Appendix F

Port Hurd Biennial Report by Aquenal Pty Ltd

AQUENAL PTY LTD

BIENNIAL ENVIRONMENTAL ASSESSMENT OF THE BIOLOGICAL IMPACT OF NUTRIENTS RELEASED FROM MARINE HARVEST'S AQUACULTURE OPERATIONS IN PORT HURD, BATHURST ISLAND

OCTOBER 2003 - OCTOBER 2005

REPORT TO

MARINE HARVEST

BY

AQUENAL PTY LTD

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1 Summary

Port Hurd Barramundi Farm was established by Marine Harvest inside the entrance to Port Hurd in 2000. The farm was first stocked in March 2001 with the first harvest occurring in May 2002. During 2002, approximately 210 tonnes of barramundi were harvested, with approximately 700 tonnes harvested in 2003. In 2004 the harvest rate was 20 to 25 tonnes per week. The fish farm and associated on-shore facilities at Barra Base are the only man-made developments on Port Hurd or its tributaries with significant nutrient output.

In October 2003, an Initial Environmental Assessment (IEA) was conducted to assess locations and parameters most subject to nutrient enrichment. The IEA found no evidence of biological impact from nutrients released from Marine Harvest's aquaculture facility in Port Hurd. This finding was not conclusive however, as there was no matching set of baseline data collected before aquaculture operations commenced.

It was concluded that follow-up monitoring over subsequent years at control sites and sites most likely to show impact was required to gain an understanding of natural variation and assess potential impact. As a result, a second environmental assessment was carried out in October 2005 to assess both short and long term changes. The second survey re-examined sites surveyed in the IEA in order to assess and monitor the impact of nutrients from Marine Harvest's aquaculture operations on the environment of Port Hurd. It was carried out at the same time of year as the IEA to eliminate seasonal effects on data and to coincide with the end of the dry season when there is expected to be an increased likelihood of fish farm related nutrient build-up in the estuary. Short term changes in water quality due to fish farm effluent have also been monitored at Port Hurd since 2003 to detect any possible consequent proliferation of planktonic and epiphytic algae. This report presents the results of ongoing monitoring at Port Hurd from 2003 to 2005.

Environmental indicators of long term biological impacts which are most suitable to this study are benthic infauna community structure, mangrove stand structure and composition and sediment redox levels. Easily measured parameters such as dissolved oxygen (DO), nutrients and planktonic algal concentrations in the water column, and proliferation of epiphytic algae on mangrove roots are all precursors to longer term biological impacts. Epiphytic algal growth and planktonic algal blooms are often the first observable biological response to increased levels of nutrients in estuarine systems (Bayard, 1992, Ward *et al,* 1998). It is these short and long term parameters that are the subject of this report. To assist in relating these parameters to environmental conditions, measurements of water temperature, salinity and rainfall were recorded. Nutrients were assessed by laboratory analysis of water samples to assess nitrates and nitrites (NOX) and total ammonium nitrogen (TAN). Planktonic algal proliferation was measured by laboratory analysis chlorophyll α in water samples. Epiphytic algal growth was monitored by observation of intertidal mangrove assemblages.

A visual assessment of cores in the monitoring study found sediments at most sites were similar to those sampled in the baseline study with soft, brown-grey mud present in most cores. A lack of gas bubbles and smell from the majority of cores indicated the natural organic loading is moderate rather than high, and reduction of organic matter is proceeding apace with its deposition. The H_2S smell from single cores at F3 and C3 in 2005 indicates deposition of organic material at these sites is more rapid than aerobic decomposition, causing sediments to become anoxic. However as anoxic sediments were found at control and farm sites this cannot be attributed to farm operations. Animal life was prolific at most sites in both years, with numerous

burrows present in the majority of cores. The absence of plant material from all cores in baseline and monitoring years is a result of the high attenuation of light in the muddy estuarine waters.

There was very little difference between redox potential at 4 cm at all sites in 2003 and 2005, with 4 farm sites showing an increase and only one farm site showing a decrease. However this decrease was within one standard deviation of the earlier value and a decrease of similar magnitude was seen at one control site so this decrease cannot be attributed directly to fish farm operations. Redox values found in these surveys are similar to those expected in a healthy, undisturbed environment.

Sediment particle size analysis indicated there has been little or no change in the sedimentation characteristic of the monitoring and control sites.

Rainfall patterns in Port Hurd recorded during 2003, 2004 and 2005 clearly reflect the wet and dry seasons and can be related to water quality parameters. Comparing rainfall and water quality measurements assists in determining whether observed changes are due to seasonality or biological impact.

Salinity was generally higher in the dry seasons and dropped in the wet with no obvious difference between control and farm sites. Lowest salinity coincided with high rainfall and the associated freshwater run-off. As expected, temperature data displayed a similar pattern to salinity in that temperatures were lower in the dry season and higher in the wet. There was no obvious difference in temperature between farm and control sites.

The average percentage of DO in Port Hurd was found to be approximately 76% with possible seasonal effects. With the exception of comparatively low F2 values, both control and farm sites displayed similar DO throughout the study period.

NO_X values (nitrate plus nitrite) were above the ANZECC Interim Trigger Levels (ITL) for estuaries at all sites at some stage throughout the monitoring period. Two sites also recorded NO_X levels above the coastal and marine ITL, one of which was a control site. As with NO_X, ammonia levels in Port Hurd regularly exceed the ITL for both estuaries and coastal and marine ecosystems. Dissolved inorganic nitrogen (DIN) values were above the estuarine ITL for total N at the majority of sites, but remained below the coastal and marine limits. Although a number of large spikes in DIN occurred, these did not appear to be related to season.

Phytoplankton abundance measured through analysis of chlorophyll α levels found a slight increase at farm sites and no change at control sites between the 2003 and 2005 EIA surveys. Periodic monitoring found chlorophyll α levels generally remained below the draft ANZECC Interim Trigger Level for estuaries of 2 μg/L in 2003. However in 2004 and 2005, the trend of increasing chlorophyll α levels at Port Hurd sites meant the majority of values were above the trigger level. This general rise in chlorophyll α levels in 2004 and 2005 was not obviously related to other parameters included in this study and cannot be directly attributed to farm operations as values at the control site in a creek on the opposite side of the estuary were often higher than the farm sites. However it is of concern and levels should continue to be regularly monitored at all Port Hurd sites to assess any further increase over time. If levels continue to rise a set of samples from Gullala Inlet should be assessed to gather additional control values.

Mangrove stand structure and composition found the main parameters showing change over the period 2003 to 2005 were the numbers of damaged and dead trees. These were most probably caused by a cyclone which passed directly over the survey sites in 2004. Several large trees at

the survey sites were completely uprooted and many snapped off a metre or two above the ground. In subsequent years this may cause a change in species dominance or increase in stem density as the damaged canopy allows increased sunlight to reach the forest floor. The changes in dominance at 3 control sites reflected natural evolution of maturing stand composition. No changes attributable to marine farming were apparent.

Examination of photographs from 2003, 2004 and 2005 has shown mangrove root and rhizome assemblages to be in excellent health with regard to epiphytic algal growth. Both farm and control sites show a similar state of health with no sign of algal growth, indicating levels of waterborne nutrients are too low for the establishment of epiphytic algae in the intertidal zone.

Benthic infaunal analysis found no detectable impacts of farming activity on benthic communities at Port Hurd. Habitat-related variation was detected, with intertidal communities distinct from the subtidal communities. Within these communities, differentiation was also observed between the farm and control sites. However, this differentiation was present in both the 2003 baseline and 2005 monitoring surveys, reflecting natural variation rather than farming impacts. Faunal dominance had declined since the 2003 baseline survey at the majority of the subtidal and intertidal farm and control sites. Similarly, increases in species richness and diversity index values were documented for most control and farm sites, suggesting that farming activity had not impacted on these parameters. At most control sites animal numbers increased, whilst remaining constant or declining at most farm sites. It seems unlikely that the declines in animal abundance at farm sites reflect farming impact, since the general response of communities to organic inputs is a decline in species numbers coupled with increased faunal abundance, which is the reverse of the findings in this study.

In summary, this monitoring survey found no biological impact attributable to nutrient output from aquaculture operations at Port Hurd. Results of sediment analysis in 2005 indicate no significant changes have occurred at monitoring sites since 2003. Similarly, analysis of benthic communities found no detectable impacts of farming activities. However, nutrient levels were not uniformly seasonal and exceeded ANZECC trigger levels on a number of sampling occasions at both control and monitoring sites. A general increase in chlorophyll α levels during monitoring between 2003 and 2005 was also observed throughout Port Hurd, with values in the latter period mostly exceeding ANZECC trigger levels for estuaries. Nutrient and chlorophyll α levels should be further monitored over time to detect any additional increase in levels and to differentiate between natural variation and biological 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 Ron Mawbey Jeremy Dudding
Client:	Marine Harvest Barramundi Farms PO Box 39899 Winnellie Northern Territory 0821 Phone: Darwin (08) 8941 5651 Fax: Darwin (08) 8941 5254
Field work:	EIA supervision by Aquenal personnel with on-going monitoring by Marine Harvest personnel
Date of fieldwork:	Nutrient sampling: 4/10/2003 to 17/10/2005 First EIA 2/10/2003 to 4/10/2003 Second EIA 6/10/2005 to 9/10/2005

2.1 Sampling rationale and nomenclature

Sample sites and parameters analysed were chosen to best detect organic pollution from the Marine Harvest Port Hurd aquaculture operations. (See *Port Hurd Environmental Monitoring Proposal*, Aquenal 2003 for detailed discussion). To this end a site survey and a drogue survey were carried out prior to selecting sample sites and deciding which parameters and sites were to be sampled. A similar estuary, Gullala Creek, 13 km to the north was selected as a control.

Both Port Hurd and Gullala Creek estuaries are relatively large (approximately 25 and 10 km^2 respectively) and sheltered. Both entrances are protected by extensive offshore sandbars, preventing any significant wave action from penetrating into the estuary. The main hydrological influences on these water bodies are the 7 m 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 causes increased salinity. During this period, nutrients from the aquaculture facility are most likely to accumulate in the estuary on intertidal flats and in deeper channels. Surveys were therefore planned to coincide with this period of peak nutrient stress in the late dry season.

To locate the areas where dissolved and suspended nutrients were most likely to accumulate at this time, a drogue survey was undertaken. This indicated that waters passing through the farm tended to remain on the northern side of the estuary. Surface waters during one tidal cycle drifted into the mangroves along a section of the northern bank extending from the mouth to 8 km upstream. Deeper waters followed the deep channels reaching 8 km into the estuary in one tide and entering both the north-eastern tributary and the south-eastern Munanampi Creek. At least a portion of waters discharging into the ocean also return to the estuary during this time of year. Six sample sites were selected in Port Hurd at locations expected to be subject to heaviest influence from fish farm nutrients. One of these, F6, was in the same location as a site sampled in an earlier baseline study carried out by Australian Underwater Technologies prior to the farm being established. Six similar sites were selected in Gullala Creek as control sites, corresponding as closely as possible to the monitoring sites in Port Hurd.

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

For regular water quality monitoring and assessment of epiphytic algal growth an additional two control sites were selected nearby. Control site C7 is an intertidal site and C8 is a deep water site. Monitoring at these sites should enable early detection of changes due to short term nutrient increases which can then be confirmed by reference to the more distant sites in Gullala Inlet.

Maps showing the location of Port Hurd and Gullala Inlet sample sites are presented in Figure 2-1 and Figure 2-2 , coordinates are listed in Table 7.1-1.

2.2 Maps

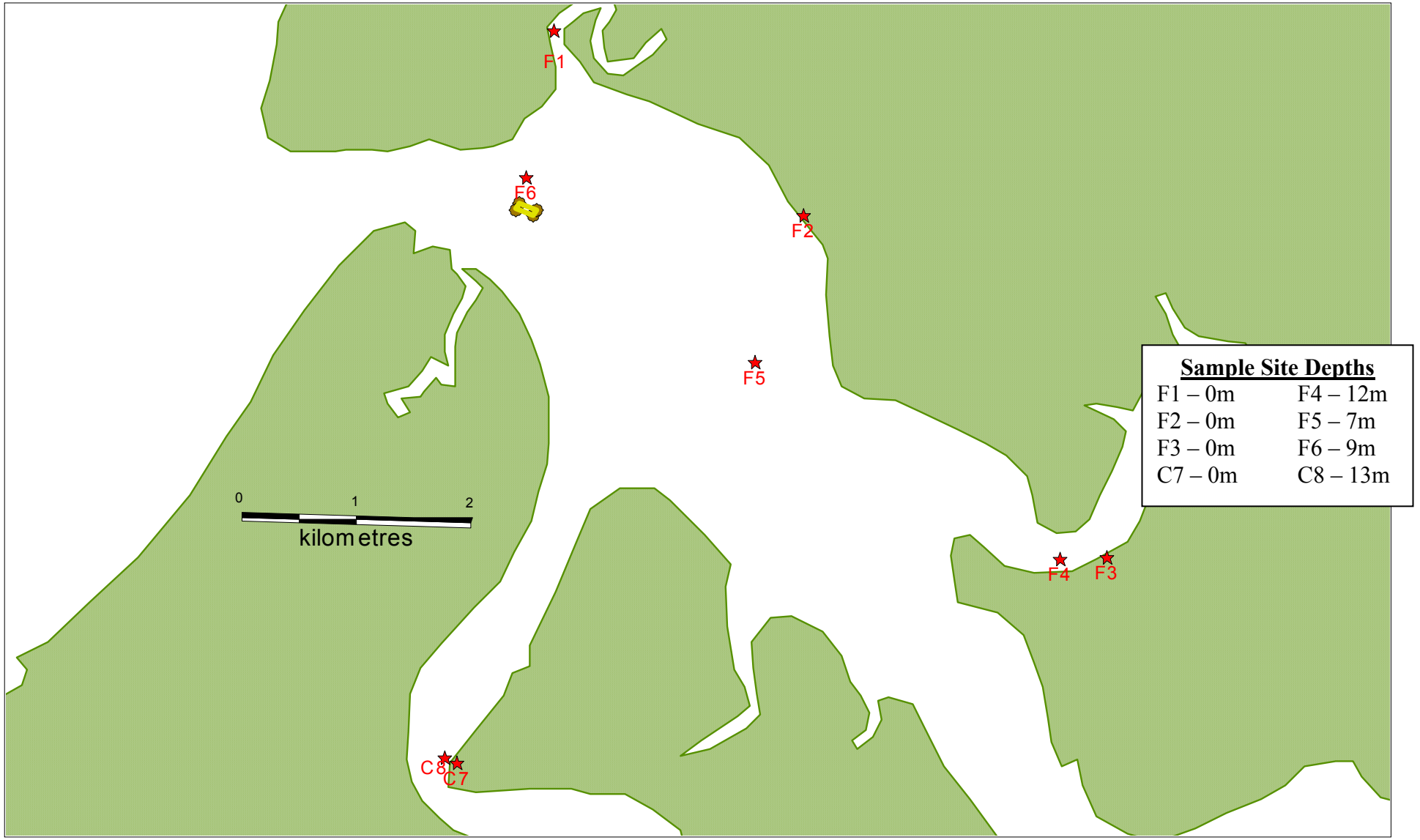

Figure 2-1 Survey map showing farm sample sites in Port Hurd

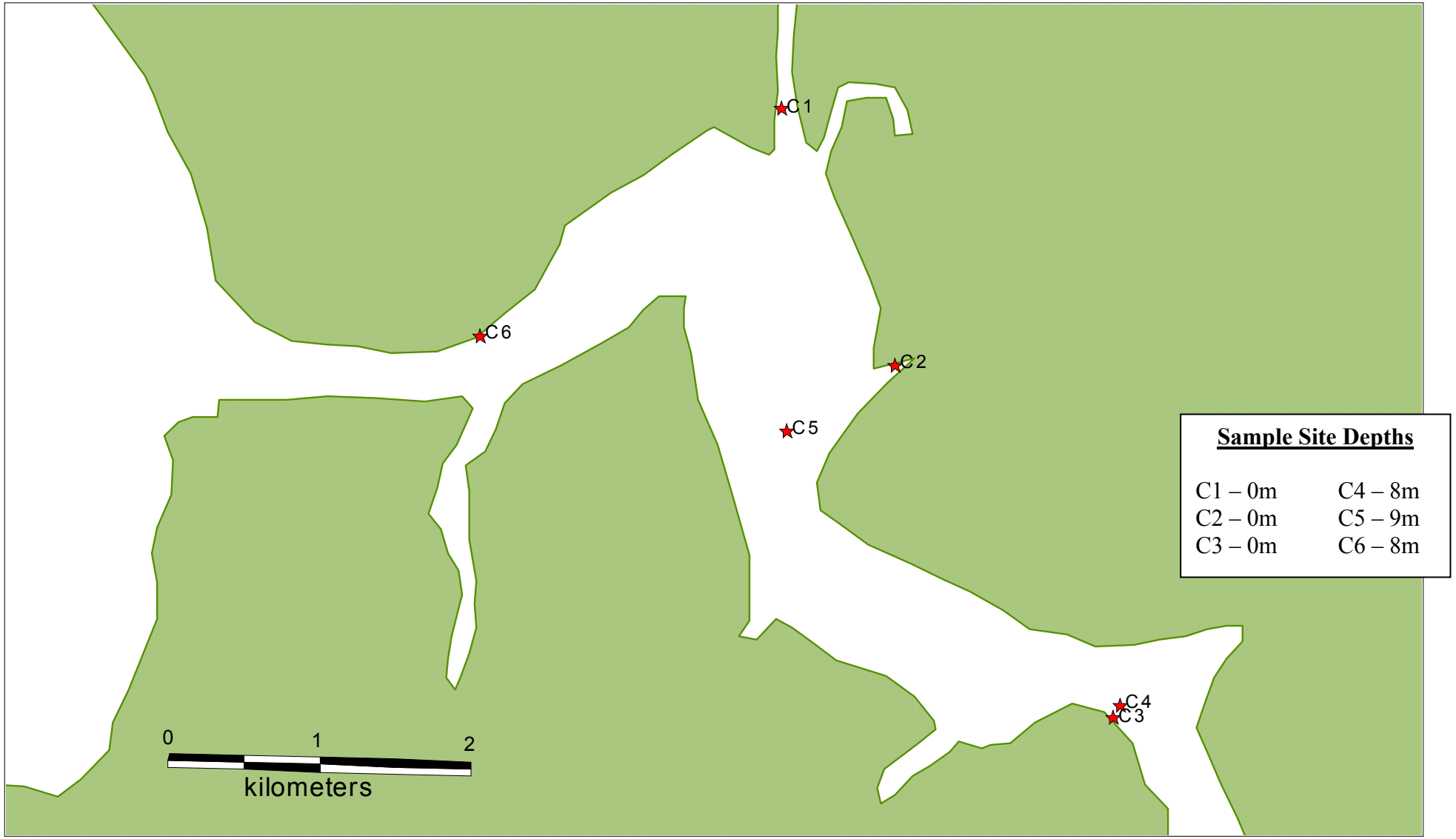

Figure 2-2 Survey map showing control sample sites in Gullala Inlet.

3 Sediment Analysis

3.1 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

Results from the 2003 survey show sediments at all sites consisted predominantly of soft, grey mud to full depth of the cores (Table 3.1-1). The depth of this mud was normally greater than 200 mm but at sites F1, F6 and C4, much older, firmer, light grey mud was encountered at less than 200 mm. The deep water sites generally had sandier surface sediments that the shallow sites. C2 had a layer of decayed mangrove detritus on the surface. Many of the sites showed some black streaks or mottling. Animal burrows were evident at all sites but no plant life was observed. There was no gas or strong smell from any of the cores.

As in the baseline study, sediments from the 2005 monitoring survey consisted of predominately soft, brown-grey mud, with a number of sites containing organic material (Table 3.1-2). Most cores displayed some sediment stratification, with the bottom sediment layer consisting mostly of brown grey mud, often streaked with black. The bottom sediment layer from C5 and C6 also contained organic material. Cores from the deep-water control sites C4 and C5 contained shell grit in the top 10-60 mm of sediment. Animal burrows were evident in most cores, however there was no plant life detected in cores from any site. A strong H_2S smell was detected in one core from F3 and one core from C3.

Interpretation

In both study years, soft, brown-grey mud was present in most cores. This is material currently being deposited in the estuary. The black streaking and mottling in the bottom layer of sediment indicates moderately high organic loading and low permeability to oxygen. A lack of gas bubbles and smell from the majority of cores indicates the natural organic loading is moderate rather than high, and reduction of organic matter is proceeding apace with its deposition. The H_2S smell from single cores at F3 and C3 in 2005 indicates deposition of organic material at these sites is more rapid than aerobic decomposition, causing sediments to become anoxic. As this slight anoxia was recorded

at both a farm and control site, it cannot be attributed as a result of nutrient output from the fish farm. Animal life is prolific at most sites in both years, with numerous burrows present in the majority of cores. The absence of plant material from all cores in baseline and monitoring years is a result of the high attenuation of light in the muddy estuarine waters.

Table 3.1-1 Visual description of sediment cores at farm and control sites in 2003. Abbreviations used in the table are: brn=brown, gy=grey, blk=black, bge=beige, det=detritus, floc-flocculant, lt=light, dk=dark, md=mud, sd=sand, sg=shell grit, spkld=speckled, stkd = streaked, mott=mottled, org=organic, burrs=burrows, yel=yellow, wh=white, sev=several tr=traces, sl-slightly, f=fine, med=medium, crs=coarse.

Core No	Length mm	Colour 1	Depth 1 mm	Colour 2	Depth 2 mm	Colour 3	Plants	Animals	Gas Bubbles	Smell
F1-1	165	gy brn sdy md	50	gy stk blk md			nil	sev burr to 90 mm	nil	nil
F1-2	140	gy brn sdy md	30	gy md	120	lt gy frm md	nil	2 burr to 30 mm	nil	nil
F1-3	145	gy brn sdy md	50	gy md	100	lt gy frm md	nil	1 burr to 20 mm	nil	nil
F2-1	200	gy brn md	60	gy stk blk md			nil	2 burr to 60 mm	nil	nil
F2-2	110	gy brn md	15	gy mott blk md			nil	2 burr to 40 mm	nil	nil
F2-3	130	gy brn md	40	gy md	100	gy stk blk md	nil	2 burr to 40 mm	nil	nil
F3-1	130	gy md	90	gy stk blk md			nil	sev burr to 60 mm	nil	nil
F3-2	145	gy md	70	gy stk blk md			nil	sev burr to 30 mm	nil	nil
F3-3	130	gy md	90	gy stk blk md			nil	sev burr to 90 mm	nil	nil
F4-1	160	gy brn sdy md	15	gy md			nil	sev burr to 140 mm	nil	nil
F4-2	100	gy brn sdy md	15	gy md			nil	1 burr to 100 mm	nil	nil
F4-3	150	gy brn sdy md	20	gy md			nil	sev burr to 120 mm	nil	nil
F5-1	195	gy brn sdy md	30	gy md			nil	sev burr to 60 mm 1 burr to 150	nil	nil
F5-2	200	gy brn sdy md	30	gy md			nil	nil	nil	nil
F5-3	200	gy brn sdy md	40	gy stk blk md			nil	1 burr to 50 mm	nil	nil
F6-1	100	gy brn sdy md & sg	25	lt gy frm md			nil	sev burr to 50 mm	nil	nil
F6-2	160	gy brn sdy md & sg	50	lt gy stk blk frm md			nil	nil	nil	nil
F6-3	130	gy brn sdy md & sg	30	lt gy frm md			nil	sev burr to 60 mm	nil	nil
C1-1	135	gy md	50	gy mott blk md			nil	1 burr to 20 mm	nil	nil
C1-2	130	gy md	50	gy mott blk md			nil	nil	nil	nil
C1-3	140	gy md	40	gy mott blk md			nil	1 burr to 20 mm	nil	nil
C2-1	125	bkl spk wh org det	25	gy mott blk sdy md & sg			nil	nil	nil	nil
C2-2	125	bkl spk wh org det	20	gy stk blk sdy md			nil	nil	nil	nil
C2-3	185	bkl spk wh org det	50	gy stk blk sdy md			nil	1 burr to 120 mm	nil	nil
C3-1	140	gy brn sdy md	70	gy md			nil	sev burr to 50 mm	nil	nil
C3-2	155	gy brn sdy md	60	gy mott blk md			nil	many burr to 60 mm	nil	nil
C3-3	185	gy brn sdy md	72	gy stk blk md			nil	sev burr to 60 mm sev tubicles 5-15 mm high	nil	nil
C4-1	170	gy brn sdy md & sg	60	lt gy frm md			nil	many burr to 60 mm 1 burr to 170 mm	nil	nil
C4-2	115	gy brn sdy md & sg	80	lt gy frm md			nil	many burr to 50 mm 7 tubicles 5-20 mm high sev sml crstcns	nil	nil
C4-3	200	gy brn sdy md & sg	120	lt gy frm md			nil	1 burr to 20 mm	nil	nil
C5-1	150	gy brn sdy md	90	gy md			nil	sev burr to 40 mm 1 burr to 90 mm	nil	nil
C5-2	150	gy brn sdy md	90	gy stk blk md			nil	sev burr to 50 mm 1 burr to 90 mm	nil	nil
C5-3	160	gy brn sdy md	70	gy md			nil	sev burr to 50 mm	nil	nil
C6-1	150	brn sd	30	gy stk blk sdy md			nil	1 burr to 60 mm	nil	nil
C6-2	105	brn sd	25	gy sdy md			nil	1 burr to 60 mm	nil	nil
C6-3	200	brn sd	25	gy sdy md			nil	sev burr to 80 mm	nil	nil

Table 3.1-2 Visual description of sediment cores at farm and control sites in 2005. Abbreviations used in the table are: brn=brown, gy=grey, blk=black, lt = light, md=mud, sd = sand, sg=shell grit, spkld=speckled, stkd = streaked, ptchy = patchy, w = with, org=organic, matt=matter, burrs = burrows.

Core No	Length mm	Colour 1	Depth 1 mm	Colour 2	Depth 2 mm	Colour 3	Plants	Animals	Gas Bubbles	Smell
F1-1	110	brn gy md spkld org matt	40	brn gy md stkd blk	110		nil	burrs to 50mm	nil	nil
F1-2	100	brn gy md spkld					nil	burrs to 60mm	nil	nil
F1-3	110	brn gy md spkld	70	brn gy md stkd	110		nil	burrs to 30mm	nil	nil
F2-1	150	brn gy md stkd gy blk					nil	burrs to 50mm	nil	nil
F2-2	110	brn gy md stkd gy blk					nil	burrs to 60mm	nil	nil
F2-3	170	brn md	20	brn gy md stkd	170		nil	burrs to 90mm	nil	nil
F3-1	170	brn md	30	brn md ptchy gy	170		nil	burrs to 90mm	nil	nil
F3-2	120	brn md spkld org matt	60	brn gy md stkd blk	120		nil	burrs to 70mm	nil	nil
F3-3	120	brn md spkld org matt & blk	30	gy md ptchy blk	70	gy md stkd blk	nil	burrs to 30mm	nil	H_2S
F4-1	150	brn sd & md ptchy gy	60	brn sd & md ptchy gy stkd blk			nil		nil	nil
F4-2	140	brn sd & md ptchy gy	20	brn sd & md ptchy gy stkd blk			nil		nil	nil
F4-3	150	brn sd & md	20	brn sd & md ptchy gy stkd blk	80	gy md stkd blk	nil	burr at 80mm	nil	nil
F5-1	180	gy md ptchy brn	50	gy md			nil	burrs to 20mm	nil	nil
F5-2	190	gy md ptchy brn	60	gy md	130	gy md stkd blk	nil	burrs to 60mm	nil	nil
F5-3	200	gy md ptchy brn	50	gy md			nil	burrs to 20mm	nil	nil
F6-1	140	gy md ptchy brn	60	gy md			nil	burrs to 70mm	nil	nil
F6-2	100	brn md spkld sg	20	gy brn ptchy md			nil	burrs to 20mm	nil	nil
F6-3	160	gy md ptchy brn	50	gy md			nil	burrs to 60mm	nil	nil
C1-1	150	brn gy md spkld org matt	50	brn gy md stkd blk			nil	burrs to 40mm	nil	nil
C1-2	100	gy brn ptchy blk					nil	burrs to 50mm	nil	nil
C1-3	150	brn gy md spkld org matt ptchy					nil	burrs to 100mm	nil	nil
C2-1	160	gy brn md spkld org matt	40	gy brn md stkd blk			nil	burrs to 70mm	nil	nil
C2-2	180	gy brn md spkld org matt					nil		nil	nil
C2-3	100	gy brn md stkd					nil	burrs to 30mm	nil	nil
C3-1	170	brn gy md spkld org matt	40	brn gy md stkd blk			nil	burrs to 80mm	nil	nil
C3-2	130	brn gy md spkld org matt	30	brn gy md stkd blk			nil	burrs to 70mm	nil	nil
C3-3	140	brn gy md spkld org matt	20	gy md stkd blk			nil		nil	H_2S
C4-1	150	ptchy brn gy md & sd w sg	30	gy md & sd	110	ptchy lt gy md & sd	nil		nil	nil
C4-2	140	brn sd w sg	10	gy md & sd spkld blk			nil		nil	nil
C4-3	130	ptchy brn gy sd w sg	40	gy md			nil	burrs to 70mm	nil	nil
C5-1	150	gy brn md spkld sg & org matt	40	gy brn md spkld org matt			nil	burrs to 120mm	nil	nil
C5-2	170	gy brn md spkld sg & org matt	60	gy brn md spkld org matt			nil	burrs to 40mm	nil	nil
C5-3	170	gy brn md spkld org matt					nil	burrs to 160mm	nil	nil
C6-1	130	ptchy gy brn md spkld org matt	40	gy md stkd blk			nil		nil	nil
C6-2	170	ptchy gy brn md spkld org matt	30	gy md spkld org matt			nil	burrs to 50mm	nil	nil
C6-3	170	gy md spkld org matt	70	gy md			nil	burrs to 40mm	nil	nil

3.2 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

Results are presented in tabular form in Table 3.2-1 and graphically in Figure 3-1 and Figure 3-2. Raw data is presented in Table 7.2-1.

In the 2003 survey, surface redox values were below 200 mV at all sites except F2, C4 and C5. Values at 4cm were all above 0 mV, and therefore not anoxic. In 2005, corrected surface redox values were again consistent across all intertidal and subtidal sites; from 81 mV at F5 to 141 mV at F6 (Table 3.2-1). At 1 cm redox values at farm sites in 2005 varied between 49 and 84 mV and at control sites between 60 and 116 mV. These were very similar to values recorded in 2003 with the exception of unusually high readings at C4 and C5 in 2003. As in 2003, all of the 4 cm values were above 0 mV, indicating that none of the sediments sampled were anoxic at that depth. The standard deviations were mostly low indicating reliable results, although they were high at three sites: the 0 cm readings from F1 and F6 and the 4 cm reading from C3 (Figure 3-1 and Figure 3-2). The results from C5-3 are not included in the analysis as they appear to be incorrect (Table 7.2-1).

Interpretation

The 0 and 1 cm values were relatively uniform throughout the two years of monitoring reflecting similar conditions across the farm and control sites. Given the influence of animal burrows and minor surface disturbance on these results, little more can be drawn from the results. 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). There was very little difference between redox potential at 4 cm at all sites in 2003 and 2005, with 4 sites showing an increase and only one farm site, F4, showing a decrease, where the mean value dropped from 28.3 mV in 2003 to 5.3 mV in 2005. However this decrease was within one standard deviation of the earlier value and a decrease of similar magnitude was seen at one control site so this decrease cannot be attributed directly to fish farm operations.

Results from the baseline and monitoring surveys show sediments at the study sites to be poorly to moderately oxygenated indicating that reduction of organic matter is proceeding at a slightly higher rate than penetration of oxygen through the sediments. Redox values found in these surveys are similar to those expected in a healthy, undisturbed environment.

Table 3.2-1 Corrected redox potential of sediments at farm and control sites in 2003 and 2005.

	Depth (cm)	0		1		4	
Site		2003	2005	2003	2005	2003	2005
F1	Corrected Mean	118.0	115.7	73.3	73.7	42.7	53.7
	Standard Deviation	38.4	58.0	43.9	28.9	3.5	23.2
F2	Corrected Mean	362.0	86.3	66.3	72.0	39.3	59.0
	Standard Deviation	27.8	23.2	37.1	8.7	9.5	8.9
F3	Corrected Mean	170.0	104.3	71.3	80.3	57.0	54.7
	Standard Deviation	58.5	34.6	26.9	37.5	15.6	25.5
F4	Corrected Mean	124.3	118.7	56.3	49.0	28.3	5.3
	Standard Deviation	37.2	11.0	11.1	22.0	8.1	36.1
F5	Corrected Mean	111.7	81.0	69.0	69.0	48.0	59.0
	Standard Deviation	14.2	4.6	1.0	4.6	9.5	6.6
F6	Corrected Mean	170.0	141.3	124.7	84.3	46.3	63.3
	Standard Deviation	92.5	61.2	99.4	31.7	27.4	24.0
C1	Corrected Mean	105.0	106.0	58.3	83.0	51.0	77.3
	Standard Deviation	33.3	20.7	4.9	10.0	2.0	15.0
C2	Corrected Mean	160.3	92.7	100.3	66.0	47.7	43.0
	Standard Deviation	38.4	9.5	26.1	12.8	13.3	19.7
C3	Corrected Mean	103.3	113.7	44.3	82.7	39.7	19.3
	Standard Deviation	35.3	22.0	17.2	21.8	11.5	80.0
C4	Corrected Mean	413.0	133.0	309.7	95.0	78.0	69.3
	Standard Deviation	47.7	20.7	65.8	25.1	1.4	21.4
C5	Corrected Mean	281.3	134.5	243.0	116.5	108.3	92.5
	Standard Deviation	93.2	2.1	103.1	12.0	16.3	34.6
C6	Corrected Mean	191.3	99.0	78.0	60.7	36.7	46.7
	Standard Deviation	167.0	5.2	52.0	23.9	22.8	14.0

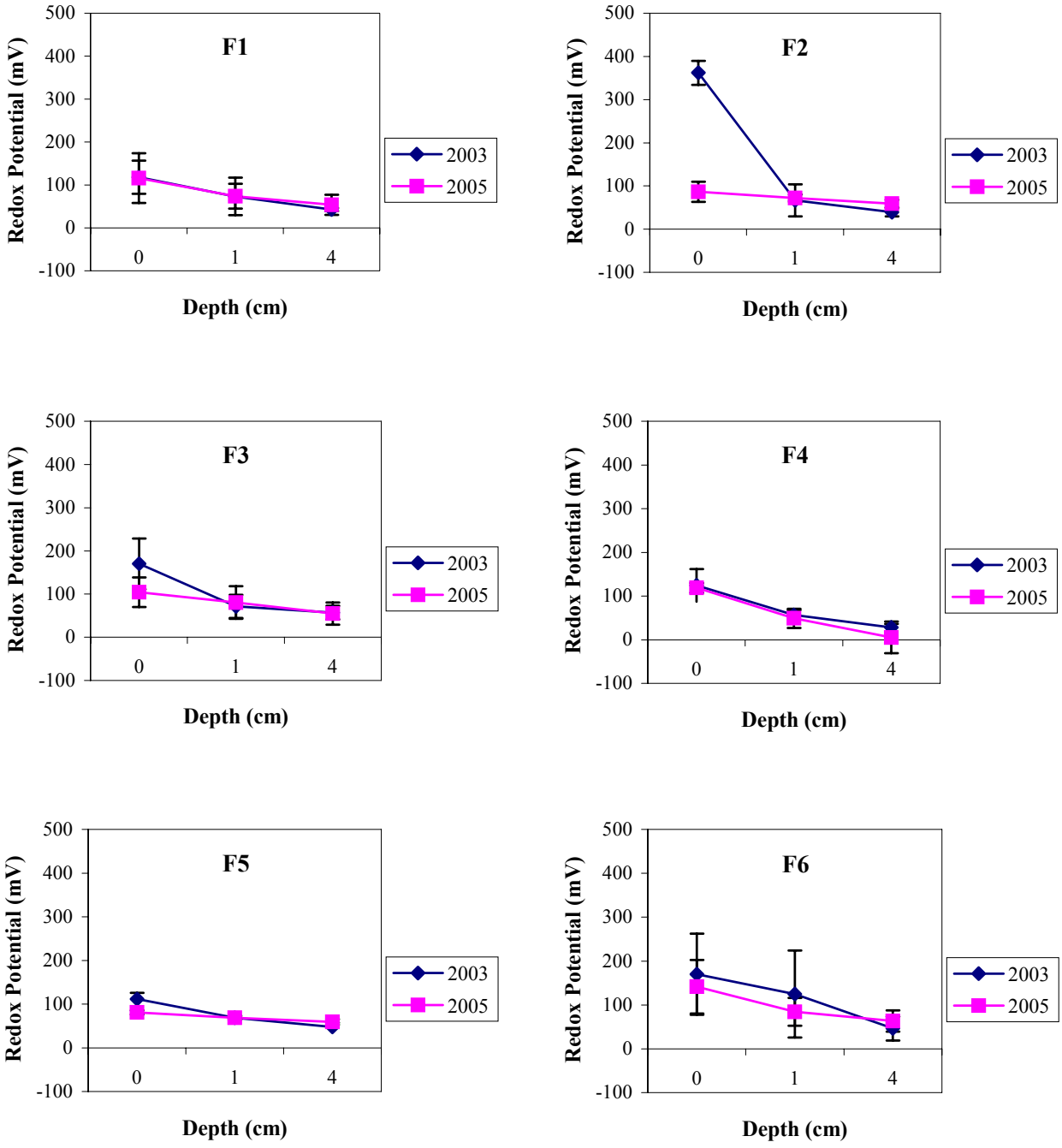

Figure 3-1 Redox potential in the top 4 cm of sediment cores at farm sites in 2003 and 2005.

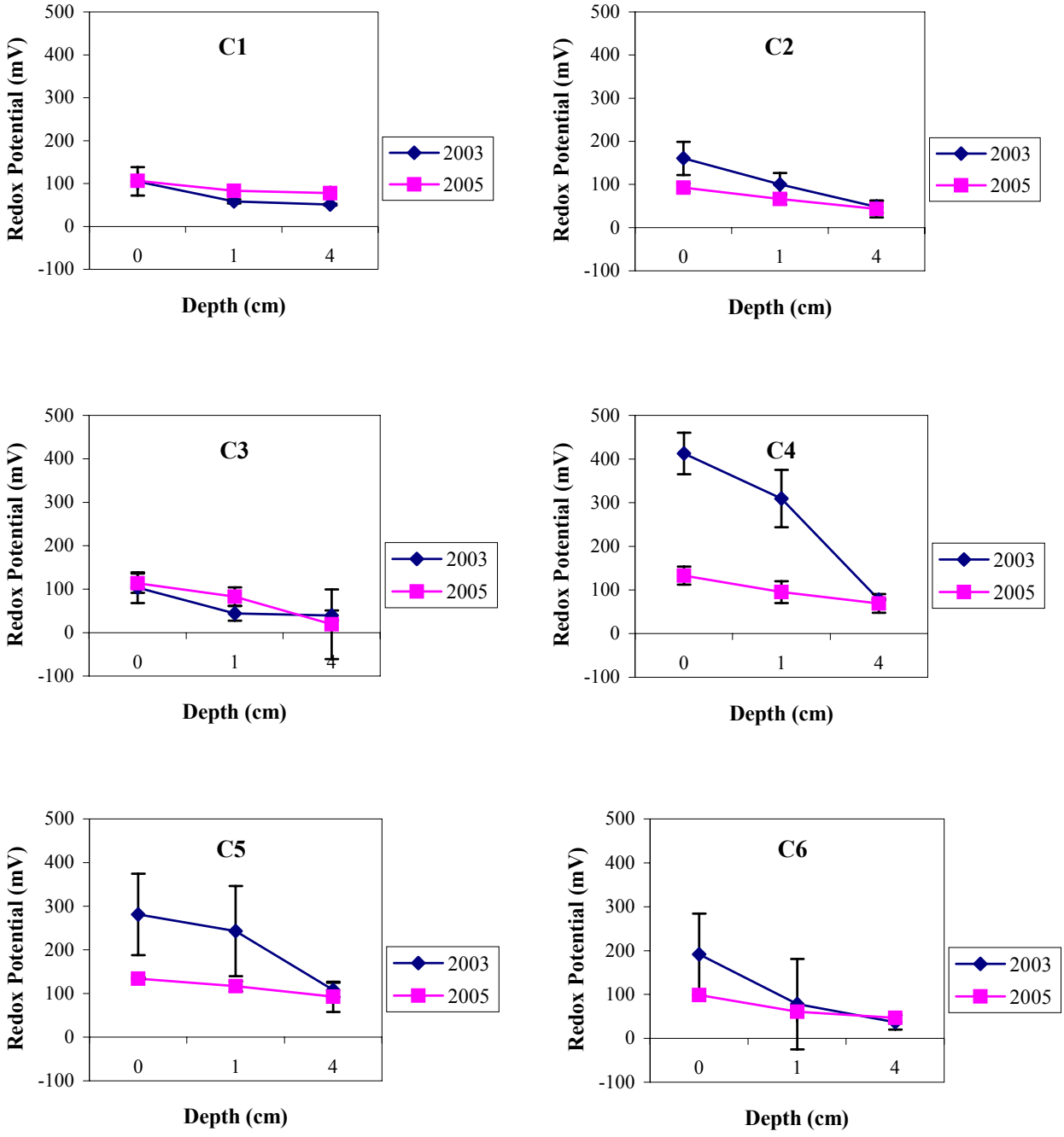

Figure 3-2 Redox potential in the top 4 cm of sediment cores at control sites in 2003 and 2005.

3.3 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

Descriptions of the material retained in the sieves after the fines had been wash out are given in Table 3.3-1 to assist in understanding the sedimentary environment. Sediment particle size analyses are presented graphically in Figure 3-3 and Figure 3-5 and raw data is presented in Table 7.3-1 and Table 7.3-2.

The 2003 study found sediments at all sites except C2 comprised of more than 50% fines, (material less than 63 μm, being silt, clay and organic matter), and were muddy in nature. Sediments at F3 and F5 were the finest with only 13% and 8% material coarser than 63 μm while those at C2 were coarser than the rest due to a large component of partially decayed plant material. This plant material was present in varying amounts in 8 of the 12 sites, confusing normal correlations with water speed. The fine material at F6 was quite firm clay which was broken down by sieving.

In 2005, the monitoring study found sediments at intertidal farm and control sites were generally comprised more than 45% fines and contained mud, woody material and silt. Subtidal sites were generally less fine and contained mud, clay and silt. Sediment at F5 was again the finest with only 5.2% of material coarser than 63 μm.

Overall there was little change in sediments from intertidal farm sites from 2003 to 2005. The main difference in intertidal sediments appears to be the decrease in medium grained particles at C2 which comprised mainly of plant material and shell grit. At subtidal sites the main change is an increase in medium grained sand at F4 and C4, with the remaining site changing little.

Interpretation

These results indicate there has been little or no change in the sedimentation characteristic of the monitoring and control 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.

Table 3.3-1 Description of sediments retained in sieves during particle size analysis

Site	2003	2005
F1	Sand, small amount fine shell grit and woody material	Mud, shell, woody material, sand and silt
F2	V fine sand, variable amounts of woody material	Mud, fine woody material and silt
F3	V fine sand, Small amount plant material	Mud, fine woody material and silt
F4	Sand, larger classes shell grit & rocks	Mud and sand
F5	V fine sand, v. small amount woody material	Mud, fine woody material and silt
F6	Clay firm grannules, shell grit in larger classes	Clay, shell fragments, shellgrit and silt
C1	Fine sand, clay particles and plant material	Mud, fine woody material and silt
C2	Plant material, v fine sand, v. small amount shell grit	Mud, fine woody material and silt
C3	Fine sand and plant material	Mud, woody material and silt
C4	Sand, larger classes shell grit & rocks	Clay, shell and sand
C5	Sand, larger classes shell grit & rocks	Mud, shell, woody material, sand and silt
C6	Sand, small amount fine shell grit and woody material	Mud, fine woody material and silt

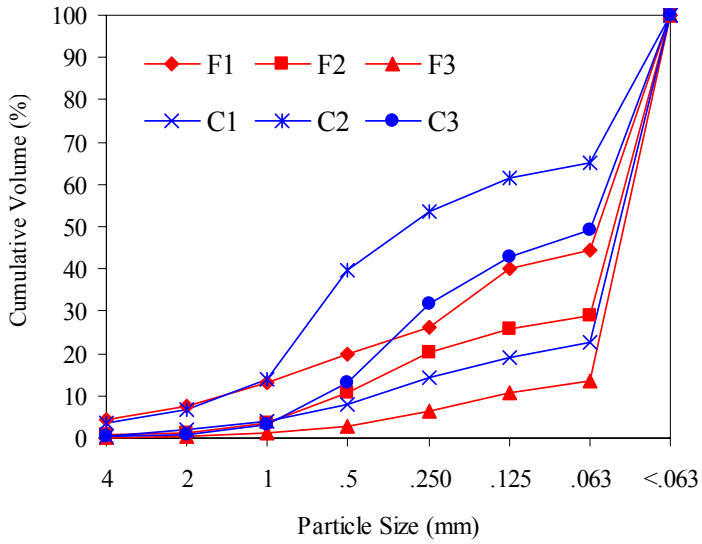

Figure 3-3 Particle size analysis of the top 100 mm of sediment cores from the intertidal farm and control sites in 2003.

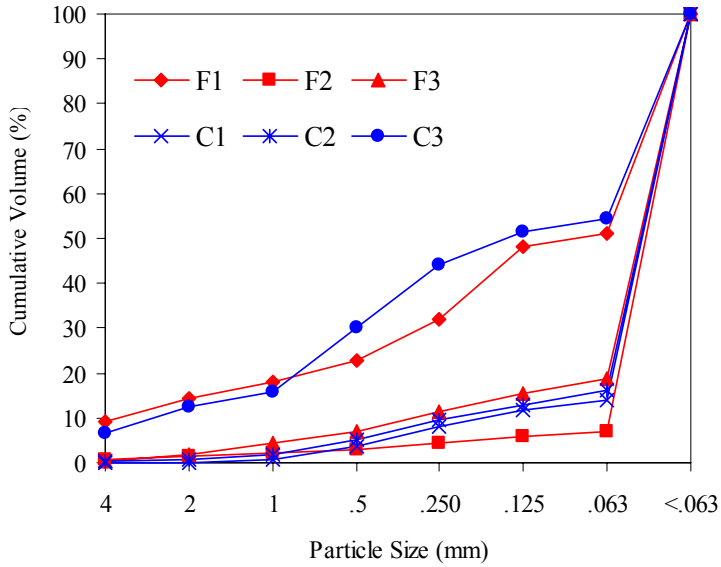

Figure 3-4 Particle size analysis of the top 100 mm of sediment cores from the intertidal farm and control sites in 2005.

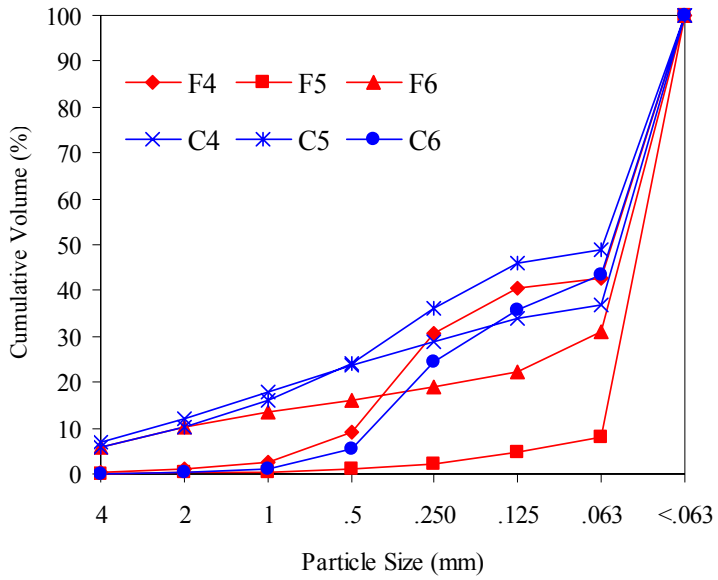

Figure 3-5 Particle size analysis of the top 100 mm of sediment cores from the subtidal farm and control sites in 2003.

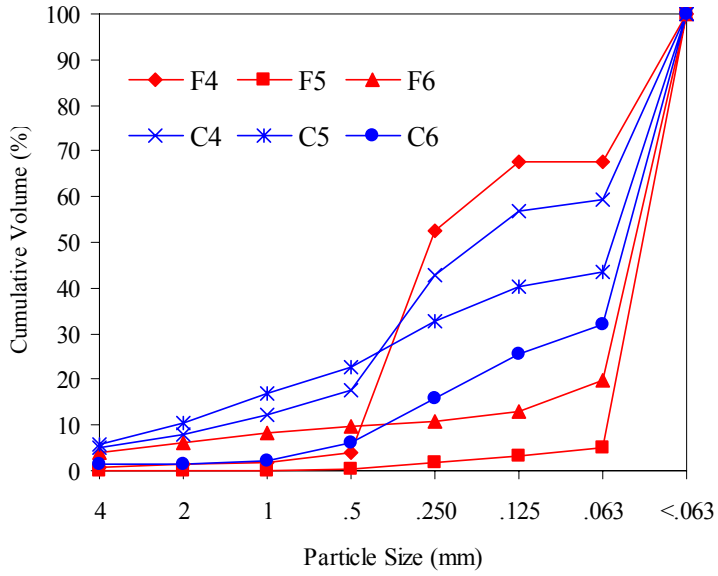

Figure 3-6 Particle size analysis of the top 100 mm of sediment cores from the subtidal farm and control sites in 2005.

4 Water Quality Analysis

4.1 Rainfall

Method

Rainfall for the Port Hurd region was recorded daily throughout the entire monitoring period by Marine Harvest staff. Data was provided to Aquenal in a Microsoft Excel spreadsheet.

Results

The highest rainfall in any one month was recorded in December 2003 when 698.05 mm fell (Figure 4-1). As the last monitoring date to be included in this report was in October 2005, no data is presented for November and December. However it can still be seen from the cumulative rainfall plot that 2005 had less rainfall from January to October than the previous two years (Figure 4-2). The greatest cumulative rainfall was seen in 2003, when a total of 2368.15 mm rain fell.

Interpretation

As expected, rainfall patterns in the Port Hurd region clearly reflect the wet and dry seasons with minimal rainfall from May to October in all years. Season can be a main factor affecting water quality and nutrient levels through changing temperatures and freshwater inflows (Padovan 2003). Therefore it is important to relate rainfall patterns to water quality and nutrient parameters in order to observe any seasonal effects and rule out biological impact.

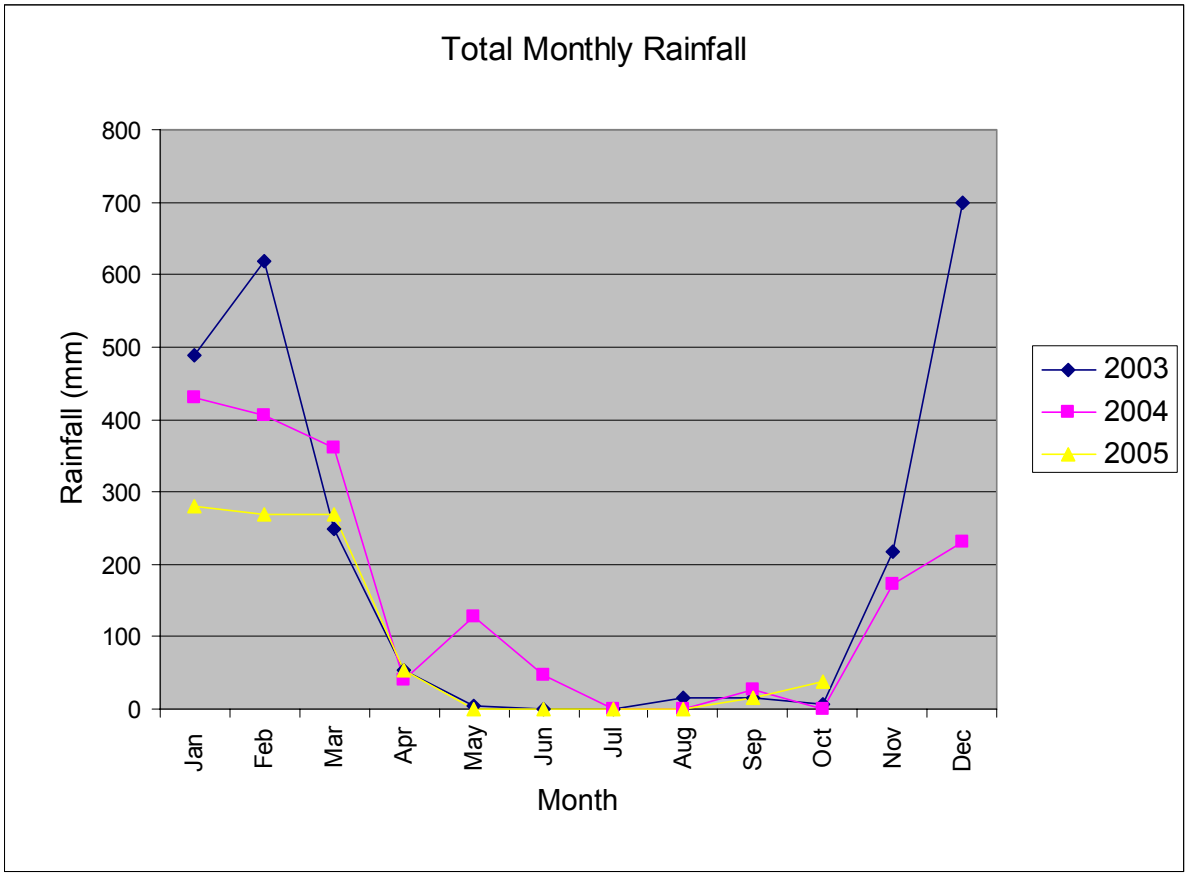

Figure 4-1 Port Hurd total monthly rainfall - January 2003 to October 2005

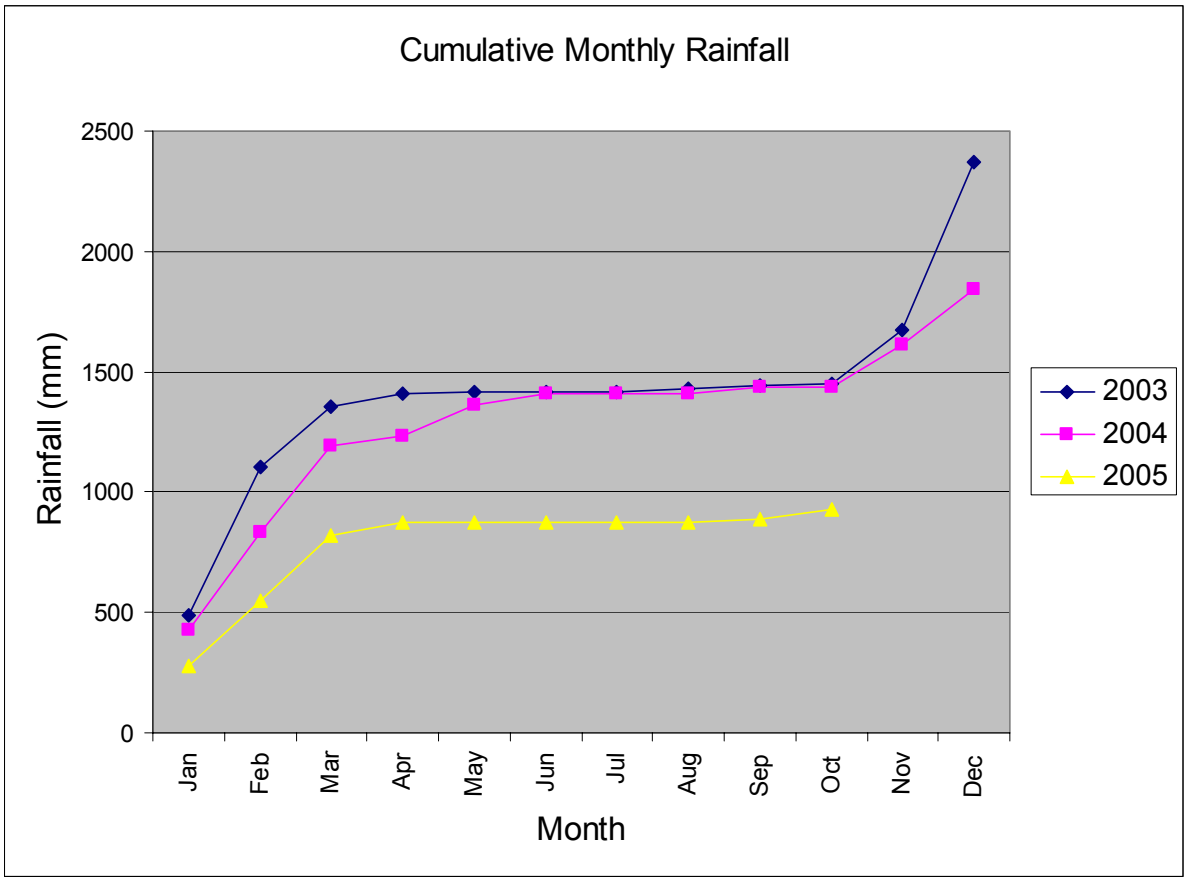

Figure 4-2 Port Hurd cumulative monthly rainfall - January 2003 to October 2005

4.2 Physico-chemical properties

Method

A number of physico-chemical parameters were measured at irregular intervals to enable detection of significant run-off during on-going monitoring, particularly as the wet season set in and assessment of change later in the dry season. Measurements were made using an electronic probe mid way through the ebbing spring 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. Two series of readings were taken 5 minutes apart at each site to assess in-site variability.

Two nearby control sites, C7 and C8, on the southern side of the estuary midline were monitored regularly throughout 2003, 2004 and 2005 rather than the distant control sites in Gullala Inlet. Drogue surveys showed no crossing of the midline of the estuary by water-borne particles during one tidal cycle and indicated a relatively small component of water passing the farm would eventually pass through the midline during the late dry season wind pattern.

Results

Results of monitoring over the past 2 years are presented in Figure 4-4 to Figure 4-6. Some data points in the figures are missing, indicating no value was recorded for that particular parameter on that date. Raw data is presented in Table 7.4-2 to Table 7.4-4.

Salinity ranged from 22.5 ppt ± 0.71 at F4 (27/11/03) to 38.5 ppt ± 0.71 at C8 (3/10/04). Salinity measurements displayed similar variation at all sites throughout the study period with a notable drop recorded at all sites in November 2003 and March 2004. A second slight drop in salinities occurred on the 26/2/2005 (NB: No salinity measurements were taken in March 2005).

The highest and lowest temperatures recorded from all sites during 2003 to 2005 were from F2, ranging from 24.65 °C on 6/7/2004 to 33.4 °C on 17/10/2005. Temperatures from all sites were lowest in June, July and August (2004-2005), with the highest temperatures for all years occurring in October and November (*NB*: there was no temperature data for December or January in any year). There was a slight drop in temperatures at all sites on 11/11/2003, with the greatest variation occurring at F2 where the temperature was 4.85 °C lower than the previous recording of 33 °C on 22/10/2003.

The greatest recorded dissolved oxygen (DO) level for all sites was 96 % at F5 on 19/8/2004. A drop in DO percentages occurred at all sites on 27/11/03, with the lowest DO recorded as 51 % at F2. Dissolved oxygen levels at the F2 farm site were regularly lower than at other sites throughout the monitoring period. There was more variation of DO measurements between sites than seen in the temperature or salinity data, with no clear trend observable. No DO measurements were taken in October of 2003 due to probe faults.

Interpretation

Salinities during the dry season of 2004 were higher than normal marine salinities reflecting high evaporation within the estuary. The drop in salinity at all sites in late 2003 / early 2004 and again in early 2005 can be related to the high rainfall recorded at that time (Figure 4-1 and Figure 4-2). Salinities were generally higher in the dry seasons, and dropped in the wet with no obvious difference between control and farm sites. Michie *et al*. (1991) and Padovan (1997) found that salinities in Darwin Harbour varied according to season with highest salinity, typically 35 ppt, measured in September-October. Lowest salinity was recorded from January to March and, as in this study, coincided with high rainfall and the associated freshwater run-off.

As expected, temperature data displayed a similar pattern to salinity in that temperatures were lower in the dry season and higher in the wet. Padovan (2003) found comparable results in Darwin Harbour where water temperatures were lowest from June to July and highest from October to November. The Padovan study also found that from December to February a decline in temperatures of up to 4 °C could be observed, which he associated with cloud cover and monsoonal activity. The sudden slight drop in temperatures observed in Port Hurd in November 2003 (Figure 4-5) may also have been due to an increase of cloud cover at the time of sampling. There was no obvious difference in temperature between farm and control sites.

Padovan (2003) found that oxygen saturation (%) in Darwin Harbour was typically 84 %, with no observable seasonal effects. In this study, the average percentage of DO in Port Hurd was found to be slightly lower at approximately 76 % with possible seasonal effects. A drop in DO at all sites in November 2003 and October 2004 may be related to the beginning of the wet season and an increase in terrestrial run-off, water movement and the inundation of hitherto oxygen depleted sediments. Similarly, F2 may have appeared less well oxygenated than other sites due to the relatively greater area of mud flats draining into the small creek it is located on, and consequently greater flushing of oxygen depleted

sediments. With the exception of comparatively low F2 values, both control and farm sites displayed similar DO.

Table 4.2-1 Physico-chemical data from surface waters at intertidal and subtidal farm and control sites 7-8th October 2005.

Site	Temperature °C	Conductivity ms/cm	Salinity ppt	DO %sat	DO mg/L	pH
F1	30.0 ± 0.1	56.9 ± 0.1	37.8 ± 0.0	65.4 ± 0.2	3.9 ± 0.0	7.5 ± 0.0
F2	29.0 ± 0.0	57.1 ± 0.1	38.0 ± 0.0	56.6 ± 0.3	3.4 ± 0.0	7.5 ± 0.0
F3	30.6 ± 0.0	55.9 ± 0.0	37.1 ± 0.0	69.2 ± 0.1	4.1 ± 0.0	7.4 ± 0.0
F4	30.2 ± 0.0	55.7 ± 0.0	36.9 ± 0.0	63.3 ± 0.3	3.8 ± 0.0	7.4 ± 0.0
F5	30.9 ± 0.0	56.4 ± 0.0	37.5 ± 0.0	80.9 ± 0.5	4.8 ± 0.0	7.6 ± 0.0
F6	30.5 ± 0.0	56.5 ± 0.0	37.5 ± 0.0	68.7 ± 1.4	4.1 ± 0.1	7.5 ± 0.0
C1	29.9 ± 0.1	55.5 ± 0.1	36.8 ± 0.0	62.5 ± 0.2	3.7 ± 0.1	7.4 ± 0.0
C2	29.7 ± 0.2	53.5 ± 0.3	35.3 ± 0.2	50.9 ± 0.5	3.0 ± 0.1	7.1 ± 0.0
C3	30.5 ± 0.1	54.8 ± 0.0	36.3 ± 0.0	63.8 ± 0.5	3.8 ± 0.0	7.2 ± 0.0
C4	29.7 ± 0.0	54.4 ± 0.0	36 ± 0.0	57.6 ± 0.7	3.4 ± 0.1	7.3 ± 0.0
C5	30.1 ± 0.0	55.2 ± 0.0	36.6 ± 0.0	68.1 ± 0.2	4.1 ± 0.0	7.5 ± 0.0
C6	30.4 ± 0.0	55.6 ± 0.0	36.9 ± 0.0	76.3 ± 0.0	4.5 ± 0.1	7.7 ± 0.0
C7	30.6 ± 0.0	56.6 ± 0.1	37.6 ± 0.0	68.5 ± 0.3	4.0 ± 0.1	7.4 ± 0.0
C8	31.5 ± 0.0	56.6 ± 0.1	37.6 ± 0.0	74.9 ± 1.5	4.4 ± 0.1	7.5 ± 0.0

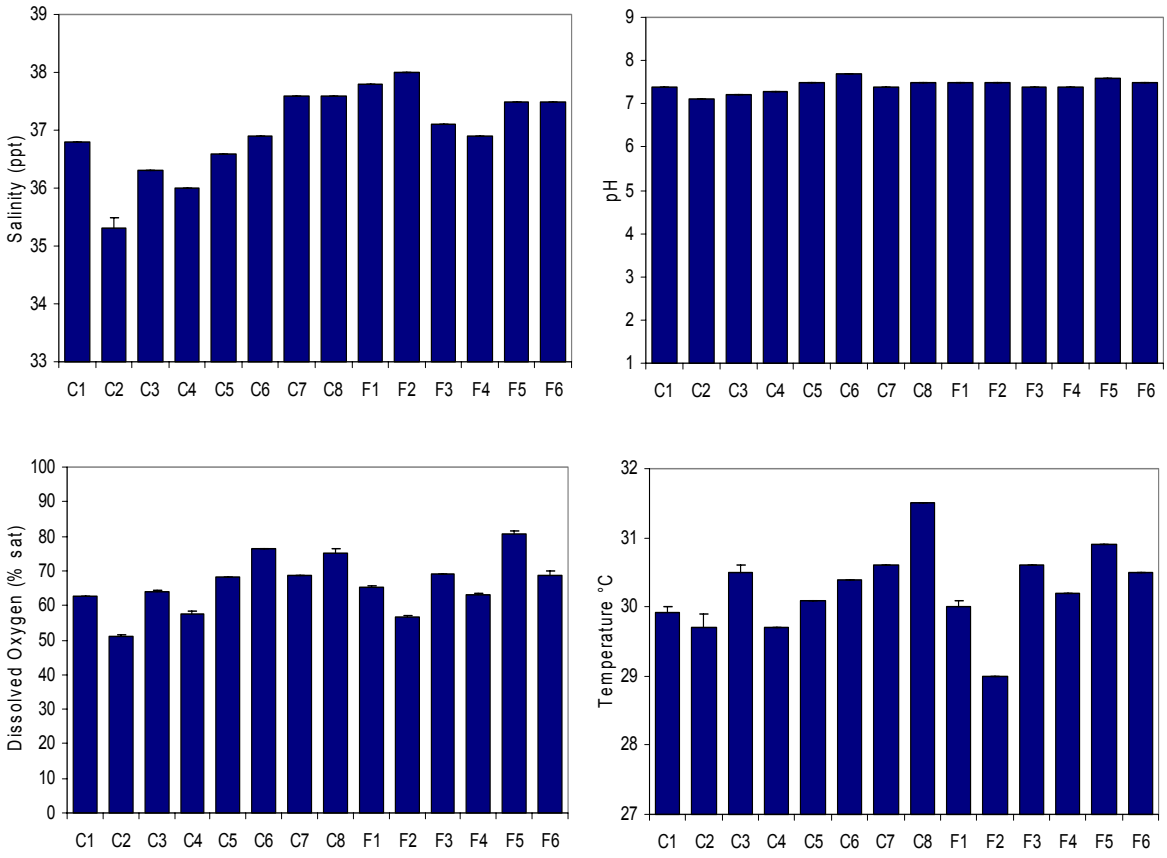

Figure 4-3 Physico-chemical data from surface waters at intertidal and subtidal farm and control sites 7-8th October 2005.

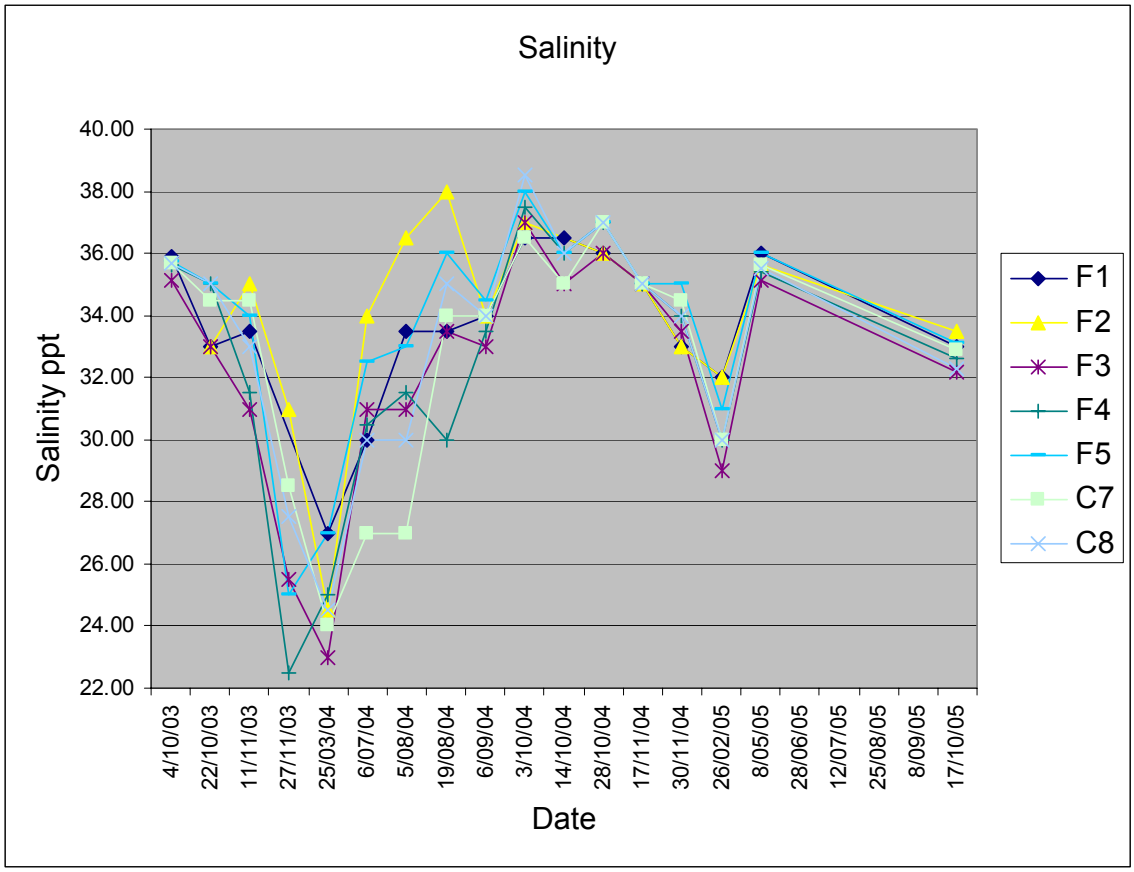

Figure 4-4 Port Hurd salinity data 2003 - 2005

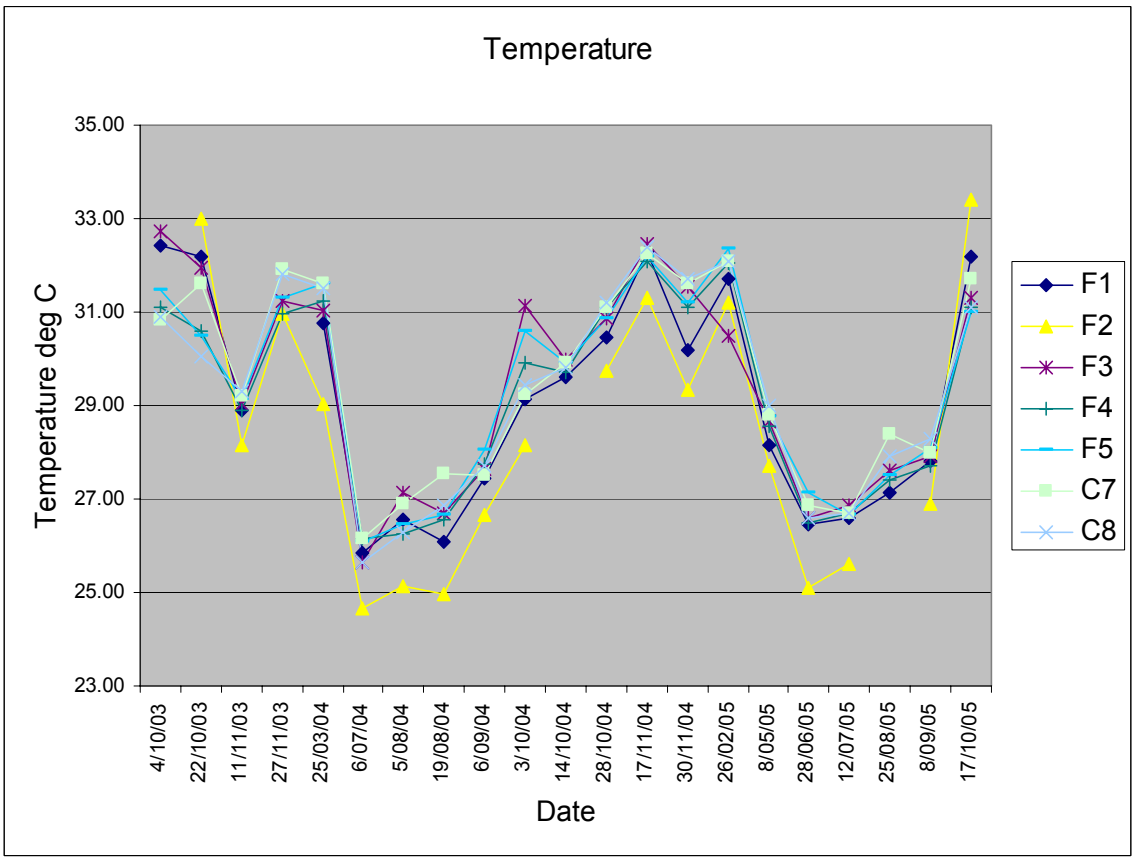

Figure 4-5 Port Hurd temperature data 2003 - 2005

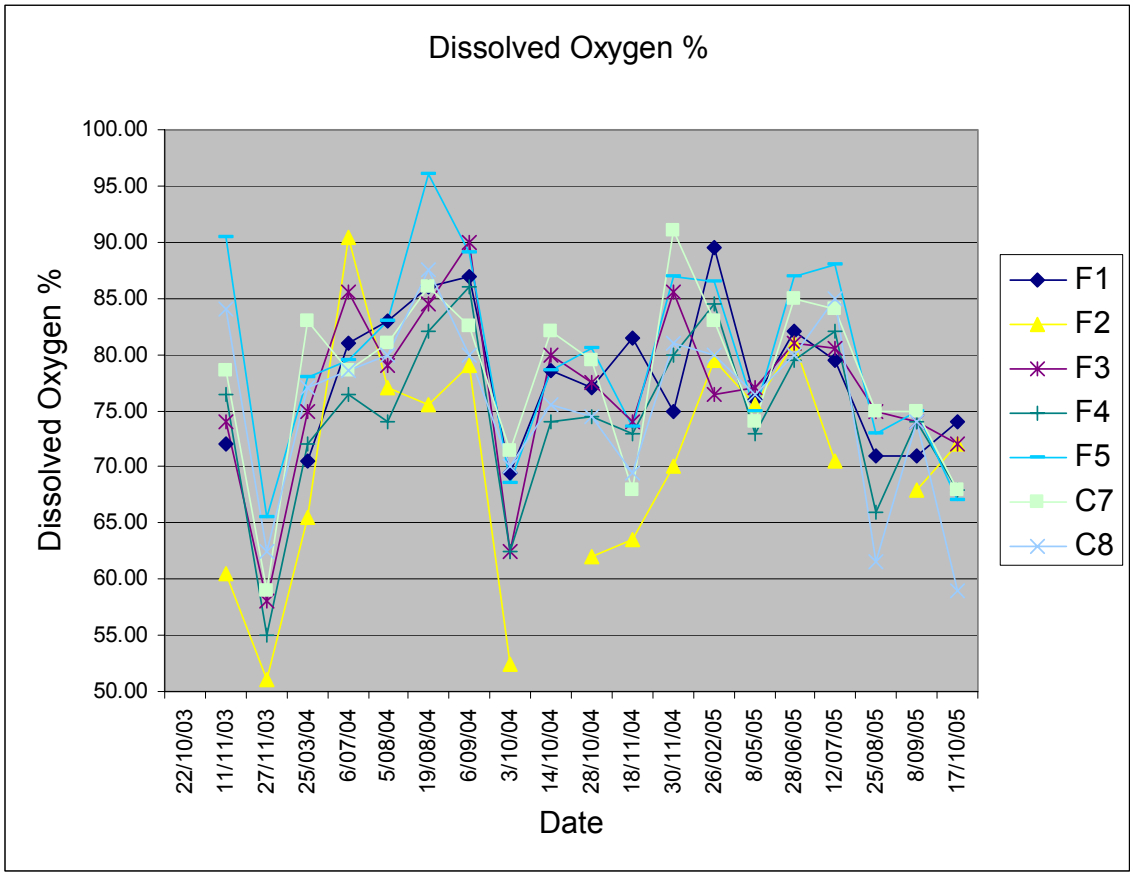

Figure 4-6 Port Hurd dissolved oxygen data 2003 - 2005

4.3 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 – measured as nitrate, nitrite (NO_X) and total ammonia nitrogen (TAN) – from 0.3 m below the surface in clean plastic bottles at shallow water sites and 0.5 m above the seabed in a Nisken bottle then transferred to clean plastic bottles 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 could be frozen at the shore base. They were kept frozen until they were delivered for processing to the Northern Territory Government Berrimah Farm Water Laboratory for analysis.

Following is a brief explanation of the relationship between the nutrients measured and bioavailable waterborne nutrients. NO_X is the sum of the two oxides of nitrogen and is measured by reducing all nitrates to nitrite and analysing the nitrite. To measure nitrate, NO_X is analysed as above then nitrite is analysed and subtracted from NO_X. The nitrate to nitrite ratio normally approximates 10:1. The occurrence of the different ammonia forms depends on pH. At the pH of average seawater ~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 total ammonia nitrogen (TAN) and NH_4^+ are equivalent in seawater. Total dissolved inorganic nitrogen (DIN) is the sum of NO_X and TAN. DIN gives a better indication of bioavailable nutrient concentration than Total N which includes bound organic nitrogen and is therefore a better indicator of conditions conducive to algal blooms (Eyre, 2000; Harris, 1994), see also the footnotes and reference to bioavailable nutrient concentrations in the ANZECC guidelines Interim Trigger Levels in their Table 3.3.2.

Results

Nitrate levels ranged from 0.00 mg/L to 0.03 mg/L at all sites with the exception of two notable spikes. These occurred at F5 and C8 on the 13/10/2003 and 28/11/2003 with nitrate levels reaching 0.040 mg/L, and again at F5 on 26/3/2004 where levels reached 0.043 mg/L (Figure 4-7 and Table 7.4-5). All sites with recorded values showed an increase in nitrate levels in October and November 2003, as well as in August 2005.

A distinct increase in nitrite levels occurred at F5 and C8 on 26/3/2004 where 0.055 mg/L was recorded at both sites (Figure 4-8). Apart from this, nitrite levels were uniformly low throughout 2003 to 2005, remaining at 0.010 mg/L or below at all sites (Table 7.4-6).

Ammonia levels peaked at F4, F5 and C8 on 3/10/2004, reaching 0.153 mg/L, 0.220 mg/L and 0.193 mg/L respectively. On all other sampling occasions, ammonia levels were approximately 0.100 mg/L or below (Figure 4-10).

The greatest total dissolved inorganic nitrogen (DIN) levels were recorded at F4, F5 and C8 on 3/10/2004, with F5 recording the highest concentration of 0.23 mg/L (Figure 4-11). With the exception of F2, all sites displayed a second spike in DIN levels in August 2005. F5 and C8 had the greatest averaged total nitrogen levels throughout 2003, 2004 and 2005.

Interpretation

ANZECC draft guidelines for Interim Trigger Levels (ITL) for nutrients in slightly to moderately disturbed estuaries and coastal waters are given in Table 4.3-1 (ANZECC, 1999). Total N includes organic nitrogen which is not readily bioavailable so is normally greater than DIN. As Port Hurd is flushed by 7 m tides twice per day 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 during the dry season when no run-off enters the estuary. 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 and taking the conservative approach, NO_X levels were above the ITL for estuaries at all sites at some stage throughout the monitoring period. There were two sites where NO_X levels exceeded the coastal and marine ITL, one of which was a control site.

As with NO_X, ammonia levels in Port Hurd regularly exceed the ITL for both estuaries and coastal and marine ecosystems. This is further justification for using either levels nearer those for coastal waters, or collecting control site data as a reference. It should be noted that ANZECC trigger levels presented below are for ammonium (NH_4), however the same levels can be applied to ammonia (NH_3).

Total dissolved inorganic nitrogen (DIN) values were above the estuarine ITL for total N at the majority of sites, but remained below the coastal and marine limits. As total N includes bound organic nitrogen as well as inorganic nitrogen, it can be assumed that if DIN values exceed ITL, then total N values would also. Although a number of large spikes in total N occurred, these did not appear to be related to season. Total N measured in Darwin Harbour from 2001 to 2004 found only a slight difference between the seasons with an average of 0.17 mg/L in the dry season and 0.15 mg/L in the wet (Water Monitoring Branch 2005).

A number of spikes in various nutrients were recorded at the deepwater sites F4, F5 and C8 with values at C7 showing lesser spikes. It should be noted that C7 and C8 are in a creek on the south side of Port Hurd, not in Gullala Inlet where C1 to C6 are. At this stage no explanation is apparent. Ongoing monitoring will be beneficial in detecting any further trend.

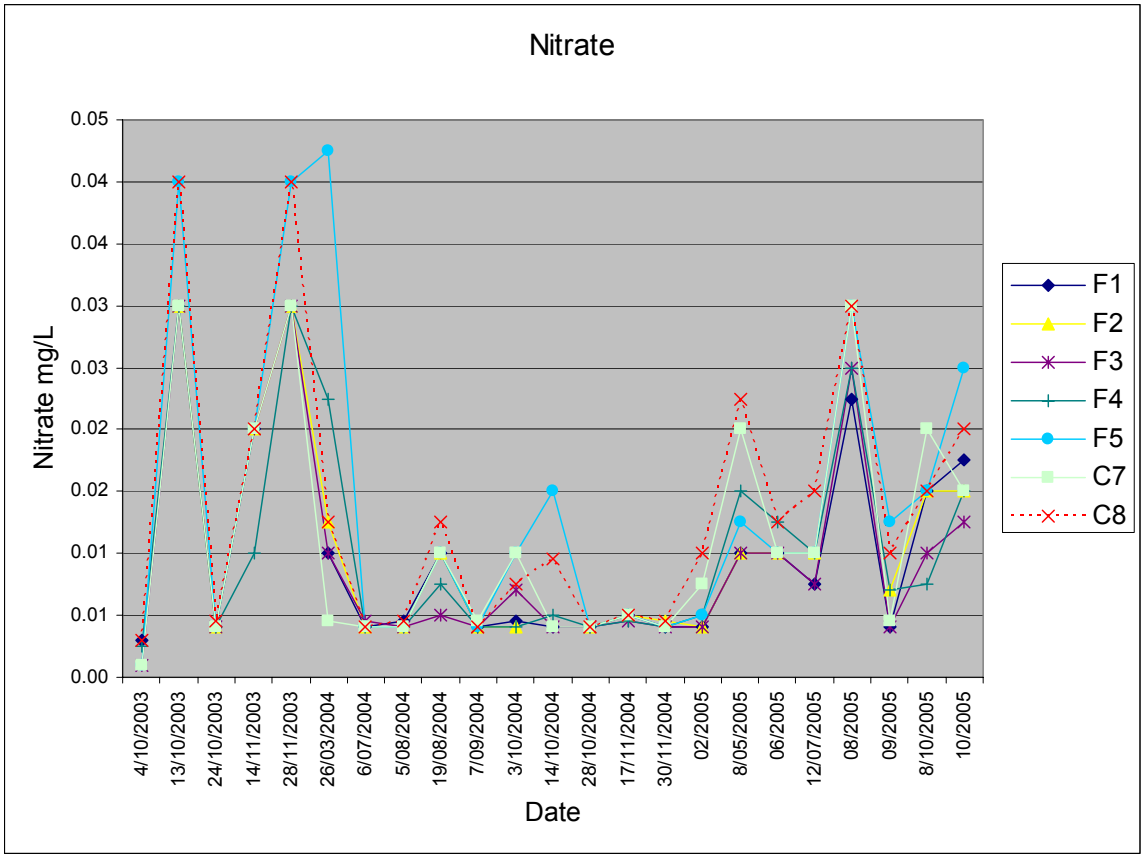

Figure 4-7 Port Hurd nitrate data 2003 - 2005

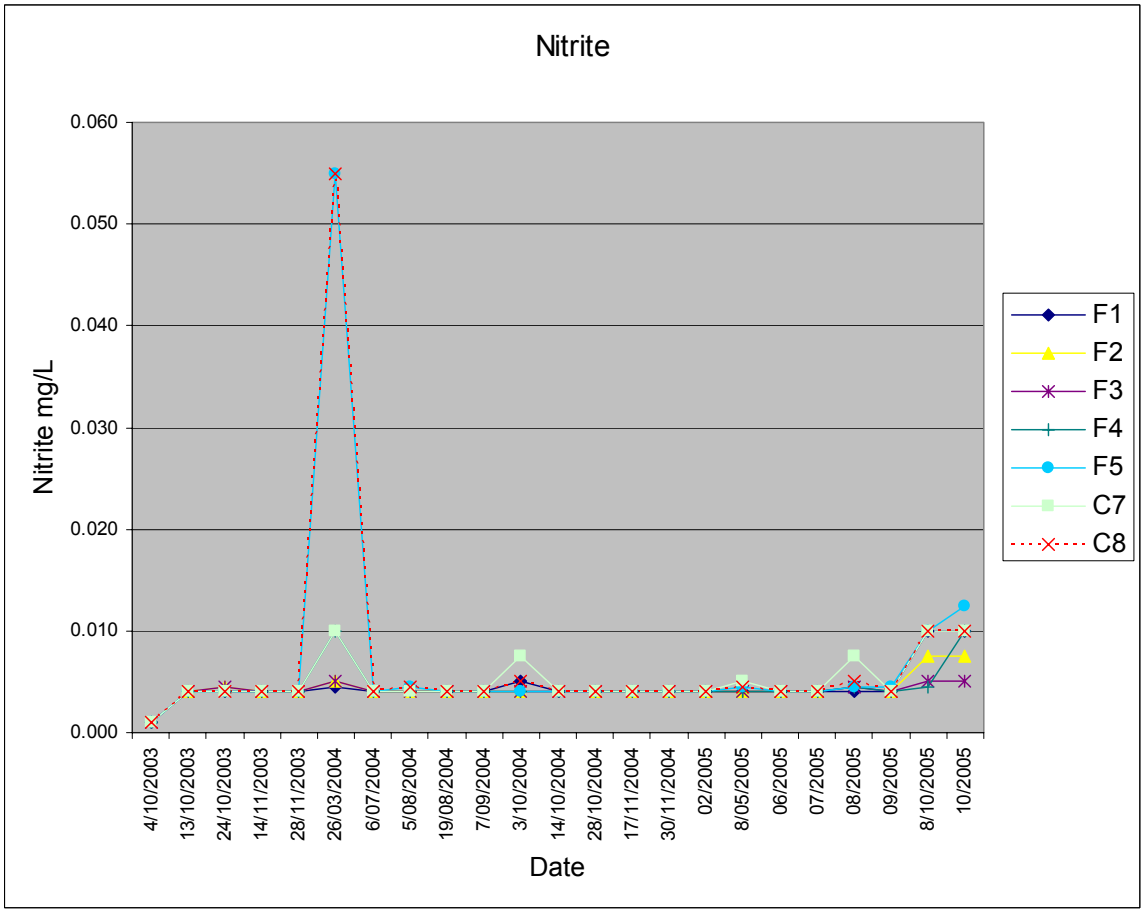

Figure 4-8 Port Hurd nitrite data 2003 - 2005

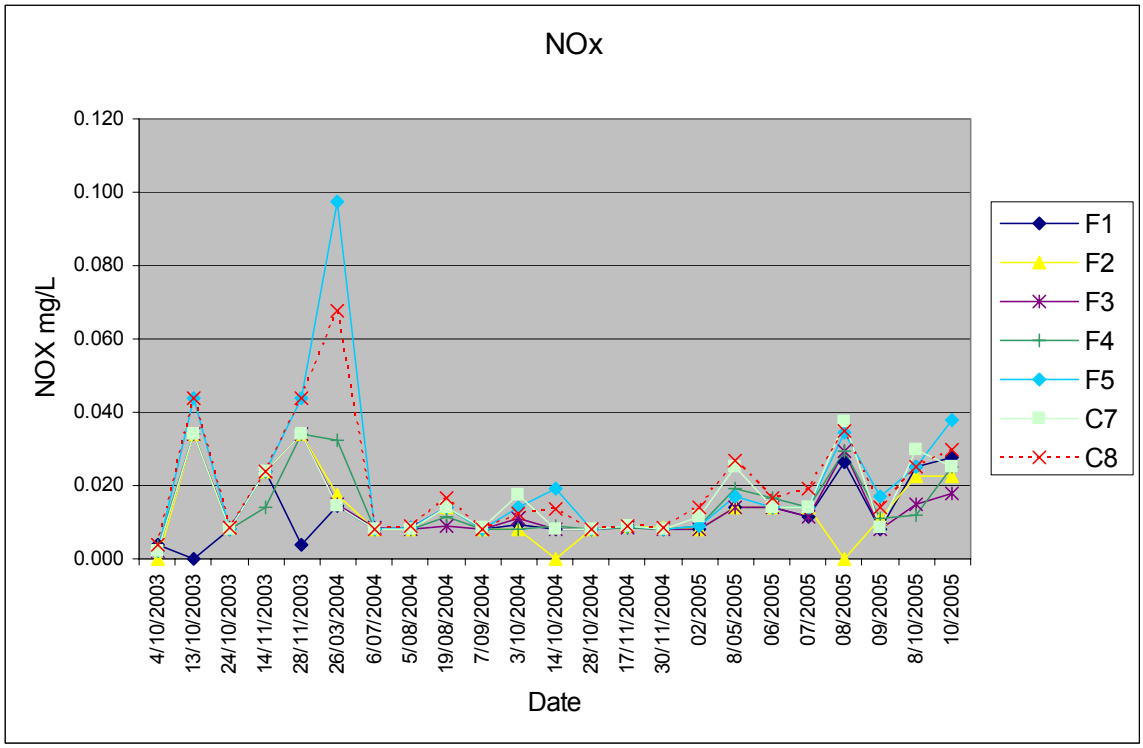

Figure 4-9 Port Hurd NOx data 2003 - 2005

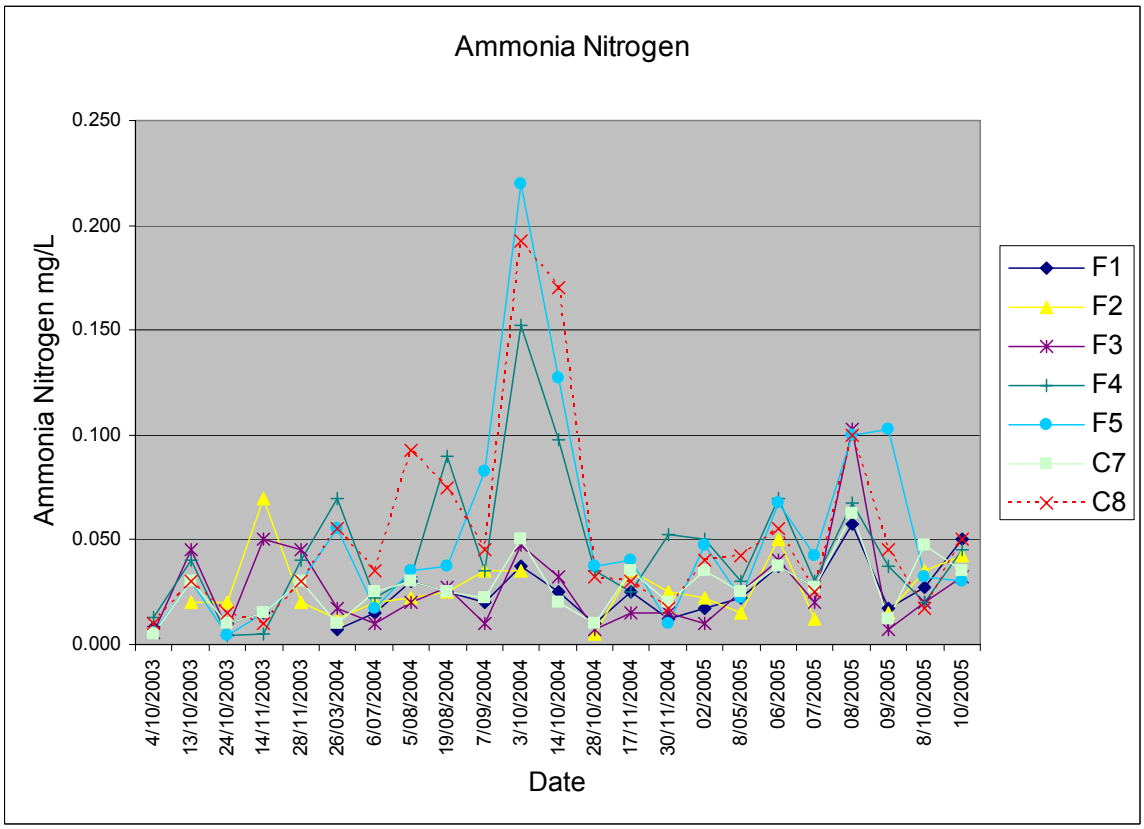

Figure 4-10 Port Hurd ammonia nitrogen data 2003 - 2005

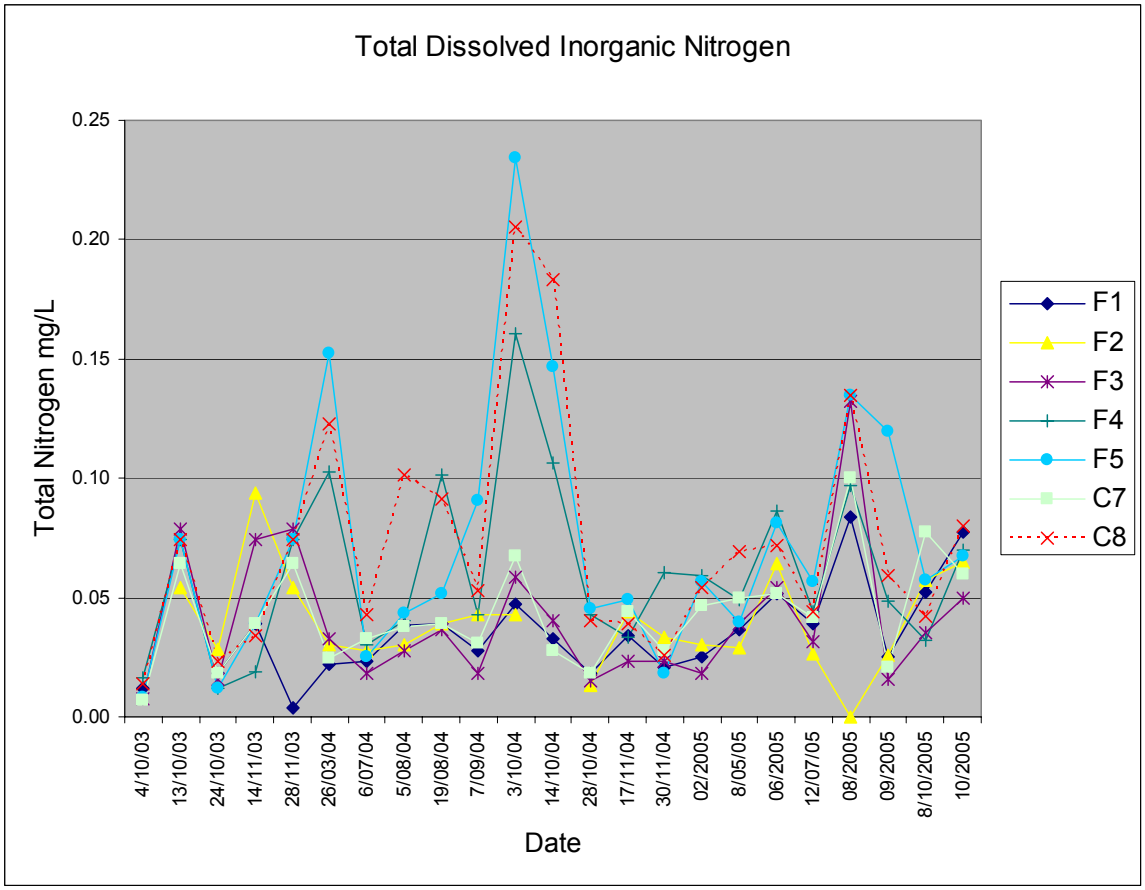

Figure 4-11 Port Hurd total dissolved inorganic nitrogen data 2003 - 2005

Table 4.3-1 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	0.080	0.005	0.020
Coastal & marine	0.350	0.060	0.040

4.4 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 for chlorophyll analysis were collected concurrently with, and in the same manner as, nutrient samples. As soon as the water samples were collected they were sealed and placed in an esky on ice to stay chilled and in the dark until they were processed. The samples were filtered at the fish farm 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 frozen until it was analysed for Chlorophyll α at the Northern Territory Government Berrimah Farm Water Laboratory.

Results

These results include two sets of data; those from samples collected during the 2003 and 2005 EIA's (EIA data) and those collected periodically through the two years between 2003 and 2005 (monitoring data). The EIA's sampled 6 farm sites and 8 control sites including those in Gullala Inlet. The monitoring sampled 3 farm sites and 2 control sites in a small creek entering the southern shore of Port Hurd. Table 4.4-1 contains the EIA data while Figure 4-12 and Table 7.4-10 contain data from both sets. There are various gaps in the data sets due to the difficulty of access and logistics involved in sample collection. F2 and F6 were not sampled in the 2003 EIA and measurements of chlorophyll α levels were taken on three occasions only at F4 during the two year monitoring period, and twice only at the deepwater sites F5 and C8.

Monitoring data indicates an overall increase in chlorophyll α levels at all sites from 2003 to 2005 as can be seen in Figure 4-12. The highest level recorded during the monitoring period was 7.5 μg/L at both F3 (17/11/2004) and C7 (02/2005) (Figure 4-12 and Table 7.4-10), while a level below the detection threshold of 1 μg/L was recorded at several sites in sampling prior to November 2003. A peak in chlorophyll α levels at all regularly monitored sites was observed in March 2004. Data collected for the EIA's found a slight rise from an average of 2.8 to 3.3 μg/L at Port Hurd farm sites associated with an insignificant rise from an average of 2.3 to 2.4 μg/L at Gullala control sites. Chlorophyll α levels found at C7 and C8 in the EIA sampling were the highest in that survey, with values of 8.9 and 16.3 μg/L recorded at C7. Given these C7 values were not seen again it is assumed the samples were unreliable. Values recorded during monitoring were often higher at C7 than the farm sites.

Interpretation

The EAI data are within the range of data collected in a similar survey at Snake Bay on Melville Island (generally 3 to 4 μg/L) but higher than those collected in similar surveys at Doug Point in Port Patterson and Channel Island in Darwin Harbour (<2 μg/L). Other studies of Darwin Harbour have found concentrations of chlorophyll α within the main Harbour to be uniformly low throughout the year (1-2 μg/L) with no apparent seasonal pattern (Wrigley *et al*. 1990, Padovan 1997, Parry and Munksgaard 1999 in Padovan 2003). Another water monitoring project in Darwin Harbour found an average chlorophyll

α value for the 2003 - 2004 sampling period of 1.09 ± 0.9 µg/L (AIMS 2005). Monitoring studies in 3 tidal tributaries to Darwin Harbour have found levels up to 10 µg/L averaging 5 µg/L between 1996 and 1998 (Parry and Munksgaard, 1999).

Draft ANZECC Interim Trigger Levels for slightly to moderately disturbed ecosystems are 2 µg/L for estuaries and 0.3 µg/L for coastal and marine waters. (Table 3.3.2, ANZECC 1999). However these were exceeded in the four mangrove estuaries surveyed on Bathurst and Melville Islands.

Monitoring data found that in 2003 in Port Hurd, chlorophyll α levels generally remained below the draft ANZECC Interim Trigger Levels for estuaries. However in 2004 and 2005, the trend of increasing chlorophyll α levels at both farm and control sites within Port Hurd meant the majority of values were above the trigger levels (Figure 4-12 and Table 7.4-10). Padovan (1997) found chlorophyll α concentrations varied with tide cycle with highest levels recorded during the mid point of a spring tide. This may explain small variations in chlorophyll α levels within a short period in Port Hurd, however it does not explain the overall increase in chlorophyll α levels at both farm and C7 and C8 in 2004 and 2005.

This general rise in chlorophyll α levels in 2004 and 2005 was not obviously related to other parameters included in this study and cannot be directly attributed to farm operations as values at the control site in a creek on the opposite side of the estuary were often higher than the farm sites. However it is of concern and levels should continue to be regularly monitored at all Port Hurd sites to assess any further increase over time. If levels continue to rise a set of samples from Gullala Inlet should be assessed to gather control values.

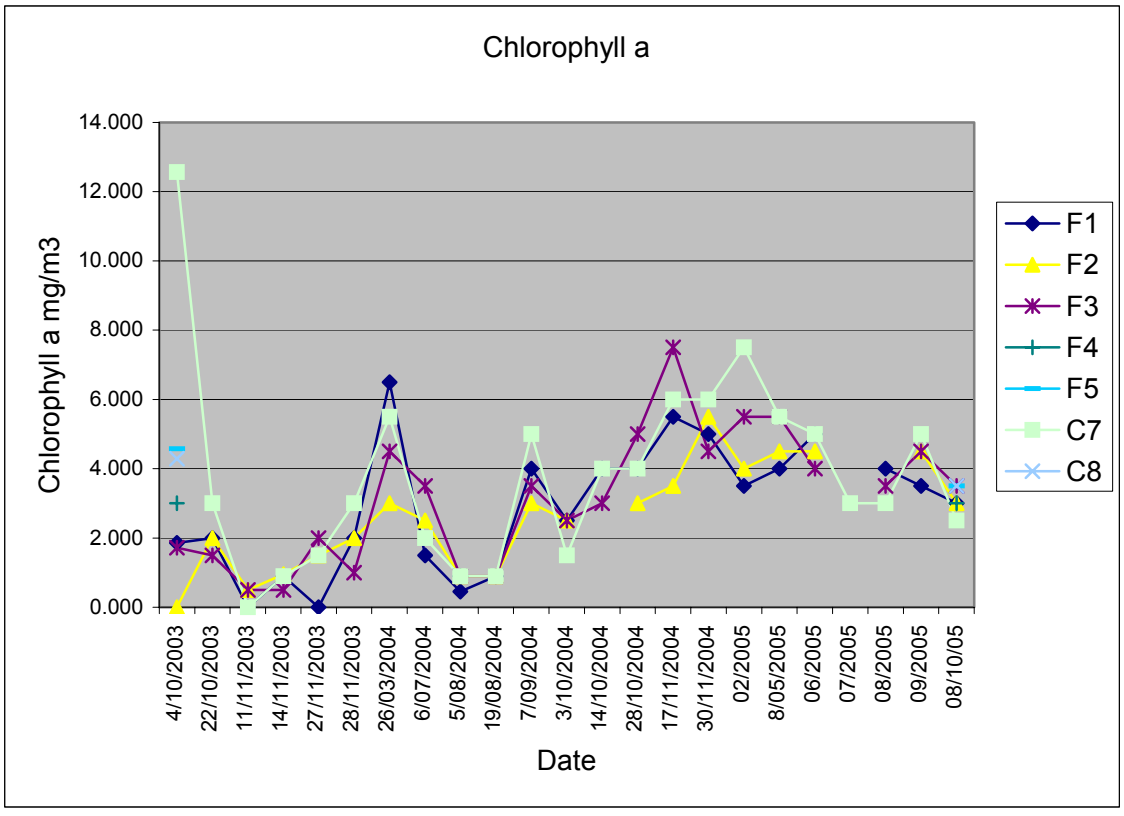

Figure 4-12 Port Hurd chlorophyll α data 2003-2005. Note: Chlorophyll units equate to µg/L.

Table 4.4-1 Port Hurd chlorophyll α data October 2003 and October 2005. Note: results from C7 and C8 are not included in the Mean or SD calculations.

Site	Chlorophyll α		Site	Chlorophyll α	
Units	μg/L			μg/L	
Year	2003	2005		2003	2005
F1	2.0	3	C1	3.7	2
F1	1.7	3	C1	2.9	2
F2	NR	3	C2	2.3	2
F2	NR	3	C2	1.4	2
F3	2.3	3	C3	2.0	3
F3	1.1	4	C3	1.7	3
F4	2.9	3	C4	1.7	2
F4	3.1	3	C4	2.0	2
F5	4.6	4	C5	2.6	2
F5	4.6	3	C5	2.6	3
F6	NR	4	C6	2.0	3
F6	NR	3	C6	3.1	3
			C7	8.9	2
			C7	16.3	3
			C8	4.6	3
			C8	4.0	4
Mean	2.8	3.3	Mean	2.3	2.4
SD	1.3	0.5	SD	0.7	0.5

5 Biological Analysis

5.1 Mangrove stand structure and composition

Method

Mangrove stand structure and composition were recorded at sites estimated to be most indicative of the various assemblages in the estuary in areas considered most likely to show impact by nutrients from Marine Harvest's aquaculture operations. 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 involves 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, 0.75. 0.5 or 0.25, was selected that counted 30 to 55 trees per sweep. All trees greater than or equal to the gap were counted, including borderline trees. Trees were identified to species and their diameter at breast height (DBH cm), height (m), status (dead or alive) and condition recorded. DBH was measured at 1.3 m 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 it 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

Mangrove transects were surveyed at three sites (two near farm and one remote from farm) in Port Hurd and two representative control sites in Gullala Creek. Transects were surveyed to determine stand structure and composition using the ACC method at three to four sweep sites across the various vegetation zones. The number of sweep sites depended on the width of the mangrove belt and the distance apart the sites must be so few individual trees were counted in more than one sweep. Transects were located using GPS adjacent to the intertidal sample sites of the same name. A mangrove tree at the seaward end was marked with a labelled orange cattle tag and the direction of the transect from this tag recorded. Each of the three to four sweep sites was marked similarly on the nearest tree and its distance along the transect was recorded. The first sweep site 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 as to species and measured for diameter, height, status and

condition and five randomly selected trees were tagged for future measurement. Only trees counted using the ACC method were identified and assessed.

Results

Mangrove condition data show a 350% increase in trees with crown damage, a 39% increase in trees with dead branches and a 65% increase in leaning trees from 2003 to 2005 (Table 5.1-1, Figure 5-1). 8% more trees were counted in 2005 than in 2003 but 6.2% were dead therefore there condition not assessed compared 2.7% in 2003. The average Total basal Area and Dominance of the most dominant species did not change significantly, increasing slightly from 20.0 to 20.3 m2/ha and decreasing from 78.4% to 76.2% respectively (Table 5.1-2 and Table 5.1-3). The were 2 sites where there was a change in dominant species. At C1-6 *Bruguiera exaristata* and *Rhizophora* sp. grew in equal numbers in 2003 but *Bruguiera exaristata* was slightly dominant whereas in 2005 *Rhizophora* sp. had out grown and dominated the site. The mean height at that site had increased from 6.7 to 8.7m during the period. At C1-22 *Rhizophora* sp. dominated in 2003 but by 2005 numbers of small *Ceriops* sp. had proliferated and now dominate. A change in the dominance between the second and third most dominant species was observed at C1-13. Raw data for each site from the 2005 survey are presented in Table 7.5-1 to Table 7.5-19.

Interpretation

The main parameters showing change over the period 2003 to 2005 are the numbers of damaged and dead trees. These were most probably caused by a cyclone which passed directly over the survey sites in 2004. Several large trees at the survey sites were completely uprooted and many snapped off a metre or two above the ground. In subsequent years this may cause a change in species dominance or increase in stem density as the damaged canopy allows increased sunlight to reach the forest floor. The changes in dominance at 3 control sites reflect natural evolution of maturing stand composition. At this stage no changes attributable to marine farming are apparent.

Table 5.1-1 Condition index count for mangroves at each site in 2003 and 2005

	Condition													
	Healthy		Trunk rot		Crown damage		Overmature		Senescent		Dead branches		Leaning	
Site	2003	2005	2003	2005	2003	2005	2003	2005	2003	2005	2003	2005	2003	2005
F1-12	24	38	0	0	0	2	4	1	0	0	2	13	6	8
F1-23	32	34	0	0	0	3	0	0	0	0	0	1	13	2
F1-35	48	68	0	0	0	0	0	1	0	0	0	2	18	11
F1-50	35	29	0	3	0	4	0	2	0	0	0	2	0	5
F2-7	31	23	0	1	0	3	0	3	0	1	0	3	0	12
F2-18	23	35	1	0	1	4	3	1	0	0	4	3	8	16
F2-37	26	27	2	0	0	1	0	0	0	0	4	0	0	0
F2-45	26	37	2	0	2	6	0	1	0	0	7	1	0	0
F3-17	26	19	0	0	0	2	0	3	0	0	0	5	0	8
F3-24	28	23	0	0	0	4	0	2	0	0	0	3	0	5
F3-34	25	21	0	0	5	6	0	0	0	0	4	4	6	2
F3-50	44	48	0	0	0	8	0	0	0	0	0	6	1	1
C1-6	39	39	0	0	4	12	5	2	0	0	2	5	6	11
C1-13	24	32	0	0	3	10	0	0	0	0	1	3	4	10
C1-22	15	20	0	0	3	13	0	1	0	0	5	6	0	2
C2-15	32	25	0	0	4	17	0	1	0	0	2	5	1	12
C2-29	23	23	0	0	3	10	0	0	0	0	4	4	3	0
C2-38	26	30	0	0	1	10	0	0	1	0	9	4	0	3
C2-50	27	25	0	0	0	2	0	0	0	0	7	1	0	1
TOTAL	554	596	5	4	26	117	12	18	1	1	51	71	66	109

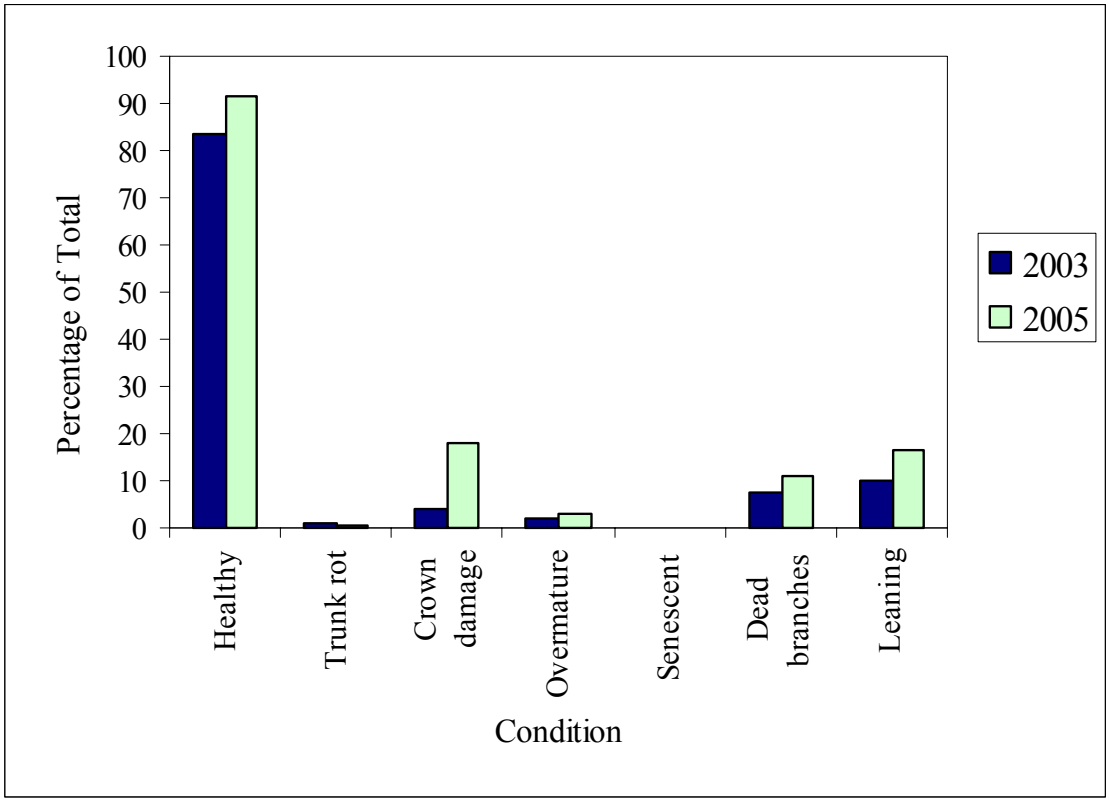

Figure 5-1 Condition of mangrove trees at all sites in 2003 and 2005. Percentage of trees is calculated based on the total number of trees assigned a condition.

Table 5.1-2 Mangrove stand structure and composition using ACC method at control and farm sites in 2003

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	12	225	2/10/2003	22.5	22.5	0.0	0.0	100.0	0.0	0.0	1412.4	1412.4	0.0	0.0	0.0	10.8
F1	23	225	2/10/2003	24.0	24.0	0.0	0.0	100.0	0.0	0.0	2751.6	2751.6	0.0	0.0	0.0	9.7
F1	35	225	2/10/2003	12.0	10.3	1.5	0.0	85.4	12.5	0.0	9915.0	2270.0	7612.0	0.0	0.0	7.9
F1	50	225	2/10/2003	8.8	8.5	0.3	0.0	97.1	2.9	0.0	1902.9	1879.0	24.0	0.0	0.0	5.6
F2	7	20	4/10/2003	23.3	23.3	0.0	0.0	100.0	0.0	0.0	1596.4	1596.4	0.0	0.0	0.0	8.8
F2	18	20	4/10/2003	39.0	39.0	0.0	0.0	100.0	0.0	0.0	11737.6	11737.6	0.0	0.0	0.0	6.6
F2	37	20	4/10/2003	8.0	8.0	0.0	0.0	100.0	0.0	0.0	13651.6	13651.6	0.0	0.0	0.0	3.6
F2	45	20	4/10/2003	8.8	8.8	0.0	0.5	100.0	0.0	5.7	10494.0	10309.7	0.0	184.3	1.8	3.5
F3	17	125	2/10/2003	26.0	17.0	9.0	0.0	65.4	34.6	0.0	6928.8	999.0	5930.0	0.0	0.0	8.1
F3	24	125	2/10/2003	23.3	13.5	8.3	2.3	58.1	35.5	9.7	5265.7	2025.0	2571.0	670.0	12.7	7.4
F3	34	125	2/10/2003	19.0	10.5	5.5	2.5	55.3	28.9	13.2	3240.4	1145.0	1274.0	423.7	13.1	7.2
F3	50	125	2/10/2003	11.5	6.0	5.0	0.5	52.2	43.5	4.3	6901.8	3576.0	3071.0	255.5	3.7	5.7
C1	6	75	3/10/2003	26.0	12.5	11.0	2.0	48.1	42.3	7.7	4737.5	3658.0	711.0	324.5	6.8	6.7
C1	13	76	4/10/2003	16.0	3.3	2.3	1.0	20.3	14.1	6.3	13248.5	1672.0	1488.0	828.0	6.2	5.1
C1	22	77	5/10/2003	12.0	8.0	3.0	0.5	66.7	25.0	4.2	24650.6	900.0	22267.9	39.5	0.2	4.6
C2	15	5	3/10/2003	27.0	25.5	1.5	0.0	94.4	5.6	0.0	2113.4	1750.0	363.0	0.0	0.0	9.7
C2	29	5	3/10/2003	22.5	17.3	5.3	0.0	76.7	23.3	0.0	22814.1	3035.0	19779.0	0.0	0.0	6.0
C2	38	5	3/10/2003	27.8	25.5	0.8	0.8	91.9	2.7	2.7	21981.2	16537.0	2645.2	1973.0	9.0	5.7
C2	50	5	3/10/2003	23.3	18.0	3.0	1.5	77.4	12.9	6.5	29344.3	17261.0	6704.2	2991.4	10.2	4.8

Table 5.1-3 Mangrove stand structure and composition using ACC method at control and farm sites in 2005

Transect	Distance	Bearing	Date	TBA	BA Sp1	BA Sp2	BA Dead	Dom Sp1	Dom Sp2	Dom Dead	TSD	SD Sp1	SD Sp2	SD Dead	Ratio Dead	Mean Ht
	m	Deg mag		m2/ha	m2/ha	m2/ha	m2/ha	%	%	%	SD/ha	SD/ha	SD/ha	SD/ha	%	m
F1-1	12	255	7/10/2005	30.8	30.0	0.0	0.8	97.6	0.0	2.4	2435.3	2435.3	0.0	0.0	0.0	11.4
F1-2	23	255	7/10/2005	26.3	25.5	0.0	0.8	97.1	0.0	2.9	4539.1	4157.2	0.0	382.0	8.4	11.0
F1-3	35	255	7/10/2005	17.5	14.8	1.8	0.3	84.3	10.0	1.4	9005.2	5131.0	3693.8	180.4	2.0	7.0
F1-4	50	255	7/10/2005	15.5	14.5	1.0	0.0	93.5	6.5	0.0	3272.6	3224.7	47.9	0.0	0.0	5.7
F2-1	7	20	8/10/2005	21.8	20.3	0.0	1.5	93.1	0.0	6.9	1153.6	1113.9	0.0	39.7	3.4	8.1
F2-2	18	20	8/10/2005	36.0	36.0	0.0	0.0	100.0	0.0	0.0	7480.1	7480.1	0.0	0.0	0.0	6.8
F2-3	37	20	8/10/2005	8.0	8.0	0.0	0.0	100.0	0.0	0.0	26291.8	26291.8	0.0	0.0	0.0	3.3
F2-4	45	20	8/10/2005	10.0	9.8	0.0	0.3	97.5	0.0	2.5	11913.9	11840.8	0.0	73.1	0.6	3.7
F3-1	17	125	8/10/2005	27.0	16.0	7.0	4.0	59.3	25.9	14.8	7722.2	1217.7	6333.3	171.1	2.2	8.7
F3-2	24	125	8/10/2005	21.8	14.3	4.5	2.3	65.5	20.7	10.3	5919.9	2280.0	2472.5	1167.0	19.7	8.5
F3-3	34	125	8/10/2005	14.0	9.0	3.5	1.5	64.3	25.0	10.7	2799.4	971.0	913.9	435.8	15.6	7.9
F3-4	50	125	8/10/2005	13.8	7.0	5.3	1.0	50.9	38.2	7.3	13236.6	8769.4	4004.6	462.6	3.5	5.2
C1-1	6	275	9/10/2005	23.0	14.5	6.0	2.0	63.0	26.1	8.7	4504.7	1908.6	1898.8	697.3	15.5	8.7
C1-2	13	250	9/10/2005	8.8	4.0	2.8	0.3	45.7	31.4	2.9	12983.7	4506.8	8445.1	31.8	0.2	5.8
C1-3	22	75	9/10/2005	12.0	7.0	4.0	0.5	58.3	33.3	4.2	47826.5	47143.9	640.5	42.1	0.1	3.7
C2-1	15	20	9/10/2005	27.0	21.8	2.3	3.0	80.6	8.3	11.1	3014.3	1303.0	1475.9	235.4	7.8	10.1
C2-2	29	20	9/10/2005	21.8	14.3	4.5	3.0	65.5	20.7	13.8	14515.1	5584.1	8155.9	775.1	5.3	6.5
C2-3	38	20	9/10/2005	29.3	21.0	3.8	2.3	71.8	12.8	7.7	56673.4	41326.0	8353.1	6994.3	12.3	5.5
C2-4	50	20	9/10/2005	22.5	13.5	4.5	2.3	60.0	20.0	10.0	60448.6	32574.2	26771.9	1102.5	1.8	4.3

Table 5.1-4 Dominant species at farm and control sites in 2003 and 2005

	Dominant Species 1		Dominant Species 2	
Site	2003	2005	2003	2005
F1-12	Rhizophora sp.	Rhizophora sp.	-	-
F1-23	Rhizophora sp.	Rhizophora sp.	-	-
F1-35	Rhizophora sp.	Rhizophora sp.	Ceriops sp.	Ceriops sp.
F1-50	Rhizophora sp.	Rhizophora sp.	Bruguiera parviflora	Bruguiera parviflora
F2-7	Rhizophora sp.	Rhizophora sp.	-	-
F2-18	Rhizophora sp.	Rhizophora sp.	-	-
F2-37	Rhizophora sp.	Rhizophora sp.	-	-
F2-45	Rhizophora sp.	Rhizophora sp.	-	-
F3-17	Rhizophora sp.	Rhizophora sp.	Bruguiera exaristata	Bruguiera exaristata
F3-24	Rhizophora sp.	Rhizophora sp.	Bruguiera exaristata	Bruguiera exaristata
F3-34	Rhizophora sp.	Rhizophora sp.	Bruguiera exaristata	Bruguiera exaristata
F3-50	Rhizophora sp.	Bruguiera exaristata	Bruguiera exaristata	Rhizophora sp.
C1-6	Bruguiera exaristata	Rhizophora sp.	Rhizophora sp.	Bruguiera exaristata
C1-13	Rhizophora sp.	Rhizophora sp.	Bruguiera parviflora	Ceriops sp.
C1-22	Rhizophora sp.	Ceriops sp.	Ceriops sp.	Rhizophora sp.
C2-15	Rhizophora sp.	Rhizophora sp.	Bruguiera exaristata	Bruguiera exaristata
C2-29	Rhizophora sp.	Rhizophora sp.	Bruguiera exaristata	Bruguiera exaristata
C2-38	Rhizophora sp.	Rhizophora sp.	Ceriops sp.	Bruguiera exaristata
C2-50	Rhizophora sp.	Rhizophora sp.	Ceriops sp.	Ceriops sp.

5.2 Epiphytic algal growth

Method

Epiphytic algal growth on mangrove roots was measured qualitatively using digital camera photographs taken from set positions at each of the intertidal sites. Two photos were taken concurrently with water samples at three locations 20 m apart at each intertidal site. One photo was taken from about 5 m distant showing general extent of growth, and the other 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 up to and including October 2005 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 shallow water mangrove monitoring site in 2003 and 2005 are presented in Figure 5-1 to Figure 5-13.

Interpretation

Examination of photographs from 2003 has shown mangrove root and rhizome assemblages to be in excellent health with regard to epiphytic algal growth. The most recent 2005 photographs of farm and control sites show a similar state of health with no sign of algal growth, indicating levels of waterborne nutrients are too low for the establishment of epiphytic algae in the intertidal zone.

Figure 5-1 Mangrove root assemblages at site F1 in 2003

Figure 5-2 Mangrove root assemblages at site F1 in 2005

Figure 5-3 Mangrove root assemblages at site F2 in 2003