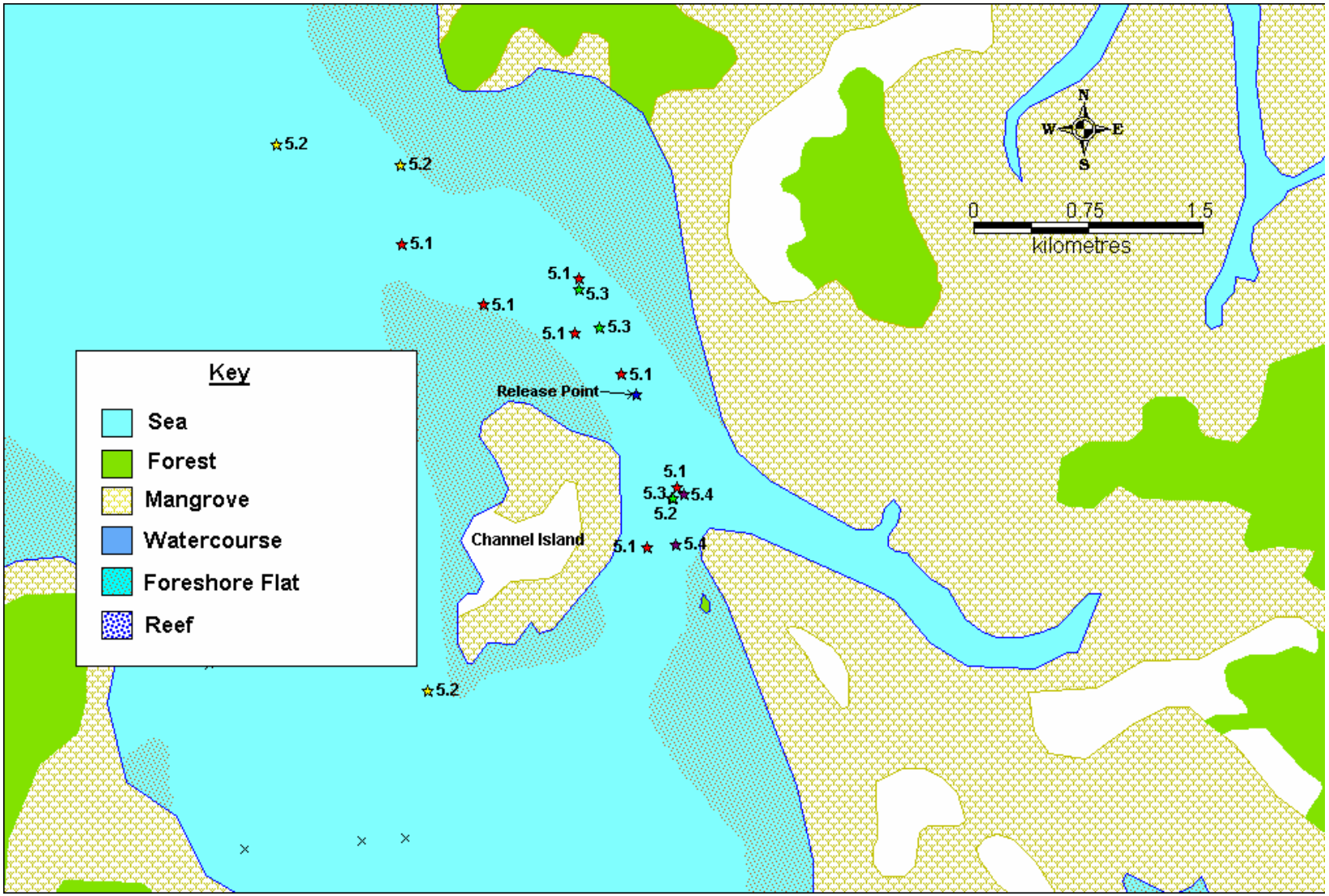

Figure 3-2 Five metre drogue survey showing positions of drogues each two hours during one spring tide cycle.

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 75-195 mm, although most exceeded 100 mm, with shorter cores taken from hard, consolidated sediments. Sediments were predominately soft, brown-grey mud, with a number of sites containing organic material and/or orange clay (Table 4.1.1). Most cores displayed some sediment stratification, with the bottom layer of sediment finer and generally lacking in organic material. The cores from the deep-water control sites C5 and C6 contained coarse sand and shell grit in the top 20-70 mm of sediment (Table 4.1.1). Many of the sites showed some black streaks or mottling. Animal burrows were evident in most cores, although none were observed at site F4. No plant life was observed in any of the cores. There was no gas or strong smell 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 C5 and C6 are indicative of rapid water flow washing out fine sediments, as expected in the faster flowing channel sites. The coarse material in samples from F5 and F6 seems to have been disguised by the muddier fraction. The numerous burrows present indicate prolific animal life, as was also found in the benthic grab samples. 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, spk=speckled, blk=black org=organic, matt=matter, orge=orange, cl=clay, sg=shell grit, crs=coarse

Core No.	Length mm	Colour 1	Depth 1 mm	Colour 2	Plants	Animals	Gas Bubbles	Smell
F1-1	110	brn gy md spk blk org matt			nil	sev burr to 40mm	nil	nil
F1-2	120	brn gy md spk blk org matt			nil	sev burr to 60mm	nil	nil
F1-3	120	brn gy md spk blk org matt			nil	nil	nil	nil
F2-1	100	brn gy md			nil	nil	nil	nil
F2-2	120	brn gy md spk orge cl			nil	sev burr to 80mm	nil	nil
F2-3	110	brn gy md spk org matt			nil	nil	nil	nil
F3-1	135	gy brn stk org mud	100	gy md	nil	sev burr to 135mm	nil	nil
F3-2	100	gy brn mott org mud			nil	sev burr to 100mm	nil	nil
F3-3	110	gy brn mott org mud	80	gy md	nil	nil	nil	nil
F4-1	120	bn md/cl	20	bn gy md stk blk	nil	nil	nil	nil
F4-2	120	bn gy md spk orge cl			nil	nil	nil	nil
F4-3	140	bn gy md stk orge cl			nil	nil	nil	nil
F5-1	190	brn md spk org matt	80	brn md	nil	sev burr to 80mm	nil	nil
F5-2	190	brn md spk org matt	100	brn md	nil	few burr to 100mm	nil	nil
F5-3	195	brn md spk org matt	60	brn md	nil	nil	nil	nil
F6-1	100	brn md stk gy			nil	nil	nil	nil
F6-2	110	brn md & sg	20	brn md stk gy	nil	nil	nil	nil
F6-3	100	brn md & sg	30	brn md stk gy	nil	few burr to 40mm	nil	nil
C1-1	100	bn gy sft md spk blk org matt	40	gy brn mott sft md spk blk org matt	nil	sev burr to 100mm	nil	nil
C1-2	90	bn gy sft md spk blk org matt	40	gy brn mott sft md spk blk org matt	nil	sev burr to 90mm	nil	nil
C1-3	110	bn gy sft md spk blk org matt	50	gy brn mott sft md spk blk org matt	nil	sev burr to 110mm	nil	nil
C2-1	180	brn gy md spk blk org matt & stk orge cl	60	brn gy md	nil	sev burr to 60mm	nil	nil
C2-2	170	brn gy md spk blk org matt & stk orge cl	80	brn gy md	nil	sev burr to 60mm	nil	nil
C2-3	180	brn gy md spk blk org matt & stk orge cl	60	brn gy md	nil	sev burr to 40mm	nil	nil
C3-1	160	brn gy md			nil	sev burr to 160mm	nil	nil
C3-2	110	brn gy md			nil	sev burr to 110mm	nil	nil
C3-3	180	brn gy md			nil	sev burr to 180mm	nil	nil
C4-1	75	gy brn md	5	gy sdy md stk blk (lt)	nil	sev burr to 10mm	nil	nil
C4-2	140	gy brn md	50	gy sdy md stk blk (lt)	nil	sev burr to 70mm	nil	nil
C4-3	115	gy brn md	20	gy sdy md stk blk (lt)	nil	sev burr to 115mm	nil	nil
C5-1	120	gy brn spk mud & sg	40	gy stk blk md	nil	sev burr to 40mm	nil	nil
C5-2	120	gy brn spk mud & sg	70	gy stk blk md	nil	sev burr to 70mm	nil	nil
C5-3	110	gy brn spk mud & sg	40	gy stk blk md	nil	sev burr to 40mm	nil	nil
C6-1	76	orge brn spk crs sd	30	gy brn md	nil	nil	nil	nil
C6-2	85	orge brn spk crs sd & gy md	30	gy brn md	nil	sev burr to 85mm	nil	nil
C6-3	90	gy brn orge spk mdy sd	20	gy brn spk mdy sd	nil	sev burr to 90mm	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 covered a considerable range; from 73 mV at F4 to 407 mV at C2 (Table 4.2.1). All of the 4 cm values were above 0 mV, indicating that none of the sediments sampled were anoxic. The standard deviations for some of the sites were high, particularly at C1, C3 and C5 (Table 4.2.1, Figure 4-2), caused by one sample returning significantly different results to the other replicates (Table 8.2.1). All values at C2 and C3 were unusually high for muddy sediments.

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 many 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. This is typical of impermeable sediments subjected to moderate organic loading. Redox values at the intertidal control sites C2 and C3 were atypically high since these sites were dominated by fine silt, with more than 80% 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	223	141	58
	Standard Deviation	36	31	39
F2	Corrected Mean	188	98	65
	Standard Deviation	67	66	51
F3	Corrected Mean	156	125	129
	Standard Deviation	24	18	15
F4	Corrected Mean	73	53	25
	Standard Deviation	14	13	16
F5	Corrected Mean	136	129	113
	Standard Deviation	89	91	85
F6	Corrected Mean	105	51	20
	Standard Deviation	83	38	22
C1	Corrected Mean	241	173	140
	Standard Deviation	147	89	56
C2	Corrected Mean	407	387	382
	Standard Deviation	10	36	36
C3	Corrected Mean	396	274	256
	Standard Deviation	60	154	129
C4	Corrected Mean	133	81	14
	Standard Deviation	40	26	19
C5	Corrected Mean	187	89	57
	Standard Deviation	112	52	44
C6	Corrected Mean	313	277	121
	Standard Deviation	67	26	73

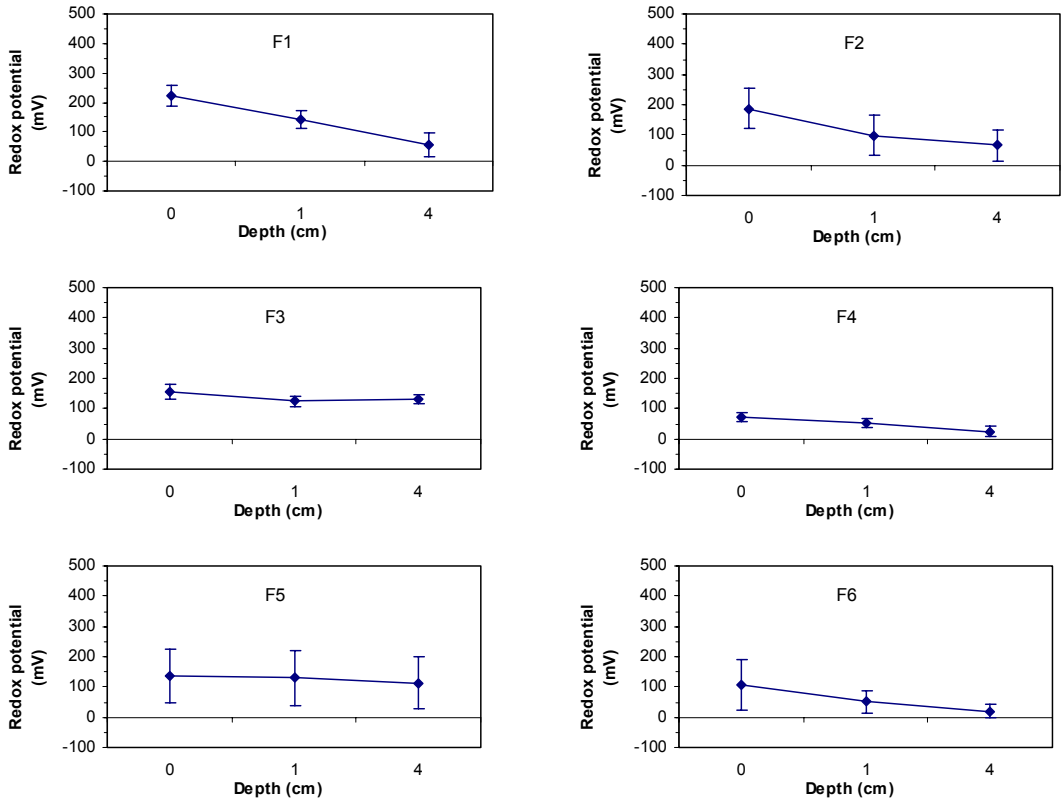

Figure 4-1 Redox potential in the top 4 cm of sediment cores at farm sites.

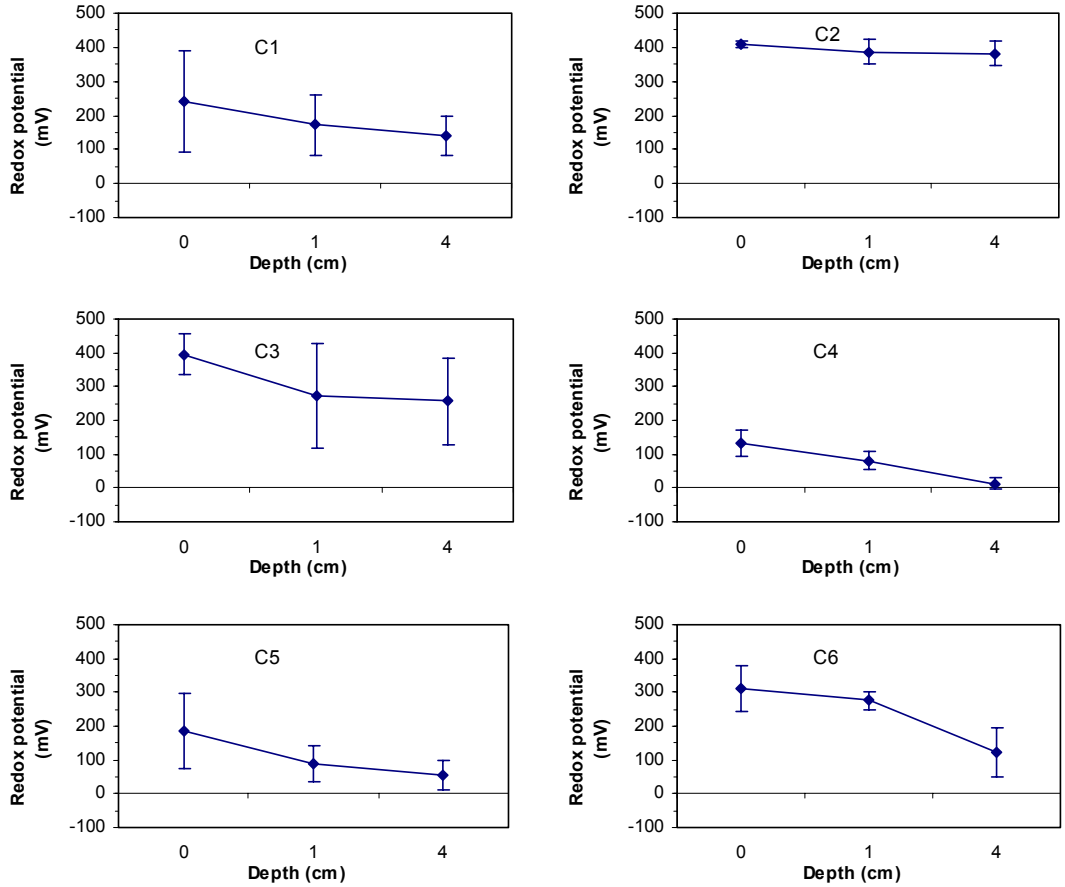

Figure 4-2 Redox potential in the top 4 cm of sediment cores at control sites.

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

There is a clear trend for the intertidal sites to contain more fines than the deep-water sites, although F4 and C4 were much finer than the other deep-water sites (Figure 4-3 and Figure 4-4). Sediments at all intertidal sites comprised more than 58% fines (material less than 63 μm, being silt, clay and organic matter), were silty in nature, and contained quantities of plant material (Table 4.3.1, Table 8.3.1). Sediments at C2 and C3 were the finest with only 16% and 18% material coarser than 63 μm, a proportion of which consisted of plant material, masking the true nature of the sediments and the correlation of sediment particle size with water speed. Sediments from all deep-water sites, except C4, contained coarse material consisting of shell grit and pebbles (Table 4.3.1). Sediments from site C6 also contained consolidated clay.

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

Site	Description of sediment remaining in sieves
F1	Very fine sand, mud and plant material
F2	Mud, silt and plant material
F3	Mud, silt and plant material
F4	Pebbles, fine clay, silt and plant material
F5	Pebbles, some shellgrit, sandy silt and plant material
F6	Pebbles, shellgrit, silt and plant material
C1	Silt and plant material
C2	Silt and plant material
C3	Silt and fine plant material
C4	Silt and fine plant material
C5	Pebbles, shellgrit, silt and coarse plant material
C6	Coarse shellgrit, sand, clay and fine plant material

Interpretation

The normal trend to coarser sediments with greater water movement is masked here by the occurrence of decayed plant material in the sediments at the sheltered backwater sites

and consolidated clay at the deep site, C6. 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 reflects this trend overall, indicating a lack of high energy water movement such as swell or wave action. The occurrence of shell grit and coarse sand in sediments from some deep-water sites also reflects this trend; however there is no clear division between intertidal sheltered sites and deep water mid-channel sites on particle size analysis alone. 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.

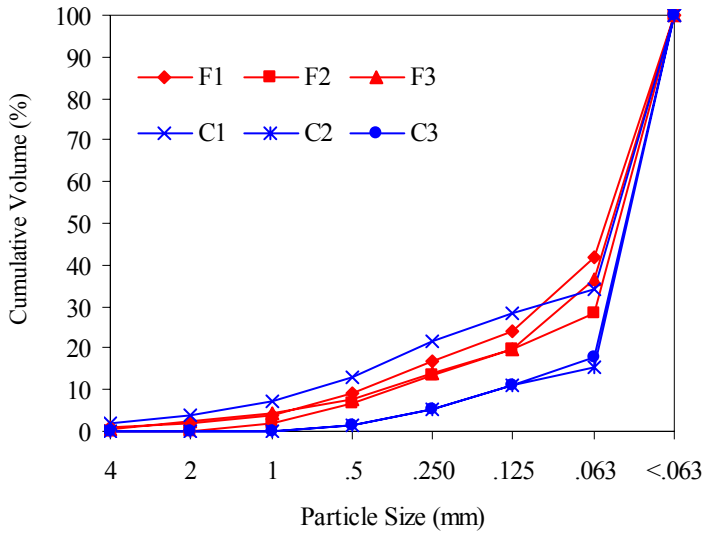

Figure 4-3 Particle size analysis of the top 100 mm of sediment cores from the intertidal farm and control sites.

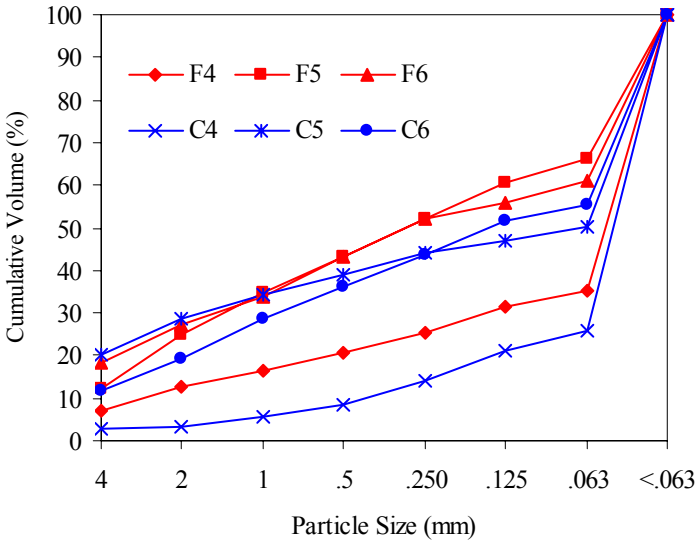

Figure 4-4 Particle size analysis of the top 100 mm of sediment cores from the subtidal farm and control sites.

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. The salinity probe was found to be reading 2.1 ppt low so results for this report were corrected accordingly.

Results

The temperature of surface waters at all sites was very consistent, with temperature ranging from 26.5 – 27.0 °C, while salinity varied between 34.8 and 36.2 ppt (Figure 5-1, Table 5.1.1 and Table 8.4.1). The pH of the water at the farm sites (F1-F6) was considerably lower than the control sites, except C1 (Figure 5-1 and Table 5.1.1), although no other parameters measured followed this pattern. The recorded dissolved oxygen (DO) was approaching or above 80% at all sites except C4 and C5 (with a mean DO of 70 and 67.6% respectively). 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 close to that of seawater (35 ppt) indicating there is minimal, fresh water input. 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	26.8 ± 0.0	34.8 ± 0.0	83.5 ± 0.1	5.5 ± 0.1	6.4 ± 0.0
F2	26.6 ± 0.0	35.1 ± 0.0	78.5 ± 1.5	5.2 ± 0.1	6.4 ± 0.0
F3	26.5 ± 0.0	33.1 ± 0.0	81.0 ± 0.3	5.4 ± 0.0	6.5 ± 0.0
F4	26.6 ± 0.0	36.9 ± 0.1	81.3 ± 2.9	5.4 ± 0.2	6.0 ± 0.2
F5	26.6 ± 0.0	35.2 ± 0.0	84.4 ± 0.2	5.6 ± 0.0	6.0 ± 0.0
F6	26.5 ± 0.0	34.8 ± 0.0	81.8 ± 0.1	5.5 ± 0.0	6.3 ± 0.0
C1	26.9 ± 0.2	35.5 ± 0.1	83.3 ± 2.4	5.5 ± 0.2	6.2 ± 0.2
C2	27.0 ± 0.0	36.2 ± 0.1	79.6 ± 0.8	5.3 ± 0.1	7.4 ± 0.0
C3	27.0 ± 0.1	35.6 ± 0.0	80.8 ± 4.3	5.3 ± 0.3	7.5 ± 0.0
C4	26.7 ± 0.0	35.4 ± 0.0	70.0 ± 2.2	4.7 ± 0.2	7.6 ± 0.0
C5	26.9 ± 0.0	35.5 ± 0.0	67.6 ± 0.3	4.5 ± 0.0	7.6 ± 0.0
C6	27.0 ± 0.0	35.1 ± 0.0	78.5 ± 0.2	5.2 ± 0.0	7.8 ± 0.0

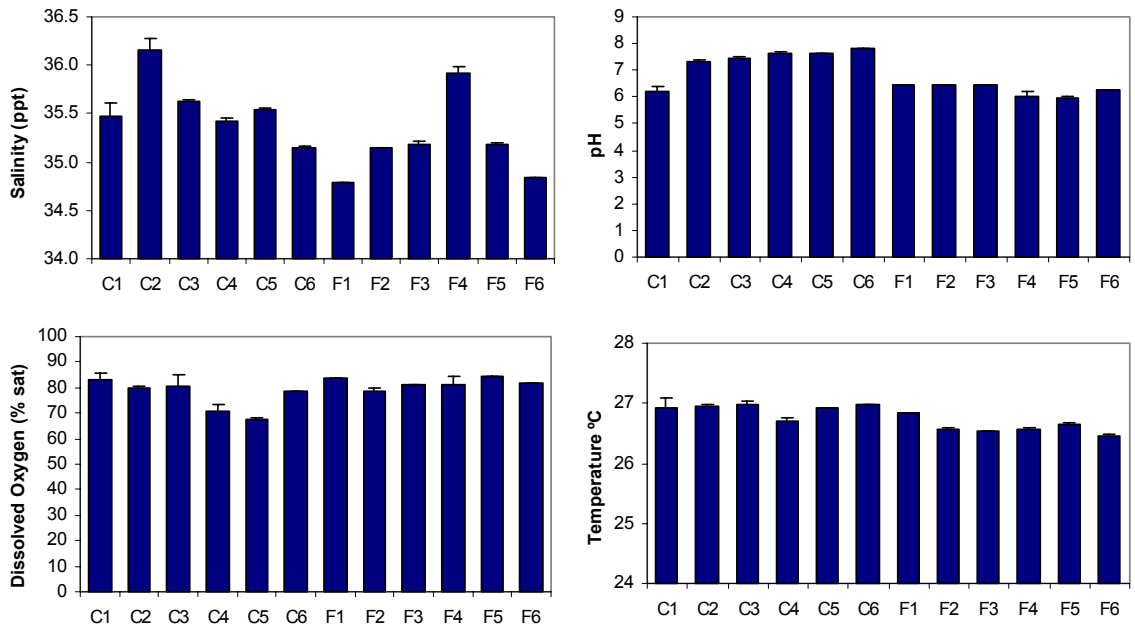

Figure 5-1 Physico-chemical data from surface waters at intertidal and deep waters at subtidal farm and control sites.

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

NOX varied from 0.005 to 0.020 mg/L with the control sites being slightly lower than the farm sites. However given the near detection threshold levels and the rounding to the nearest 0.005 mg/L little can be interpreted from this variation.

Ammonia levels ranged from <0.005 mg/L (detection threshold level) to 0.035 mg/L with values above 0.020 mg/L at 2 shallow sites, F2 and C1, and one deep site, C5.

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 consistent with those found in earlier studies (Pardovan 1997, Parry and Munksgaard 1999, Pardovan 2002). Ammonia levels were also consistent with the exception that the 0.035 mg/L concentrations were approaching the highest wet season level of 0.040 mg/L measured in Ludmiller Creek (Parry and Munksgaard 1999). However these studies were small and of short duration therefore little can be interpreted from the results. The main use for these data will be 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 the Port of Darwin is inundated by 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 and TAN levels were above ITL for estuaries at several sites at both farm and control sites but below ITL for coastal waters at all sites.

Table 5.2.1 Dissolved inorganic nitrogen analysis

Site	Ammonia (mg/L)	Nitrite (mg/L)	Nitrate (mg/L)	NOX (mg/L)
F1-1	0.015	<0.005	0.010	<0.015
F1-2	0.035	<0.005	0.015	<0.020
F2-1	0.020	<0.005	0.010	<0.015
F2-2	0.005	<0.005	0.010	<0.015
F3-1	0.005	<0.005	0.010	<0.015
F3-2	0.015	<0.005	0.010	<0.015
F4-1	0.010	<0.005	0.010	<0.015
F4-2	0.005	<0.005	0.010	<0.015
F5-1	0.005	<0.005	0.010	<0.015
F5-2	0.005	<0.005	0.010	<0.015
F6-1	0.005	<0.005	0.010	<0.015
F6-2	0.010	<0.005	0.010	<0.015
C1-1	<0.005	<0.005	0.005	<0.010
C1-2	0.020	<0.005	0.005	<0.010
C2-1	0.035	<0.005	0.005	<0.010
C2-2	0.005	<0.005	0.005	<0.010
C3-1	0.015	<0.005	0.010	<0.015
C3-2	0.015	<0.005	0.005	<0.010
C4-1	0.005	<0.005	0.005	<0.010
C4-2	0.005	<0.005	0.005	<0.010
C5-1	0.035	<0.005	0.015	<0.020
C5-2	0.025	<0.005	0.01	<0.015
C6-1	0.005	<0.005	0.005	<0.010
C6-2	0.01	<0.005	0.01	<0.015

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). Less than 1 μg/L of chlorophyll α was found at deep water control sites, while levels at shallow water control sites were all 2 μg/L. 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 study were consistent with results of earlier studies within Darwin Harbour (Wrigley *et al*. 1990, Pardovan 1997, Parry and Munksgaard 1999, Pardovan 2002, Sly *et al*. 2002). They were equal to or below draft ANZECC Interim Trigger Levels (ITLs) of 2 μg/L for slightly to moderately disturbed ecosystems for estuaries (Table 3.3.2, ANZECC 1999).

The results of this survey are within the range of those recorded during the initial stages of monitoring at Port Hurd (<2 μg/L) and Doug Point (<2 μg/L) and lower than those recorded at Snake Bay (generally 3 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.

Table 5.3.1 Chlorophyll α data

Site	Chlorophyll α (μg/L)
F1-1	<1
F1-2	1
F2-1	2
F2-2	1
F3-1	1
F3-2	2
F4-1	1
F4-2	1
F5-1	2
F5-2	1
F6-1	1
F6-2	1
C1-1	2
C1-2	2
C2-1	2
C2-2	2
C3-1	2
C3-2	2
C4-1	<1
C4-2	<1
C5-1	<1
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 Channel Island 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 Little West Arm.

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 study areas of Channel Island and Little West Arm was dominated by *Rhizophora* sp. and *Ceriops* sp. 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*. the only way the species can be differentiated is by their flowers and fruit. Since very few Ceriops were in flower or fruit no distinction could be made between these species either.

The other species occurring in significant numbers were *Avicennia marina* dominating the water's edge at F2 and *Bruguiera exaristata* and *Bruguiera gymnorrhiza* at several control sites.

Mangrove condition was generally healthy with less than 10% dead trees per hectare at all sites but 4. At two of these sites, F2-2 and C1-4, the high calculated percent dead was the result of measuring one very small dead Ceriops adjacent to the measuring position. Low numbers of trees with crown damage or dead branches were recorded. 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 8.6.21.

Interpretation

Mangrove communities assessed in the vicinity of Channel Island and Little West Arm were typical for similar Darwin Harbour (see Brocklehurst and Edmeades, 2003). They were composed mainly of *Rhizophora* sp. and *Ceriops* sp. and were healthy and vibrant. 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 Deg M	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		100	21/08/2005	22.5	22.5	0	0	100	0	0	2137	2137	0	0	0	7.7
F1-2	14	100	21/08/2005	27.5	9.0	9.0	2.3	38.7	38.7	9.7	37318.6	37318.6	0.0	0.0	0	5.4
F1-3	30	100	21/08/2005	27.0	25.5	0.8	0.8	0.8	2.8	2.8	27803.2	21105.0	6631.0	66.0	0	4.8
F1-4	30	100	21/08/2005	24.8	24.0	0.0	0.8	97.0	0.0	3.0	4129.1	4129.1	0.0	95.0	2	5.4
F1-5	50	100	21/08/2005	8.5	6.8	1.8	0.5	79.4	20.6	5.9	11570.1	5072.0	6305.0	192.0	2	3.2
F2-1		300	22/08/2005	29.3	22.5	4.5	1.5	76.9	15.4	5.1	30992.9	37319	0	0	0	5.4
F2-2	9	320	22/08/2005	23.3	9.0	9.0	2.3	38.7	38.7	9.7	44437.8	28202.0	454.0	7185.0	16	6.1
F2-3	19	320	22/08/2005	17.0	13.5	3.0	0.5	79.4	17.6	2.9	16602.1	16486.0	105.0	11.0	0	7.7
F2-4	37	320	21/08/2005	35.3	32.3	0.0	3.0	91.5	0.0	8.5	63958.7	61495.7	0.0	2463.0	4	4.4
F3-1		160	21/08/2005	26.3	20.3	5.3	0.0	77.1	20.0	0.0	13281.8	4002.0	8898.0	0.0	0	6.9
F3-2	15	160	22/08/2005	31.0	31.0	0.0	0.0	100.0	0.0	0.0	104121.5	104121.5	0.0	0.0	0	4.1
F3-3	25	160	22/08/2005	35.0	30.0	3.0	2.0	85.7	8.6	5.7	90007.4	82385.0	1168.0	6455.0	7	4.3
F3-4	35	200	22/08/2005	29.3	15.0	9.0	1.5	51.3	30.8	5.1	49089.0	1369.0	44297.0	646.0	1	7.6
C1-1	0		23/08/2005	36.0	35.0	1.0	0.0	97.2	2.8	0.0	10473.6	10473.6	0.0	0.0	0	11.1
C1-2	23		23/08/2005	18.0	9.5	5.0	1.5	52.8	27.8	8.3	15795.6	5512.0	4642.0	619.0	4	4.6
C1-3	32		23/08/2005	27.8	24.0	1.5	2.3	86.5	5.4	8.1	31619.0	26676.0	1230.0	3713.0	12	5.3
C1-4	44		23/08/2005	8.8	8.3	0.0	0.5	94.3	0.0	5.7	10876.4	8594.4	0.0	2282.0	21	6.1
C2-1	0	20	30/08/2005	32.3	18.8	5.3	4.5	58.1	16.3	14.0	6633.3	2925.0	2967.0	576.0	9	9.2
C2-2	12	340	30/08/2005	25.0	8.5	8.0	1.0	34.0	32.0	4.0	18244.7	9593.0	1674.0	348.0	2	6.2
C2-3	23	335	30/08/2005	30.8	27.8	0.0	3.0	90.2	0.0	9.8	29571.2	29571.2	0.0	0.0	0	5.0
C2-4	33	340	30/08/2005	37.0	31.0	0.0	6.0	83.8	0.0	16.2	42503.5	38156.5	0.0	4347.0	10	4.1

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.	-	F2-4	Ceriops sp.	-	C1-1	Rhizophora sp.	-
F1-2	Rhizophora sp.	Ceriops sp.	F3-1	Rhizophora sp.	Ceriops sp.	C1-2	Ceriops sp.	Rhizophora sp.
F1-3	Rhizophora sp.	Ceriops sp.	F3-2	Ceriops sp.	-	C1-3	Ceriops sp.	Bruguiera gymnorrhiza
F1-4	Rhizophora sp.	-	F3-3	Ceriops sp.	Rhizophora sp.	C1-4	Ceriops sp.	-
F1-5	Rhizophora sp.	Ceriops sp.	F3-4	Rhizophora sp.	Sp. 1	C2-1	Rhizophora sp.	Bruguiera exaristata
F2-1	Avacennia marina	Rhizophora sp.				C2-2	Ceriops sp.	Rhizophora sp.
F2-2	Ceriops sp.	Avacennia marina				C2-3	Ceriops sp.	Bruguiera gymnorrhiza
F2-3	Ceriops sp.	Avacennia marina				C2-4	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.

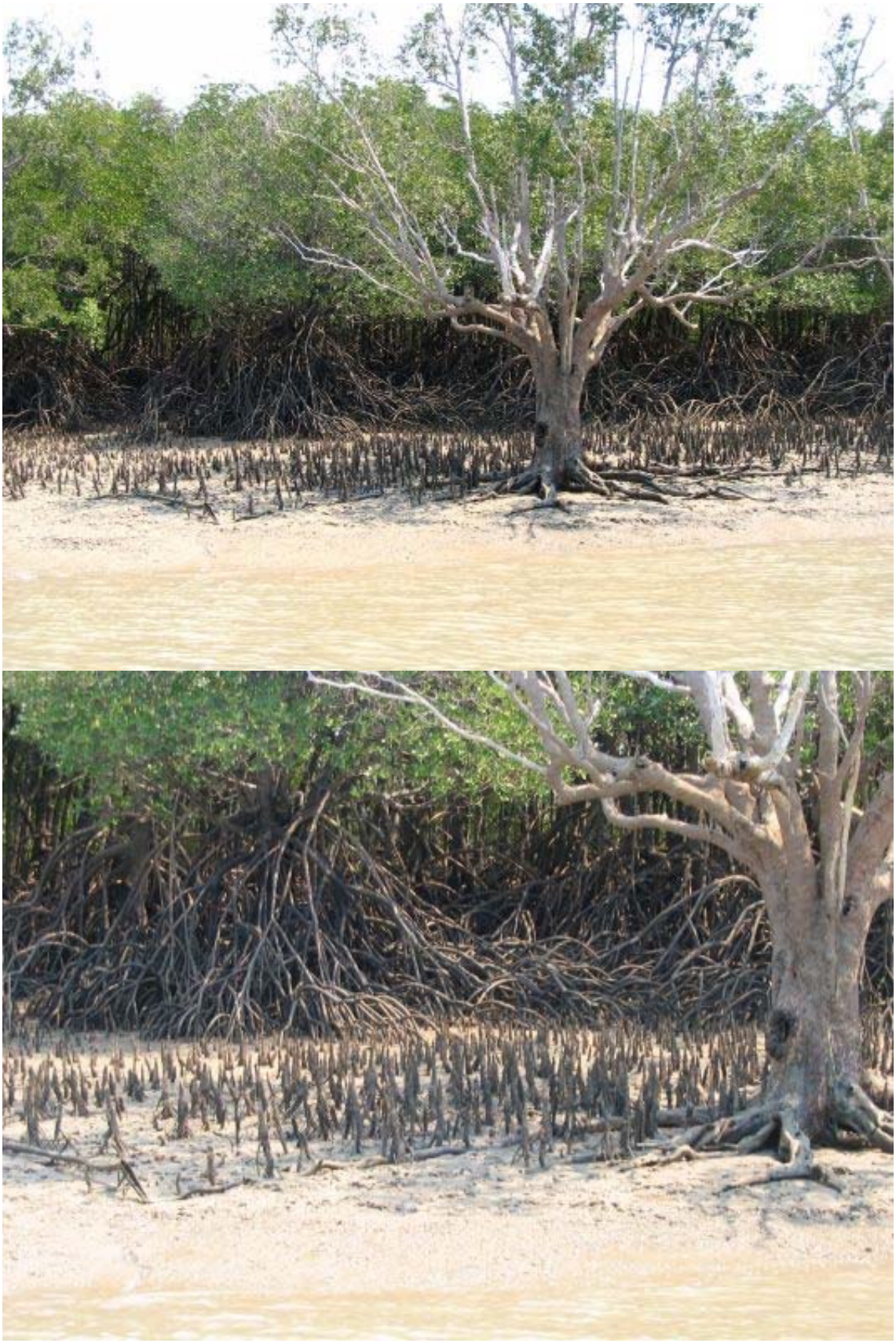

Figure 6-1 Mangrove root assemblages at site F1

Figure 6-2 Mangrove root assemblages at site F2

Figure 6-3 Mangrove root assemblages at site F3