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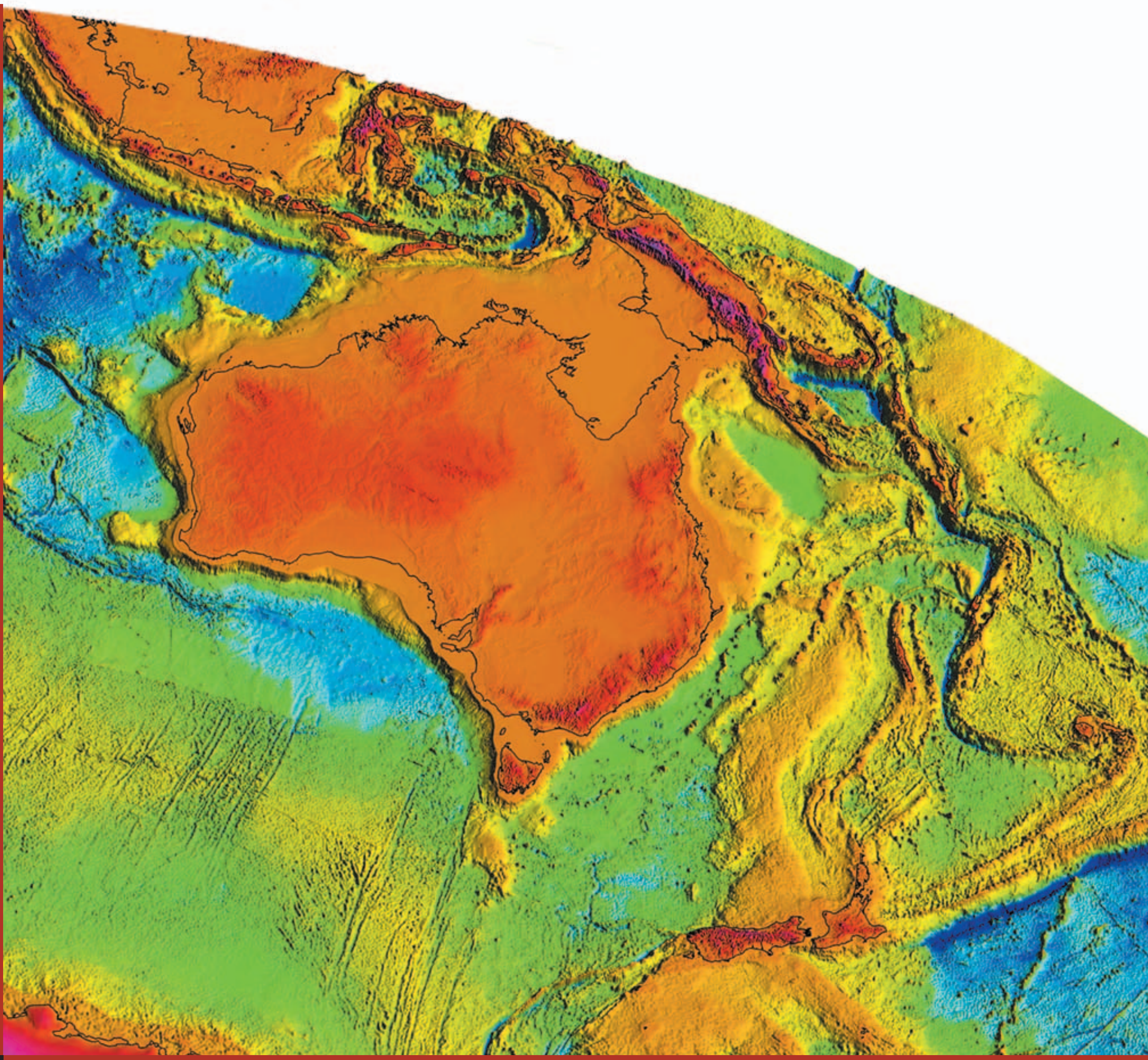
Biogeochemical Properties of the Water Column and Underlying Sediments

Radke, L.C., Ford, P.W., Webster, I.T., Douglas, G., Oubelkheir, K., Atkinson, I., Robson, B., Verwey, P., MacKenzie, K. and Clementson, L.

Record

2005/18



Results of Two Dry-Season Surveys of Keppel Bay and Casuarina Creek: Biogeochemical Properties of the Water Column and Underlying Sediments

GEOSCIENCE AUSTRALIA
RECORD 2005/18

by

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Minister for Industry, Tourism & Resources: The Hon. Ian Macfarlane, MP
Parliamentary Secretary: The Hon. Warren Entsch, MP
Secretary: Mark Paterson

Geoscience Australia
Chief Executive Officer: Dr Neil Williams

ISSN 1448-2177
ISBN 1 920871 57 8 (hardcopy)
ISBN 1 920871 58 6 (web)

GeoCat # 63537

This record fulfils milestone (AC49) for the Contaminants Dynamics sub-project in the Coastal CRC Agricultural (Fitzroy) Project.

Bibliographic reference: Radke, L.C., Ford, P.F., Webster, I., Douglas, G., Oubelkheir, K., Atkinson, I., Robson, B., Verwey, P., MacKenzie, K. and Clementson, L. 2005. Results of two dry-season surveys of Keppel Bay and Casuarina Creek: Biogeochemical properties of the water column and underlying sediments. Geoscience Australia, Record 2005/18. 121pp.

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Acknowledgements

We acknowledge and thank the following people for their various contributions to this work:

Kirrod Broadhurst, Graham Wassell, Paul Ridett and Darcy, the captain and first officers of the *Rum Rambler*, managed navigation and shared local knowledge.

Ray Degraaf, Stan Rucinski, Andrew Hislop, Tim Johnson and Craig Wintle of the Field and Engineering Support Group at Geoscience Australia developed and produced equipment used on the survey (sediment grab, continuous flow apparatus and filtering apparatus).

Ralf Haese engaged in helpful discussions pertaining to science and methods, and provided constructive criticism to an earlier version of this report.

Mark Hemer translated the files .TL files provided by the hydrodynamic and sediment dynamics models and explained the nature of the measurements.

Alan Hinde (Geoscience Australia) wrote a macro that converts conductivity and water temperature readings to practical salinity units.

Angie Jaensch and Veronika Galinec drafted the figures.

Algis Juoldvalkis (Geoscience Australia) prepared and analysed samples by XRD/SiroQuant. Tan Kok Piang (CRC Leme: Australian National University/Geoscience Australia) provided some advice on the methods.

John Pyke, Liz Webber and Bill Pappas (Geoscience Australia) prepared and analysed the XRF and LECO-TOC samples. Liz Webber conducted FeO analyses.

Andy Longmore (MAFRI) undertook analysis of the different types of sediment P.

Nugzar Margvelashvili and Mike Herczeg provided preliminary model output of the coupled hydrodynamic-sediment model for comparison with the bottom sediment data.

Alex McLachlan and Neil Ramsay (Geoscience Australia) conducted the grain size analyses on the water column and bottom sediments.

Luis Neumann and David Page (University of Queensland) provided advice on quality control measures for grain size analysis.

Bob Noble and Bob Packett (DNRM Queensland) assisted with logistics and provided local knowledge. Bob Noble also provided a review of this manuscript.

David Ryan, Helen Bostock and Brendan Brooke answered questions pertaining to sedimentology. Helen also alerted us to the World Ocean Circulation Experiment (WOCE).

Rachel Davenport and Carolyn Sandison (Geoscience Australia) ran the mass spectrometer, and provided advice on the analysis of carbon isotopes in sediments with low TOC contents.

Peter Taylor (Geoscience Australia) milled the sediment samples.

Colin Tindall provided support in the field and with the survey logistics.

Tony Watson conducted the $CaCO_3$ analyses.

Phil White and staff at J.M. Rendel Laboratories (CSIRO Tropical Beef) provided lab space and allowed for the storage of equipment prior to the survey.

Dan Wruck and team at Queensland Health – Pathology and Scientific Services ran the nutrient analyses.

Executive Summary

The Fitzroy Estuary is one of several macrotidal estuaries in tropical northern Australia that face ecological change due to agricultural activities in their catchments. The biogeochemical functioning of such macrotidal estuaries is not well understood in Australia, and there is a pressing need to identify sediment, nutrient and agrochemical pathways, sinks and accumulation rates in these extremely dynamic environments. This is particularly the case in coastal northern Queensland because the impact of water quality changes in rivers resulting from vegetation clearing, changes in land-use and modern agricultural practices are the single greatest threat to the Great Barrier Reef Marine Park.

The main aims of Fitzroy Contaminants Sub Project (AC) in the Coastal CRC are to develop understanding and predictive modelling and assessment tools that can be used to support the management of the Fitzroy Estuary and its catchment. The project has many objectives and seeks to address several questions. The current report contributes mainly to the following aspects of the work:

- Establishing links between primary production and biogeochemistry in tropical estuaries.

- Determining processes that are likely to be important for the dynamics of tropical macrotidal estuaries.

Teams from Geoscience Australia (GA) and CSIRO Land and Water undertook two dry season surveys of the Fitzroy Estuary and Keppel Bay in the periods from September 4 -12, 2003 and August 15 to September 1, 2004. The surveys were conducted along a series of daily ship tracks with intermittent stations. Durng the 2004 survey, the boat was anchored at 7 stations and measurments were taken at regular intervals over a 24 hour period.

The data gathering was focussed on making observations which would be of immediate use in parameterising and validating aspects of the mathematical models under development, and in facilitating the use of remotely sensed chlorophyll *a* and suspended sediment concentrations to provide synoptic data for the whole of Keppel Bay. The primary focus of this report is on the interpretation of total suspended matter and nutrient concetration measurements made during the surveys, with particular emphasis on the spatial context of these paramaters. Preliminary interpretations are also provided for geochemical measurements made on a suite of bottom sediment samples with good spatial coverage in Keppel Bay, and for a more limited number of carbon, N_2 and nutrient flux measurements.

The study found that nutrient dynamics in Keppel Bay under dry season conditions reflect the internal biogeochemical processes. These depend on the initial chemical characteristics of the sediment and the supply of oxidants to the sediments. Importantly, three distinct zones of physical, biogeochemical and ecological characteristics were identified in Keppel Bay and these reflect the influence of the hydrodynamic regime on the distribution of Fitzroy River sediment and relict sand deposits. The zones are:

- *The Zone of Maximum Resuspension (ZMR)* near the estuary mouth and in Casuarina Creek. This zone arises because of the large currents and asymmetric tides. Resuspension and entrainment of sediment in this high energy zone cause high levels of TSM in the water column and are conducive to hydrodynamic sorting of particles based on different densities and settling velocities. The large concentrations of suspended sediment cause light limitation of photosynthesis in this region, and therefore allows dissolved nutrient concentrations to build up in the water column. The mobile surface sediments also produce an efficient decomposition system for particulate organic matter and diatoms washed from the mud banks, characterised by repetitive redox oscillations. Consequently the region is a source of nutrients to Keppel Bay. Net N_2 fluxes were the most negative for the study in this region, and the FeIII concentrations were correspondingly high.

- *The Coastal Transitional Zone (CTZ)* was characterised by turquoise coloured water, and was coincident with the western and eastern lobes of Fitzroy Estuary sediments in Keppel Bay proper. These sediments generally had mud contents >10%, and were subject to resuspension when current speeds were high. The resuspension caused large variations in TSM and P concentrations and TN:TP molar ratios, in the order of 2-10 mg L^{-1} in the case of TSM and 18-61 in the case of TN:TP ratios. Variation in these parameters, and general turbulence, probably allowed for the co-dominance of pico-phytoplankton and micro-phytoplankton (mainly diatoms) that was observed in this region. The alternating resuspension/deposition cycles also promoted efficient decomposition by oxic and sub-oxic processes: the highest FeII:TOC and FeII:FeIII ratios in surface sediments were found in this zone. N_2 fluxes were all negative in the core incubations from these sediments, implying net nitrogen fixation in this zone.

- *The Blue Water Zone (BWZ)* was characterised by water that was deep blue in colour, and coincided with the occurrence of the relict sand sediments in Keppel Bay. The mud contents of these sediments were low (<10%) and TSM concentrations did not exceed 2 mg L^{-1} at any time in the tidal cycle. The underlying sediments also had very low Fe and P concentrations and most of this P (>70%) was in biologically unavailable forms. Pico-phytoplankton dominated phytoplankton communities in this region, and nano-phytoplankton were found in higher abundance. These phytoplankton groups are frequently P-limited and are known to utilise components of the organic-P pool. Utilisation of organic-P might account for the observed increase of DON:DOP ratios. N_2 fluxes were all positive in the core incubations from these sediments, implying net denitrification in this zone. The bulk of the N and P demand in this zone is probably met by microbial breakdown of organic matter in the water column.

Some more general findings of the study include:

- The chemistry of Keppel Bay sediments reflects the large size of the Fitzroy River Basin and the integration of the weathering products of a large number of rock types to give a composition similar to that of a partially weathered average continental crust.

- The best indicator of modern Fitzroy River sediments in Keppel Bay was an Al_2O_3:K_2O ratio of >4. The Al_2O_3:K_2O ratio reflects chemical changes that occur during weathering and fining of sediment. The ratio is also affected by hydrodynamic sorting.

- Nutrient (TN and TP), TOC, Fe and the concentrations of most metals increased with the Al_2O_3:K_2O ratio. The most weathered, metal and nutrient-rich sediments occurred in Casuarina Creek and in the near shore region alongside Long Beach.

- Most sediment in Keppel Bay and Casuarina Creek had TOC:TN molar ratios and $\delta^{13}C$ signatures suggesting either a marine phytoplankton and/or bacterial source for the organic matter.

- CO_2 decomposition rates at eight sites in Keppel Bay were in the oligotrophic range, and O_2/CO_2 flux ratios were consistently less than 1.3, suggesting that more CO_2 is generated than can be accounted for by oxic diagenesis alone.

- The process of repeated suspension and deposition in Keppel Bay was conducive to mineralization of organic matter by both oxic and suboxic processes. Indicators for the occurrence of iron oxyhroxide reduction was particularly widespread (*i.e.* elevated with FeII:TOC and FeII:FeIII ratios).

- N_2-N fluxes ranged from -3.5 to 1.6 mmol m^2 d^{-1} implying net denitrification in some sediments and net nitrogen fixation in others. FeIII concentrations of the sediment were positively correlated with the N_2-N flux and should be explored as an indicator of benthic N uptake and release.

- TSM concentrations were higher over the muddier substrates derived from the Fitzroy River. TSM concentrations at a given location also varied substantially over the tidal cycle due to advection and to sediment resuspension/settling.

- Particulate nutrients dominated nutrient pools near the estuary mouth and in Casuarina Creek where TSM was higher than 10-25 mg L^{-1}, due to resuspension. Dissolved inorganic nutrient concentrations were also highest in this region because continual resuspension of the surface layer and high levels of TSM interfered with nutrient uptake by phytoplankton.

- Zones of elevated salinities relative to seawater were observed in Casuarina Creek and along the shallow western shore of Long Beach due to evaporation. A reverse salinity gradient was also apparent in the mixing diagrams: *i.e.* high salinity waters flowed out of Casuarina Creek and were a source of NOx, FRP, SiO_4 and DON to Keppel Bay.

- Dissolved inorganic concentrations decreased to below detectable levels when TSM concentrations were <10-25 mg L^{-1}, marking a switch from light-limitation of photosynthesis to nutrient-limitation.

- DON, DOP and NH_4 did not behave conservatively, and these concentrations dropped to below detectable limits at some of the 24 hour stations. This suggests that phytoplankton was either directly utilising the DON or some form of rapid re-cycling was taking place; either way, a component of the DON pool was available for biological uptake.

- DON:DOP and TN:TP molar ratios and the percentage of P in organic forms (%DOP-P) increased in the direction of Great Keppel Island. This was probably due to biological utilisation of part of the organic-P pool by pico- and nano-phytoplankton. The percentages of both these phytoplankton groups also increased in the direction of Great Keppel Island (pico-phytoplankton with %DOP-P and nano-phytoplankton with the TN:TP molar ratios) and this was matched with a parallel decrease in micro-phytoplankton.

1. Introduction

1. 1. BACKGROUND

The Fitzroy Estuary (Figure 1.1) is one of several macrotidal estuaries in tropical northern Australia that face ecological change due to agricultural activities in their catchments. Other such estuaries include the Burdekin, the Ord and the estuaries of the Gulf of Carpentaria. These "tide-dominated estuaries" differ from southern "wave-dominated estuaries" in their strong tidal currents, high concentrations of suspended sediments and the expected greater importance of wetlands and intertidal flats in biogeochemical cycling and fine sediment dynamics (Heap *et al.*, 2000; Ryan *et al.*, 2003). The biogeochemical functioning of tide-dominated estuaries is not well understood in Australia, and there is a pressing need to identify sediment, nutrient and agrochemical pathways, sinks and accumulation rates in these extremely dynamic environments. This is particularly the case in coastal northern Queensland where the impact of water quality changes in rivers resulting from vegetation clearing, changes in land-use and modern agricultural practices are the single greatest threat to the Great Barrier Reef Marine Park (Zann, 1995; Williams, 2001).

Brodie *et al*. (2003) used SedNet (and its nutrient module ANNEX) to identify high risk drainage basins in the Great Barrier Risk Catchment Area (GBRCA). An important conclusion from this study was that the Fitzroy River Basin (FRB) should be prioritised for management to reduce sediment and nutrient exports. Specific mention was also made of the eastern part of the FRB because of the high soil erosion in this region. In fact, the Fitzroy River together with the Burdekin River, is responsible for the major inputs of sediments and nutrients to the coastal zone, including the Great Barrier Reef Lagoon (Furnas, 2003). As a study of the fate and impact of contaminants within the zone fringing the GBR, the Fitzroy contaminants study results, together with those from other CRC Fitzroy projects, will support the recently implemented *Reef Water Quality Protection Plan* (http://www.deh.gov.au/coasts/pollution/reef/). Moreover, the project addresses the important estuary and coastal zone areas, which have received little attention so far in the context of GBR health. The strategic imperative of the Fitzroy Contaminants Sub Project (AC) in the Coastal CRC was thus to develop better systems understanding and predictive capability in terms of water quality in the Fitzroy Estuary and Keppel Bay, that could be used more broadly to assist with the management of tropical macrotidal estuaries in northern Australia. Some novel developments to be undertaken in the greater project include: (i) the development of coupled hydrodynamics-sediment dynamics-biogeochemistry models that link the biophysical function of the estuarine-bay system to terrestrial inputs; and (ii) the integration of remote sensing with modelling and assessment.

This report provides a preliminary interpretation of suspended sediment and nutrient data collected from the water column of the Fitzroy Estuary, Keppel Bay and Casuarina Creek during two dry season surveys and constitutes milestone AC49 in the project. The data gathering was focussed on making observations which would be of immediate use in parameterising and validating aspects of the mathematical models under development, and in facilitating the use of remotely sensed chlorophyll and suspended sediment concentrations to provide synoptic data for the whole of Keppel Bay. Preliminary interpretations are also provided for geochemical measurements made on a suite of bottom sediment samples with good spatial coverage in Keppel Bay, and for a limited number of carbon and nutrient flux measurements. The flux studies were made possible by supplementary funding provided by the Fitzroy Basin Association (ACsupp2). The bottom sediment samples were collected during these dry season survey's: (i) to assist with the interpretation of water column processes (this study); (ii) for use in the development of the geomorphic framework understanding of Keppel Bay (Ryan *et al.*, 2005); (iii) to validate aspects of the sediment dynamics model (Margvelashvili *et al.*, in prep); and (iv) to explore the indicator-potential of some relatively inexpensive and easily measured sediment constituents. The findings from this study report will contribute to research needs and questions as outlined below, and will support the development of the predictive models.

1. 2. AIMS & RESEARCH QUESTIONS

The main aims of Fitzroy Contaminants Sub Project (AC) in the Coastal CRC are to develop understanding and predictive modelling and assessment tools that can be used to support the management of the estuary and its catchment. The project will progress our understanding of processes such as:

- resuspension and flocculation dynamics in macro-tidal estuaries;
- links between primary production and biogeochemistry in tropical estuaries.

Some specific research questions to be addressed in the project include:

- Quantitatively, how are sediments and nutrients transported through the Fitzroy Estuary and Keppel Bay to the Great Barrier Reef?
- What is the role of the Fitzroy Estuary and Keppel Bay - as regions for accumulating, transforming and redirecting contaminants from the catchment?
- What bio-physical processes are likely to be important for the dynamics of tropical macrotidal estuaries.

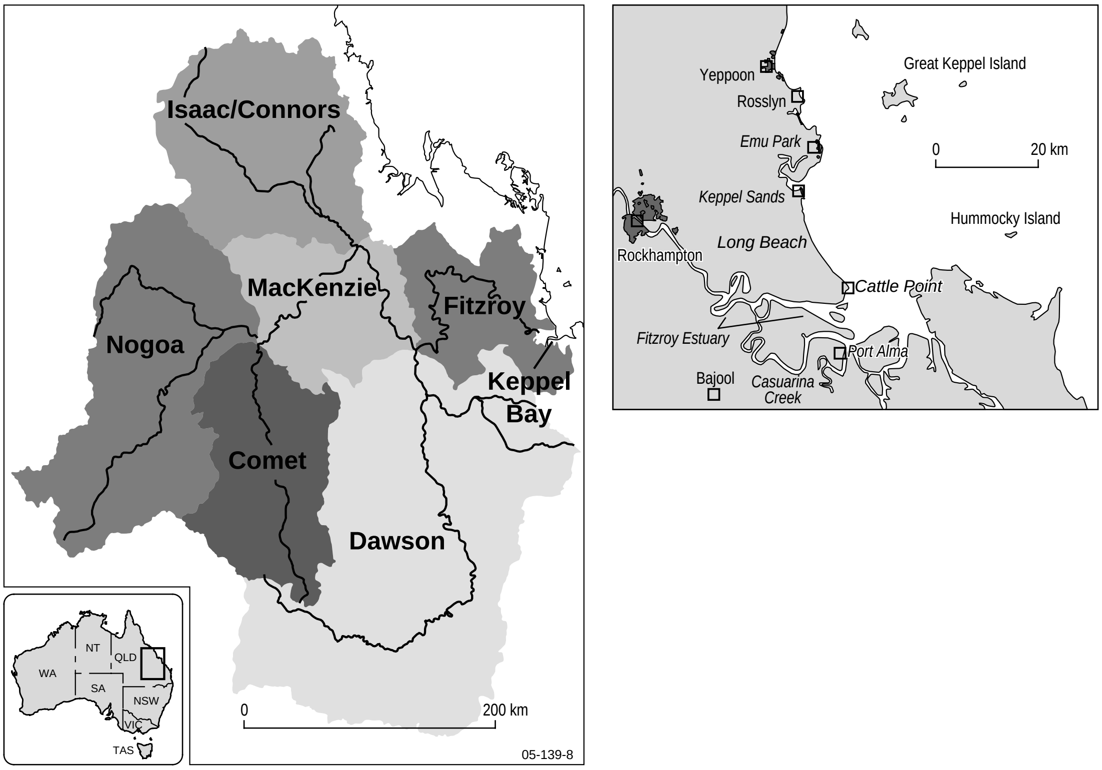

Figure 1.1. *Maps of: (a) the Fitzroy Catchment showing major River Basins; and (b) Keppel Bay showing landmarks and towns.*

2. Study Area

2.1. CLIMATE & HYDROLOGY

The Fitzroy River Basin (FRB) in central Queensland covers an area of ~144,000 km^2, and is the second largest seaward-draining catchment in Australia. Situated in the dry tropics, the climate of the FRB is described as sub-tropical and sub-humid with summer-dominated rainfall (Noble et al., 1997). Rainfall in the FRB is extremely variable inter-annually, and decreases with distance from the coast; from 1500 mm in the northern near-coastal region to ~600 mm inland (Noble et al., 1997). Topographically, the FRB consists of a series of low ranges separated by extensive low-lying areas, and is divided into five large river sub-catchments. The major river systems that contribute flows to the Fitzroy River include the: Nogoa; Connors/Isaac; Comet; Dawson; and the MacKenzie. As with rainfall, stream flow in the FRB is extremely variable and follows seasonal, inter-annual and decadal fluctuations in predominantly summer (wet season) rainfall associated with the summer monsoon, ENSO oscillations and unpredictable cyclones. There is little freshwater discharge in the dry season. The Fitzroy River is moderately regulated with several weirs (Fitzroy Barrage, Theodore and Moura), a number of small dams (Callide, Theresa) and one major dam (Fairbairn). The Fitzroy River flows into the Pacific Ocean through the Fitzroy Estuary, and has a mean annual discharge of 5.7 million ML (Kelly and Wong, 1996). It has been estimated that 264 million tonnees of sediment have been exported from the Fitzroy River between 1965 and 1994 (Kelly and Wong, 1996).

The land-ward limit of the Fitzroy Estuary is defined by the barrage in the city of Rockhampton (population *ca.* 65,000), approximately 60 km upstream from the estuary mouth. The Fitzroy estuary has been classified as tide-dominated estuary, implying that its gross geomorphology is shaped by tides (Heap *et al*., 2000). The estuary is considered to be at a mature stage of evolution because the major present day focus of sedimentation is in inter-tidal and shallow sub-tidal areas near the estuary mouth, rather than on the floodplain (Ryan *et al*., 2004). Because the majority of sediment by-passes the estuary, and mangrove areas are limited, the potential for fine sediment to move further off shore is greater than in less mature estuaries (Ryan *et al*., 2004). Offshore, Keppel Bay is a shallow oceanic embayment with semi-diurnal tides that range in height from ~2.5 to 5 m over the spring-neap cycle. The tides in Keppel Bay are mixed, dominant semi-diurnal type implying that there are two high and two low tides per day, and one of the high tides is significantly larger than the other most of the time (Webster *et al*., 2003). The tides undergo a two-weekly cycle of neap and spring tides. The bay has numerous bedrock islands, including the popular tourist destination, Great Keppel Island.

2.2. GEOLOGY

The geology of the FRB comprises more than 100 different types of rocks and has been divided into 5 major structural units (Figure 2.1; Douglas et al., 2005): The Thomson Fold Belt, the New England Fold Belt, the Bowen Basin, the Surat Basin and the Tertiary Basins. The Thomson Fold Belt (TFB) is found in the western-most part of the catchment and comprises Cambrian-Ordovician metamorphic rocks, Devonian-Carboniferous siliclastics and calc-alkaline volcanic rocks. The New England Fold Belt (NEFB) is found in the easternmost part of the FRB and is composed of Devonian-Carboniferous calc-alkaline volcanics, Permian siliclastics and volcaniclastics and Carboniferous-Cretaceous granitoids. The Tertiary Basin occurs within and sub-parallel to the strike of the NEFB, and comprises the Tertiary siliciclastics, lignites, oil shales and basalts of the Duaringa Formation and the mudstones, sandsones, oil shales and lignites of the Biloela Formation. Permian-Triassic siliclastics, limestone, coal and andesite are found in the Bowen Basin (BB), in the central FRB, while Jurassic-Cretaceous siliclastic rocks and coal are found in the Surat Basin (SB) in the south of the catchment. Cainozoic volcanics (principally basalts) occur in isolated patches throughout the basin, but cover large patches of the BB.

An extensive Cainozoic weathering sequence also overlies the major structural units and may include duricrust, laterite, local scree deposits and soils. Clay and duplex soils account for more than half the area of soil cover (Furnas, 2003). Average TOC, TN and TP contents of soils in FRB are 1.3%, 0.09% and 0.042% respectively (data compiled by Furnas, 2003).

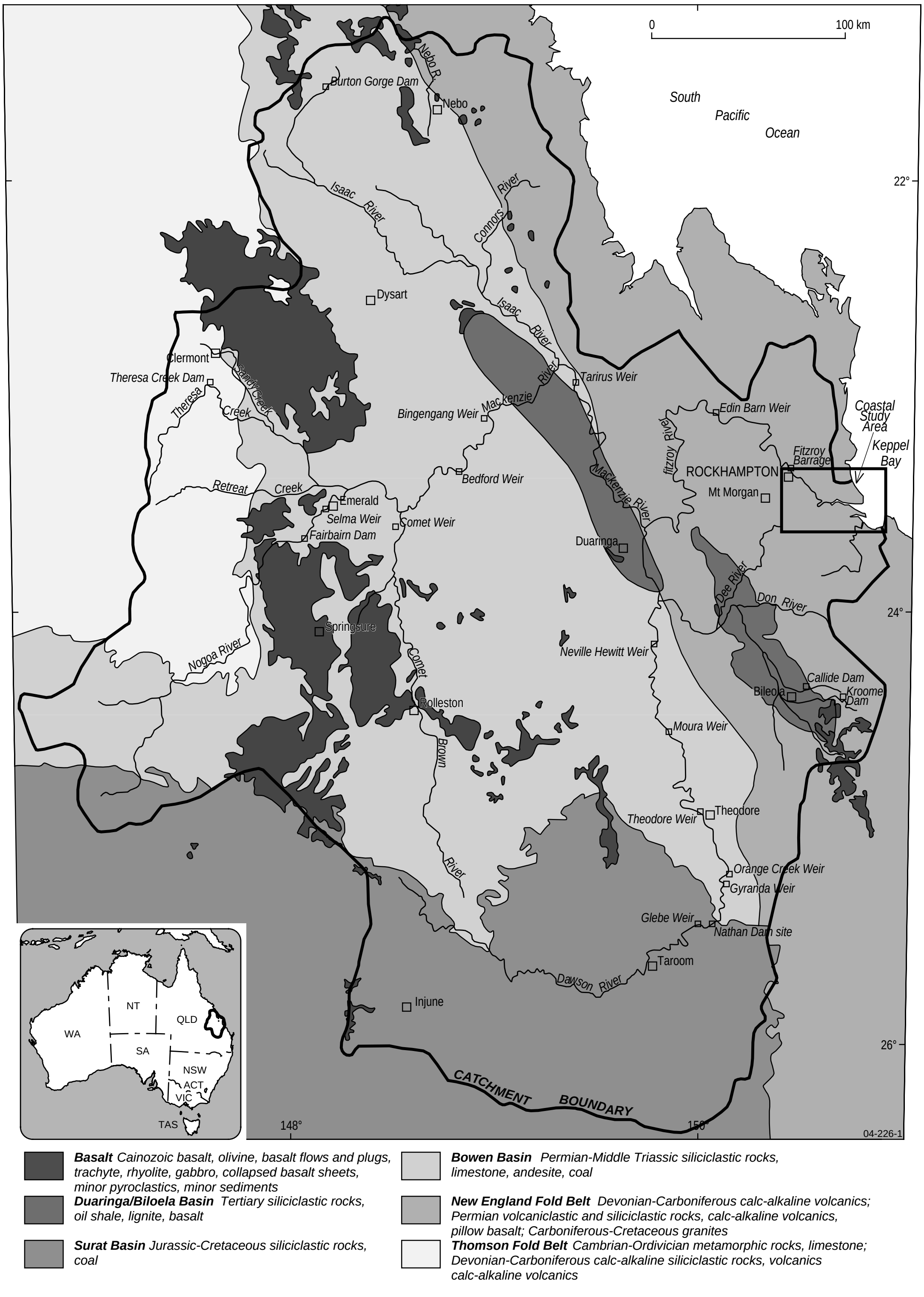

Figure 2.1. *Major geological features of the Fitzroy catchment (after Douglas et al., 1995).*

2.3. VEGETATION & LAND USE

The FRB is located in the Brigalow Belt bioregion (Furnas, 2003). Approximately 60% of the native vegetation cover in FRB has either been cleared or has been subject to thinning (Furnas, 2003). The greatest losses have been to the *Acacia*-dominated Brigalow communities (woodlands and open forests), and there has been a roughly parallel increase in the areas of tussock grasslands and open woodlands (Furnas, 2003). Rangeland beef grazing occurs over at least 80% of the total area of the FRB and is the principle land use in the catchment (Furnas, 2003). Cropping (sorghum, wheat, cotton, legumes and sown grass and pastures) accounts for a further 6% of the land use. Coal production utilizes only ~1% of the catchment area yet makes the major contribution to the value of the primary commodity production (66%; Noble *et al.*, 1997). It has been estimated that catchment sediment yields have increased 4.1 times in response to the land use intensification (Neil *et al.*, 2002).

3. Methods

3.1 SAMPLING STRATEGY

Teams from Geoscience Australia (GA) and CSIRO Land and Water undertook two surveys of the Fitzroy Estuary and Keppel Bay in the periods from September 4 -12, 2003 and August 15 to September 1, 2004. These surveys formed the integral 'dry season' component of the project. The *Rum Rambler*, a 42 ft motor vessel, was locally chartered for the project.

The study activities undertaken in Keppel Bay included measurements of water column physical and biogeochemical properties at a series of locations situated along a set of daily transects. These raw data have already been reported (Radke *et al*., 2004a and 2005a). *In situ* conductivity, water temperature, turbidity and position data were recorded continuously along the daily tracks using sondes housed in a continuous flow apparatus. We also took the opportunity to gather a spatial coverage of the bottom sediment composition and texture data (Radke et al., 2004a and 2005a). This bottom sediment data set was enlarged with the inclusion of grab sample collections made by Skene *et al.* (2004) in near shore waters alongside Long Beach (these numbers are followed by an *a*) and with inter-tidal sediments collected by Brooke *et al.* (2005) along the Capricorn Coast (the numbers of these samples start with *cc*).

During the August 2004 survey only, the boat was anchored at 7 stations and an upward-looking Acoustic Doppler Current Profiler (ADCP provided by CSIRO Marine Research) was placed on the sea floor. The ADCP measured current speed (water column average) and direction through the water column over 24 hour periods coinciding with spring tide conditions at the first three stations and neap tide conditions at the next four stations (Figure 3.1b, c). The ADCP also measured water pressure in dbars. Sondes attached to the ADCP and boat recorded turbidity at 10 second intervals, while samples for nutrients, TSM, chlorophyll *a* and TOC&DOC (from surface and bottom water) were collected at hourly intervals over the initial 12 periods. Detailed measurements of particle characteristics (size and settling velocities) and vertical profiles of salinity, water temperature, fluorescence, dissolved oxygen and scattering were also made by CSIRO at half hourly intervals over the same 12 hours period. This information, and the results from the chlorophyll *a* and TOC&DOC samples will be integrated with the data collected by GA in the final reporting phase of the Fitzroy Contaminants project.

A sediment biogeochemistry component of the survey was also conducted in conjunction with the Keppel Bay Vibracoring survey (Skene *et al.*, 2004), from aboard the Pacific Conquest. Sediment cores were collected by vibra- and box coring techniques. Cylindrical cores of sediment were removed from the box corer and incubated for 24 hours at *in situ* temperatures. Changes in physical and chemical properties in the water column overlying these sediments were used to estimate carbon decomposition, denitrification/nitrogen fixation and nutrient release rates. The raw data from the core incubation experiments have already been reported (Radke *et al.*, 2005b).

Maps showing the sampling locations and graphs showing fluctuations in tidal height during September 2003 and August 2004 surveys are provided in Figure 3.1a,b,c,d. The tidal plots are based on output from the WXTide32 program (version 3.1; Hopper, 1998-2003). Both neap and spring tide conditions were encountered during both surveys. A table with sample & station locations, the date & time sampled and water depths at time of sampling is provided in Appendix A.

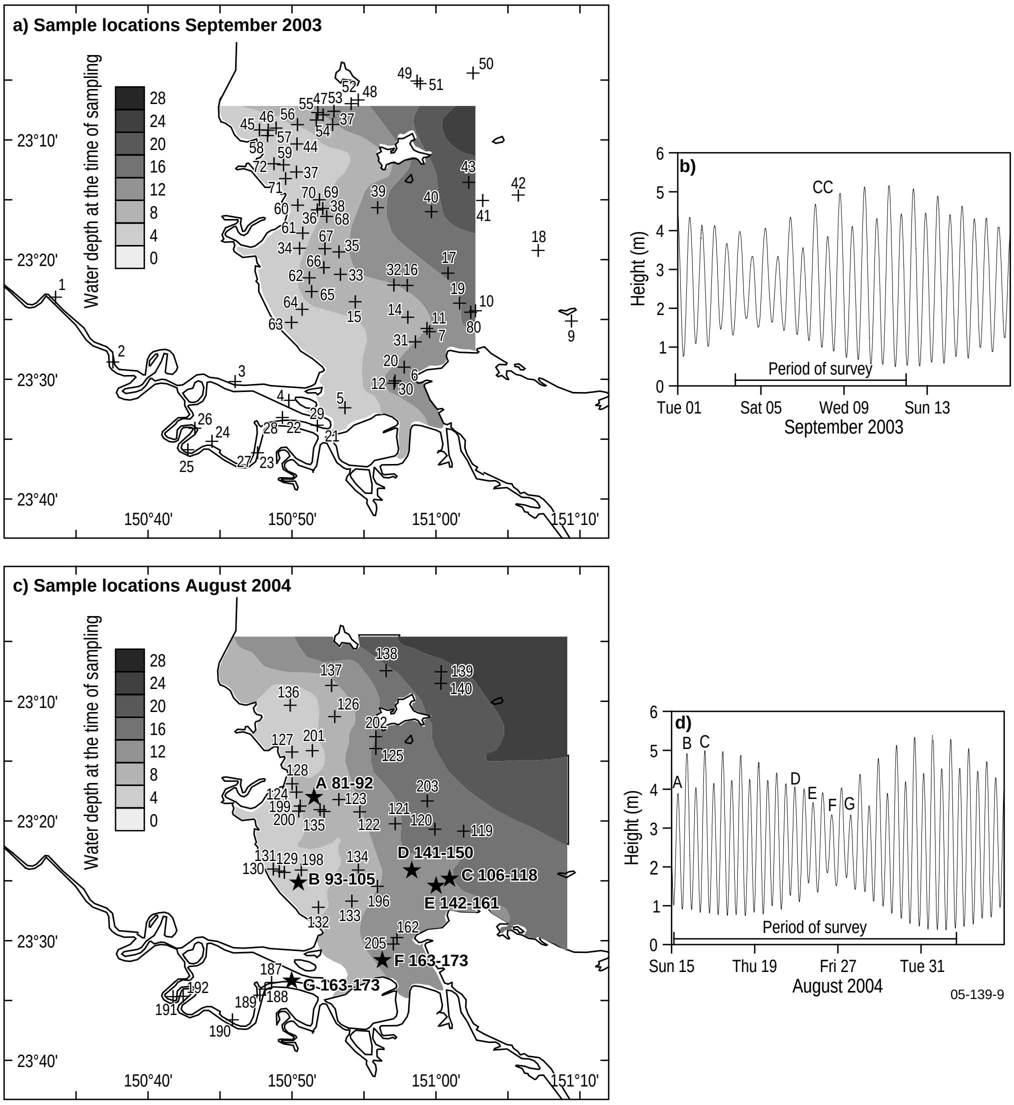

Figure 3.1. *Maps showing water depths at the time of the sampling (m) and the locations where samples were taken during the September2003 survey (a) and (c) the August 2004 survey (b) Tide heights during the period of the September 2003 survey (CC = Casuarina Creek); (d) Tide heights during the period of August 2004 survey (letters A-G correspond to the 24 hour stations).*

3.2. WATER COLUMN OBSERVATIONS AND SAMPLES

3.2.1. Water Column Physical Properties in Relation to Position

In situ conductivity, water temperature, turbidity and position data were recorded continuously along the daily tracks. The position of the vessel was recorded at 20 second intervals using a GARMIN GPSMAP 76S. The GPS position was referenced to the World Geodetic System 1984 (WGS 84) Datum. Conductivity, water temperature and turbidity data were also recorded at 20 second intervals using a YSI 6000upg sonde fitted in a continuous flow cell apparatus.

The continuous flow cell apparatus consisted of two adjacent chambers (a de-bubbling chamber and a flow cell) constructed of clear acrylic and grey PVC plastics. Low pressure was generated in the head of the de-bubbling chamber by a water-driven Venturi vacuum device causing inflow into the chamber at ~ 0.5 m depth. The water was strained through a stainless steel filter mesh (pore size 350 um), to prevent marine animals from entering the chamber. The low pressure in the de-bubbling chamber caused fine bubbles to expand, enabling them to readily float out of the sample water. This was essential because the bubbles cause anomalous readings on the optical probes. The water was then drawn from the de-bubbling chamber to the flow cell containing the sondes via a diaphragm pump. The water flow rate through the system was 6 litres per minute. It took 3 minutes to fully exchange the water in the chamber.

The YSI sonde was fitted with a YSI model 6026 nephelometric turbidity probe that measured turbidity in Nephelometric Turbidity Units (NTU's). The probe was calibrated with the appropriate AMCO CLEAR® solutions that were N.I.S.T. traceable standards. The probe was fitted with a wiper that had to be manually activated due to technical difficulties. It should also be noted that the turbidity data from this probe should be interpreted with caution because the probe occasionally became fouled by substances in the water.

The conductivity, water temperature and turbidity data that was collected continuously along the daily tracks was circulated to the modellers for use in validating and parameterising aspects of the mathematical models. For the purposes of this report, we utilise only the conductivity, water temperature and turbidity measurements that were taken at the specified station locations (Figure 3.1a). These measurements were usually made in conjunction with nutrient, chlorophyll TOC & DOC sample collections. During the September 2003 survey, additional turbidity data were collected at some stations during the vertical profiling exercise, using an Analite NEP 260 90° turbidity probe. This data (from surface and bottom waters) is reported in addition to that from the YSI sonde. During the August 2004 survey, surface and bottom turbidity measurements were always made simultaneously with TSM sample collection using the Analite sonde, and these data are reported exclusively.

Salinity is reported in Practical Salinity Units (PSU's). PSU's were calculated from the *in situ* conductivity and temperature data using the UNESCO International Equation of State (IES 80), as described in Fofonoff (1985). The conductivity probes were calibrated against a KCl reference solution, in which 32.4356g of KCl in a one kilogram mass of solution equates to a salinity of 35.000 PSU's at 15°C (as per Seawater Equation of State).

The data collected continuously along the daily tracks was forwarded to the modelling and remote sensing teams and will not be discussed here.

3.2.2. Vertical Profiles of Physical Properties

Vertical profiles of conductivity, water temperature, dissolved oxygen and turbidity were undertaken at selected stations using probes that were hand deployed to various depths in the water column. During the September survey, conductivity (reported in PSU's), water temperature, water depth and dissolved oxygen were measured using a YSI 600XL sonde. A Clark type oxygen sensor with rapid pulsed electrodes and a Teflon membrane was used. Turbidity was measured nephelometrically using an Analite NEP 260, 90° turbidity probe (McVan Instruments). The probe was calibrated with the appropriate AMCO CLEAR® solutions that were N.I.S.T. traceable standards. During subsequent surveys, collection and management of vertical profile data was the responsibility of CSIRO.

3.2.3. Total Suspended Matter Concentrations (TSM)

Water samples for TSM analysis were collected from approximately half a metre depth. Samples of bottom waters (~40 cm from bottom) were also taken in some cases. The bottom water samples were pumped to the surface through a non-collapsing wire re-enforced 12 mm ID food grade PVC hose, using a diaphragm pump. A stainless steel filter mesh (350 um) prevented marine animals from entering the hose.

Samples of water, 1L in volume, were measured into High Density Polyethylene (HDPE) sample bottles using a PMP plastic graduated cylinder. The graduated cylinder and the sample bottles were well rinsed with the water being sampled prior to sample collection. In most cases, two 1L samples were taken. The samples were vacuum filtered through one of pre-weighed Millipore Durapore® membrane filters or Pall Tuffryn® filters. Both types of filter paper were 47 mm in diameter, and had pore sizes of 45 µm. In most cases, the full 1L of sample was filtered. However, if the filter paper clogged with sediment before the sample was fully filtered, the amount of unfiltered water remaining was measured, and the final TSM concentration was scaled to one litre. Distilled water was used to wash TSM remaining in the sample bottle into the filtration canister after the samples had been discharged. Distilled water was also used to wash TSM off the walls of the filtration canister, and to flush dissolved salts through the filter paper. The filter papers were removed from the canisters following filtration, and were promptly placed in plastic containers. The filter papers were oven-dried at 60°C and then re-weighed. The TSM values used in the study are the average of the sediment weights (mg L^{-1}) retained on the two types of filter paper.

3.2.4. Grain Size Distribution of Water Column TSM

During the September survey, water samples for grain size analyses were collected from approximately half a metre depth. Samples of bottom waters were also taken in some cases. The bottom water samples were pumped to the surface through a non-collapsing wire re-enforced 12 mm ID food grade PVC hose, using a diaphragm. A stainless steel filter mesh (350 µm) prevented marine animals from entering the pump.

Approximately 1L samples of the water were measured into HDPE sample bottles using a graduated cylinder; the lids of the bottles were made of the same material and did not have liners. The graduated cylinder and the sample bottles were well rinsed with the water being sampled prior to sample collection. A few drops of sodium hypochlorite solution were added to the samples immediately after collection to stop biological activity. In the laboratory, the grain size of the sediment in the samples was measured directly by laser diffraction, using a Malvern Mastersizer 2000. The laser diffraction measures particles as volume percentages in 34 logarithmically spaced bins, from 0.06 – 2000 µm. A small number of samples were analysed a second time after being subject to ultra-sonification.

3.2.5. Water Column Nutrient Concentrations

Water samples for nutrient analyses were collected from approximately half a metre depth. Samples of bottom waters were also taken at some stations. The bottom water samples were pumped to the surface through a non-collapsing wire re-enforced 12 mm ID food grade PVC hose, using a diaphragm pump A stainless steel filter mesh (350 µm) prevented marine organisms from entering the pump.

Raw water samples for total nutrient analysis (TN and TP) were collected in 60ml HDPE bottles. Water samples for filterable reactive dissolved nutrient analysis (total oxidised nitrogen (NOx), ammonia (NH_4^+), phosphate (PO_4^{3-}) and silicate (SiO_4^{2-})) were syringe-filtered through 0.45 um nylon membrane filters into 60ml environmental-grade HDPE bottles. The lids of the sample bottles were not lined and were made with the same material as the bottles. The sample bottles and caps for both total and dissolved nutrient analyses were machine-washed with a phosphate-free caustic solution (sodium hydroxide/sodium hypochlorite solution). The bottles and caps were then repeatedly rinsed with deionised water and soaked over night, also in deionised water. The bottles were then rinse, dried and capped prior to field sampling.

In the field, the bottles were rinsed with appropriate sample water prior to obtaining the sample (*e.g.* the bottles for dissolved nutrients were rinsed with filtered water and the bottles for total nutrient analyses were rinsed with raw water). The syringe filters were rinsed prior to use, by allowing approximately 10 ml of water to pass through. The samples were stored on ice immediately after sample collection, and were frozen in the evening of collection.

Water samples were analysed for filterable reactive phosphorus (FRP), total oxidised nitrogen (NOx), nitrite (NO_2^-), ammonia (NH_4^+) and silica simultaneously using an automated LACHAT 8000QC flow injection system. The methods used in the system are based on: (a) ascorbic acid reduction of phosphomolybdate for FRP (Standard Methods 1998 – 4500-P G); (b) cadmium reduction of nitrate to nitrite by diazotizing the nitrite with sulfanilamide and coupling with N-(1-naphthyl)ethylenediamine dihydrochloride for NO_x (Anonymous, 1998; Standard Methods – 4500-NO_3 I); and (c) production of the indophenol blue colour complex for NH_3 (Anonymous, 1998; Standard Method 4500- NH_3 H). Silica species were reacted with molybdate at 37°C and pH 1.2 to form a yellow silicomolybdate complex. The complex was subsequently reduced with stannous chloride to form a heteropoly blue complex which is measured spectrophotometrically at 820nm (Anonymous, 1998; Standard Method – 4500-SiO2 F).

Nitrate (NO_3^-) and dissolved inorganic nitrogen (DIN) concentrations were calculated as follows:

$NOx - NO_2^- = NO_3^-$; and

$DIN = NOx + NH_4^+$

Samples for total nitrogen (TN) and total phosphorus (TP) analyses (both filtered and unfiltered samples) were digested using a modified version of the simultaneous persulfate procedure (Hosomi and Sudo, 1986). Analyses for TN and TP were then performed on the digest using the same instruments and procedures as those described for NOx and FRP. TN and TP concentrations were also determined on the filtered water samples so that dissolved organic nitrogen (DON) and dissolved organic phosphorus (DOP) concentrations could be calculated:

DON = TN (of dissolved sample fraction) - DIN;

DOP = TP (of dissolved sample fraction) - FRP.

Total particulate nitrogen (TPN) and total particulate phosphorus (TPP) concentrations were then calculated as follows:

TPN = TN (raw water sample) – (DIN + DON)

TPP = TP (raw water sample) – (FRP + DOP)

3.2.6. Phytoplankton diagnostic pigments (analysed by High Performance Liquid Chromatography, CSIRO Marine)

Water samples were filtered through a 47 mm GF/F glass-fiber filter (Whatman) with 0.7 µm pore diameters and stored in liquid nitrogen until analysis. Phytoplankton pigments were analyzed by *HPLC* (High Performance Liquid Chromatography) following the method described in Clementson et al. (2001). An index of the size structure of the algal population can be derived from individual pigments which are specific to a given phytoplankton group (diagnostic pigments). The contribution of small (pico-phytoplankton, < 2 µm), medium (nano-phytoplankton, 2-20 µm) and large (micro-phytoplankton, 20-200 µm) cells to the algal population were computed as described in detail in Vidussi et al. (2001) and Uitz et al. (submitted).

3.3. BOTTOM SEDIMENT PROPERTIES

3.3.1. Sample Collection

Bottom sediment samples were collected from throughout Keppel Bay and Casuarina Creek during both the August and September surveys, using a grab sampler. The grab has a spring-loaded scoop that is triggered by the sliding weight on the top. The grab collects intact benthic sediment sample sections up to 5 cm by 12 cm in area and 5 cm radially in depth. The sample is covered during recovery so that wash-out of the sample cannot occur. The top 2 cm of the sediment (wet) sample was sub-sampled into separate containers for later analyses: (i) porosity and bulk density; (ii) grain size distribution (and nitrogen isotopic composition); and (iii) mineralogy, major element oxide composition, nutrient contents and carbon isotopic composition. The samples were chilled on ice immediately after collection, and were later refrigerated prior to further processing or analyses. The samples from the different surveys were integrated into a single data set for the purpose of spatial mapping of sediment properties.

During the August 2004 survey only, bottom sediment was also collected for chlorophyll analysis. For each chlorophyll-*a* (Chl-a) analysis, an area of 3 cm^2 wet surface sediment with a depth of 3-5 mm, was added to a 15 ml polyethylene vial. The samples were wrapped in Aluminium foil and frozen prior to their subsequent analysis.

3.3.2. Porosity and Bulk Density

Samples of wet sediment for porosity and bulk density analysis were collected in 10cc volumetric sample tubes, and were pushed into pre-weighed vial using a plunger. The sample and the vial were then weighed before they were transported to Geoscience Australia (GA) laboratories for analysis (see below). In the laboratory, the samples were freeze-dried and then weighed. Porosity was determined by dividing the volume of water (sample wet weight minus dry weight) by the volume of sample. Wet bulk density was determined by dividing the weight of the wet sample by the volume of the wet sample. Dry bulk density was determined by dividing the weight of the dry sample by the volume of the dry sample. The volume of the dry sample was determined by subtracting the volume of water from the volume of the wet sample. Volumes were corrected for seawater density in all cases.

3.3.3. Grain Size Distribution

Surface sediment grab samples were analysed for percentage mud, sand and gravel using nested 2mm and 63µm analytical sieves. Grain size distributions were determined on the sand and mud fractions separately by laser diffraction, using a Malvern Mastersizer 2000. Laser diffraction measures particles as volume percentages in 34 logarithmically spaced bins, from 0.06 – 2000 um.

3.3.4. Sediment Composition

Sediment samples designated for mineralogy, major element oxide composition, solid phase total nutrient contents and carbon isotopic composition were collected in 85ml centrifuge tubes. The samples were centrifuged at 11,000 rpm (in the case of muds) and 6000 rpm (in the case of sands) for five minutes and the supernatant (pore water) was decanted. The sample residues were then refrigerated. The samples were freeze-dried and ground prior to the determinations listed below. During the September survey both mud and sand samples were centrifuged using standard centrifuge tubes. However, these centrifuge tubes were not appropriate for the sand samples because they did not have inserts that were perforated at the bottom to permit pore water drainage. Therefore, corrections had to be made to bottom sediment TS concentrations for the sulphate concentrations of seawater. These corrections relied on the bulk density and porosity and bulk density measurements. Appropriate centrifuge tubes were used during the March survey.

3.3.4.1. Mineralogy

Approximately 5 g of sample was ground with ethanol to a fine consistency (1-10 μm) in a mortar with a pestle. Each dried sample was randomly packed into a 50 x 50 mm sample holder and inserted into an automatic sample changer. The samples were scanned from 2° to 70° 2θ, at a speed of 2° per minute and a step size of 0.02°, using a Siemens^{TM} D500/D501 series X-ray diffractometer. Mineral identification software (EVA^{TM}) was used to identify the d-spacings of a series of peaks corresponding to individual minerals. *SiroQuant*^{TM} was used to derive a semi-quantitative estimation of the mineral abundance. The software replicates a measured diffraction pattern by implementing a least-squares fitting routine which adjusts the scaling factors until the calculated profile best approximates the measured one. The differential pattern produced in the procedure indicates the degree to which the calculated pattern replicates the measured one.

3.3.4.2. Carbonate Analyses

Carbonate contents were determined on the bulk sediment samples using the carbonate bomb method (Muller and Gastner, 1971). 20% orthophosphoric acid, warmed to 50°C, was placed in a warm (35°C) Perspex chamber. Dried and crushed sediment samples, weighing 0.9 g, were introduced to the chambers. Pressure gauges were screwed onto the top of the chambers, forming a seal. The chambers were then agitated until all the carbonate dissolved, producing CO_2 gas. The mass of carbonate is determined by a calibration curve of CO_2 gas pressure as a function of carbonate content. The accuracy of the method is $\pm 0.5\%$.

3.3.4.3. Major Element Oxides

Major and minor element concentrations were determined by x-ray fluorescence (XRF) using a modified version of Norris and Hutton's (1969) method, whereby no heavy absorber was added to the flux. The instrumentation used was a Philips PW2404 4kW sequential spectrometer. The instrument was calibrated using a range of USGS and SARM (S.African Ref. Material) international standards. Detection limits for Al_2O_3%, SiO_2%, CaO%, MgO%, Fe_2O_3%, TiO_2% Na_2O%, K_2O%, MnO% and SO_3% and are 0.001%, 0.006%, 0.002%, 0.004%, 0.002%, 0.002%, 0.004%, 0.002% 0.001% and 0.001% respectively. Detection limits for Cr, Cu, Ni, Sc, V and Zn are 1.9, 0.8, 1.3 1.6, 2.8 and 0.5 ppm respectively.

Ferrous iron (FeO) was determined by wet chemistry using a modified version of Shapiro and Brannock's (1962) method. Ten millilitres of 1:3 H_2SO_4 and 5 ml of 40% hydrofluoric acid were added to five hundred milligrams of sample. The sample was digested on a hotplate for ten minutes before being transferred to a beaker containing 400ml of deionised water, 15g H_3BO_3 and 10ml of 1:1 H_3PO_4. The solution was then titrated with $K_2Cr_2O_7$ using a Metrohm 716 DMS Titrino using a LL combined Pt wire electrode. The instrument is calibrated against a range of in-house standards and USGS International Standards. The detection limit for FeO is 0.01%.

3.3.4.4. Total Organic Carbon Concentrations

TOC was determined on finely ground sediments using a LECO combustion furnace (RC412), and the method outlined in the manual. The samples (1.0 g) were treated with 1:1 HCl to digest the carbonates, and were dried at 40°C prior to their combustion in a LECO furnace.

3.3.4.5. Nitrogen and Phosphorus Contents

Sediment samples (0.25-0.40g) were analysed for nitrogen and phosphorus at Queensland Health – Pathology and Scientific Services. Samples (0.25-0.40gm), standards and quality control samples were subject to a digestion process using a Kjeldahl Digestion Mix (potassium sulfate/sulfuric acid/copper sulfate). The automated digestion process using block digesters was programmed to give a final digestion temperature of 360ºC for a period of 2 hours. The procedure is based on Standard Methods 1998 – 4500-Norg D procedures (with modifications to allow analysis for freshwater, saline waters and sediments). Analyses for TKN and TP were then performed simultaneously on the digest using a segmented flow instrument (BRAN+LUEBBE). TKN analysis for NH_3 was based on Standard Methods 1998 (20th Edition) – 4500- NH_3 H, with the modification that sodium salicylate was used instead of phenol. TP analysis was based on the ascorbic acid reduction of phosphomolybdate for FRP (Standard Methods 1998 (20th Edition) – 4500-P).

Twenty of the sediment samples were also sent to the laboratory at the Marine and Freshwater Research Institute in Victoria (MAFRI) for determination of the following P fractions: total P, organic P, Fe/Al bound P including loosely exchangeable phosphate (non-apatite phosphorus), Ca-bound P (apatite-P) and residual inorganic P using a modification of the extraction schemes of Williams et al. (1976) and Strom and Biggs (1982). TP was determined by peroxide/sulphuric acid reflux digestion (Nicholls, 1975) followed by segmented flow orthophosphate analysis. Organic P was determined by the difference in orthophosphate concentration between 1N HCl extracts of ignited (500^{o}C) and non-ignited sediment. Fe/Al bound P was determined by segmented flow analysis after extraction of the sediment by 0.1N NaOH/0.1M NaCl solution. Carbonate-bound P was determined by segmented flow analysis after extraction by 1N HCl. Residual inorganic P was the difference of total P minus (organic P + Fe/Al bound P + Ca-bound P).

3.3.4.6. Carbon and Nitrogen Isotopes (and contents)

Sediments were analysed for $\delta^{15}N$, $\delta^{13}C$ and Total Nitrogen% (TN%) at Geoscience Australia using a Thermo Finnigan Flash EA series 1112 interfaced to a Thermo Finnigan Conflo (II)I. The isotopic measurements were carried out on a Finnigan Mat 252 using ISODAT NT software. The Flash EA was operated using EAGER software. The oxidation furnace of the Flash EA was packed with Copper Oxide and Silvered Cobaltous Oxide and operated at 900^{o}C. The reduction furnace was packed with pure Copper and operated at 600^{o}C. Combustion products were separated on a packed GC column run isothermally at 40^{o}C. Carbon and Nitrogen analysis were carried out separately to improve reproducibility and accuracy. All analyses were carried out in duplicate or triplicate.

For carbon analysis, approximately 200 mg of ground dry (bulk) sediment samples were loaded into baked glass vials. 6% HCl was added drop wise to the vials and was allowed to react with the sediment until effervescing stopped (at least 15 minutes). The samples were then dried for 1-2 hours in an oven at 100^{o}C to drive off the acid. The acid addition and drying procedures were repeated a second time. The acidified sediments were then weighed into tin foil cups and placed in the auto-sampler along with a series of blanks and standards used for isotope correction. Standards ANU Sucrose, TO2 and caffeine were used along with caffeine for isotopic calibration. Water was removed from the gas stream using a 6 to 18 mesh Magnesium Perchlorate water trap.

For the nitrogen analysis, approximately 50 mg of ground dry sediment sample were loaded into tin foil cups. The mud grain size fraction (<63 um) was used in this analysis because the TN% contents of the bulk samples were too low. The cups were placed in the auto-sampler along with a series of blanks and standards used for isotope correction and TN% calculation. International standards IAEA N1 and IAEA N2 were used along with caffeine. The caffeine was used as a secondary standard (it has been previously calibrated against international standards) and also to calculate TN% (mud fraction only). Carbon dioxide was removed in all nitrogen analysis by passing the gas stream from the GC through a trap of Carbosorb AS Self Indicating Granules (BDH Prod # 331634T). Water was removed from the gas stream using a 6 to 18 mesh Magnesium Perchlorate water trap.

3.3.4.7. Chlorophyll a Content

In the laboratory at Geoscience Australia, 10 mL's of acetone (90 %, saturated with $MgCO_3$) was added to each thawed sample. The vial was then closed and placed on a Vertex mixer for vigorous mixing of the sediment and the acetone. Chl-a rich sediments were immediately recognized by the green coloration. The vial was then placed into an ultrasonic bath for ~ 30 min, centrifuged, and the supernatant extraction solution poured into a second vial. From this vial, we transferred 1 mL of solution into a photometric glass cell and placed it in a photospectrometer for the photospectrometric analysis of Chl-a (and pheophytin, a degradation product). The sample was analysed at wavelengths of 664 nm and 750 nm and the result recorded. We then added 100 µl of 0.1 N HCl to the solution in the glass cell and again analysed at wavelengths of 664 and 750 nm. The concentration of Chl-a and pheophytin was given as µg / g dry sediment and calculated according to the following US-EPA equations:

$$Chl-a[\mu g/g] = \frac{26.7((664-750)-(664a-750a))extr-vol}{sed-massL}$$

$$Pheophytin[\mu g/g] = \frac{26.7(1.7(664a-750a)-(664-750))extr-vol}{sed-massL}$$

in which 664/750 is the optical density of the original extraction solution; 664a/750a is the optical density after acidification; extr-vol is the volume of the extraction solution (*e.g.* 10 ml); sed-mass is the weight of the dry sediment (*e.g.* 2 g); and L is the path length of the photo-spectrometric cell (*e.g.* 1 cm).

3.4. CORE & BOTTLE INCUBATIONS

3.4.1. Core Incubations

One sediment core was collected at each of 8 sites in Keppel Bay (VC01, VC03, VC05, VC06, VC09, VC13, VC17 & VC20) during the vibracoring survey (Skene *et al.*, 2004). The sediment cores were collected by hand-pushing a PVC tube, ~80 mm in diameter, into an undisturbed area of surface sediment obtained with a box corer. The box core comprised a 900 cm^2 area of sediment to a depth of ~25 cm, together with about 50 L of the overlying bottom water. Once in the sediment, the core barrel was sealed at the bottom core with an o-ring-fitted plastic plug (Figure 3.2). We obtained a sediment depth in the range from 200-240 mm in each sediment barrel. We also added 200 – 250 mm of the bottom water above the sediment in each core barrel. A gas-tight lid, fitted on the underside with a magnetic stirrer, sealed the top of each core, and constantly mixed the bottom water to avoid stratification. The stirrer was spun by means of a second magnet, situated on top of the lid, driven by a small motor (Figure 3.2). Core incubations proceeded in darkness and at in-situ temperature (21 ± 1°C) for approximately 24 hours.

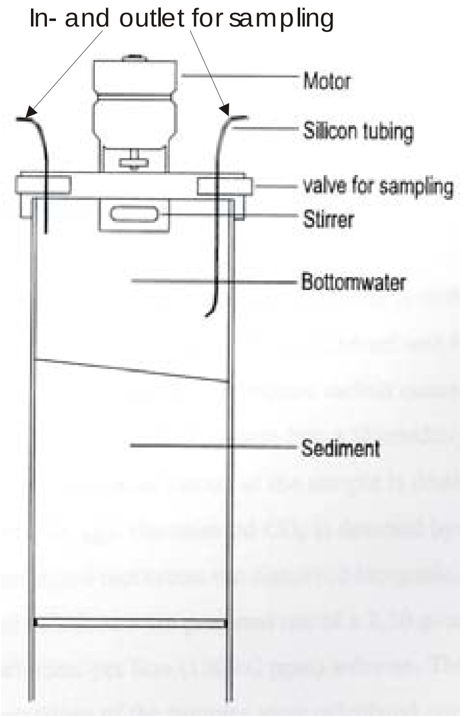

Figure 3.2. *Core incubation experimental set up for the determination of total fluxes across the sediment-water interface. The silicon tubing is only required if water samples are taken during the incubation period, therefore, we did not use it for this study (from Murray et al., in press).*

DO and pH was measured at the beginning (time = zero or t_0) and end of the experiment (time = one or t_1) using a HACH HQ20 O2pH/mV probe Orion pH metre and Metrohm aquatrode pH probe. Bottom water samples for nutrients (SiO_4^{2-}, NO_2^-, NO_3^-, NH_4^+, PO_4^{3-}), N_2, alkalinity and TCO_2 were also collected at the beginning (t_0) and end (21.75-24.75 h = t_1) of each incubation. Sub-samples for SiO_4^{2-}, NO_3^-, NO_2^-, NH_4^+, PO_4^{3+}, alkalinity and TCO_2 were filtered using 0.45 µM disposable filters. Samples for N_2, alkalinity and TCO_2 were refrigerated in gas-tight containers, whereas samples for NH_4^+, SiO_4^{2-}, NO_2^-, NO_3^-, and PO_4^{3-} were frozen. The alkalinity and TCO_2 samples were analysed within 3 days of collection. Samples for N_2 (% coefficient of variation averages 0.05%; Eyre *et al*., 2002) were submitted to Southern Cross University Environmental Analysis Laboratory for analysis. The alkalinity was determined by Gran titration, while the carbonate alkalinity (CA) was estimated by subtracting the alkalinity contribution of $B(OH)_4^-$. Carbon dioxide (TCO_2) was estimated from pH and carbonate alkalinity according to Mehrbach et al. (1973) using:

$$TCO_2 = CA\frac{1 + K_2 / a_H + a_H / K_1}{1 + 2K_2 / a_H}$$

where: a_h is the activity of the hydrogen ion and K_1 and K_2 are the first and second ionisation constants of carbonic acid.

As outlined by Murray et al. (in press), the laboratory and instrumentation used for N_2 analysis was that of Kana *et al*. (1994) with the following modifications. Gases were detected with a Balzers QMS422 quadrupole mass spectrometer and a water bath (± 0.01°C) was used to stabilize sample temperature in the water line upstream of the membrane. The effect of O_2 in the sample on the N_2 signal measured by the membrane inlet mass spectrometer was corrected by making a standard curve of O_2 concentration against N_2 : Ar ratios using water standards made from the incubation water equilibrated with the atmosphere at constant temperature (Eyre *et al*. 2002).

Concentrations were measured at the beginning, and end of each incubation (at time t_0 and time t_1) and assumed the rate of uptake or release of solutes between these times was linear.

3.4.2. Bottle Incubations

Bottle incubations were undertaken on surface sediment collected from box cores at stations VC03, VC04, VC01, VC20 & VC17 during the vibro-coring survey (see milestone report CG04.01). The sediment samples were stored at 4°C for transport back to the laboratory at Geoscience Australia and during the two weeks prior to analysis. Approximately 25 g of the wet sediment was weighed into 15 ml polyethylene vials. The vials were then completely filled with seawater that was collected from the low turbidity (*i.e.* <1.5 mg L^{-1} TSM) "blue-water" zone of Keppel Bay. The seawater was frozen soon after collection and was thawed over a roughly 12 hour period prior to the incubations. The corresponding TSM of the "fluid mud" in the vials ranged from 300 to 400 g L^{-1}. Three replicate were prepared for each sample for each incubation period (*i.e.* t = 0, 1, 2, & 3 days), giving a total of nine incubations per sample.

The vials were wrapped in aluminium foil and were laid down horizontally in a shaker/incubator set at ~130 rpm's and 21.5°C. The shaker had the effect of sloshing the sediment back and forth over the course of the incubation. The incubated samples were opened serially over time (at t = 1, 2, & 3 days) and sampled for alkalinity, dissolved oxygen and pH. DO was measured at t_0 and t_1 using a HACH HQ20 O_2pH/mV probe. Alkalinity was determined by Gran titration, while the carbonate alkalinity (CA) was estimated by subtracting the alkalinity contribution of $B(OH)_4^-$. Carbon dioxide (TCO_2) was estimated from pH and carbonate alkalinity according to Mehrbach *et al.* (1973) as per the core incubations (Section 3.4.1). The calculated fluxes were normalised to the sediment concentrations.

3.5. DATA ANALYSIS

3.5.1. Principal Components Analysis

Principal Components Analysis (PCA) was performed independently on each of the water column and bottom sediment data sets using STATISTICA 6, to investigate spatial patterns in, and significant relationships between, the physical and chemical variables. PCA is an eigenvector analysis of a multi-variate data matrix. It sequentially extracts components, that explain diminishing amounts of variance in the data, and which are linear combinations of the original variables. The first principle component passes through the direction of greatest spread in the n-dimensional scatter of points (*i.e.* the data collected at the station); this variance is measured by an eigenvalue (λ). Succeeding axes, each with their own corresponding eigenvalues, pass through successive directions of major variation, and are uncorrelated (orthogonal) to all the other axes. Typically, the first few principle components account for the most of the variance of a data set, and effectively summarise the salient features of the data.

In the case of the water column data set, the input variables included: turbidity, TSM, water temperature, salinity (in PSU's), SiO_4, TP, TN, FRP, DOP, TPP, NH_4^+, NO_2^-, NO_3^-, DON and TPN, as well as percentages of the various P (%PP, %DOP & %FRP) and N species (%DON, %DIN & %PN). Chlorophyll *a*, pheophytin *a*, total organic carbon (TOC), dissolved organic carbon (DOC), total carbon dioxide (TCO_2) and total particulate carbon (TPC) data (P.Ford, in press) were also utilised in the analysis, as were the following ratios: TN:TP, DON:DOP, chlorophyll *a*: pheophytin *a* and DOC:DON.

The input variables for the PCA on bottom sediment parameters were: the major and minor element concentrations (in molar proportions), the percentage mud based on the criteria of Folk

(1980), carbon and nutrient contents, mud and quartz, greigite and kaolin-group mineral percentages (*i.e.* % kaolin plus halloysite) and the following ratios and indices:

- TOC:TS, FeII/FeIII, TS:FeII, TP:TS and Fe(II):TOC ratios were used as crude indicators of sediment redox condition;
- quartz:feldspar ratio (*i.e.* %quartz: %albite + %anorthite + %microcline + %orthoclase + %sanidine) was used as an indicator of sediment maturity. The feldspar content should theoretically decrease with the distance the sediment travels from its source (Anonymous, 1979).
- CIA values ([$Al_2O_3/(Al_2O_3+CaO+Na_2O+K_2O)*100$]) of (Nesbitt and Young, 1984) and Al_2O_3/K_2O ratios were used in the capacity of weathering indices (see discussion in Radke *et al*., 2004b). Both CIA values and Al_2O_3/K_2O ratios increase during weathering and related fining of sediment. The CaO contents were corrected for Ca in $CaCO_3$ using the bulk carbonate determination from the carbonate bomb method.

TOC, TS and Fe(II) as molar percentages of TOC + TS + Fe(II) were also used in the analysis (*i.e.* TOC/TOC+TS+Fe(II)*100, TS/TOC+TS+Fe(II)*100 and Fe(II)/TOC+TS+Fe(II)*100). Again, these parameters were trialled as indicators of sediment redox status, to get a rough idea as to the importance of sulphate reduction versus iron reduction in breakdown of sediment organic matter. The sediment Fe(II) content was corrected for its minor percentage (<3%) in chalcopyrite, arfedsonite, biotite, hedenbergite, illite and riebeckite. The TS contents were corrected for its minor percentage (<3%) in chalcopyrite and gypsum.

The data were transformed ($\log_{10}$) prior to analysis to produce an approximately normal distribution.

3.5.2. Kriging

Contour maps of the distributions of various physical and chemical parameters (water column and sediment) were generated using the default kriging options in SURFER®7.

4. Results

4.1. SEPTEMBER 2003 WATER COLUMN SURVEY

4.1.1. Synoptic Perspective

The results of the PCA on the water column data are shown in Table 4.1 (variable scores) and Figures 4.1a,b (site scores). Maps showing the distribution of the site scores for axis 1 and axis 3 in Keppel Bay are provided in Figures 4.2a,b. The interpretation of PCA is relatively straightforward. Variables that are strongly correlated to a principal axis have large principle component loadings (or factor coordinates) on that axis. These loadings may be negative or positive. Variables that share in common either large negative or large positive loadings are positively correlated; whereas variables with positive loadings are negatively correlated to variables with negative loadings. The magnitude of the site scores (or factor coordinates of the stations) is a measure of the spread (or variance) of the stations along an axis.

Axis 1 accounted for most of the variation in the data (*i.e.* it explains 48.4% of the variance), and represents a strong gradient of changing suspended solid (TSM and turbidity), chlorophyll *a* contents and total and particulate nutrient concentrations (Table 4.1). With the exception of DOP, NH_4^+ and NO_2^-, the dissolved nutrient concentrations (organic and inorganic) also varied most substantially along axis 1 (Table 4.1). Stations 1 & 2 in the Fitzroy Estuary stood out on axis 2 (11.8% of the variance) on the basis of lower salinity levels (*i.e.* 29.1 and 32.7 PSU's), and much higher NH_4^+ and NO_2^- concentrations than the other stations (Figure 4.1a). Axis 3 explained 9.9% of the variance in the data set and identified the southeast portion of Keppel Bay as having had regionally low TOC and POC concentrations at the time of the survey, and also low DOC:DON ratios. Aspects of the study pertaining to carbon dynamics (and also primary productivity) will not be discussed here, but will be provided in relevant reports led by P. Ford (CSIRO Land and Water). Dissolved organic phosphorus concentrations (DOP) and DON:DOP ratios varied most substantially on Axis 4 (5.3% of the variance). The data from Casuarina Creek varied most substantially long this axis (Figure 4.1b).

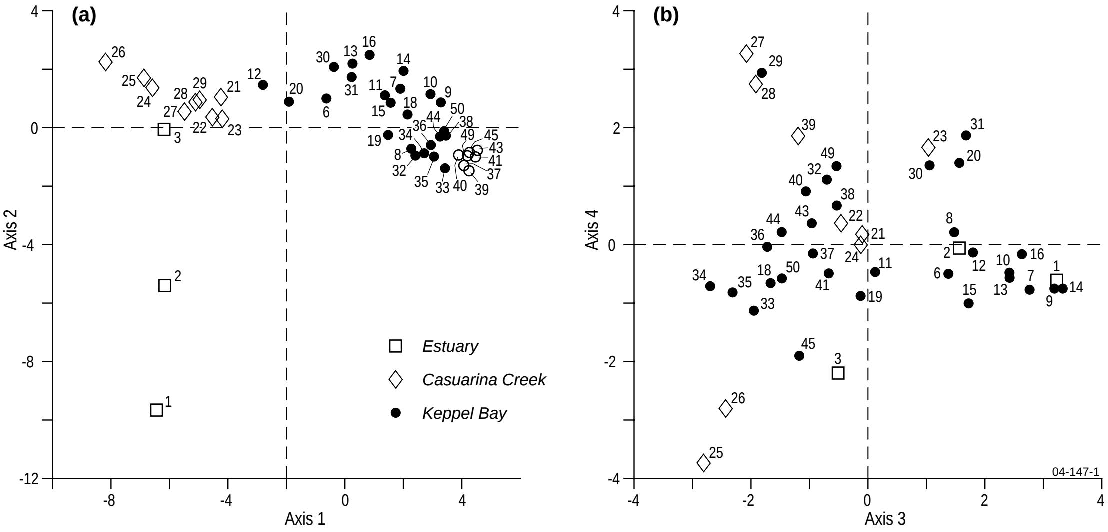

Figure 4.1. *September 2003 factor coordinates of the stations on: (a) axis 1 and axis 2; and (b) axis 3 and axis 4 of the water column PCA.*

Table 4.1. Factor coordinates of the variables on axes 1, 2, 3 & 4 of the PCA.

	Axis 1	Axis 2	Axis 3	Axis 4
TP	**-0.97**	0.05	0.05	-0.19
TN	**-0.94**	-0.23	0.01	-0.15
TSM	**-0.93**	0.15	-0.05	0.07
NO_3^-	**-0.93**	-0.26	-0.06	0.01
chlorophyll *a*	**-0.92**	0.11	0.09	0.19
FRP	**-0.91**	-0.37	-0.02	0.01
TPP	**-0.91**	0.19	-0.10	-0.05
%DIN	**-0.90**	-0.02	0.13	0.13
SiO_4^{2-}	**-0.88**	-0.24	0.07	-0.06
TPN	**-0.82**	0.34	-0.23	0.07
pheophytin *a*	**-0.81**	0.23	-0.02	-0.02
turbidity	-0.69	0.16	0.18	-0.19
DON	-0.68	-0.52	0.34	-0.22
%TPN	-0.68	0.38	-0.16	0.16
TCO_2	-0.65	0.09	-0.01	0.49
%TPP	-0.60	0.29	0.03	-0.02
chlor *a* :pheo *a*	0.46	-0.26	0.11	0.19
NO_2^-	-0.62	**-0.69**	0.20	-0.09
NH_4^+	-0.40	**-0.77**	0.36	-0.09
PSU	0.06	**0.72**	-0.46	-0.13
%FRP	0.34	**-0.74**	-0.14	0.39
DOC	-0.07	**-0.73**	-0.54	-0.16
TOC	-0.33	-0.47	**-0.73**	-0.29
DOC:DON	0.42	-0.32	**-0.74**	0.00
TPC	-0.38	-0.03	-0.65	-0.12
DON:DOP	0.07	-0.16	-0.22	**0.54**
DOP	0.02	0.08	0.59	**-0.61**
water temperature	-0.02	0.19	-0.52	-0.37
%DOP	**0.87**	0.00	0.22	-0.02
TN:TP	**0.91**	-0.31	0.04	0.18
%DON	**0.95**	0.02	0.19	0.08

The site scores with the most negative loadings on axis 1 of the PCA coincided with the estuary and Casuarina Creek (Figure 4.2a). Site scores then progressively increased toward the northeast in Keppel Bay. Correspondingly, TSM concentrations ranged from 100 to 400 mg L^{-1} in Casuarina Creek and 50 to 130 mg L^{-1} near the mouth of the estuary (Figure 4.2c). TSM levels then diminished to the north and the east, and were <1 mg L^{-1} over most of Keppel Bay.

TP concentrations ranged from 0.4 to 0.14 mg L^{-1} in the Fitzroy Estuary and from 0.05 to 0.43 mg L^{-1} in Casuarina Creek, and were <0.01 mg L^{-1} over most of Keppel Bay (Figure 4.3a). Similarly, TN concentrations were <0.1 mg L^{-1} over most of Keppel Bay, but were considerably higher in the Fitzroy Estuary (0.18 to 0.81 mg L^{-1}) and Casuarina Creek (0.22 to 0.73 mg L^{-1}; Figure 4.4a). Particulate nutrients and dissolved inorganic nutrients were detected near the estuary mouth and in Casuarina Creek, but were below detection over most of Keppel Bay (Figures 4.3 and 4.4). In comparison dissolved organic nutrients were measured throughout most of the study area, but there was a seaward decrease in concentration (Figures 4.3c and 4.4c).

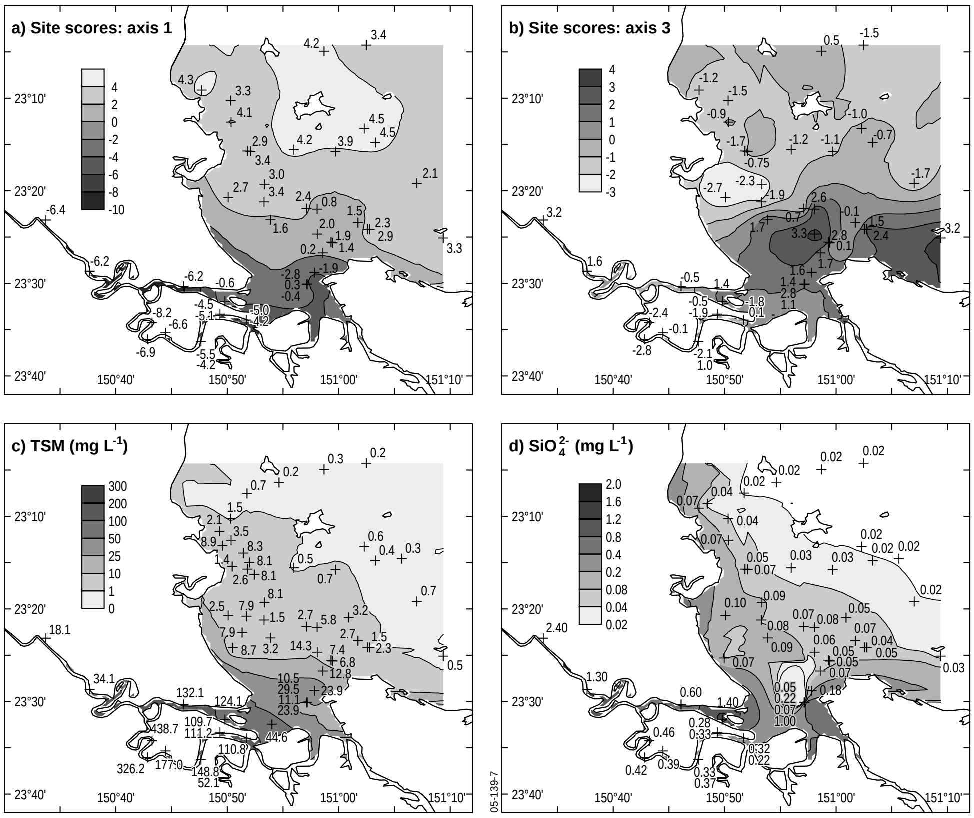

Figure 4.2. *September 2003 distributions of: (a) site scores for axis 1; (b) site scores for axis 3; (c) TSM concentrations; and (d) SiO_4^{2-}concentrations (mg L^{-1} as Si)*

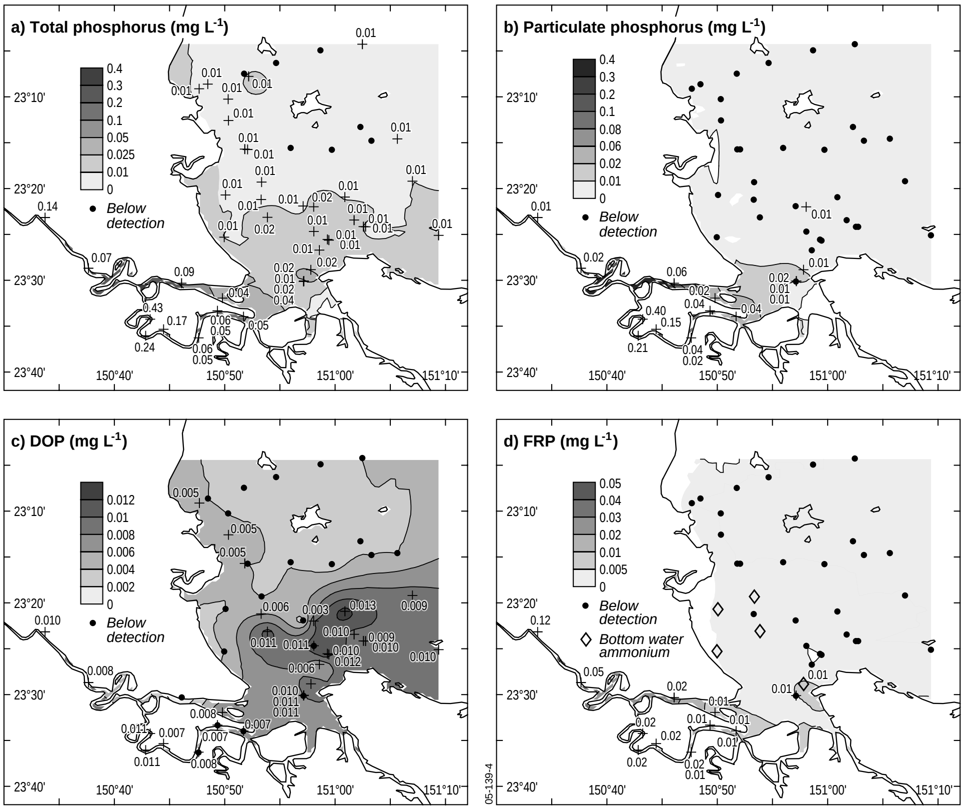

Figure 4.3. *September 2003 phosphorus distributions in Keppel Bay at the time of sampling (mg L^{-1} as P): (a) total phosphorus; (b) particulate phosphorus; (c) dissolved organic phosphorus (DOP); and (d) and filterable reactive phosphorus (FRP).*

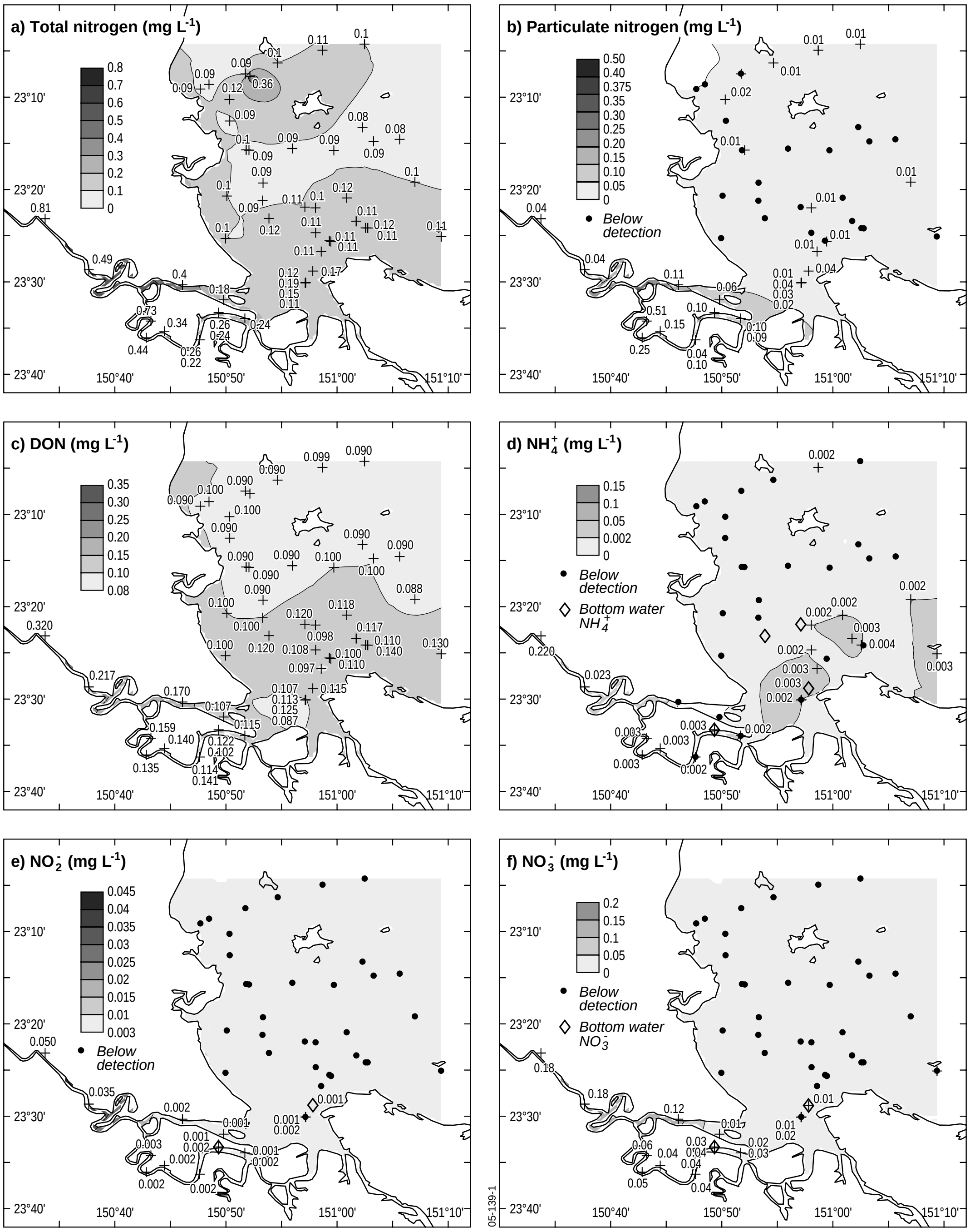

Figure 4.4. *September 2003 nitrogen distributions in Keppel Bay at the time of sampling (mg L^{-1} as N): (a) total nitrogen; (b) particulate nitrogen; (c) dissolved organic nitrogen (DON); (d) ammonium (NH$_4^+$); (e) nitrite (NO$_2^-$); and (f) nitrate (NO$_3^-$).*

DIN:FRP molar ratios were lower than 16 (i.e. the Redfield ratio; Redfield, *et al*., 1963) in the surface waters of Casuarina Creek (5.5 - 7.9), the Fitzroy Estuary (8.3 – 11.6) and just beyond the estuary mouth (2.2) (Figure 4.5a), whereas DON:DOP and TN:TP molar ratios increased steadily from the mouth of the estuary toward the north-east of Keppel Bay (Figure 4.5b,c). Interestingly, the nano-phytoplankton percentage increased with TN:TP and DON:DOP molar ratios (Figure 4.5d). DIN:FRP molar ratios could not be determined for the whole of Keppel Bay because dissolved inorganic nutrient and FRP concentrations were generally below detection limits (Figure 4.3d and 4.4d,e,f). For example, FRP was detectable in surface waters at only one location in Keppel Bay (stations 6 & 12; Figure 4.3d), while NH$_4^+$ was detectable in Keppel Bay surface waters only in a small number of samples taken near the southeast margin (Figure 4.4d).

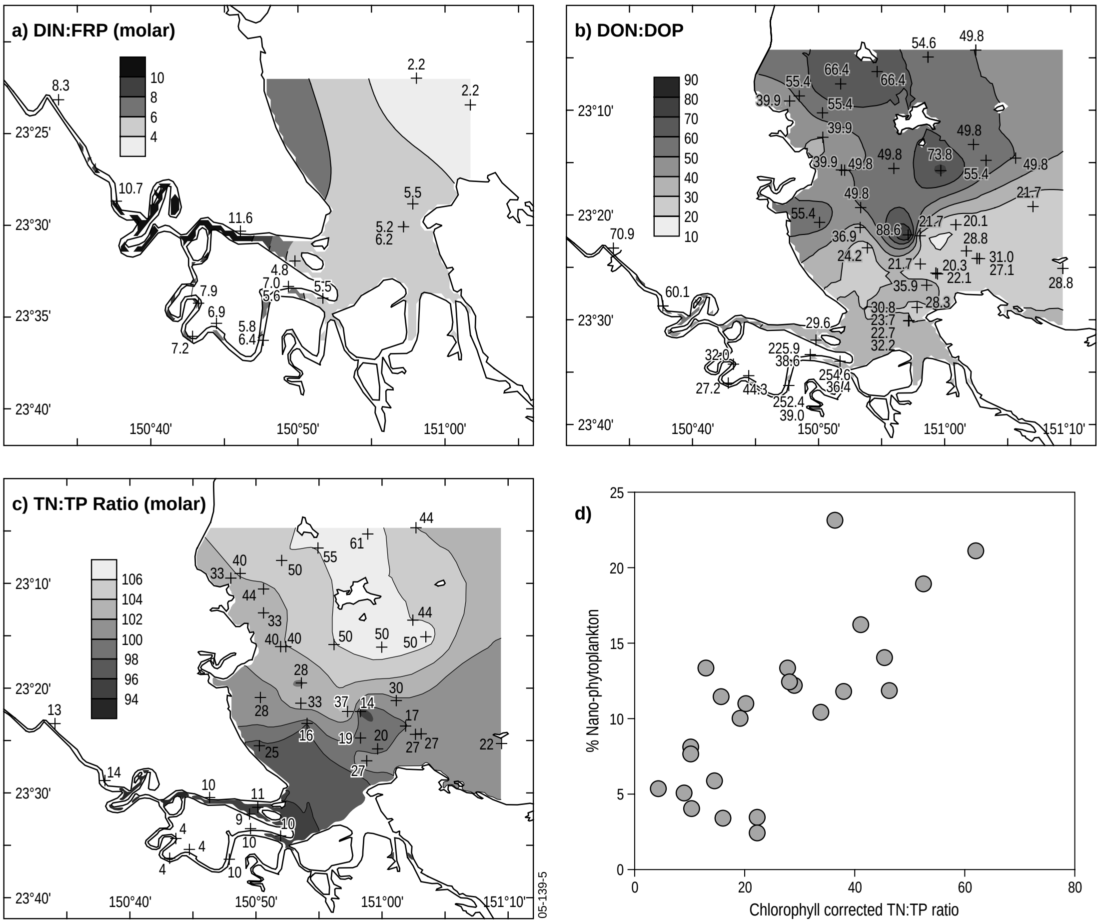

Figure 4.5. *September 2003 distributions of: (a) DIN:FRP molar ratios; (b) DOP:DON molar ratios; and (c) TN:TP molar ratios. Changes in % nano-phytoplankton as a function of increasing TN:TP molar ratios are shown in (d), and are corrected for the concentrations of N and P in chlorophyll a..*

The most distinguishing feature of the salinity and water temperature distributions at the time of the survey was the zone of elevated salinity (36.4 to 39.4 PSU's; Figure 4.6a) and water temperatures (21.5 – 22.8 ^{o}C; Figure 4.6b) along the shallow western shore (<10 m). Elsewhere in Keppel Bay, salinity levels ranged from 36.1 – 36.3 PSU's and water temperatures were close to 21^{o}C. With the exception of five stations in the southeast (9, 10, 11, 30 & 32), and at a few stations in the north (45, 48 & 50), surface and bottom waters were supersaturated with dissolved oxygen (>100%) in Keppel Bay at the time of the survey (Figure 4.6c,d). Importantly, dissolved oxygen saturation levels are highly dependent on time of day and the chlorophyll concentrations.

Surface and bottom salinity levels differed by only 0.1 PSU over most of the study area, at the time of the survey (Figure 4.7a). Differences between surface and bottom water temperatures were largest in the deepest, eastern part of the Bay, and most specifically in the southeast where they ranged from 0.8 – 1.2 ^{o}C (Figure 4.7b). As with water temperature, the largest differences between surface and bottom dissolved oxygen saturation levels at the time of sampling were in the southeast (Figure 4.7c). However, it is noteworthy that dissolved oxygen saturation never dropped to below 85% at any bottom water station in Keppel Bay. In the case of turbidity, the biggest differences between surface and bottom waters were observed in the lower estuary and tidal creek and in the estuary mouth (Figure 4.7d). Again, it is important to note that differences between surface and bottom water salinity and turbidity levels were highly dependent on tidal phase (Section 4.2.3)

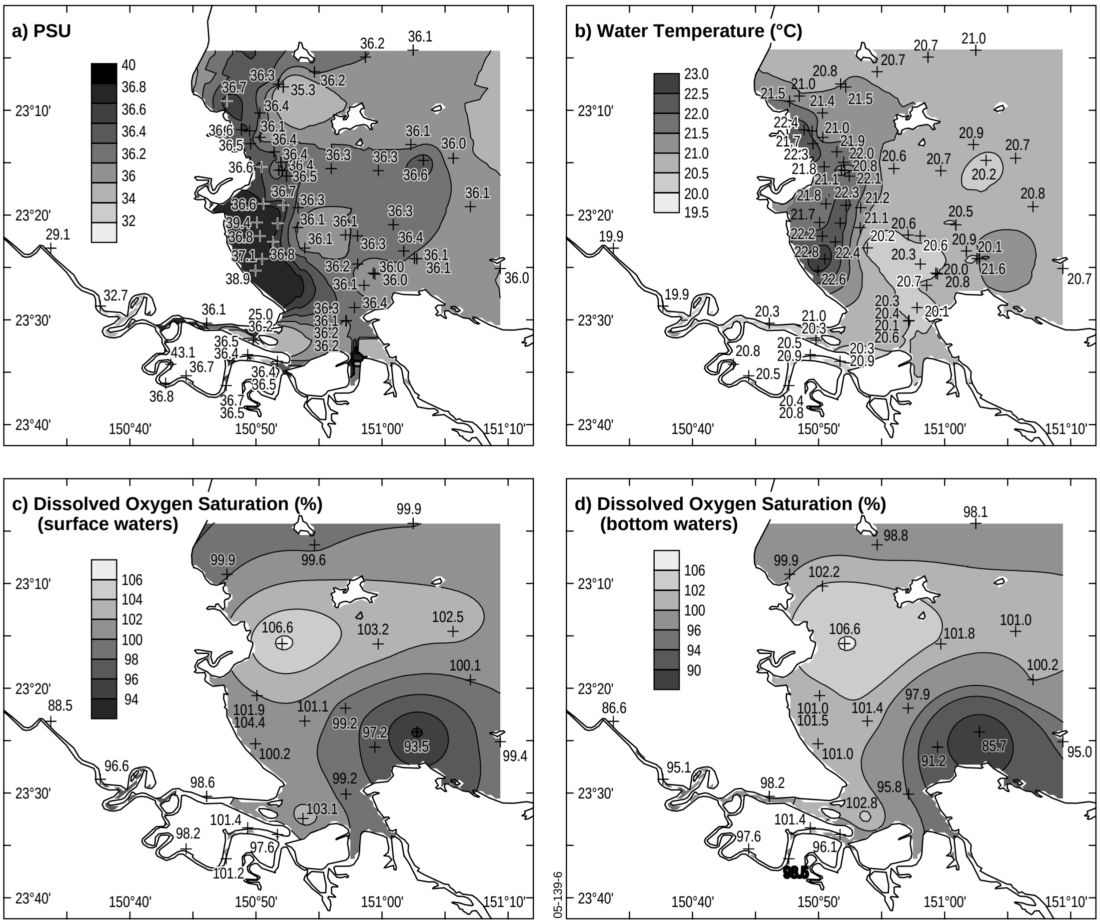

Figure 4.6. *September 2003 distributions of: (a) surface water PSU's; (b) and sea surface temperatures; (c) surface water dissolved oxygen saturation; and (d) bottom water dissolved oxygen saturation.*

Based on a limited data set, the biggest differences between bottom and surface TN & TP concentrations also occurred in the lower estuary, the tidal creek and in the estuary mouth (Figure 4.7e,f). This result is not surprising given particulate nutrients dominate water column nutrient pools in these regions. Bottom water TN & TP concentrations were also higher than surface water concentrations in a band that roughly coincides with the distribution of sandy-muds and muddy-sands (Figure 4.7e,f). Elsewhere in Keppel Bay, differences between surface and bottom water TN & TP levels were within the limits of analytical detection (Figure 4.7e,f). Dissolved inorganic nutrients (FRP, NH_4^+, NO_2^- and NO_3^-) were detectable in bottom waters at only a few sites in Keppel Bay (see diamonds in Figures 4.3d, 4.4d,e,f).

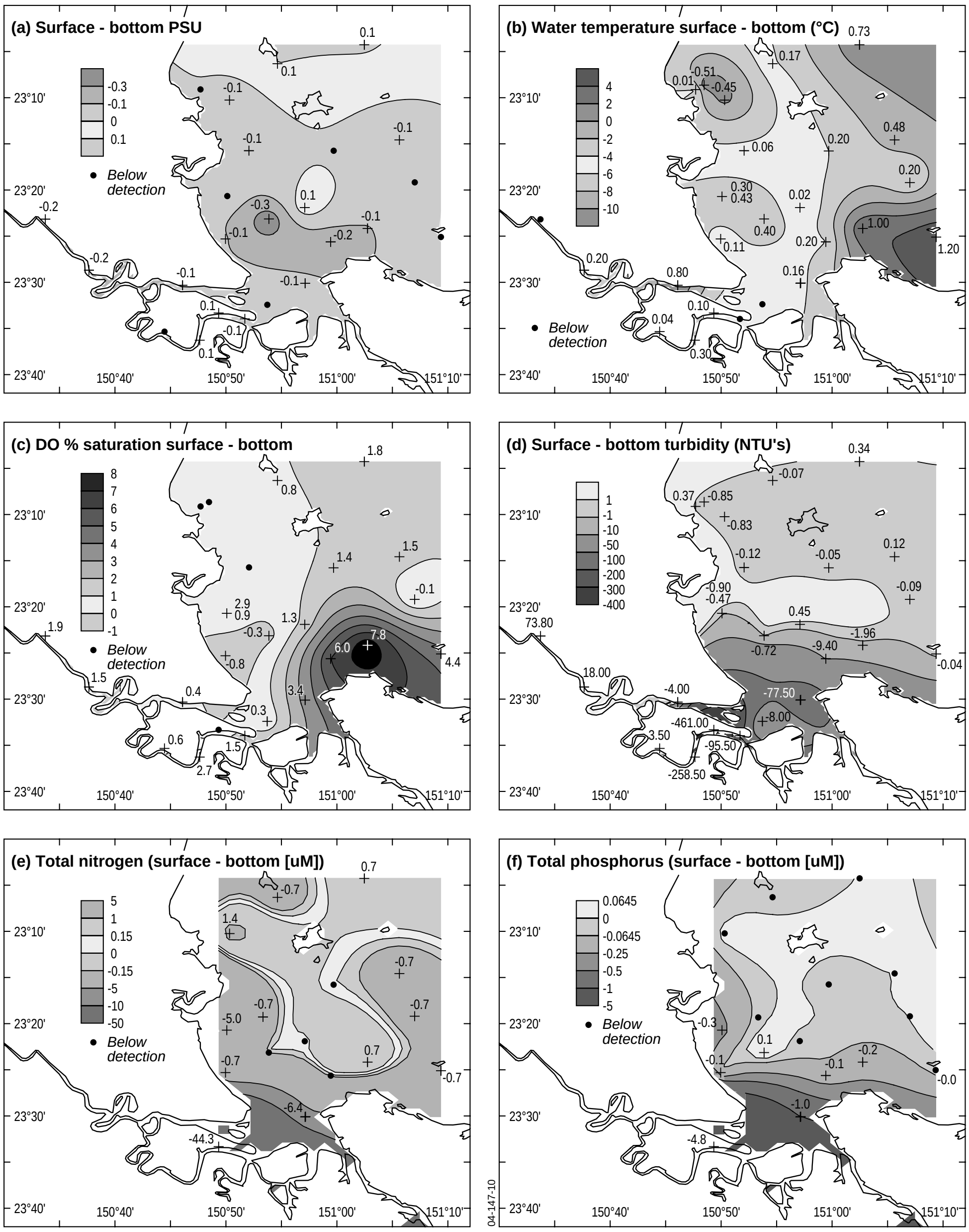

Figure 4.7. *September 2003 distributions of surface water minus bottom water concentrations of: (a) PSU; (b) water temperature; (c) dissolved oxygen (DO) % saturation; (d) turbidity; (e) total nitrogen; and (f) total phosphorus.*

4.1.2. Relationships between Nutrients and TSM

Grain size data pertaining to the TSM are given in Table 4.2. TSM within Casuarina Creek, the Fitzroy Estuary and just beyond the estuary mouth consisted mainly of silt-sized particles (>80%) with modal grain sizes ranging from 3.5 to 9.3 µm (Table 4.2). Clay and colloid percentages were in the range from 5.1 -15.3% and 0.9 - 4.3% respectively, and were highest in the river and lowset in the estuary mouth. Very fine sands were evident in most samples taken in Casuarina Creek and from beyond the estuary mouth. We were unsuccessful in measuring sizes of the TSM at concentrations lower than 20 mg L^{-1}. Consequently, grain sizes of TSM could not be determined over most of Keppel Bay.

Table 4.2. Summary of water column grain size data (% volume)

Station	Location*	Water depth (m)	Modal grain size ± SD (µm)	%colloid	%clay	%silt	%very fine sand	%fine sand	%medium sand
1	FE	0.5	3.5 ± 2.8	2.6	15.3	82.1			
2	FE	0.5	3.9 ± 4	2.9	14.3	82.7			
3	FE	0.5	4.6 ± 9.5	4.1	13.2	82.1	0.6		
5	FE	0.5	4.5 ± 5.2	2.4	11.5	86.2			
21	CC	0.5	4.3 ± 11.6	3.5	12.6	82.8	0.9	1.0	
22	CC	0.5	4.7 ± 8.7	2.5	10.8	86.2	0.4		
23	CC	0.5	4.3 ± 4.2	2.3	12.1	85.6			
24	CC	0.5	4.4 ± 10.3	4.3	12.9	82.1	0.7		
27	CC	0.5	4.6 ± 11.3	3.9	12.0	83.1	0.9	1.0	
28	CC	0.5	9.3 ± 13.5	2.5	5.7	90.2	1.4	1.0	
29	CC	0.5	4.4 ± 10.1	3.0	11.9	84.3	0.7		
11	LKB	0.5	5.1 ± 10.3	0.9	6.7	92.2	0.3		
12	LKB	0.5	4.6 ± 11.4	2.6	10.6	85.7	1.0		
13	LKB	0.5	4.4 ± 6.7	2.1	11.5	86.3			
14	LKB	0.5	4.5 ± 8.0	1.7	9.7	88.4	0.3		
15	LKB	0.5	3.9 ± 7.7	1.1	11.4	87.4	0.1		
15	LKB	4.8	4.3 ± 6.4	1.1	9.3	89.6			
16	LKB	0.5	4.2 ± 6.1	1.8	11.7	86.3	0.2		
17	LKB	0.5	4.9 ± 5.9	0.6	5.7	93.7			
20	LKB	0.5	4.8 ± 9.3	1.7	9.1	88.7	0.5		
30	LKB	0.5	4.8 ± 14.5	2.5	9.5	86.1	1.8	1.0	
30	LKB	16.6	9.4 ± 33.2	2.3	5.1	87.2	3.2	1.0	0.5
31	LKB	0.5	4.7 ± 15.2	1.4	7.8	88.6			

*FE = Fitzroy Estuary; CC = Casuarina Creek; LKB = lower Keppel Bay

When all the data were considered (YSI sonde only), there was a near 1:1 correlation between TSM and turbidity: *e.g.* TSM = 1.07 * NTU - 2.8 (R^2 = 0.73; not shown). However, the correlation coefficient between TSM and turbidity was improved (TSM = 1.39 * NTU - 4.48; R^2 = 0.94) when stations 1, 4, 5, 9 and 26 were removed from the full suite of samples (Figure 4.8a). Stations 1, 4 and 5 were in the estuary (or its mouth in the case of site 5), whereas site 26 was located upstream in Casuarina Creek, not far from the cut-through from the Fitzroy Estuary. Individual data sets from Keppel Bay (TSM = 0.85 * NTU – 1.68; R^2 = 0.82) and Casuarina Creek (TSM = 1.08 * NTU + 45.8; 0.86) yielded correlations between TSM and turbidity that differed from each other, and from the overall data set, both in terms of their slopes and y-intercepts (Figure 4.8*b,c*). There was a robust linear relationship between TSM and turbidity in the bottom waters (TSM = 0.57 * NTU + 0.99; R^2 = 0.998; Figure 4.8*d*). However this correlation was based on quite limited suite of samples that lacked data in the range between 200 and 450 NTU's. Nonetheless, we have reason to believe that the Analite sonde used to make these bottom-water measurements provided a more reliable assessment of turbidity than the YSI sonde used in the continuous tracking, because the latter lacked a wiping facility and was thus prone to fouling.

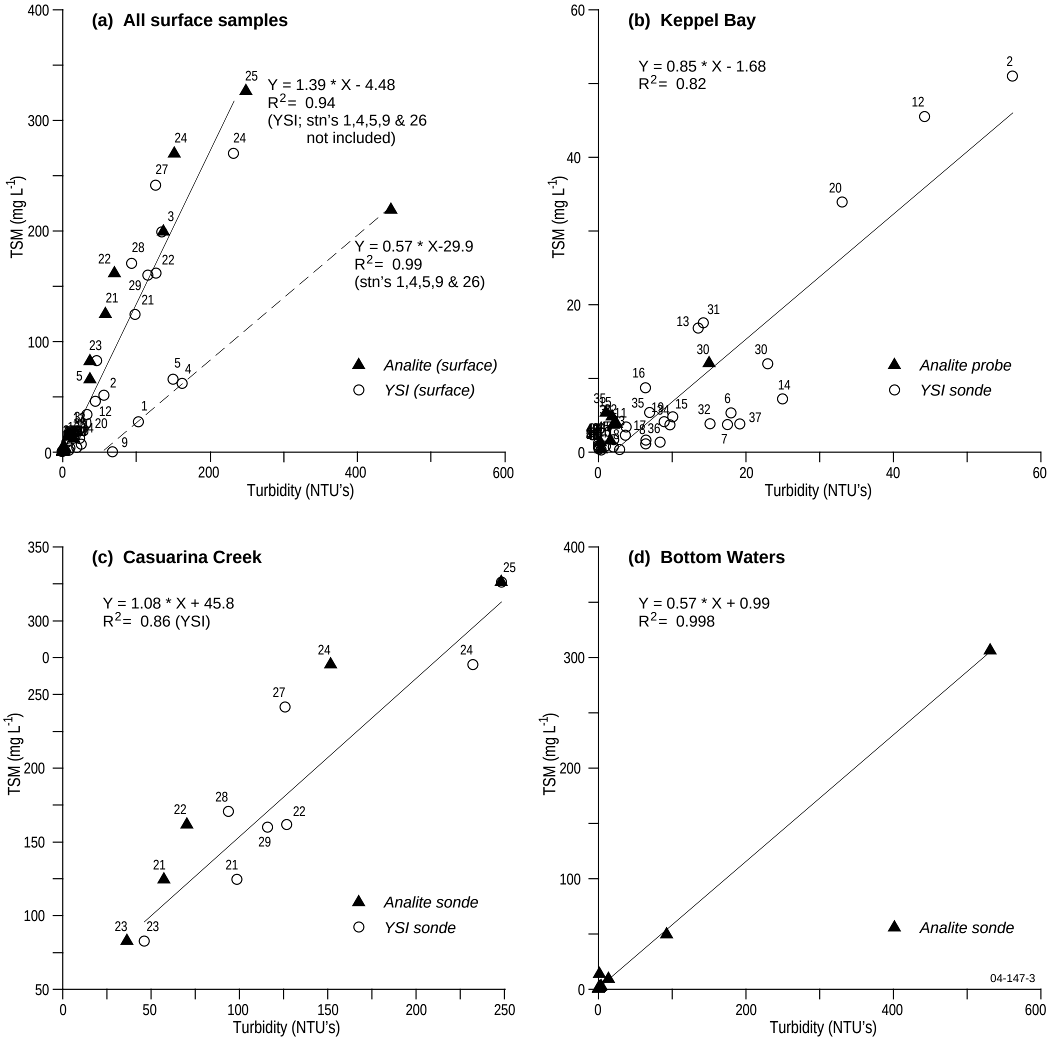

Figure 4.8. *September 2003 TSM vs Turbidity for (a) all data (with the exception of stations 1, 4, 5, 9 & 26); (b) data from Keppel Bay; (c) data from Casuarina Creek; and (d) bottom water data. Note that TSM is plotted on the ordinate because there is more turbidity data collected in the study and the modellers can use this to derive TSM values based on the calibrations.*

There was a linear relationship between TPN and TSM (TPN (mg L^{-1}) = 0.000826 * TSM + 0.00054; Figure 4.9a) and TPP and TSM (TPP (mg L^{-1}) = 0.000235 * TSM - 0.0016 or TPP = 0.000584 * TSM - 0.0033 if data from sites 24, 25 & 26 are included the analysis; Figure 4.9b). By comparison, the relationship between FRP and TSM could be described by a logarithmic function (FRP = 0.003 * ln TSM – 0.003; R^2 = 0.89) in samples taken from the Fitzroy Estuary and Casuarina Creek, after the removal of data from sites 1 and 2 (Figure 4.9c). DIN was linearly correlated to TSM (DIN = 0.0002 * TSM + 0.007; R^2 = 0.84) in the same suite of samples (Figure 4.9a).

Particulate phosphorus dominated water column nutrient pools in the lower estuary and Casuarina Creek (Figure 4.3b). By comparison, with the exception of stations 1 & 2 (*i.e.* the two outliers on axis 2; Figure 4.1a), DOP dominated water column P-pools when TSM concentrations were less than ~25 mg L^{-1} (*i.e.* over most of Keppel Bay), while DON was the dominant form of N when TSM was below 125 mg L^{-1} (Figure 4.10a,b). Interestingly, the percentage of the phytoplankton community dominated by micro-phytoplankton and pico-phytoplankton were both better correlated with %DOP than with any of the other variables used in the PCA (including TSM; Figure 4.10c). The percentage of pico-phytoplankton increased linearly with %P in organic forms (%DOP), while the percent composition of micro-plankton decrease linearly with %DOP (Figure 4.10c)

The distribution of %DOP in Keppel Bay (September 2003 and August 2004 data) is shown in Figure 4.10d.

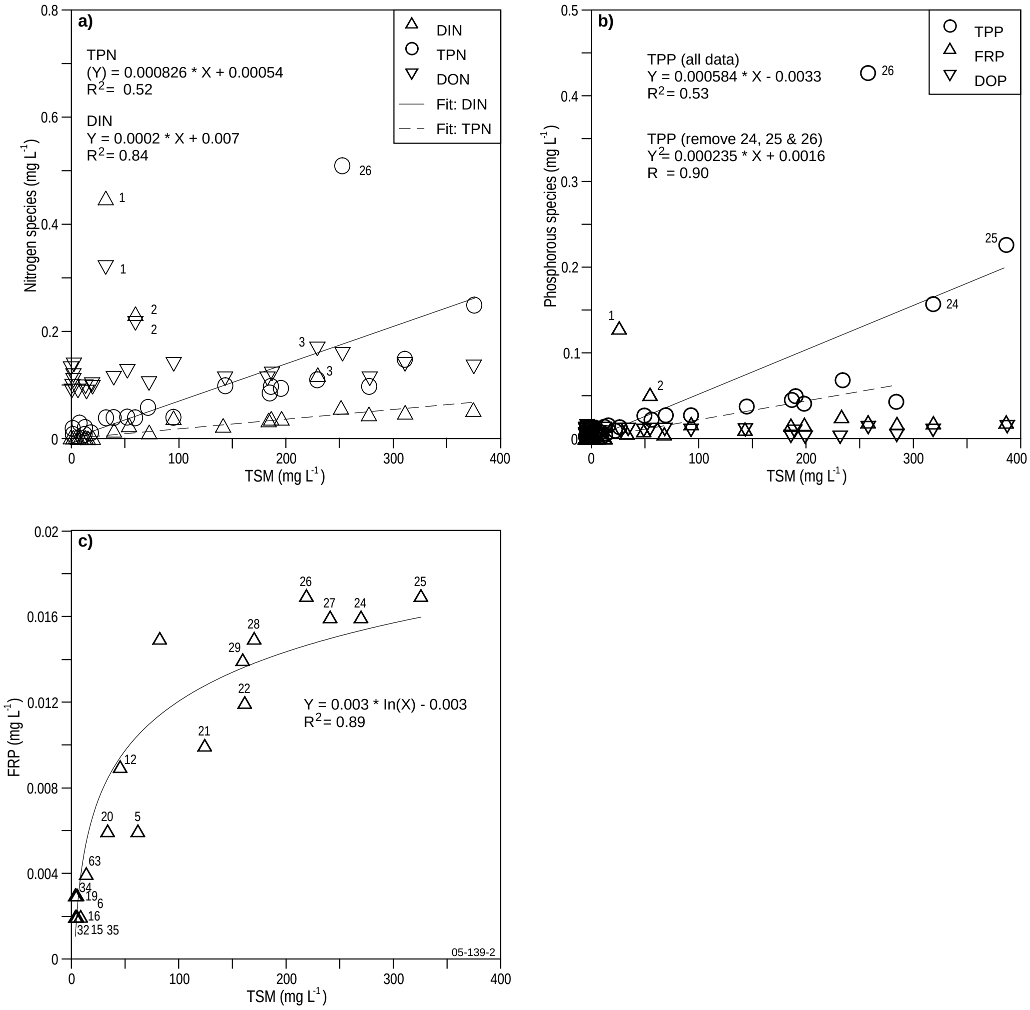

Figure 4.9. *September 2003 cross plots of TSM vs: (a) nitrogen species (DIN, TPN & DON); (b) phosphorus species (TPP, FRP & DOP); and (c) FRP.*

4.2. AUGUST 2004 WATER COLUMN SURVEY

4.2.1. Synoptic Perspective

The distribution of TSM, PSU, water temperature, TP & TN concentrations and TN:TP ratios are provided in Figure 4.11a-f. The distribution of TSM was similar during the August 2004 and September 2003 surveys, with much higher concentrations near the mouth of the estuary and tidal creeks and lower concentrations in the more off-shore regions of Keppel Bay (Figure 4.11a). However, TSM concentrations were lower in Casuarina Creek at the time of sampling in August 2004 than in September 2003. The distribution of PSU's during August 2004 was also similar to that of September 2003 (Figure 4.11b). However, salinity levels were about 1 PSU higher in the tidal creeks and 0.2 PSU's higher in Keppel Bay in August 2004. Water temperatures were similar during the August 2004 survey as they were during September 2003 (Figure 4.11c). However the distribution of water temperature was different in August 2004 in that there was not a pronounced warm water region along the shallow western shore. The distribution of water column TP was also similar between the two surveys, as were the magnitudes of the TP concentrations in Keppel Bay (Figure 4.11d). The distribution of water column TN was different in August 2004 with slightly higher concentrations observed in the mid-Bay region (Figure 4.11e). TN concentrations were also slightly higher overall in Keppel Bay during the August 2004 survey, and were slightly lower in the tidal creeks in comparison to the September 2003 survey. As in the case of the September 2003 survey, water column TN:TP ratios decreased seaward and were lowest in the vicinity of Great Keppel Island (Figure 4.11f). Indeed, the two measurements made nearest to Keppel Island (*i.e.* 81.2 and 103.3) were considerably higher in August 2004 than measurements made nearby in September 2003 (*i.e.* 50 to 61). Importantly, there is considerable variability at the different 24 hour stations. This will be discussed in detail in Section 4.2.3.

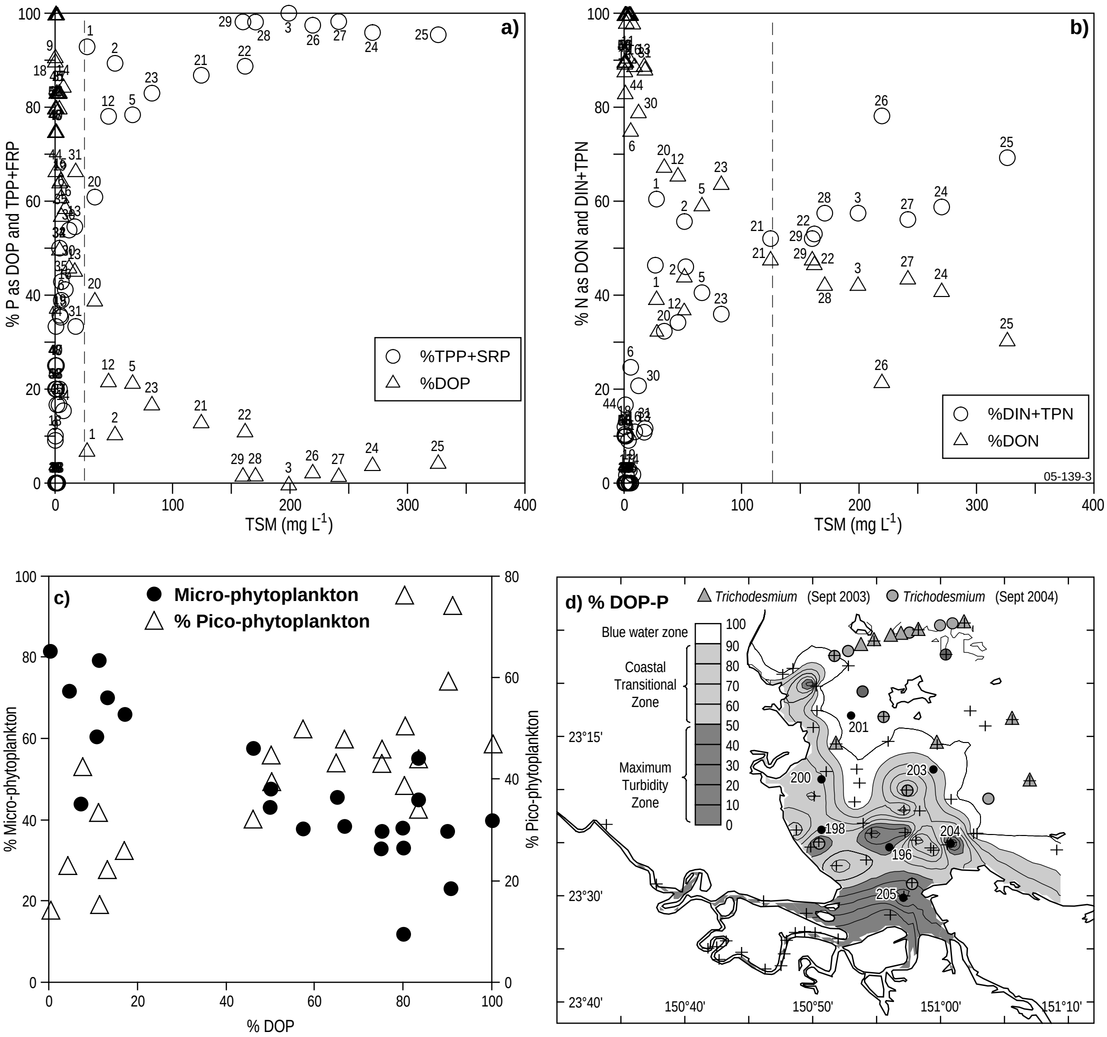

Figure 4.10. *September 2003 cross plots of TSM versus: (a) %TPP+FRP and %DOP; and (b) %DIN+TPN and %DON; (c) % micro-phytoplankton and % pico-phytoplankton vs %P as DOP; and (d)Map of % P as DOP (September 2003 and August 2004 data). Locations where Trichodesmium were observed are also shown.*

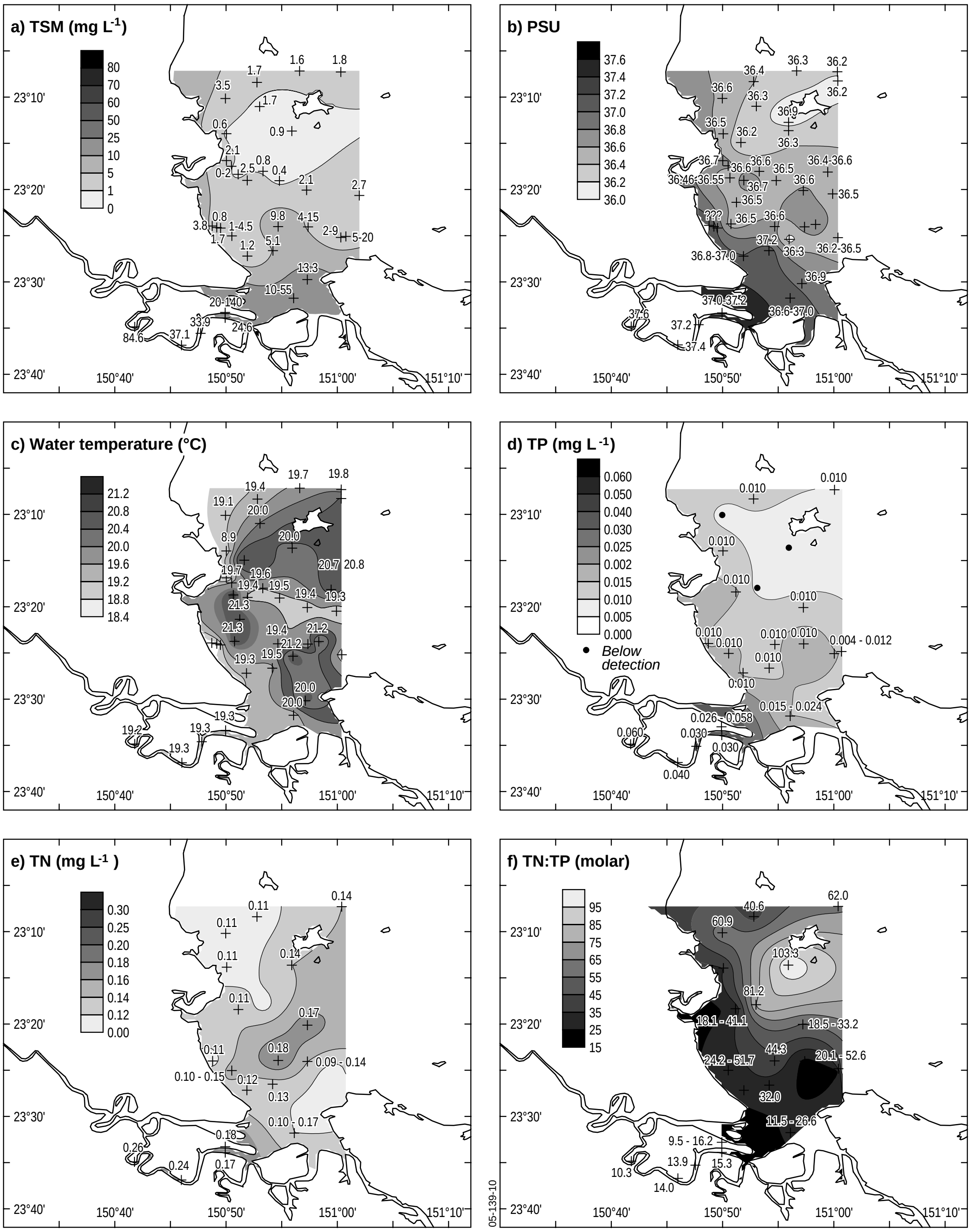

Figure 4.11. *August 2004 maps of: (a) TSM; (b) PSU; (c) water temperature; (d) TP; (e) TN; and (f) molar TN:TP ratios.*

4.2.2. Relationships between Nutrients and TSM

In the previous chapter (September 2003 survey), comparisons were made between dissolved nutrient concentration data and TSM. For the purposes of the current sections, TPN and TPP data are corrected for the N and P contents of chlorophyll collected concurrently with the nutrient samples (assuming a carbon: chlorophyll ratio of 50 and Redfield C, N & P ratios). These data are then compared to TSM data that was also 'chlorophyll corrected', by subtraction of the chlorophyll weight from the weight of the TSM (Figure 4.12). Chlorophyll correction was undertaken in order to better estimate the concentrations of N and P associated with suspended mineral particles (mg g^{-1}), so that comparisons could be made with N and P contents of bottom sediments underlying a given site. Deductions could then be made concerning whether the suspended sediment at a given site was derived largely from advection from elsewhere, or from re-suspension at or near a given site. However, it is important to mention that bacteria (in addition to phytoplankton) can contribute to the N and P pools of sediment, and also that the additive errors of the calculations were large (± 0.05 mg L^{-1} in the case of chlorophyll corrected TPP) in comparison to the magnitudes of the corrected sample calculations. These data can therefore only be used in an 'indicative' rather than a quantitative capacity.

As with the previous survey, DOP was the dominant form of P when TSM concentrations were low (*i.e.* <10-15 chlorophyll corrected TSM units), and this was the case over most of Keppel Bay (Figure 4.13a). Except at a few sites, the water column N pool was usually dominated by DON, while TPN+DIN assumed a larger proportion of the N-pool at higher TSM concentrations (Figure 4.13b).

Chlorophyll corrected TPP concentrations were strongly linearly correlated to chlorophyll corrected TSM during the August 2004 survey (*i.e.* TPP = 0.00036 * TSM + 0.00017; R^2 = 0.91; Figure 4.12a). A plot of TPP versus TSM from the previous survey (this time based on chlorophyll corrected data) is shown for comparison (Figure 4.12b), and although the relationship between these variables could also be described by a linear function, the slope was higher, and the strength of the relationship, as measured by the correlation coefficient, was less robust (*i.e.* TPP = 0.00058 * TSM - 0.00348; R^2 = 0.52). Removal of anomalously high TPP samples from stations 24, 25 & 26 located far upstream in the tidal creek improved the correlation coefficient and drastically lowered the slope between TPP and TSM (*i.e.* TPP = 0.00023 * TSM + 0.001; R^2 = 0.9). There was no obvious relationship between chlorophyll corrected TPN and TSM during the August 2004 survey (Figure 4.12c). Chlorophyll corrected TPN versus TSM data from the September 2003 survey are also plotted for comparison (Figure 4.12d). A linear relationship was found when all the data were included (TPN = 0.00073 * TSM +0.0025; R^2 = 0.5), and the relationship improved when data from sites 25 and 26 were excluded from the linear regression equation (TPN = 0.00042 * TSM +0.0097; R^2 = 0.9).

In Figure 4.12e, the FRP and TSM data from the August 2004 survey are shown with those from the September 2003 survey. As with the case of the September 2003 data (Figure 4.9c), the combined data set (surface and bottom waters from both surveys) yielded a relationship between FRP and TSM that could be described by the logarithmic function: FRP = 0.003 * ln TSM – 0.003 (Figure 4.12e). However, the August 2004 data set had a more restricted range of TSM levels, and correspondingly lower FRP concentrations. In Figure 4.12f, NOx, NH_4 and TSM data from the August 2004 survey are shown together with those from the September 2003 survey. A linear relationship between DIN and TSM was present in the September 2003 data (Figure 4.9a), and importantly is manifested in a relationship between NOx (rather than NH_4) with TSM (*i.e.* NOx = 0.000195* TSM + 0.00044; R^2 = 0.89). As with FRP, NOx concentrations during August 2004 were similar to those in September 2004 survey, over a similar range of TSM. Ammonium concentrations were generally low or below detectable concentrations in both surveys.

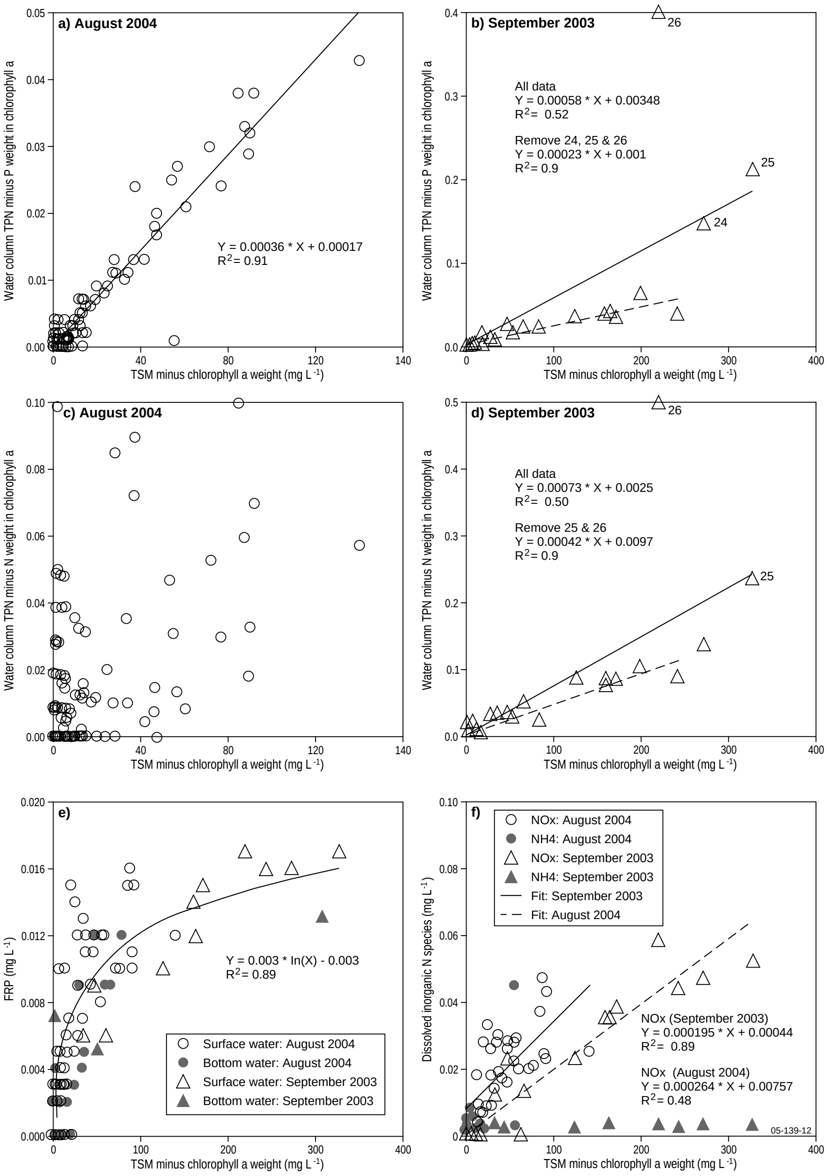

Figure4.12. *Cross plots of: chlorophyll-corrected TPP vs. chlorophyll corrected TSM for (a) Sept 2003 and (b) Aug 2004. Chlorophyll-corrected TPN vs. chlorophyll-corrected TSM for (c) Sept 2003 and (d) Aug 2004. (e) FRP vs chlorophyll corrected TSM (Sept 2003 & Aug 2004); and (f) dissolved inorganic N species vs. chlorophyll-corrected TSM .*

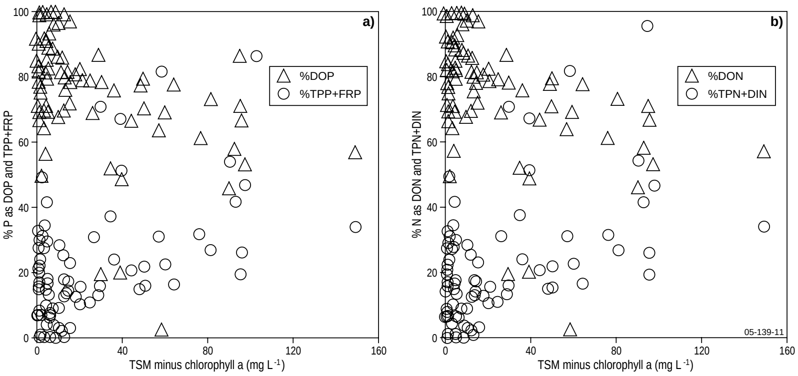

Figure 4.13. *August 2004: (a) %P as DOP and TPP+FRP vs chlorophyll-corrected TSM; and b) %N as DON and TPP+DIN vs chlorophyll- corrected TSM.*

As in September 2003 data set (all data; Figure 4.8a), there was an approximate 1:1 relationship between TSM and turbidity: *e.g.* TSM = 1.08 * NTU – 0.97 ($R^2 = 0.93$; all data; Figure 4.14a). However, in the August 2004 survey, there was a greater similarity in the slope between surface and bottom TSM and turbidity levels than in September 2003. The strength of the relationships as measured by the correlation coefficients (surface, b*ottom* and all data) were also consistently high (*i.e.* $R^2 > 0.91\text{-}0.95$) in August 2004.

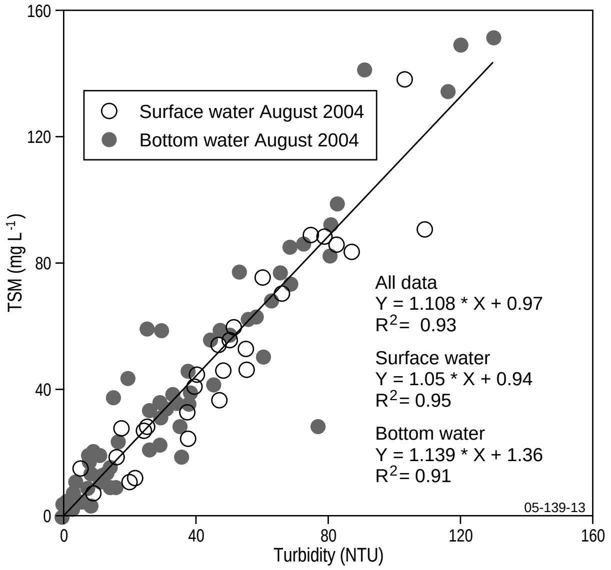

Figure 4.14. *August 2004 TSM vs Turbidity for surface water and bottom waters in Keppel Bay.*

4.2.3. Tidal cycle measurements at the 24 hour stations

The tidal conditions at Port Alma during the August 2004 survey are shown Figure 3.1b,c and are based on WXTide32 program (version 3.1; Hopper, 1998-2003). Spring tide conditions prevailed during sampling at the first three stations (Stations A, B & C), while neap tide conditions occurred at the next four stations (D, E, F & G). It is important to note that Stations 3 and E are essentially the same location sampled at different times in the tidal cycle. Therefore, the data from this site are combined in the plots that follow.

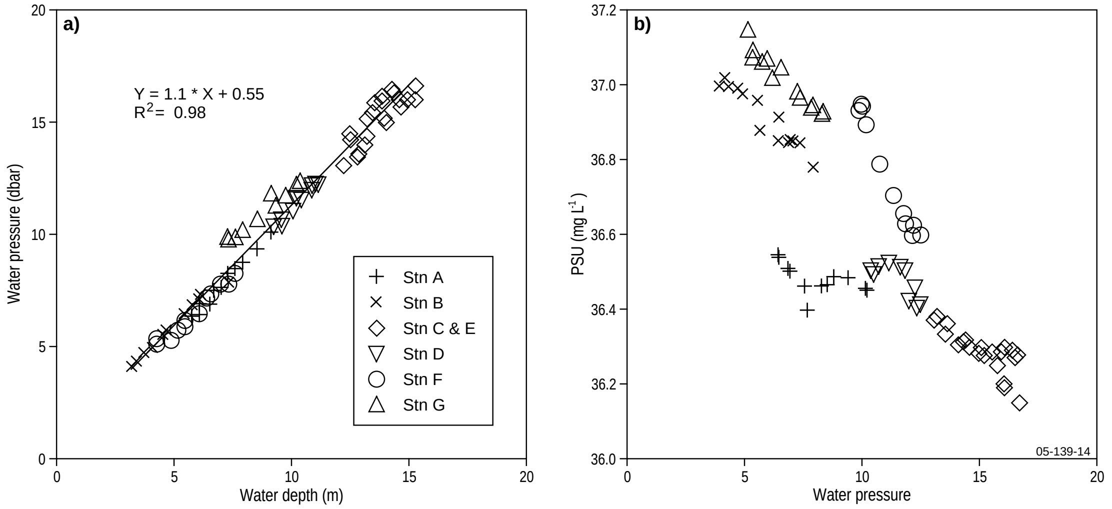

Figure 4.15. *August 2004 (a) Water pressure vs. water depth; and (b) PSU vs water pressure.*

Changes in water pressures and water depths at the stations during the periods of nutrient and TSM sampling (hourly intervals) are shown in Figure 4.15. As expected, water pressures and water depths were very highly linearly correlated and similar in numerical magnitude (Figure 4.15a). For simplicity, water pressure and water depth are used inter-changeably in this report. Water depths changed by 3.3, 4.1, 3, 2, 1.8, 3.1 and 3.3 m at stations A, B, C, D, E, F & G during the period of nutrient and TSM sampling. The changes in PSU (a tracer of water mass) that coincided with water depth changes at the different stations over the same period are shown in Figure 4.15b. There is overlap in the salinity ranges at stations B, F & G, and at stations A and D, while PSU's at station C/E were lower than those recorded at any of the other stations.

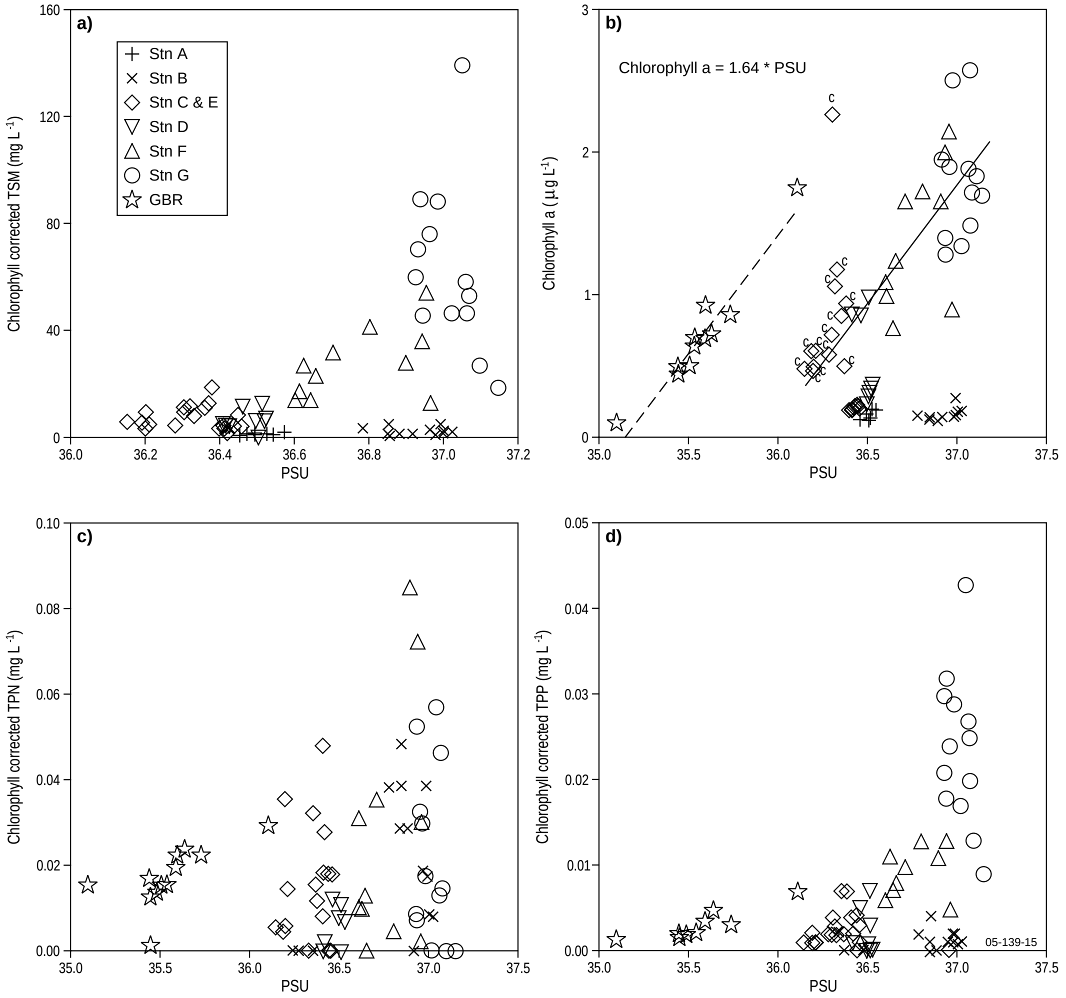

Figure 4.16. *August 2004 PSU at the 24 hour stations versus: (a) chlorophyll-corrected TSM; (b) Chlorophyll a; (c) chlorophyll-corrected TPN; and (d) chlorophyll-corrected TPP.*

In Figures 4.16a-d and 4.17a-f, concentrations of TSM (chlorophyll corrected), chlorophyll *a* and the various dissolved and particulate nutrients are plotted against salinity (PSU). With the exception of the dissolved organic nutrients and NH_4 (Figure 4.17e,d), the concentrations of all of these parameters were found to increase with salinity (Figure 4.17a,b; 4.17a,b,c,f). In the case of NOx, FRP, SiO_4 and chlorophyll a the main trend is close to linear (Figures 4.16), whereas there is a concave deviation from a linear trend in the TSM and particulate nutrient versus PSU data (Figure 4.16a,c,d). Concentrations that deviate from the main trend include: (i) the TSM, chlorophyll a, particulate nutrient and silicate data from stations A and B (Figure 4.16a,b,c,d; Figure 4.17c); (ii) the NOx and FRP data at station C/E (Figure 4.17a,b); the chlorophyll data at station E (Figure 4.16b); and (iii) some of the chlorophyll data from station G (Figure 4.16b). In the case of station A, silicate concentrations are inversely proportional to chlorophyll *a* concentrations, and the slope is very close to that of the Redfield stoichiometry assuming a chlorophyll:C weight ratio of 50 (*i.e.* chlorophyll *a* = -0.112* SiO_4 + 0.295; R^2 = 0.66; Figure 4.18a). There is no obvious relationship between DON or DOP and PSU (Figure 4.17e,f). However, it is noteworthy that: (i) the DON concentrations at station G in Casuarina Creek are higher than those of all the other data (Figure 4.17e); and (ii) that DON and DOP concentrations decline to zero at station F (Figure 4,17e,f). Interestingly, chlorophyll a concentrations are inversely proportional to DON concentrations, and the slope is also very close to that of the Redfield stoichiometry, assuming a chlorophyll:C weight ratio of 50 (*i.e.* chlorophyll *a* = -0.145 * DON + 2.2; R^2 = 0.79; Figure 4.18b). The DON declines to zero over a TSM range of 13.7 to 54.7 mg L^{-1}.

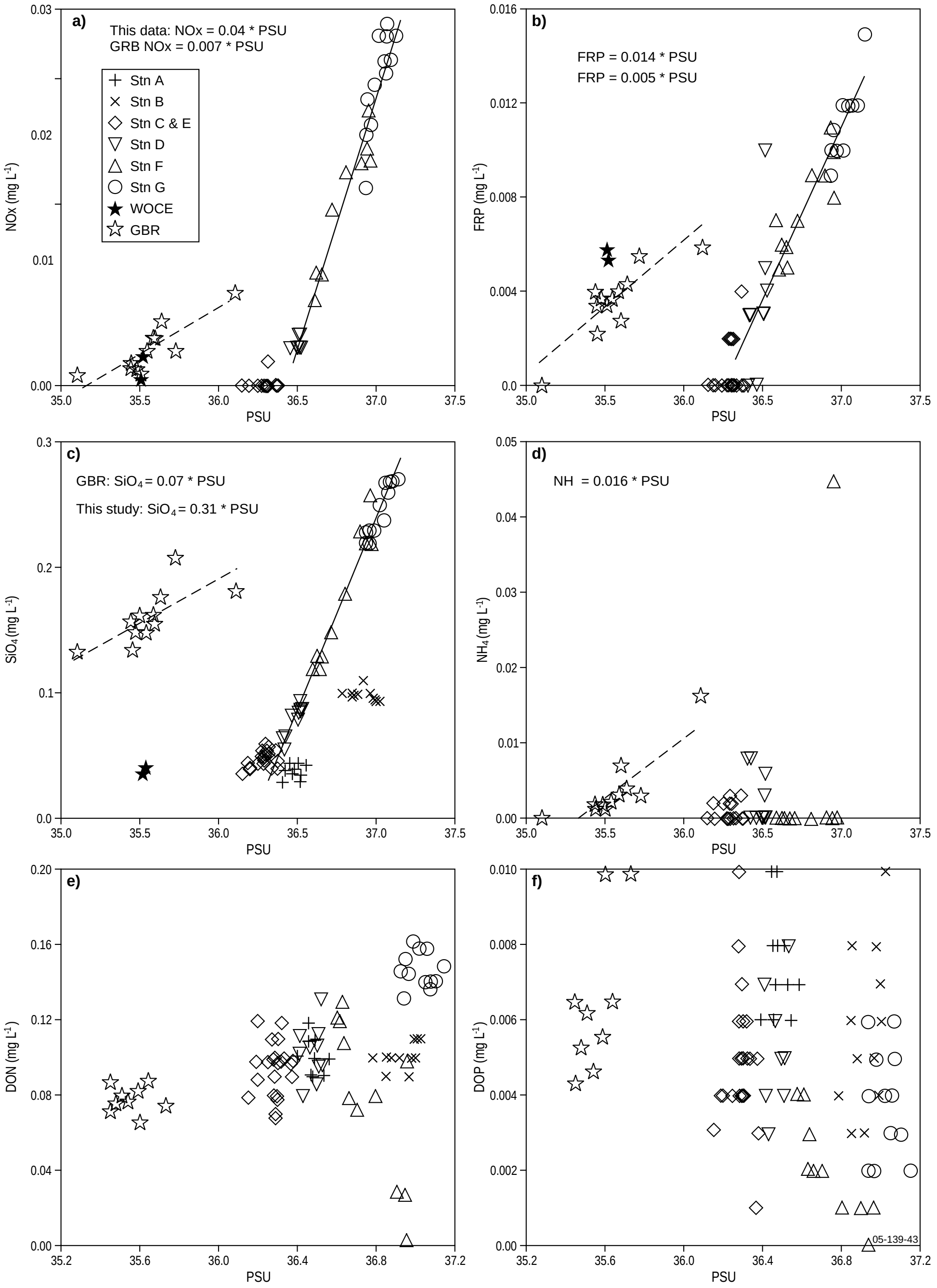

Figure 4.17. *August 2004 PSU at the 24 hour stations versus: (a) NOx; (b) FRP; (c) SiO_4; (d) NH_4; (e) DON; and (f) DOP. Also shown are data collected from the region during the World Ocean Circulation Experiment (WOCE; Church, 1993) and the means and means plus and minus standard deviations from the representative data of Furnas and Brodie (1996) and Devlin et al. (2001).*

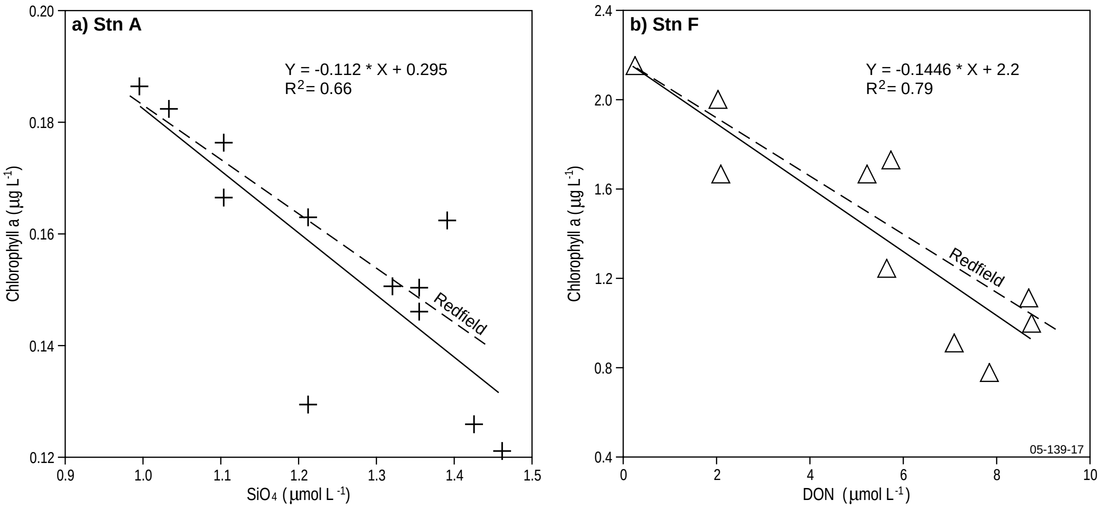

Figure 4.18. *August 2004 chlorophyll a versus (a)* SiO_4 *(Station A); and (b) DON (Station F).*

Diagrams showing changes in surface TSM (stations A&B) or turbidity (average NTU's per minute; stations C, D, E, F & G) as a function of changes in water pressure and current speed are given in Figures 4.19a-f and Figure 4.20a-d. TSM did not correlate to either water pressure or current speed at stations A and B, although there is a very slight trend of increasing TSM with: (i) decreasing water pressures at station A; and (ii) increasing current speed at station B (Figure 4.19a,b). At stations C/E there was a rather strong linear relationship between turbidity and water pressure: turbidity increased as water pressure diminished with the ebbing tide (Figure 4.19c). At station C/E there were some apparent hysteresis in the data: during the flood tide there was an initial decrease in turbidity, followed by a period of stabilisation (at ~ 5 NTU's at Stn. C and ~2 NTU's at Stn. E), and then a linear decrease with increasing water pressure (Figure 4.19d). There was no discernable relationship between turbidity and either water pressure or current speed at station D, although turbidity was certainly more variable when water levels were higher (Figure 4.19e,f). At stations F and G the relationships between turbidity and water pressure were very complex, but there was a general trend of increasing turbidity with current speed (Figure 4.20a-d).

A box and whisker diagram showing TPP:TSM (mg g^{-1}) at stations C, F, D, G and E is shown in Figure 4.21 in relation to the range of P contents of: (i) mud and sandy mud sediment in Keppel Bay and Casuarina Creek; and (ii) suspended sediment in the Fitzroy catchment (from Noble et al., (1996)). The P contents of the bottom sediment at the specified sites are also shown with asterixis. All sites had suspended sediment P contents suggestive of a mixture of sand and mud grain sizes. With the exception of Stn G, the bottom sediment P content at each site was also within the quartile ranges (either upper or lower) of the suspended sediment. The P content of the suspended sediment at Station G was similar to that of bottom sediment from Casuarina Creek.

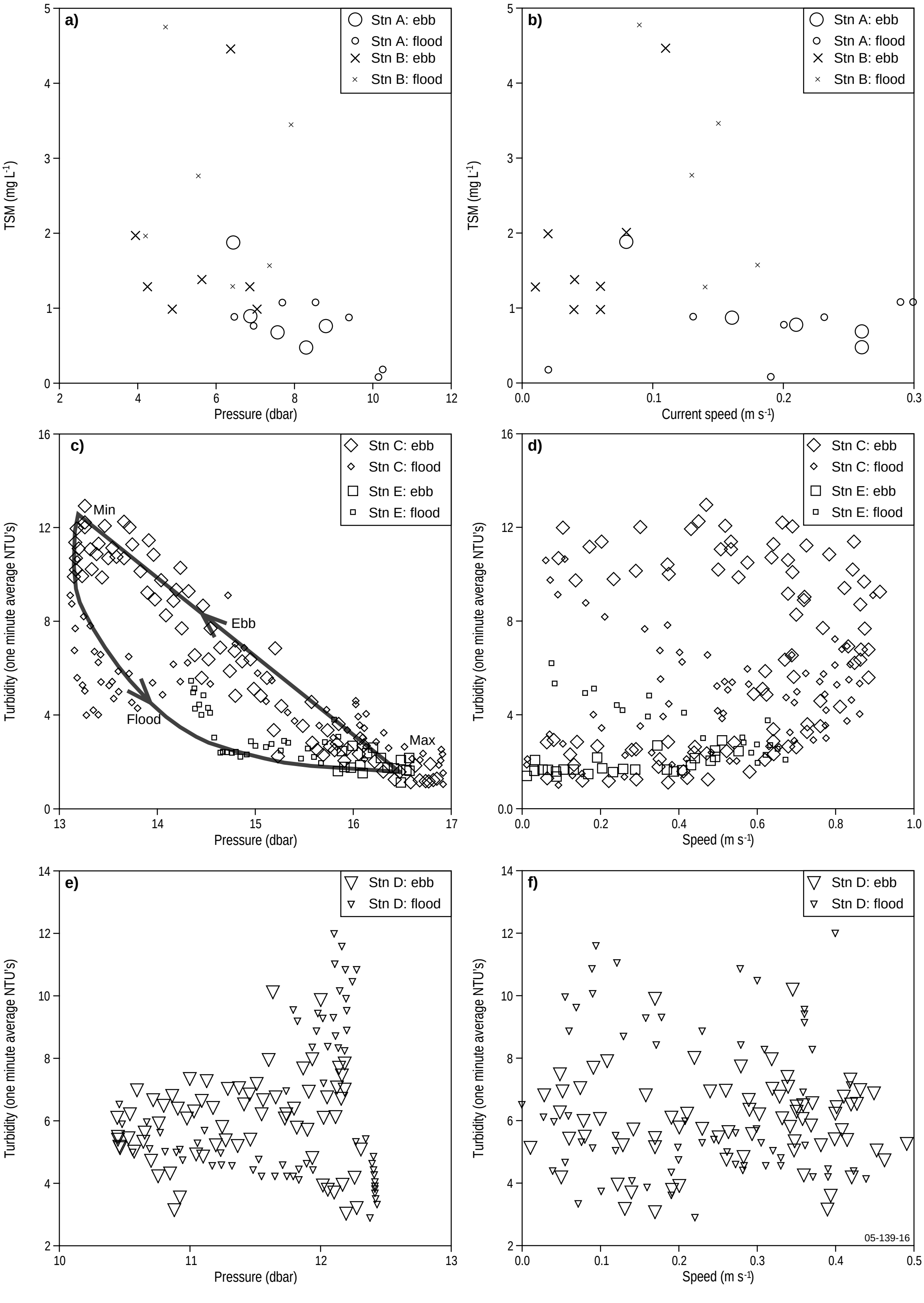

Figure 4.19. *August 2004: TSM versus (a) water pressure at Stn's A&B and (b) current speed at Stn's A&B. Turbidity (one minute average NTU's) vs water pressure and current speed at Stations C and E (c,d) and D (e, f).*

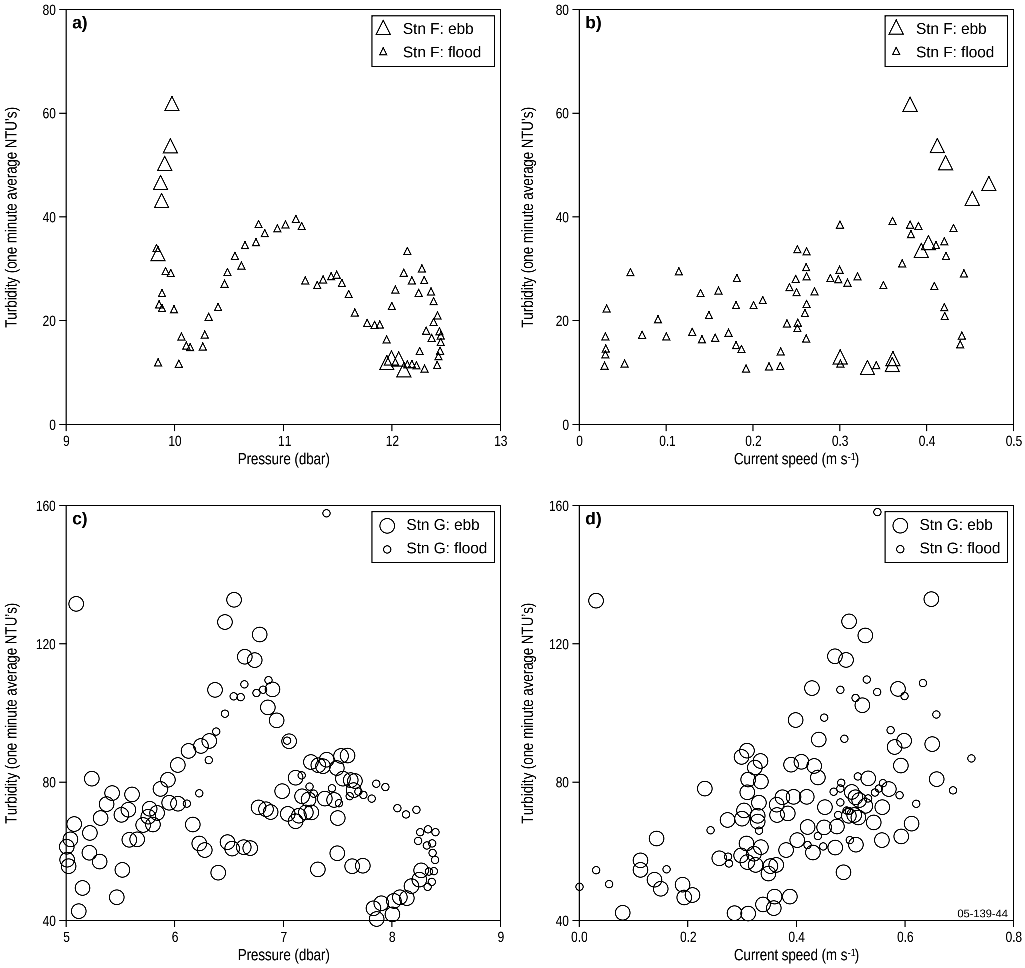

Figure 4.20. *August 2004 turbidity (one minute average NTU's) vs water pressure and current speed at stations: F (a,b); and G (c,d).*

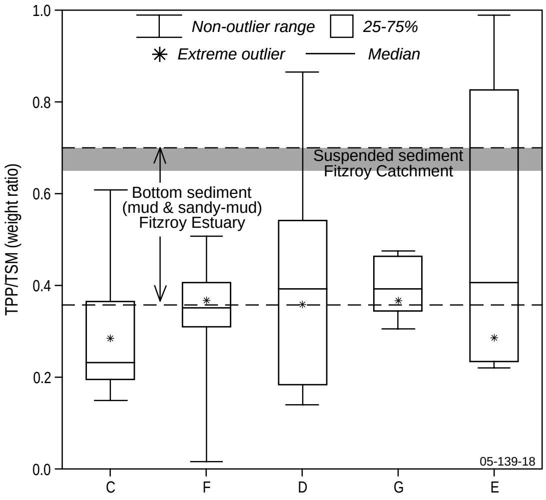

Figure 4.21. *August 2004 box and whisker diagrams (medians and 25th and 75th percentiles) of TPP:TSM ratios at Stations C, F, D, G and E. The range of TP concentrations in mud and sandy-mud bottom sediments in Keppel Bay (this study) and suspended sediment from the Fitzroy catchment (Noble et al. 1996) are also shown.*

4.3. BOTTOM SEDIMENTS (AUGUST & SEPTEMBER)

4.3.1. Comparisons between the different TOC and TP data sets

A comparison between TOC determined using the LECO combustion furnace and TOC measured by isotope ratio mass spectrometry (IRMS) (Sept 03 data only) is made in Figure 4.22a. The two data sets were highly linearly correlated ($R^2 = 0.99$). However, TOC contents measured by IRMS were systematically higher than TOC contents measured by LECO combustion (*e.g.* IRMS-TOC (mmol g^{-1}) = 1.35 * LECO-TOC + 0.016). Possible reasons for the disparity in the results may include one or more of differences in the linear range of standards used to calibrate the instruments, differences in sample combustion and errors that may be attributable to weighing as discussed below:

- **Linear range of standards**. The IRMS determinations were calibrated over a range of standards of known TOC composition: urea (20%), sucrose (42%), cellulose (44%) & caffeine (49%). The mass spectrometer has been shown to be linear from the blanks (0% TOC) through the range of these standards, with a standard deviation of approx. 1.3% (assuming peak height of 2-7V range). In comparison, the LECO analysis was calibrated based on blanks (0%) and the LECO 1 standard. The LECO 1 standard evolves a CO_2 content of 4.1% which translates into a %TOC of 1.12%.

- **Sample combustion**. IRMS determination is carried out subsequent to a sample being introduced to a furnace and combusted at 950^{o}C. In comparison, LECO analysis ramps the temperature from 200 to 1150^{o}C to determine the number of carbon bearing phases in the sample. This differential treatment of the sample may affect the final value.

- **Sample weighing**. Mass of sample is very important when calculated weight percent of an element. IRMS samples (~200 mg) were accurately weighed on a Sartorius® microbalance accurate to 0.0003mg, whereas the LECO samples (1 g) were weighed on a balance accurate to only 20 mg.

Although the IRMS determination is generally considered more sensitive than the LECO analysis, the calibration curve for the IRMS determination included no standards with <10% TOC, the critical area of these samples. Moreover, the standards used in IRMS consisted of sucrose, cellulose and caffeine, whereas the LECO 1 standard was crushed rock sample. For the purposes of this report we use TOC measured by LECO because: (i) the LECO calibration range was closer to the carbon range of the samples (*i.e.* < 1% TOC); and (ii) the LECO analysis drew on a larger (*i.e.* 1 g), and possibly more representative, sample than the IRMS determinations (200 mg); and (iii) the data set for TOC measured by LECO was complete, whereas the IRMS data set was not. Although error was almost certainly introduced into the LECO analyses through weighing, the method was found to be 98.9% accurate on the basis of the average of 18 replicate determinations of the LECO 1 standard (Helen Bostock, personal communication). The standard error of the same 18 determinations of the LECO 1 standard (*i.e.* 1.12% TOC) was ± 0.26, giving a precision of better than 2.5% (coefficient of variation; Helen Bostock, personal communication).

Comparisons between TP measured on samples subject to different digestion procedures and TP determined by XRF is shown in Figure 4.22b. The TP measured after the Kjeldahl extraction (QLD) was approximately 20% lower than TP measured by XRF (*i.e.* $TP_{digestion} = 0.78 * TP_{XRF} + 0.0004$; $R^2 = 0.81$), while there was a near 1:1 correlation between the XRF-P and TP determined from the peroxide/sulphuric acid reflux digest (MAFRI). Interestingly, there was also a near 1:1 relationship with XRF-TP when the residual inorganic-P fraction of the MAFRI determinations was added to the TP based on the Kjeldahl digest (*i.e.* $TP_{digestion} = 0.95 * TP_{XRF}$; $R^2 = 0.97$). This suggests that the Kjeldahl Digestion Mix used by the Queensland laboratory was less aggressive than the acid/peroxide method used by MAFRI, and was not extracting more resistant sedimentary

P minerals. These resistant P minerals may include rare earth phosphates such as Xenotime and Monazite. Such minerals probably occur in the granitic terrain of the New England Fold Belt, and can contain as much as 25% phosphate by weight. Therefore TP determined by XRF was used subsequently in the subsequent analyses and graphs.

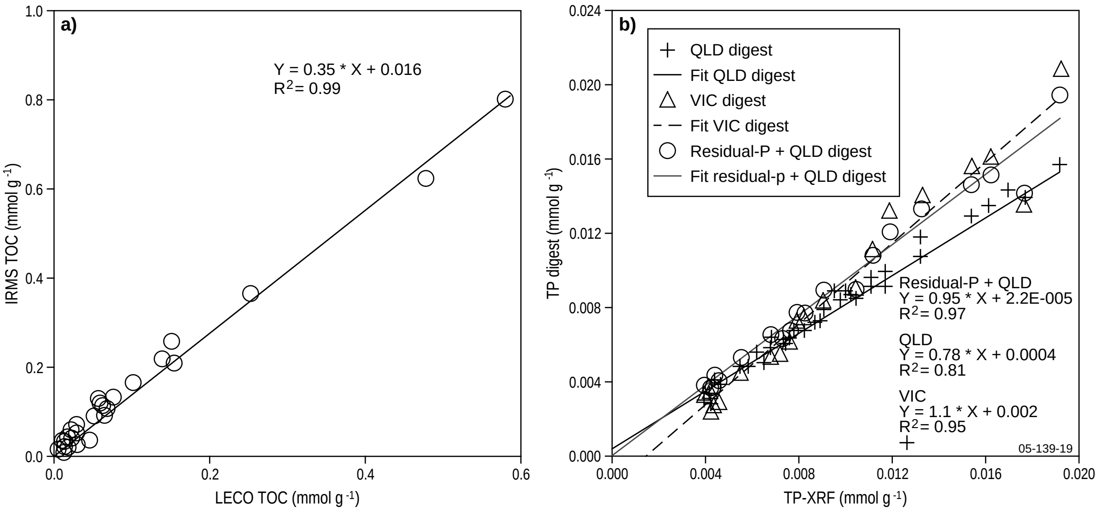

Figure 4.22. *Sept 2003: (a) TOC from LECO versus TOC from IRMS; (b) TP from XRF versus TP based on digests. Note that residual-P plus P from the digest of the Queensland laboratory yields a total P content that is close to P based on XRF.*

4.3.2. Principal Components Analysis

The results of the PCA on the bottom sediment data are shown in Table 4.3 (variable scores) and Figure 4.23a (site scores; axis 1 & 2). The locations of the samples used in the analyses are shown in Figure 4.23b. Axis 1 of the PCA explained most of the variance in the bottom sediment data set (~53%). The change from large positive loadings to large negative loadings along axis 1 represents a gradient of sediment fining. For example, the vast majority of the sandy sediments have positive loadings on axis 1, whereas muddy-sand, sandy-mud and mud sediments have increasingly negative loadings, also on axis 1 (Figure 4.23a). The percentage quartz, the quartz:feldspar ratio and the TP:TS ratios correlate positively with axis 1, and therefore with sediment coarsening. In comparison, the kaolin-group minerals, major and minor elements (with the exception of Ca), solid-phase nutrients (TN & TP) and TOC, weathering indices and the percentage mud correlate negatively with axis 1, and thus with sediment fining. The correlations of total iron (Fe(tot)), Al and the Al_2O_3/K_2O ratio with axis 1 are particularly strong.

Axis 2 explained a further 11.1% of the variance in the sediment data set. The FeII:FeIII and FeII:TOC ratios and %Fe-(TOC+TS+FeII) varied most substantially along this axis (Table 4.3). The sandy-mud, mud and about half the muddy-sand and sand samples fit a trend from negative to positive loadings across both axis 1 and axis 2 (*i.e.* from the lower left hand quadrant of Figure 4.23a to the upper right hand quadrant). Deviating from this main trend are a group of samples that we subsequently label *Sand(-)* or *S-* because they had exclusively negative loadings on axis 2. Axis 3 explained 7.8% of the variance in the data, and is strongly dominated by the percentage of carbonate, and likewise Ca, in the sediment (Table 4.3). Axis 3 will not be subject to interpretation in this report. Rather, it will fall within the context of the discussion of the sediment framework of Keppel Bay (Ryan *et al*., 2005).

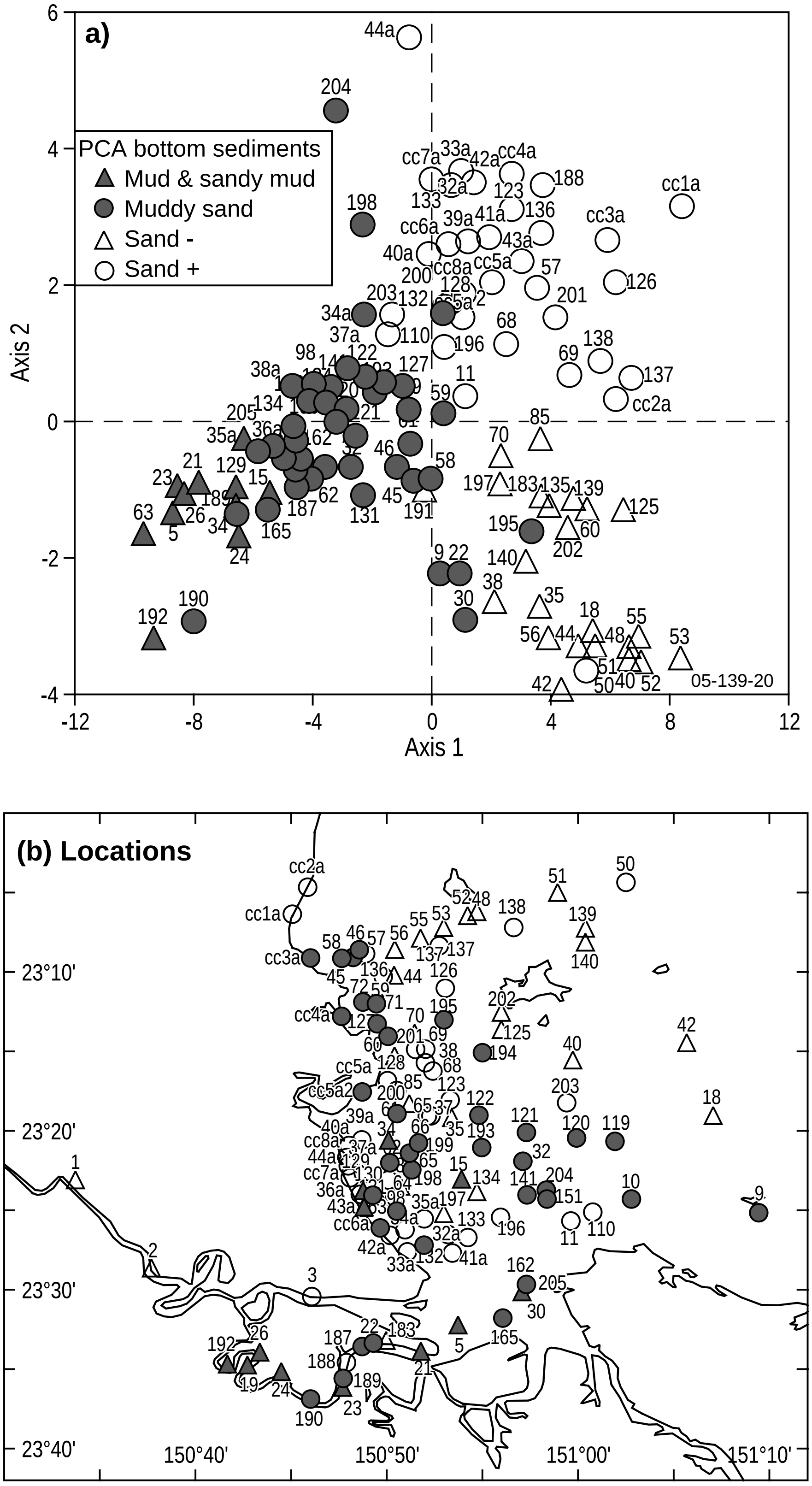

Figure 4.23. *Sept 2003 & Aug 2004: (a) site scores for axis 1 and axis 2 of the bottom sediment PCA; and (b) map showing the location of these bottom sediment samples in Keppel Bay.*

Table 4.3. Factor coordinates of the variables on axes 1, 2, & 3 of the PCA.

Variables	Axis 1	Axis 2	Axis 3
Fe(tot)	**-0.97**	0.10	0.03
$Al_2O_3:K_2O$	**-0.97**	0.07	-0.06
Al	**-0.96**	0.10	0.08
TP	**-0.92**	0.08	-0.02
TOC	**-0.92**	-0.17	0.16
CIA index	**-0.92**	0.09	0.14
Zn	**-0.90**	0.14	-0.01
TN	**-0.90**	-0.20	-0.13
FeIII	**-0.89**	-0.17	0.20
Mg	**-0.89**	0.05	-0.32
Na	**-0.89**	0.08	-0.06
%Mud	**-0.88**	-0.14	-0.04
S	**-0.86**	-0.27	0.02
K	**-0.85**	0.19	0.14
Ti	**-0.85**	0.19	-0.12
Cr	**-0.84**	0.07	0.01
Ni	**-0.81**	-0.13	0.21
Cu	**-0.79**	0.28	0.16
Kaolite minerals	**-0.78**	-0.14	0.15
TN:TP	**-0.75**	-0.33	-0.18
Cl	**-0.72**	-0.38	-0.06
FeII	-0.69	0.59	0.02
TP:TS	0.57	0.48	-0.02
%TOC-(TOC+TS+Fe(II))	-0.50	-0.58	0.17
Mn	-0.48	0.24	0.03
%S-(TOC+TS+Fe(II))	0.46	-0.51	-0.15
TS:FeII	-0.42	0.05	0.19
TOC:TN	-0.39	-0.05	0.57
FeII:FeIII	-0.26	**0.72**	0.03
%FeII-(TOC+TS+Fe(II))	0.25	**0.83**	-0.09
Fe(II):TOC	0.11	**0.86**	-0.13
Ca	-0.21	0.11	**-0.89**
Carbonate	-0.12	-0.01	**-0.92**
Greigite	0.11	-0.49	**-0.50**
TOC:TS	-0.07	0.24	0.03
TP:Fe	**0.92**	-0.12	-0.07
Si	**0.87**	0.04	0.32
Quartz	**0.77**	0.05	0.47
Quartz:feldspar	**0.70**	-0.32	0.15

4.3.2.1. Axis 1: The Distribution and Character of the Course to Fine Sediment

Site scores (Axis 1), $Al_2O_3:K_2O$ ratios and percentage mud show that the fine sediments (with large negative loadings on axis 1 and elevated $Al_2O_3:K_2O$ ratios and % mud contents) occur in a northwest to southeast band extending from Yeppoon to Hummocky Island, and particularly in Casuarina Creek and near its mouth, and alongside Long Beach (Figure 4.24a,b,f). The TOC and nutrient contents of sediment were also highest in the mud and sandy-mud sediments in this zone

(Figures 4.24c,d,e). Indeed, reasonably robust exponential functions describe the relationships between the degree of weathering of the sediment (as assessed by the Al_2O_3:K_2O ratio) and the concentrations of TOC and the solid-phase nutrients (TN & TP), although in the case of TP, a linear function provides a better fit to the data (Figure 4.25a-f). Sediment Fe concentrations and the percentage mud increase exponentially with the Al_2O_3:K_2O ratio (Figure 4.25d).

The major minerals phases for a given sediment in terms of A-CN-K (*i.e.* Al_2O_3, CaO+Na_2O and K_2O) and A-CNK-FM (*i.e.* Al_2O_3, CaO+Na_2O+K_2O, FeO+MgO) parameters are plotted in Figure 4.26a,b and 4.26c,d together with 'average basalt' and 'average granite' compositions, and reference compositions for the Upper Continental Crust (UCC, Tayor and McLennan, 1995), the North American Shale Composite (NASC, Gromet *et al.*, 1984) and the Post Archean Australian Shale (PAAS, Taylor and McLennan, 1985). The approximate theoretical weathering trend extending from the UCC though PAAS and several idealised weathering trends are also plotted, with weathering increasing towards the Al_2O_3 apex of the ternary diagram. In general, mud and muddy-sand sized Keppel Bay sediments define two distinct arrays that are sub-parallel to and in between the idealized basaltic and granitic weathering trends. The Keppel Bay sediments originate at a composition similar to that of the Upper Continental Crust (UCC) and follow a trajectory similar to that defined by the theoretical weathering trend (Figure 4.26a,b). It is noteworthy that a substantial proportion of the sediment samples are displaced away from the theoretical UCC weathering trend towards lower FeO + MgO compositions in Figure 4.26c,d. The box and whisker diagrams in Figure 4.27a-d highlight that the Al_2O_3:K_2O ratios generally increase with modelled mean current speeds (in bottom waters), and likewise with mean and maximum bed shear velocities.

Figure 4.28b includes TOC and TN data from both surveys (Sept 2003 and Aug 2004). The line of best fit for all the data (*i.e.* TN = 0.12 * TOC + 5.8; $R^2 = 0.85$) is about 20% depleted in N relative to the Redfield stoichiometry. The $\delta^{13}C$ signatures and TOC:TN ratios of sediment organic matter collected during the September 2003 survey are shown in Figure 4.28a. As suggested by Goni *et al*. (2005), the TOC:TN ratios were corrected for the presence of inorganic N by subtracting the magnitudes of the Y-intercepts from separate regressions (not shown) conducted on each of the sand, muddy-sand and sandy-mud & mud data (September 2003 only) in Figure 4.28b. The shaded boxes refer to expected values for fresh marine phytoplankton (Bird *et al.*, 1995; Gagan *et al.*, 1987), soil organic matter (as interpreted by Kuhnen, 2004 and Ford *et al.*, 2005), fresh terrestrial-C3 plant debris (Meyers 2003) and fresh lacustrine algae (Meyers, 2003). The open box encloses the area of bacterial $\delta^{13}C$ signatures and TOC:TN ratios reported by Fukuda *et al*. (1998) and Goni *et al*. (2005). Two example mixing lines that extend through the marine phytoplankton field to terrestrial-C3 plant field are also shown. With the exception of sample 2, all of the sand samples had TOC:TN ratios (range = 2.4 to 6.3; mean = 3.7) that were consistent with bacteria, while the range of most of the $\delta^{13}C$ signatures (-18 to -21.5; mean = -20) corresponded to that of either marine phytoplankton or bacteria. In comparison, most of the muddy sand samples fell within the field of expected values for phytoplankton (TOC:TN range = 4.9 – 9.8 and mean = 7.1; and $\delta^{13}C$ range = -18.7—21.1; and mean = -19.6). The mud and sandy-mud samples also had TOC:TN ratios (range = 7.1 – 15.1; mean = 8.9) and $\delta^{13}C$ signatures (range = -18.2 – 24.2; mean = -20.7) that were suggestive of marine phytoplankton. The organic matter in samples 2 (a sand) and 24 (a sandy-mud) could be ascribed to mixtures of phytoplankton and terrestrial-C3 plant debris or soil, assuming a $\delta^{13}C$ end-member of -18.

All of the sediment samples were strongly enriched in P relative to Redfield ratio (Figure 4.29a). The relationship between TP and TOC was best described by a logarithmic function of the form: TP = 2.5 * ln (TOC) – 0.89 ($R^2 = 0.73$; Figure 4.29a), although the muddy-sand (some), sandy-mud and mud data are more closely aligned to the Redfield slope, albeit with a very large intercept on the ordinate (equating to ~50% of the measured P). The P concentration of the different sediment classifications in the format of box and whisker diagrams (mg g^{-1}) for comparison with suspended sediment-P are shown in Figure 4.29b. For example, suspended sediment-P, concentrations based on TPP versus TSM calibrations from the September 2003 and August 2004 surveys (Figure 4.29b), bracket the upper (25th to 75th) percentile range of the sediment TP concentrations, while the average P content of a suite of suspended sediment samples collected between 1993 and 1995 in the Fitzroy catchment (Noble *et al.*, 1997) corresponds to the highest 25% of observations from the mud and sandy-mud sediment samples. A breakdown of a sub-set of the bottom sediment data (20 samples) in terms of the percentage of TP that is: (i) bound to either Fe/Al or Ca; (ii) incorporated into organic matter; or (iii) is part of a residual pool is given in Figure 4.29c-f. Ca-P accounted for >50% of TP across the suite of grainsizes, while medians for organic-P were in the range from 22 to 25%. Approximately 10-15% of TP resided in the residual pool across the different size classes. However, this residual pool was as high as 30% in the sands (S-) that had negative loadings on axis 2 of the PCA (Figure 4.29e). The P that was bound to Fe/Al accounted for <5% of TP, except in the mud and sandy mud samples where it constituted ~16% of TP.

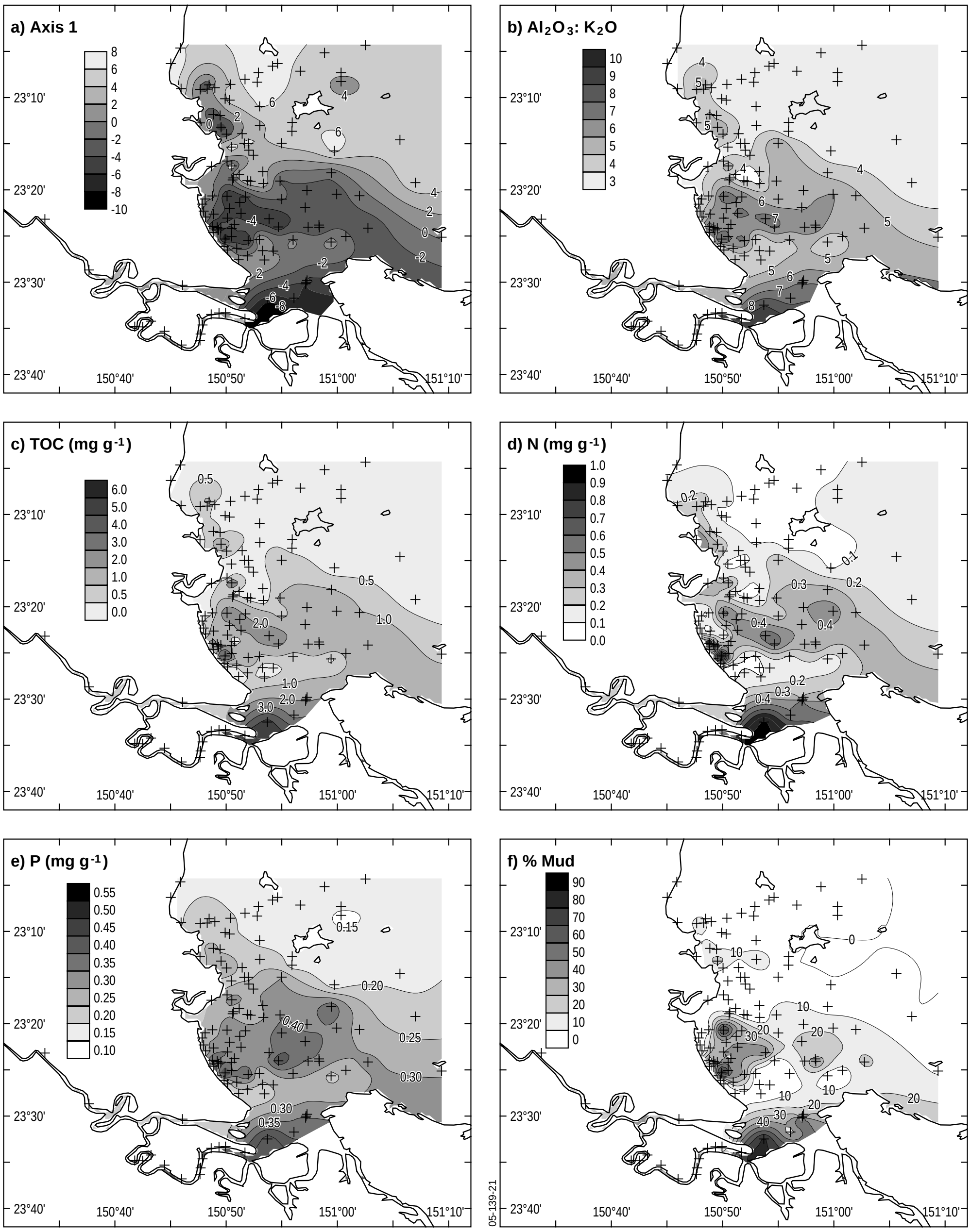

Figure 4.24. *Sept 2003 & Aug 2004 bottom sediment maps for: (a) sites scores on axis 1 of the PCA; (b) Al_2O_3:K_2O ratios; (c) TOC; (d) TN; (e) TP concentrations; and (f) mud contents.*

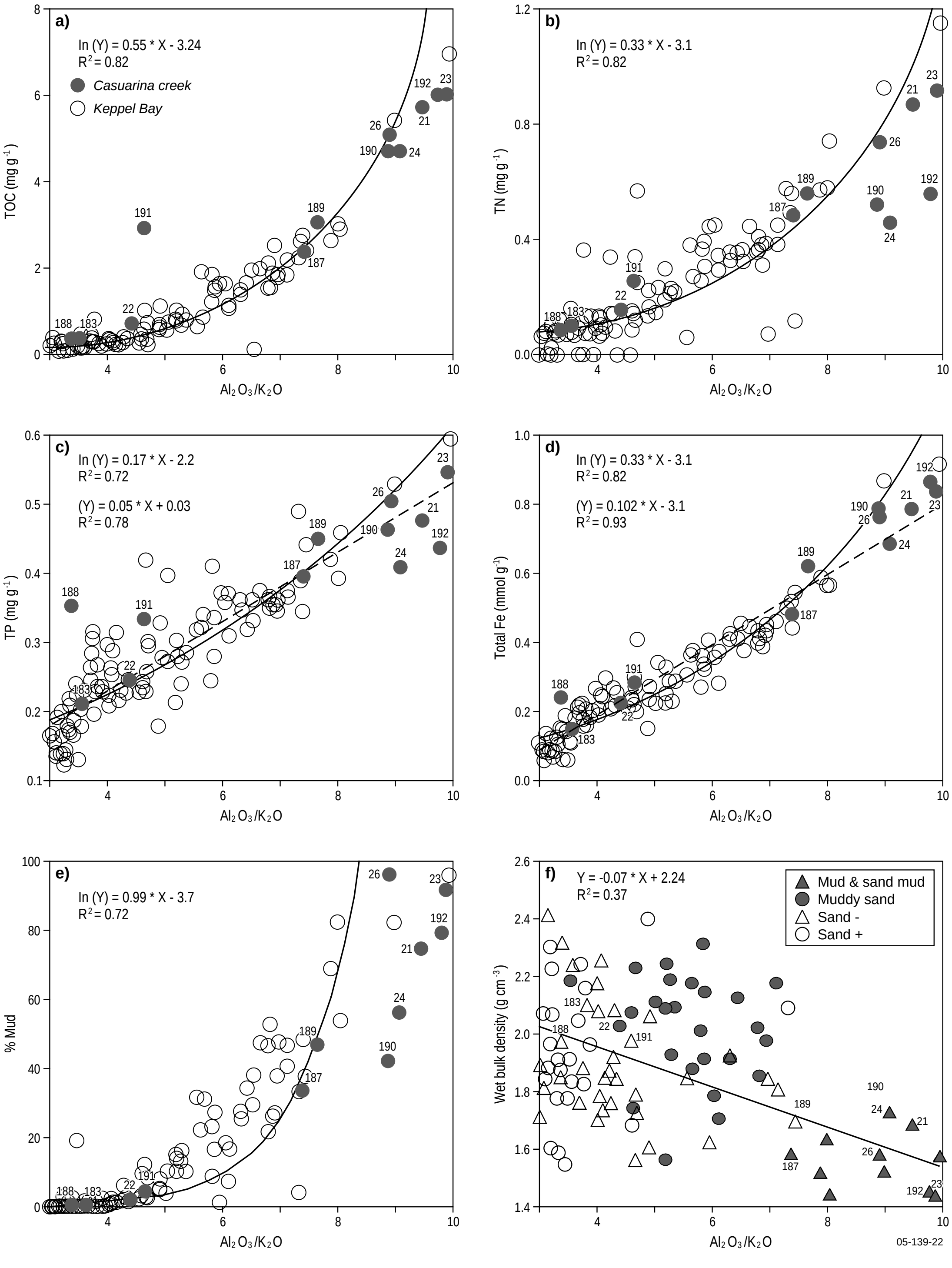

Figure 4.25. *Sept 2003 & Aug 2004: bottom sediment: (a) Al_2O_3:K_2O ratios versus: (a) TOC; (b) TN; (c) TP; (d) total Fe; (e) %mud; and (f) wet bulk density. Filled circles with sample numbers in a-e correspond to samples taken from Casuarina Creek. The Casuarina Creek samples are labelled in (f).*

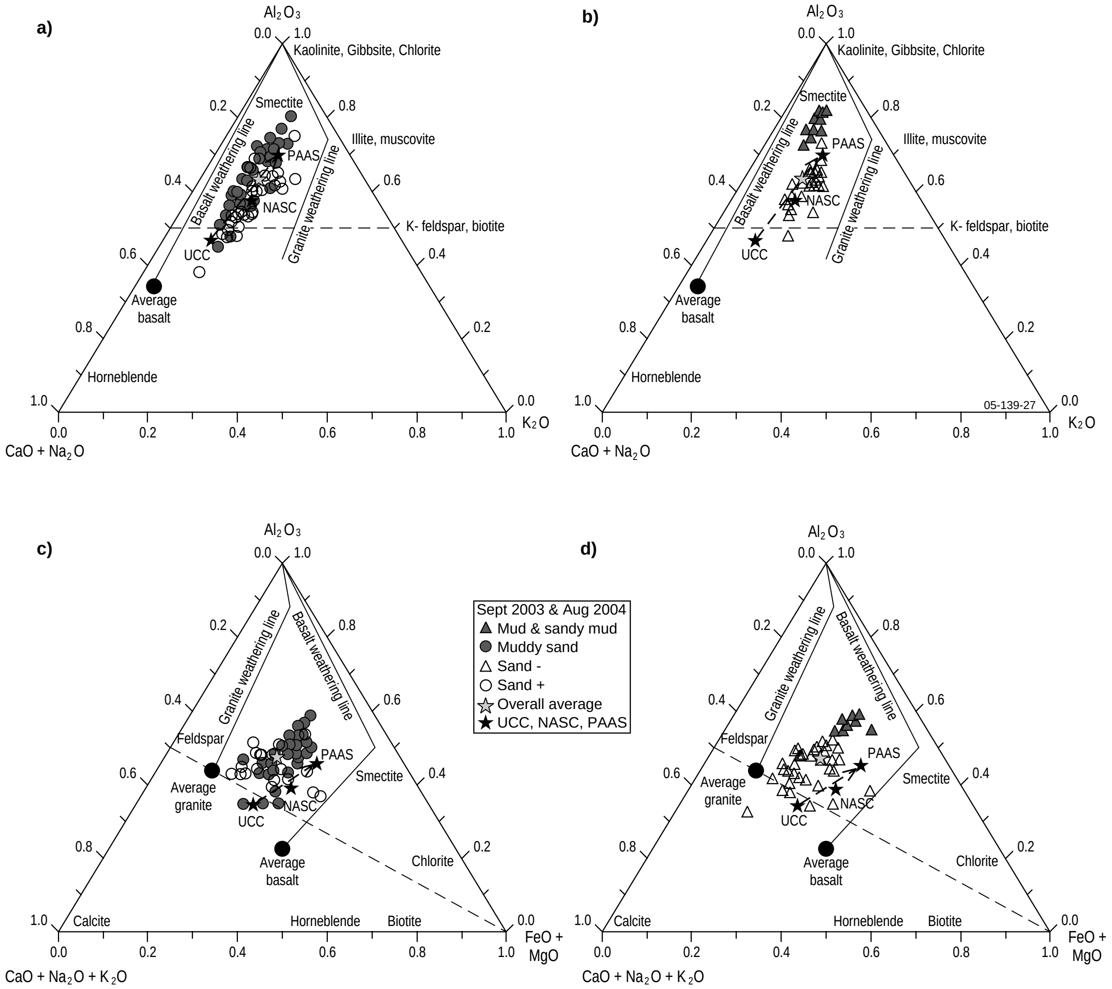

Figure 4.26. *Sept 2003 and Aug 2003 A-CN-K diagrams of (a) muddy sand and sand + samples; and (b) mud and sandy-mud and sand - samples. A-CNK-FM diagrams of (d) muddy sand and sand + samples; and (e) mud and sandy-mud and sand - samples.*

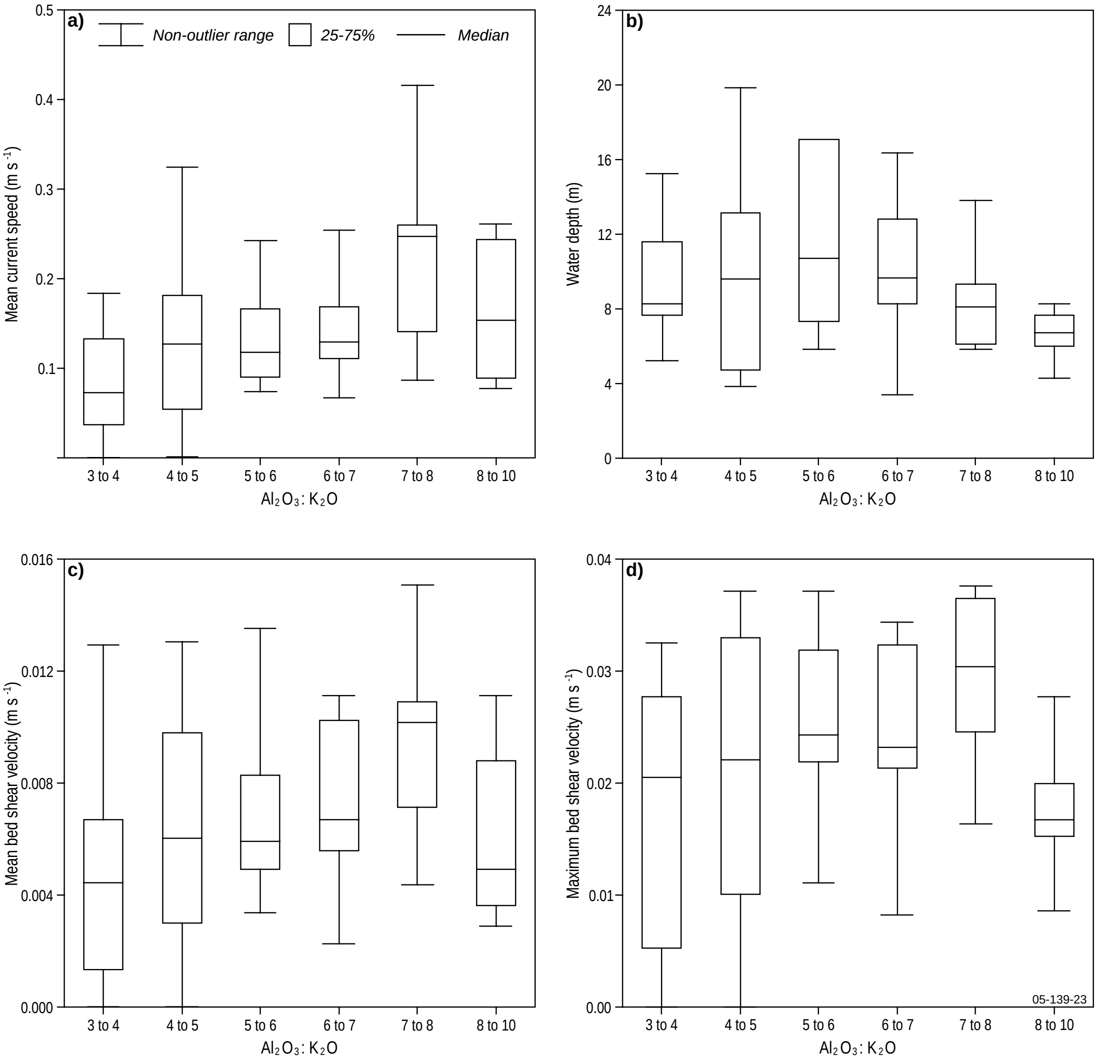

Figure 4.27. *Sept 2003 & Aug 2004 Box and Whisker diagrams (medians and 25th and 75th percentiles) of bottom sediment Al_2O_3:K_2O ratios versus: (a) mean current speed; (b) water depth; (c) mean shear velocity; and (d) maximum bed shear velocity.*

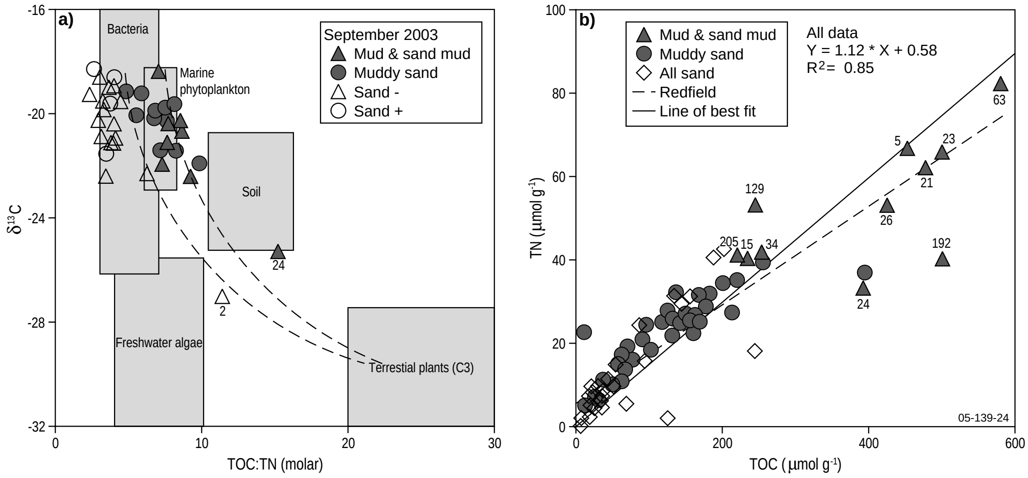

Figure 4.28. *Sept 2003 and Aug 2004 bottom sediment: (a) $\delta^{13}C$ signatures versus TOC:TN ratios for different grain sizes of Keppel Bay and Casuarina Creek sediments; and (b) TN versus TOC for Keppel Bay and Casuarina Creek sediments.*

Table 4.4. Chemistry and mineralogy of bulk sediment in Keppel Bay

	Mud and sandy-mud (n = 11)		Muddy sand (n= 118)		Sands (+) (n= 37)		Sand (-) (n = 26)	
	Mean ± st.dev.	Range	Mean ± st.dev.	Range	Mean ± st.dev.	Range	Mean ± st.dev.	Range
Quartz^1	0.59 ± 0.07	(0.42 - 0.67)	0.72 ± 0.11	(0.42 - 0.93)	0.75 ± 0.09	(0.57 – 0.93)	0.81 ± 0.09	(0.54 – 0.91)
%Kaolinite Group	*0.05 ± 0.03*	*(0.01 – 0.09)*	*0.01 ± 0.02*	*(0 - 0.09)*	*0.01 ± 0.01*	*0 – 0.07*	*0.01 ± 0.01*	*0.00 – 0.02*
Halloysite^1	0.02 ± 0.01	(0.00 – 0.05)	0.00 ± 0.01	(0 - 0.05)	0.00 ± 0.01	(0 – 0.04)	0	(0 - 0.01)
Kaolinite^1	0.03 ± 0.02	(0.01 – 0.07)	0.01 ± 0.01	(0 - 0.07)	0.01 ± 0.01	(0 – 0.03)	0	(0 - 0.01)
%Feldspar	*0.26 ± 0.09*	*(0.14 – 0.34)*	*0.21 ± 0.06*	*(0.1 - 0.34)*	*0.23 ± 0.1*	*0 – 0.4*	*0.14 ± 0.03*	*0.03 – 0.29*
Albite^1	0.09 ± 0.05	(0.03 – 0.17)	0.04 ± 0.03	(0.01 - 0.17)	0.02 ± 0.02	(0.01 – 0.09)	0.03 ± 0.02	(0.01 - 0.08)
Anorthite^1	0.03 ± 0.03	(0 – 0.11)	0.01 ± 0.02	(0 - 0.11)	0.01 ± 0.01	(0 – 0.05)	0.01 ± 0.01	(0 - 0.03)
Microcline^1	0.01 ± 0.01	(0 – 0.04)	0.02 ±0.02	(0 - 0.07)	0.03 ± 0.02	(0 – 0.07)	0.02 ± 0.01	(0 - 0.05)
Muscovite^1	0.02 ± 0.03	(0 – 0.07)	0.00 ± 0.02	(0 - 0.07)	0	0	0	0
Orthoclase^1	0.10 ± 0.05	(0.04 – 0.2)	0.09 ± 0.05	(0 - 0.2)	0.11 ± 0.06	(0 – 0.06)	0.07 ± 0.05	(0 – 0.19)
Sanidine^1	0.01 ± 0.01	(0 – 0.04)	0.01 ± 0.01	(0 - 0.04)	0.01 ± 0.01	(0 – 01)	0.01± 0.01	(0 – 0.04)
Total Carbonate^2	*0.06 ± 0.07*	*(0 – 0.25)*	*0.10 ± 0.07*	*(0 - 0.41)*	*0.08 ± 0.04*	*0.01 – 0.18*	*0.07 ± .06*	*0 - 0.24*
Aragonite^1	0.03 ± 0.05	(0 – 0.17)	0.04 ± 0.04	(0 - 0.18)	0.02 ± 0.02	(0 – 0.1)	0.03 ± 0.03	(0 - 0.1)
Calcite^1	0.03 ± 0.05	(0 – 0.17)	0.03 ± 0.04	(0 - 0.29)	0.01 ± 0.01	(0 – 0.04)	0.01 ± 0.02	(0 – 0.05)
Nutrients & TOC								
TP^3	0.46 ± 0.07	(0.35 – 0.59)	0.31 ± 0.07	0.18 - 0.46	0.26 ± 0.08	0.14 ± 0.44	0.21 ± 0.08	0.12 – 0.49
TN^3	0.73 ± 0.21	(0.46 – 1.15)	0.28 ± 0.15	0.00 - 0.56	0.14 ± 0.14	0.00 ± 0.57	0.12 ± 0.1	0.03 – 0.57
TOC^3	4.67 ± 1.5	(2.64 – 6.95)	1.30 ± 0.93	0.11 - 4.72	0.56 ± 0.56	0.07 ± 2.41	0.47 ± 0.65	0.08 – 2.94
Major elements								
Al^4	2.74 ± 0.62	(1.8 – 3.5)	1.12 ± 0.74	(0.2 - 3.5)	0.93 ± 0.47	(0.21 – 2.1)	0.55 ± 0.31	(0.20 – 1.9)
Fe(tot)^4	0.72 ± 0.16	(0.44 – 0.92)	0.30 ± 0.19	(0.06 - 0.92)	0.24 ± 0.12	(0.06 – 0.54)	0.15 ± 0.09	(0.06 – 0.5)
Mn^4	0.01± 0.01	(0.01 – 0.03)	0.01 ± 0.01	(0 - 0.24)	0.01 ± 0.01	(0 – 0.04)	0.01	(0 – 0.02)
Ti^4	0.11 ± 0.01	(0.08 – 0.13)	0.06 ± 0.04	(0.01 - 0.24)	0.05 ± 0.04	(0.01 – 0.24)	0.03 ± 0.02	(0.01 – 0.09)
Ratios & Indices								
FeII:FeIII^5	0.20 ± 0.07	(0.07- 0.34)	0.52 ± 2.41	(0 - 26.1)	1.22 ± 4.3	(0.09 – 26.1)	0.05 ± 0.08	(0.00 – 0.32)
FeII:TOC^5	0.33 ± 0.13	(0.11 – 0.52)	1.19 ± 1.71	(0 - 11.9)	2.35 ± 2.3	(0.37 – 11.8)	0.19 ± 0.31	(0 – 1.3)
Fe:Al^5	0.26 ± 0.03	(0.23 – 0.35)	0.28 ± 0.05	(0.19 – 0.39)	0.27 ± 0.08	(0.19 – 0.54)	0.28 ± 0.1	(0.16 – 0.61)
Feldspar:kaolinite^6	8.6 ± 6.2	(2.6 – 19.5)	27.5 ± 27.1	(4.9 – 144.5)	68.5 ± 51.2	(4.7 – 198.5)	50.7 ± 44.7	(4.1 – 166)
Al_2O_3: K_2O^6	8.9 ± 0.9	(7.4 – 9.9)	5.1 ± 1.82	(3 - 9.9)	4.36 ± 1.1	(3 – 7.4)	3.7 ± 0.86	(3.1 – 7.3)
CIA	77.8 ± 3.7	(70.5 – 81.4)	62.9 ± 8.6	(40.9 - 81.4)	58.5 ± 6.2	(44.5 – 69.2)	58.4 ± 6.3	(40.9 – 69.7)

1. decimal % (XRD); 2. decimal % (carbonate bomb) note that percentages might be higher than aragonite + calcite (XRD) due to the presence of magnesian calcite or dolomite; (3) concentrations in mg g^{-1}; (4) concentrations in mmol g^{-1}; (5) molar ratios; and (6) % ratios.

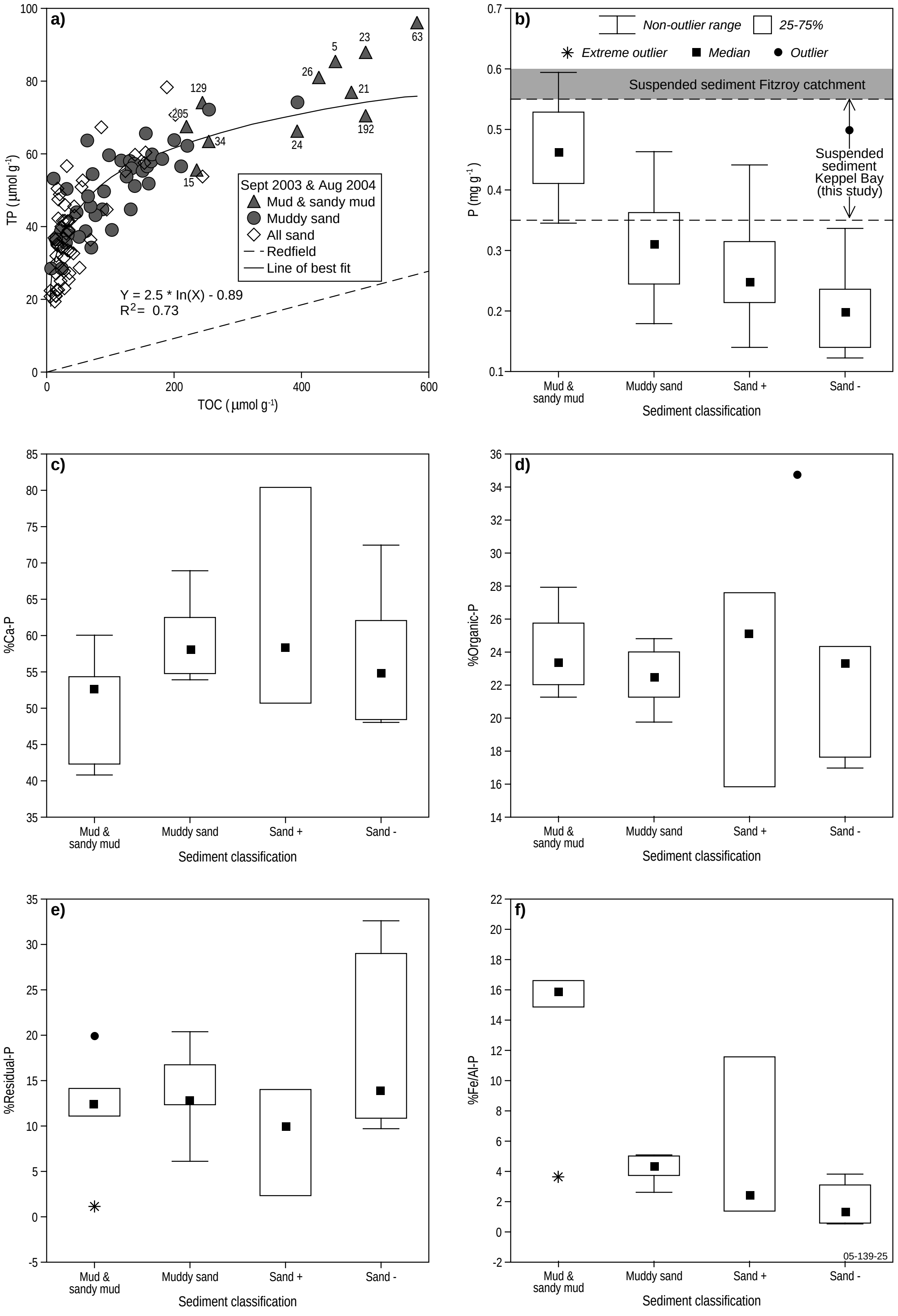

Figure 4.29. *Sept 2003 and Aug 2004 (a) sediment TP versus TOC; (b) box and whisker diagrams (medians and 25th and 75th percentiles) showing P contents of muds and sandy-muds, sand (+) and sand (-) sediments with respect to suspended sediment from the Fitzroy catchment (Noble et al. 1996) and suspended sediment from Keppel Bay (this study). Box and whisker (medians and 25th and 75th percentiles) diagrams of (c) %P bound to Ca; (d) % P in organic forms; (e) % residual-P; and % P bound to Fe or Al.*

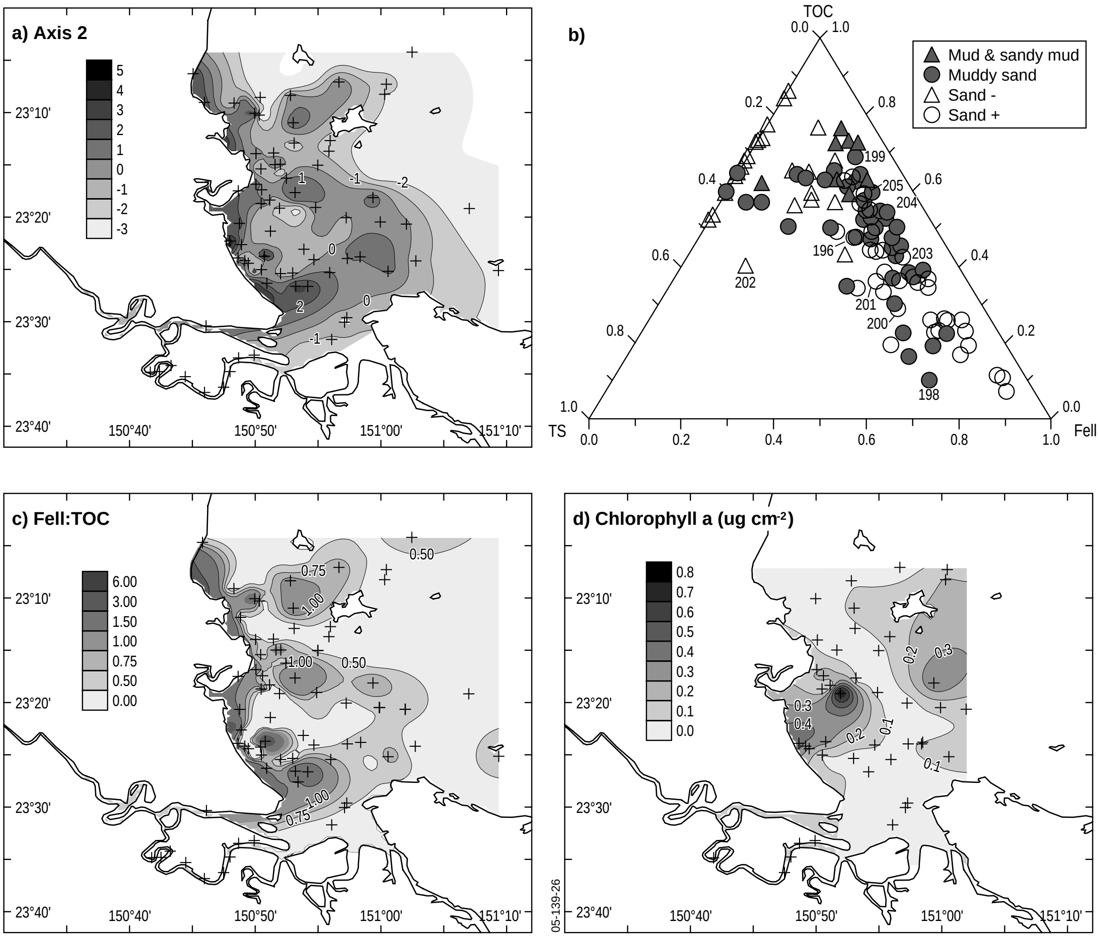

Figure 4.30. *(a) Distribution of site scores from axis 2 of the bottom sediment PCA in Keppel Bay; (b) Trilinear diagrams showing the relative amounts of sulfur (TS), total organic carbon (TOC) and ferrous iron (FeII) for the different grain size classes in Keppel Bay; (c) distribution of FeII:TOC ratios in Keppel Bay; and (d) distribution of sediment chlorophyll a concentrations in Keppel Bay (August 2004 data only).*

4.3.2.2. Axis 2: The Distribution and Character of the relatively FeII-rich sediment

A map showing the distribution of site scores from axis 2 of the PCA is provided in Figure 4.30a. Samples with positive loadings on this axis are indicative of sediments having high FeII contents relative to: (i) TOC+TS (Figure 4.30b); (ii) TOC; and (iii) FeIII. These sediments, and likewise sediments with high FeII:TOC ratios (Figure 4.30c), are found along the western shore of Keppel Bay, describing an arcuate trend around the zone where fine sediment accumulates (*i.e.* with high Al_2O_3: K_2O ratios; Figure 4.24b), alongside Long Beach, and extending around north-west side of Great Keppel Island. Interestingly, sediment chlorophyll *a* concentrations tended also to be low throughout much of this zone, at least in the areas where the measurement was actually made (in August 2004 only). Note that chlorophyll *a* was not measured as part of the surveys of either the Capricorn Coast or Long Beach. This explains the deficit of sediment chlorophyll a data along the western shore.

The data in Table 4.4 highlight some ways in which the sands with positive and negative loadings on axis 2 of the PCA differ geochemically (Table 4.3; Figure 4.23a). Apart from the obvious differences in terms of the relative amounts of ferrous iron relative to ferric iron (*i.e.* higher FeII:FeIII ratio's) and TOC (*i.e.* higher FeII:TOC ratios) that accord with the differentiation of these samples on axis 2, the sands with positive loadings on the PCA had higher overall contents of feldspar (especially orthoclase) and refractive element than the sands with the negative loadings. By comparison, the sands with negative loadings on PCA axis 2 had correspondingly higher quartz contents.

Figure 4.31a-d shows Folk (1980) grain size classifications conform to the same trend as the Al_2O_3:K_2O ratios (Figure 4.27a-d) such that the smaller grain sizes were found underlying parts of the water column where bottom current speeds and shear velocities were highest (Figure 4.27a,c). The diagrams also show that the sands with negative loadings on axis 2 of the PCA were found under-lying waters with slighter lower bottom-water current speeds and bed shear velocities than those with positive loading on axis 2 (). The sands with negative loadings on PCA axis 2 also occurred in deeper waters than the other sediment classifications (Figure 4.31b,), and that had a greater southward component in their current speeds (Figure 4.31d).

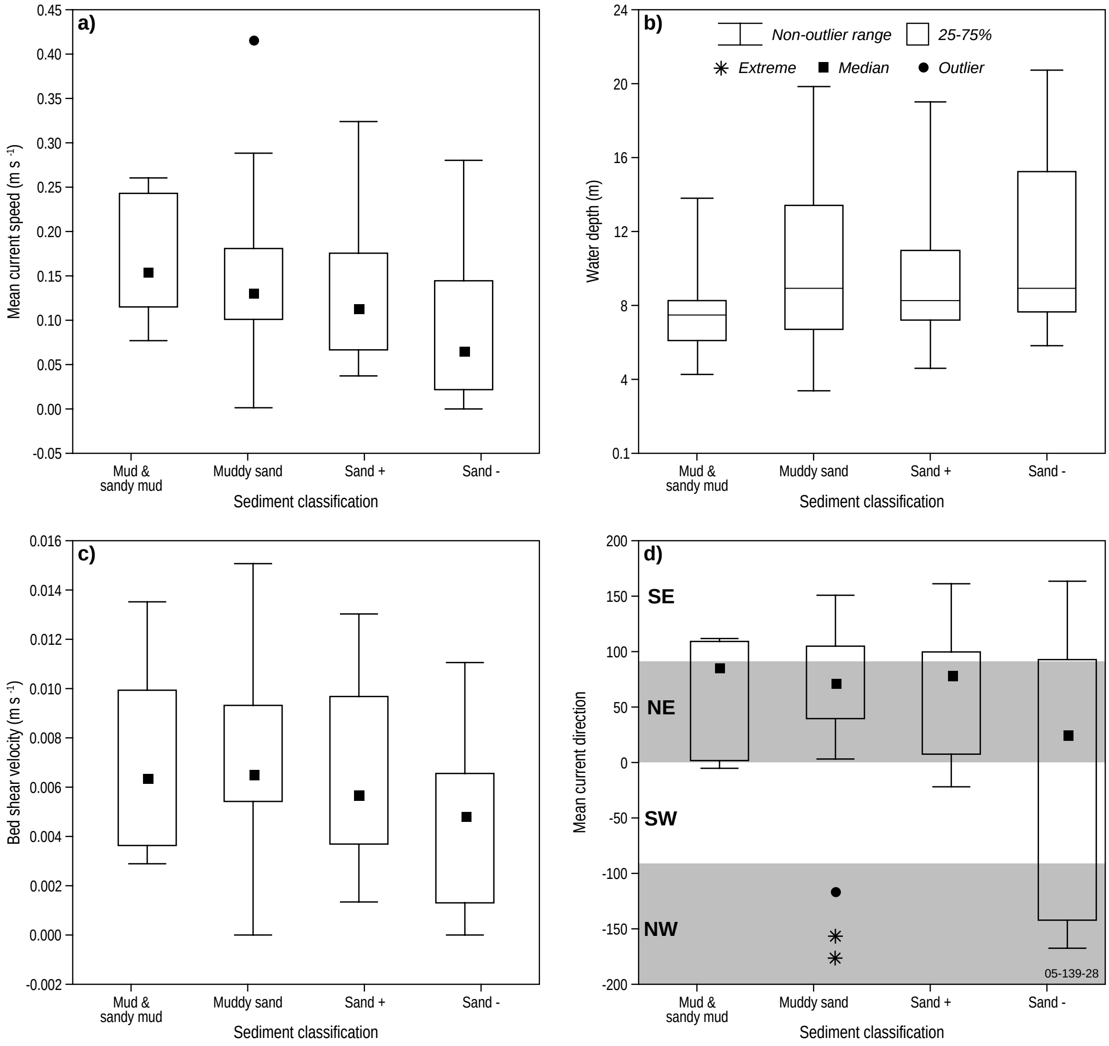

Figure 4.31. *(a) Box and whisker diagrams showing bottom sediment data from the various grain size classifications (mud and sandy-mud, muddy sand, sand +, and sand-) as a function of (a) mean current speeds; (b) water depth; (c) bed shear velocity; and (d) mean current direction. In (d) SE, NE, SW and NW refer to south-east, north-east, south-west and north-west respectively.*

4.3.3. FLUX DATA

4.3.3.1. Core Incubations

The results of the core incubation experiments are presented in Table 4.5 and Figure 4.32. Carbon dioxide (CO_2) fluxes ranged from 9.8 to 41.2 mmol m^{-2} d^{-1} and were indicative of oligotrophic conditions (<48 mmol m^{-2} d^{-1}) in the classification scheme of Eyre and Ferguson (2002). Oxygen uptake rates and CO_2 efflux had a stoichiometry that was close to 1:3 in three of the incubations (200, 202 & 204), while the same stoichiometry was >1.3 in the remaining incubations (196, 198, 201, 203 and 205; Figure 4.32a). In the six samples where dissolved inorganic nutrients were measured, SiO_4, FRP and total-N fluxes were all less than the Redfield ratio, and all of the NH_4 fluxes and four of the FRP fluxes were negative (Figure 4.32b,c,d; Table 4.5). NOx fluxes were detectable in only two incubations, and one was negative (201) and the other was positive (196; Table 4.5). The N_2 fluxes were generally small but higher than the average analytical uncertainty of the instrument (Table 4.5). Denitrification efficiencies based on these measurements ranged from 4.4 – 128.9% in samples 201, 202 & 203, if we assume that DIN was produced in Redfield stoichiometric proportions to CO_2, and that carbonate precipitation was negligible (Table 4.5). Likewise there was net N_2 uptake by sediment in the remaining samples (196, 198, 200, 204 & 205).

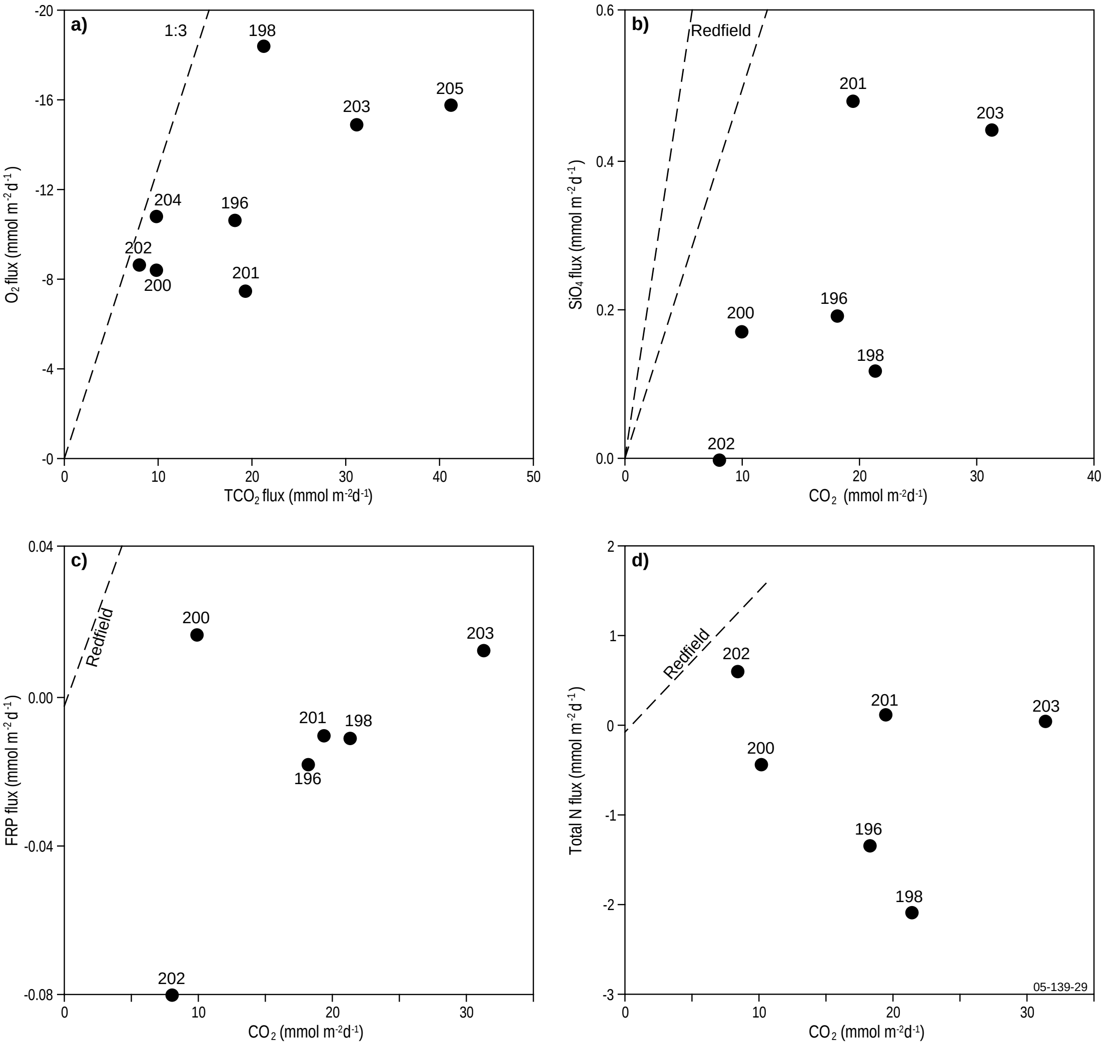

Figure 4.32. *Results of the core incubation experiments: (a) CO_2 flux versus O_2 flux; (b) SiO_4 flux vs CO_2 flux; (c) FRP flux vs CO_2; and (d) total N flux vs. CO_2 flux. Note negative fluxes imply uptake by sediment and positive fluxes imply release from sediment.*

Table 4.5. Results of the core incubation experiments. Note negative fluxes imply uptake by sediment and positive fluxes imply release from sediment.

sample #	O_2 flux (mmol/m2/d)	CO_2 (mmol/m2/d)	N as N_2 (mM/m2/d)	NH_4 Flux (mM/m2/d)	FRP flux (mM/m2/d)	NOx flux (mM/m2/d)	SiO_4 (mM/m2/d)	Denitrification efficiency (%)
196	-10.7	18.1	-1.2	-0.40	-0.02	0.2	0.2	
198	-18.5	21.3	-2.0	-0.05	-0.01	0.0	0.1	
200	-8.5	9.9	-0.4	-0.04	0.02	0.0	0.2*	
201	-7.5	19.3	0.7	-0.45	-0.01	-0.1	0.5	23.1
202	-8.7	8.0	1.6	-0.94	-0.08	0.0	0.0*	128.9
203	-15.0	31.2	0.2	-0.12	0.01	0.0	0.4	4.4
204	-10.9	9.8	-0.9					
205	-15.9	41.2	-3.5					

**denotes measurements that were within the limits of analytical uncertainty.*

There was a strong positive correlation between the flux of N as N_2 (N_2-N) and the ferric iron concentration of the underlying sediment (Figure 4.33a). The map of calculated N_2-N fluxes based on this calibration is shown in Figure 4.33b. The sediments that had negative N_2 fluxes were those that had negative loadings (fine sediment) on axis 1 of the PCA. These sediments occur in a northwest to southeast band extending from Yeppoon to Humpy Island, and also in Casuarina Creek and near its mouth. There was a general trend of increasing CO_2 with %mud content of the sediments: *i.e.* CO_2 flux = 0.36 * %Mud + 9.9 ($R^2 = 0.64$).

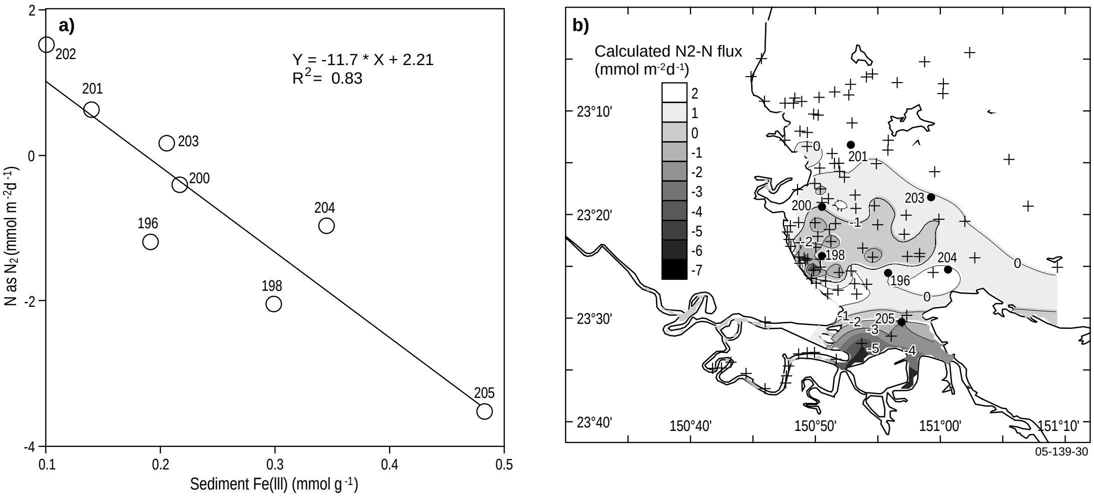

Figure 4.33. *(a) N_2 as N flux versus ferric iron (FeIII) concentrations of the underlying sediment; and (b) distribution of calculated N as N_2 fluxes in Keppel Bay based on the calibration in (a) i.e. y=-11.7*X +2.2. Numbers in both plots correspond to the numbers of these samples.*

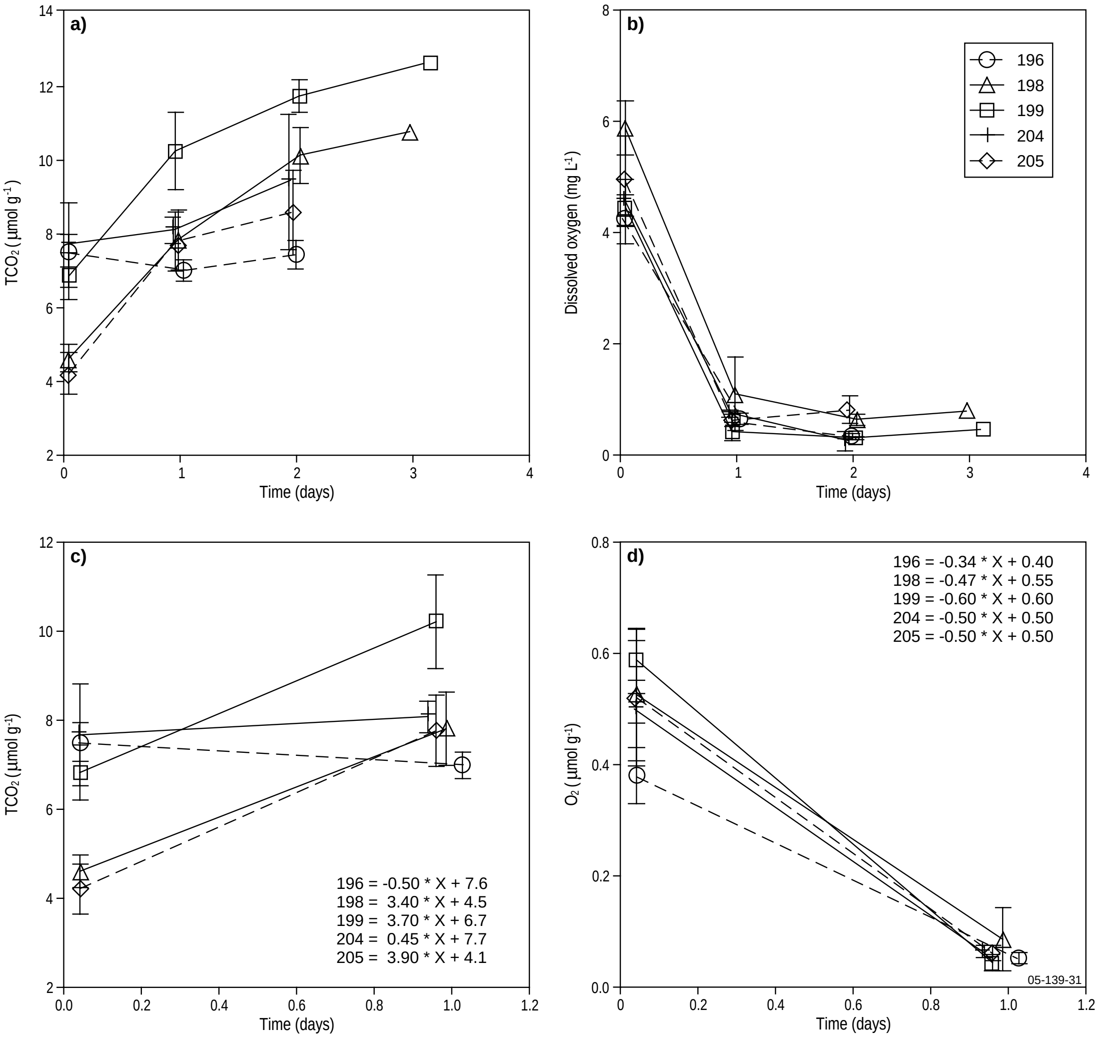

Figure 4.34. *Results of the bottle incubation experiments: (a) TCO_2 (umol g^{-1}) vs. time; (b) O_2 (mg L^{-1}) vs time (t = 0 to t=1); (c) TCO_2 (umol g^{-1}) vs time (t=0 to t=1); and (d) O_2 (umol g^{-1}) vs. time.*

4.3.3.2. Bottle Incubations

The results of the bottle incubation experiments are presented in Figure 4.34*a,b,c,d*. With the exception of sample 196, CO_2 concentrations continued to increase over the course of the incubations. In comparison, all of the incubations became anoxic (< 1mg L^{-1}; < 10 % O_2-saturation) at some time during the first day (t_0 to t_1). The system was therefore considered too perturbed to calculate fluxes from the full suite of data, and fluxes were calculated by linear regression of the CO_2 and dissolved oxygen concentrations between time t_0 and time t_1 (~24 hours). The resulting fluxes are considered minimum estimates because the exact time at which the dissolved oxygen was consumed is not known. The minimum O_2 fluxes ranged from -0.34 to 0.6 umol d^{-1} on a per gram dry weight sediment basis, while minimum CO_2 fluxes ranged from 0.45 to 3.9 umol d^{-1}. Sample 204 (a muddy sand) and sample 196 (a sand (-)) had low or negligible CO_2 fluxes. Interestingly, the Mn contents of these sediments were in the upper 25th percentile range of the full suite of data from Keppel Bay (Figure 4.35*a,b*)

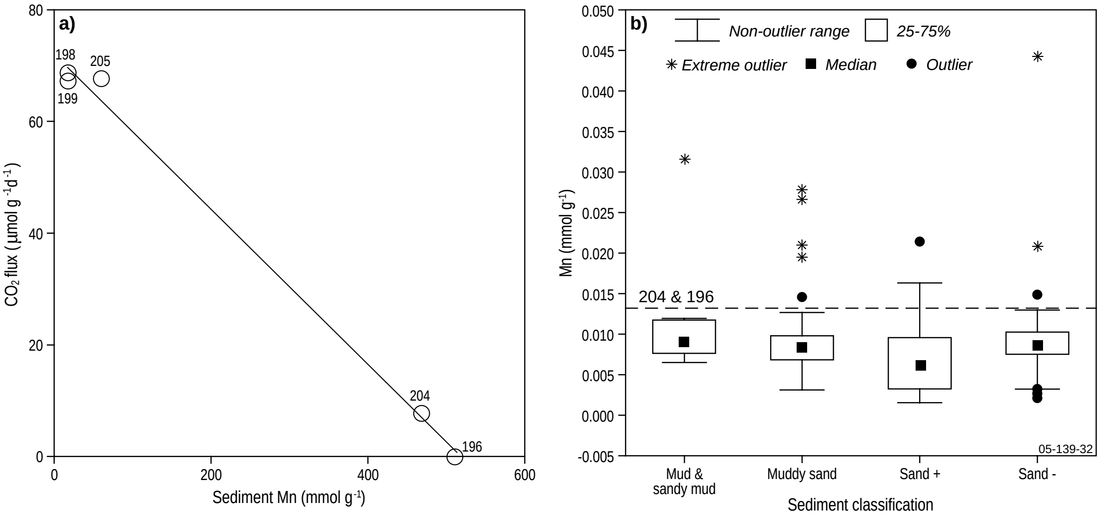

Figure 4.35. *Results of the bottle incubation experiments: (a) CO$_2$ flux vs. sediment Mn contents; and (b) box and whisker diagrams showing the sediment Mn contents of sediments belonging to the different grain size classifications (mud and sandy-mud, muddy sand, sand + and sand-).*

5. Discussion

5.1. THE ROLE OF KEPPEL BAY IN ACCUMULATING AND REDIRECTING SEDIMENT & NUTRIENTS FROM THE CATCHMENT

5.1.1. Source, Composition and Distribution of Nutrient-bearing Sediment in Keppel Bay

The long-term sediment load of the Fitzroy River is estimated at 3.09 Mt yr^{-1} (Joo *et al*., 2005). From a geologic perspective, the Fitzroy Estuary is in a mature stage of evolution because much the accommodation space for sediment is already full and mangrove areas are limited (Ryan *et al*., 2004). As a consequence, the Fitzroy "Estuary" is evolving into a tide-dominated delta, and as such, much of the sediment that delivered from the FRB is exported to Keppel Bay (Ryan *et al*., 2004). A major stratigraphic study nearing completion (Ryan *et al*., 2005) shows that main present day focus of sedimentation in the Fitzroy Estuary is in inter-tidal and shallow sub-tidal areas near the estuary mouth (including the tidal creeks), rather than on the floodplain (see preliminary interpretation in Ryan *et al*., 2004). Studies of flood plumes in the GBR catchment area have shown also that most terrestrial sediment settles out of flood plumes within a few kilometers of the river mouths (Devlin and Brodie, 2005). Flocculation hastens the settling of clay and colloid-sized particles in the near-shore region during flood events (at salinity levels of 1-2 PSU's; P. Ford, unpublished data in Webster *et al*., 2003) as particle-laden fresh water mixes with advancing seawater. However, the volume of river discharge and the direction and strength of the wind are the most important controls on the size and distribution of a sediment plumes (Devlin *et al*., 2001), and there is evidence that sediment-bearing plumes of low salinity occasionally reach mid-shelf regions of the GBR (McCulloch *et al*., 2003a; Lough *et al*., 2002). Typical GBR plume waters have suspended sediment concentrations <20 mg L^{-1} (Furnas, 2003), and retain only a small percentage of the original sediment load (McCulloch *et al*., 2003a). Neodymium isotope studies have shown that the relative proportion of fine-grained, basalt-derived soil in GBR sediments can be disproportionately large (McCulloch *et al*., 2003b).

5.1.1.1. Geological aspects and weathering

In general, Keppel Bay sediments define three distinct arrays in A-CN-K space (Figure 4.26a,b) that are sub parallel to the idealized basaltic and granitic weathering trends but which originate at a composition similar to that of the Upper Continental Crust (UCC). Sediment maturity (and Al_2O_3:K_2O ratios) increases in the direction of the arrows, and follows a trajectory similar to that defined by the theoretical weathering trend (Figure 4.26a,b). This general association reflects the large size of the Fitzroy River Basin and the integration of the weathering products of a large number of rock types to give a composition similar to that of a partially weathered average crust (c.f. UCC) for sediment that is deposited into Keppel Bay. As this average composition is weathered, this initially results in the loss of both Na and Ca, initially from feldspar and then from secondary clays and ultimately into formation of kaolinite and a suite of other minerals. Weathering products may also be size fractionated during transport and deposition with the finer mud and sandy-mud sediments becoming progressively kaolinite-, and probably illite-enriched. Note that the most weathered sediments with the highest Al_2O_3:K_2O ratios have the lowest bulk densities (Figure 4.25f). It is likely that smectite clay is concentrated into the mud and sandy-mud fraction due to its inherently small particle size. Smectite clay is principally derived from the weathering of Tertiary basalts in the FRB (Douglas *et al*., 2005). The reason that smectite was not detected in the XRD trace was probably because the requisite glycolation procedure was not undertaken (this procedure represents work in progress). The geochemical processes and mineralogical differences outlined above cause displacement of the mud, sandy-mud and about half the muddy sand sediment from the theoretical UCC weathering trend toward higher %Al_2O_3 contents (and

Al_2O_3:K_2O ratios), and leads to their pronounced compositional separation from the sand groupings. In comparison, the sands and some of the muddy sands are more closely aligned to the theoretical weathering trajectory of the UCC because of their significantly lower mud contents.

5.1.1.2. Spatial distribution of muds and sands

Mud sediments are delivered from the Fitzroy River into Keppel Bay where they are intermixed with the existing sediments. The Beach Protection Authority (Anonymous, 1979) used the feldspar and mud contents of Keppel Bay sediment to indicate the region of recent influence of the Fitzroy River in the sedimentation along the Capricorn Coast. The river-derived sediment is feldspathic (>10% feldspar) and has mud contents of >10%. The chemical differentiation of these sediments from "relict sands" is evident on axis 1 of the PCA, and explains more than 50% of the variance in the sediment data set (Figure 4.24a). Note that the quartz:feldspar ratio is inversely correlated to axis 1, while the percentage mud is positively correlated to axis 1 (Table 4.3; See also Ryan *et al*., 2005). The Fitzroy River sediments include muds, sandy muds, muddy sands and sands (+) (axis 1 PCA loadings of -10 to +4) and occur in Casuarina Creek, and in two distinct lobes in Keppel Bay. The first (western) lobe follows the coast northwards and becomes thin and discontinuous to the north of Keppel Sands. The second (eastern) lobe extends in an east-ward direction from the estuary entrance toward Hummocky Island. The "relict sands" correspond to sand (-) and are found in the distal north-east of the study area (axis 1 PCA loadings >4). The Beach Protection Authority (Anonymous, 1979) sees the relict sands as a former sandy coastal plain that was drowned by rising sea levels in the early Holocene. The low feldspar and mud contents of the relict sands is thought to reflect the longevity of these sediments in the marine environment (Anonymous, 1979): feldspars are broken down into mud, which is subsequently winnowed out of the sediment by hydrodynamic sorting, while more resistant quartz is retained. About half of the residual sand samples are also distinguished by their much higher residual-P contents than the recent river-derived sediments (Figure 4.29e).

5.1.1.3. Phosphorus sources in the solid phases

Nutrient concentrations (TN and TP), TOC and Fe concentrations and mud contents increased with the Al_2O3:K_2O (Figure 4.24c,d,e; Table 4.3) and therefore with the mud content/degree of weathering of the sediment. These species all have large negative loadings on axis 1 of the PCA (Table 4.3) and the concentrations of TP and TN were highest in the muds. All sediment classifications contained about the same proportions of Ca-P, organic–P, and residual-P, while the Fe-P proportion was highest (~15%) in the muds. Ca-P and organic-P were linearly correlated to the Al_2O_3:K_2O ratio (Ca-P (mmol g^{-1}) = 0.0008 * Al_2O3:K_2O - 0.0003 (0.74); and organic-P (mmol g^{-1}) = 0.0004 * Al_2O3:K_2O - 0.0007 (R^2 = 0.89)), while Fe/Al-P correlated exponentially with this weathering index (ln Fe/Al-P (mmol g^{-1}) = 0.59 * Al_2O3:K_2O - 11.6 (R^2 = 0.79)). Residual-P did not correlate with the Al_2O_3:K_2O ratio. By implication, Fe/Al-P is P bound to Fe (and/or Al), so it is not surprising that it behaved the same way as iron with respect to the degree of weathering. Weathering increases the specific surface area of sediment (with fining), and enhances the secondary iron content due to the destruction of Fe-bearing primary minerals. Iron oxides occur as coatings on mineral grains and are a major control on P concentrations (dissolved and solid-phase), and indeed the whole P cycle (see review in Haese, 2000). The linear relationship between the weathering index and organic-P and Ca-P suggests that these constituents were behaving differently than the Fe/Al bound P-fraction. It is likely that Ca-P and most organic-P are simply size/density fractionated (rather than bound) and transported with the weathered material. Indeed, some of the Ca-P might have a continental origin (see for example Andrieux-Loyer and Aminot, 2001). As only 25% of sediment P was in the organic form, overall P concentrations were much higher than the Redfield ratio (Figure 4.29d), while sediment N was about Redfield ratio in both the muds and the muddy sands (Table 4.4).

5.1.1.4. Organic carbon in the sediments.

The organic carbon concentrations of the Keppel bay sediments is generally low relative to most estuarine systems with TOC of 0.4% in the muds decreasing to 0.04% in the sands. These low values reflected the frequent resuspension and deposition cycles passing through oxic and anoxic environments (Aller et al. 1986). The percentage TOC co-varies with sediment surface areas in Keppel Bay, and in most continental margin settings (see review by Hedges and Keil, 1995), because most sedimentary TOC is bound to the finest mineral grains (Mayer, 1993). This association reflects two mechanisms: sorption onto mineral surfaces (*i.e.* the *sorptive preservation hypothesis*; see review in Hedges and Keil, 1995); and (ii) formation of organo-clay aggregates (Krull *et al*., 2003). Aggregates are the main form of organic materials in marine sediments (Ransom, *et al*. 1997), and nitrogen and amino-acid enriched organic matter preferentially enters into these organo-mineral associations (Aufdenkampe *et al*., 2001). Importantly, sorption (Keil *et al*., 1994) and organo-clay aggregate formation (Arnarson and Keil, 2005) have a retarding effect on microbial degradation of organic matter in marine environments. As a consequence of the above processes, muddy sediment deposits may be important sinks for carbon and nutrients in Keppel Bay. The most weathered/muddy and nutrient-rich sediments occurred in Casuarina Creek (Figure 4.24b and 4.25) and in the near shore region between Cattle Point and Keppel Sands (Figure 4.24b). The spatial extent and accumulation rates of these muddy sediments are currently under assessment (Ryan *et al*. 2005).

With few exceptions mud, sandy-mud and muddy-sand bottom sediments in Keppel Bay and Casuarina Creek had TOC:TN molar ratios and δ^{13}C signatures that suggested either a phytoplankton and/or bacterial origin for the organic matter (Bird *et al.*, 1995; Gagan *et al.*, 1987; Fukuda *et al*. 1998; Goni *et al*., 2005). The lack of a strong terrestrial signature for organic matter in Casuarina Creek was initially surprising because abundant mangrove detritus was observed floating in this tidal creek. In addition, Ford *et al.* (2005) identified soil organic carbon as the principal form of organic matter entering the Fitzroy Estuary, and the TOC, TN and TP concentrations of muddy sediments were within the range of carbon (13 ± 6 mg g^{-1}), nitrogen (0.9 ± 0.5 mg g^{-1}) and phosphorus (0.41 ± 0.25 mg g^{-1}) measurements made on soils from the Fitzroy catchment based on data compiled by Furnas (2003). Despite the above, evidence for a soil organic carbon origin was strong only in sample 24 in Casuarina Creek (Figure 4.28a). However, it has frequently been observed that a component of terrestrial organic matter (TOM) is replaced in deltas and estuaries by recently formed marine substances, suggesting that terrestrial particles undergo major transitions in surface characteristics, chemistry and microbiology when they meet the sea; after which protective sorption of organic matter may then again be possible (Hedges *et al*., 1997; Keil *et al*., 1997; Hedges and Keil, 1999). Even seemingly recalcitrant (highly degraded) organic substances can be de-sorbed from particles and remineralised, as has been shown in important Amazon delta studies (Aller *et al*., 1996).

5.1.2. Sediment Resuspension and Transport

Sediment and bound nutrients derived from the modern Fitzroy River enter cycles of entrainment and deposition whereby they are eventually dispersed into Casuarina Creek (and the other tidal creeks) by tidal pumping (Ryan *et al*., 2004), or to the north or south of the estuary mouth under the influence of winds and currents (Anonymous, 1979). We expect that the southeast Trade Winds combined with the Coriolis effect would result in a nearshore coastal current towards the northwest which would transport fine sediments with it (*i.e.* the western sediment lobe). During times when the southeast Trades relax, flows along the coast would tend to flow in the other direction due to the longshore pressure gradient that also gives rise to the East Australian Current near the shelf break. Thus, there is the potential for fine sediments from the Fitzroy to be transported in both directions along the Capricorn coast.

In the opinion of the Beach Protection Authority (Anonymous, 1979), the relict sand sediments (sand (-)) are undergoing active transportation. The mean tidal current direction is often to the south west in bottom waters overlying this relict sediment body (Figure 4.31d), based on the average of three months (March to May) of preliminary output of the hydrodynamics model (no wind forcing and dry season conditions; Herzfeld and Margvelashvili, personal communication). Low-density, nutrient-rich sediments (Al_2O_3:K_2O ratios >7) were found to underlie regions of the greatest tidal current speeds and shear velocities, based on the same preliminary model output of Herzfeld and Margvelashvili (personal communication). Although this result seems counterintuitive and will have to be scrutinized with respect to wind-related hydrodynamic factors, a seminal study on the high-energy tidal system in the Severn Estuary also found that shear velocities were highest in association with finer grain sizes with the high excess shear velocities being dissipated through the resuspension of mud and sands (Hamilton, 1979). Large accumulations of fluid mud can form under such conditions, and are important for the biogeochemical functioning of macrotidal systems (Abril *et al.*, 2000). In the case of Keppel Bay, an accumulation of low density mud was identified at the junction of Raglan and Casuarina Creek, near Port Alma (Ryan *et al*., 2005). This mud body was 5 m thick and pinched out over a kilometer in the direction of Keppel Bay (Ryan *et al*., 2005).

As abundant nutrient-rich muddy sediment is available for resuspension in the near shore regions of Keppel Bay, and other GBR coastal regions (Belperio, 1983), controls on water column suspended sediment concentrations are mainly hydrodynamic in nature (Larcombe *et al.*, 1995; Larcombe and Woolfe, 1999). The distribution of water column TSM concentrations (Figure 4.2c and 4.11a) was generally similar to the occurrence of Fitzroy River sediment (Figure 4.24); that is, TSM concentrations were higher over the muddier substrates. This is in part due to wave- or tide-driven resuspension, and in part to material being carried northward by prevailing currents and winds. In September 2003, TSM concentrations ranged from 100 to 400 mg L^{-1} in Casuarina Creek and 10 to 130 mg L^{-1} in southern Keppel Bay near the estuary mouth; they then diminished from 10 to <1 mg L^{-1} in a north-east direction in Keppel Bay (Figure 4.2c). However, it should be noted that TSM concentrations at a given location also varied by large amounts over the tidal cycle due to advection and to sediment resuspension/settling as discussed below. The high concentrations of suspended sediment in south west Keppel Bay, Casuarina Creek and channels leading into the estuary mouth occur due to the vigorous tidal currents in these regions (as described above). As expected, TSM concentrations were lower in Casuarina Creek in August 2004, when the survey coincided with neap tides (Figure 4.11a), than they were under spring tide conditions in September 2003 (Figure 4.2c).

5.1.2.1. Processes controlling TSM concentrations

In Figures 4.19 and 4.20, turbidity (or TSM) levels are shown as a function of current speeds and water pressures (water depth). Given that TSM shows an overall decrease in concentration away from the mouth of the Fitzroy (Figures 4.2c and 4.11a), it is expected that high tides will transport lower TSM concentration waters towards a specified measurement location. Conversely low tides will be associated with higher concentrations. Some of the sites show this pattern (Stations A, B and the ebb tide at C/E). This variation in TSM concentration is due to advection. In general, however, the sediment concentration reflects both advection (movement of sediment–laden waters from some distance**)** plus purely local resuspension reflecting the sediment composition and the water velocity in the immediate vicinity because resuspension increases markedly with current speed. Therefore, at sites where local effects dominate resuspension rates should be at a maximum at mid-tide when speeds are highest. Only at stations G and F in Casuarina Creek and near its mouth, are suspended sediment concentrations roughly proportional to current speed. This suggests that active local resuspension across the tidal cycle dominates over advection at these stations, and that horizontal gradients in the background TSM concentration are small. The quick response at Station G to increasing current speeds might reflect the shallowness of Casuarina

Creek and rapid mixing of bottom water into the upper water column. Higher concentrations of suspended sediment were observed in the bottom waters than surface waters in Casuarina Creek and the estuary mouth region during September 2003 (Figure 4.7d) a phenomenon caused by active resuspension raising TSM concentrations near the bottom.

The relative contributions of resuspension and advection to TSM concentrations, noted above, will vary across the tidal cycle as the current speed changes leading to complex relationships between TSM concentration, tidal phase and current speed, including hysteresis effects at particular points. For example, resuspension during the flood tide probably causes the deviation of turbidity (and TSM) levels at stations B, D and C/E (Figure 4.19a,c,e) from the linear trend that would be expected if advection were the only cause of increasing TSM. Further evidence for resuspension at these sites (stations D and C/E; as well as F & G) comes from the range of water column TPP:TSM ratios which match the P-contents of the underlying sediment (Figure 4.21 and 4.11d).

5.1.3. Mixing Processes

Dissolved nutrients and sediments are likely to be transported throughout Keppel Bay by wind-driven tidal currents. Given the fluctuating nature of the tides particularly, much of this transport may have the character of dispersion. Dissolved substances, such as dissolved nutrients, will move differently from fine sediments. Relatively speaking, large currents are more important for moving sediment due to the non-linear dependence of resuspension rates on current speed. Moreover, dissolved nutrient transport is confounded by biological uptake by primary producers and bacteria in the water column and on the bed. Mixing diagrams, or property-salinity plots, provide useful information on nutrient inputs, sinks and degree of conservative behaviour in estuaries (Eyre, 2000; Devlin *et al*., 2001; Devlin and Brodie, 2005). When changes in nutrient concentration are caused only by dilution associated with mixing of freshwater with seawater, nutrients tend to conform to linear trendlines between end members and are said to mix conservatively. Salinity is the conservative component of seawater, which typically has lower concentrations of nutrients than inflowing freshwater. The most distinguishing feature of the salinity distributions in the September 2003 and August 2004 surveys were the zones of elevated salinities in Casuarina Creek and along the shallow (<5 m) western shore of Long Beach (36.5 to 38.9 PSU; Figure 4.6a and 4.11b), where evaporation has had the effect of concentrating dissolved salts. Elsewhere in Keppel Bay, salinity ranged from 36.1 – 36.3 PSU and water temperatures were close to 21^{o}C (Figure 4.6b and 4.11c).

As a consequence of the very small inputs of freshwater and vigorous tidal mixing, the water column of the bay was not significantly stratified during the surveys. Surface and bottom salinity levels differed by only 0.1 PSU over most of the study area in September 2003 (Figure 4.7a), while differences between surface and bottom water temperatures were largest in the deepest, eastern part of the Bay, especially in the southeast where they ranged from 0.8 – 1.2 ^{o}C (Figure 4.7b). Figure 4.15b shows that the backwards and forwards motion of the tides gives rise to salinity variations at a given station in the order of 0.4 PSU's.

A reverse salinity gradient is apparent in the mixing diagrams based on data from the suite of 24 hour stations in Keppel Bay (August 2004; Figure 4.17); that is highest nutrient concentrations were observed in the highest salinity water. These high salinity waters flow out of Casuarina Creek and were a source of NOx, FRP, SiO_4 and DON to Keppel Bay. Most NOx, FRP and SiO_4 data adhere to linear relationships suggesting that conservative dilution is an important control on the concentrations of these constituents in Keppel Bay. Diatoms washed from the mud banks in Casuarina Creek accounted for the highest chlorophyll a concentrations in the dry season surveys (Figure 4.16b), and the evidence suggests that a significant proportion of these are also exported to Keppel Bay (P. Ford, in prep). However, it would appear that significant biological uptake of SiO_4 occurs in the water masses that are transported over stations A and B, judging from the lower than expected concentrations at these sites (Figure 4.17c). Likewise, biological uptake of NOx and FRP may occur in the water masses that advect past stations C, D and E (Figure 4.17a,b).

Interestingly, DON, DOP and NH_4 did not behave conservatively at any stations, and in some cases these concentrations declined to below detectable limits (Figure 4.17d,e,f; discussed below), again suggesting biological uptake. It is worth mentioning that the slopes of the conservative mixing lines of the Keppel Bay data (Figure 4.17) were steeper than those constructed on the basis of summary data from inshore and offshore waters of the Great Barrier Reef (*i.e.* means ± standard deviations in the representative data of Furnas and Brodie, 1996 and Devlin *et al*., 2001). It is also noteworthy that the salinities at all the stations in Keppel Bay are also higher than observed at other sites in the GBR cited above and dissolved nutrient concentrations were generally higher than these other sites. The mixing lines for these other GBR sites had a positive slope also. This behaviour arises from the frequent (tidal) resuspension, and the area is a source of higher nutrient concentrations because: (i) turbulence promotes organic matter mineralisation; and nutrients are not completely utilised because (ii) photosynthesis is light limited (see Cloern, 1987); and (ii) tidal mixing reduces the residence time for algae in the more limited photic zone (see for example Monbet, 1992). As reviewed by Devlin and Brodie (2005), TSM levels generally have to be reduced to below 10 mg L^{-1} in order for there to be sufficient light for phytoplankton growth.

5.2 SEDIMENT BIOGEOCHEMISTRY

5.2.1. Oxic and Sub-oxic Processes

The importance of alternating oxic and sub-oxic processes facilitated by mixing in dynamic coastal environments was recognised in foundational work on Amazon Delta sediments (Aller *et al*., 1986), and underscored in subsequent studies by Aller (1998) and Aller and Blair (2004). Those studies found that sediment mixing and re-working in energetic coastal environments regenerates oxidised Mn and Fe compounds and enhances overall mineralisation rates by (i): increasing the transport rate of Fe and Mn oxides from oxic to anoxic sediment layers where they can be reduced; and (ii) facilitating the upward transport of mainly solid but also dissolved reduced Fe and Mn species into the oxic layer where they can be re-oxidised (rather than buried). In common with Amazon Delta sediments, muddy Keppel Bay sediments share low S concentrations (<0.1%) and Fe concentrations in the range of 0.77 – 0.9 mmol g^{-1} (42.8 – 50.0 mg g^{-1}). Although bacterial densities were not directly measured in the current study, they cannot be ruled out as an important contributor to the sediment organic matter pools of most Keppel Bay sediments, on the basis of TOC:TN ratios and $\delta^{13}C$ signatures (Figure 4.28a). Bacteria, rather than macrofauna often dominate benthic biomass in energetic coastal sediments with sub-oxic diagenetic patterns (Alongi 1995; Alongi and Robertson, 1995; Aller, 1998).

The *suboxic fluidised bed reactor* was a term coined by Aller (1998) to describe seafloors where bacterial-laden fluid mud and mobile surface sediments subject to a continual supply of fresh plankton produce an efficient decomposition system characterised by repetitive redox successions (oxic to sub-oxic, temporarily sulfidic), reoxidation and metabolite exchange. Our bottle incubation experiments (Figure 4.34) were designed with the aim of measuring dissolved oxygen consumption and CO_2 generation in highly concentrated sediment slurries *(i.e.* with suspended sediment concentrations of 300 – 400 g L^{-1}). These experiments showed that oxygen was completely consumed by the end of the first 24-hour period in all of the different samples, at *minimum* rates ranging from -0.34 to -0.6 umol g^{-1} day^{-1}. The oxygen consumption rates are considered minimum because the first measurement time was ~24 hours after the start of incubation and dissolved oxygen concentrations had reduced to zero by then. Indeed, indications are that consumption rates may have been much higher than these minima. A similar bottle incubation experiment undertaken during the wet season on suspended sediment collected near the estuary mouth (over ~2 days) found O_2 consumption rates about a 1000 times higher (*i.e.* -640 µmol g^{-1} day^{-1}). Moreover, the (the non-chlorophyll corrected) TSM levels in that *wet season* experiment were several thousand times lower (*i.e.* 104.8 mg L^{-1}) because this bottle incubation was designed with intention of observing heterotrophic processes in the water column. Likewise the O_2:TCO_2 ratios were lower than 1:3 in all eight of the core incubations undertaken in Keppel Bay, suggesting that more CO_2 was generated than could be accounted for by oxic mineralisation with complete nitrification (Figure 4.32). Ferrous iron (FeII) is also inversely proportional to TOC in terms of the system TS+TOC+Fe(II) in Keppel Bay sediments (Figure 4.3b) highlighting the potentially important role of iron oxy-hydroxide reduction in these sediments.

Clearly there is a need to better quantify the contributions of dissimilatory iron and manganese reduction for the decomposition of organic matter in Australian tropical coastal waters. This is especially the case in regions subject to natural or anthropogenic loads of highly-weathered lateritic debris, rich in Fe, Mn and Al because the manganese and iron can be cycled several hundred times prior to burial (see review in Haese, 2000).

5.2.2. Nitrogen Fixation in Turbid Waters: The role of Iron

An unexpected result from the August 2004 survey of Keppel Bay, was that a net uptake of N_2 (as well as NH_3) by sediment was observed in some of the core incubation experiments (Table 4.5). This result was surprising because this evidence for nitrogen-fixation was observed under dark conditions, and in situations where we would have anticipated net denitrification to be occurring; for example, in the resuspension zone (*e.g.* sample 205) where efficient nitrification was raised as a potential explanation for low NH_3 concentrations. The correlation between N_2-N fluxes and the ferric iron concentration of the underlying sediment is striking (Figure 4.33a), lending further support to the occurrence of nitrogen fixation under dark conditions. Nitrogen fixation is arguably the most iron-expensive process within phytoplankton because the two major sub-units of the nitrogenase enzyme collectively contain 32-36 iron atoms, and it now known that iron limits primary productivity in high-nutrient, low chlorophyll (HNLC) oceanic areas (Hutchins, 1995; Kustka *et al.*, 2002; Wilhelm, 1995). Evidently, several species of marine cyanobacteria (including *Synechococcus* spp.) can also fix nitrogen in the dark, due to a temporal separation of nitrogen fixation and photosynthesis within a cell cycle (Mitsui *et al.*, 1986; Zehr *et al.*, 2000). As reviewed by Kustka *et al.* (2002): (i) night time N_2-fixing ability could allow for a more efficient use of cellular iron due to the potential for iron recycling associated within the diel cycle of degradation and synthesis of nitrogenase; and (ii) the temporal decoupling of N_2 and C fixation could reduce the redundancy of certain iron-containing catalysts.

It is worth mentioning that unicellular diazotrophic (N-fixing) bacteria, both heterotrophs (*i.e.* that feed on pre-formed carbon) and autotrophs, were recently discovered in the pelagic pico-phytoplankton and nano-phytoplankton in the subtropical North Pacific Ocean (Zehr *et al.*, 2001a,b), and these organisms can fix nitrogen at very high rates (Montoya *et al.*, 2004). The heterotrophic diazotrophs also require an order of magnitude more iron than other heterotrophic species (Kustka *et al.*, 2002). Genetic sequences (*nifH*) indicative of a group of diazotrophs with phylogenetic affinities to N_2-fixing sulfate reducing bacteria have also recently been found in *nitrogen-rich* sediments of Chesapeake Bay and the Neuse River (Burns *et al.*, 2002), and nitrogen-fixing microbial (gene) assemblages were also found to vary along a salinity gradient in the Neuse River Estuary (Affourit *et al.*, 2001). Clearly, nitrogen-fixing bacteria (heterotrophs and autotrophs) occupy a plethora of specialised niches allowing N-fixation to occur over a wide-range of environmental conditions. The ability of heterotrophic bacteria to acquire from the N_2 pool the nitrogen they require to metabolise organic matter, would reduce competition with phytoplankton for scarce nitrogen under these nitrogen-limiting conditions.

5.3. LINKS BETWEEN PRIMARY PRODUCTION, BIOGEOCHEMISTRY AND SEDIMENT DYNAMICS: A PRELIMINARY ZONATION FOR KEPPEL BAY

Nutrient dynamics in Keppel Bay under dry season conditions reflect the internal biogeochemical processes. These depend on the initial chemical characteristics of the sediment and the supply of oxidants to the sediments. Importantly, three distinct zones of physical, biogeochemical and to a lesser extent ecological characteristics were identified in Keppel Bay and these reflect the influence of the hydrodynamic regime on the distribution of Fitzroy River sediment and relict sand deposits. These zones include: (i) the zone of maximum resuspension; (ii) the coastal transitional zone; and (iii) the blue water zone.

5.3.1. The Zone of Maximum Resuspension

Processes occurring in the Zone of Maximum Resuspension (ZMR) exert a fundamental control on nutrient cycling in coastal areas (Abril *et al*., 2000; Goni *et al*., 2005). This zone arises in the Fitzroy because of the large currents and asymmetric tides. In other systems tidal asymmetries, gravitational circulation and stratification (see references in Goni *et al*., 2005) all contribute. Resuspension and entrainment in these high energy zones contributes to hydrodynamic sorting of particles based on different densities and settling velocities. It has already been suggested that Keppel Bay sediments are size fractionated with transport. It was also shown that the most highly weathered, nutrient-rich sediment was found in association with high current speeds (Figure 4.27a), mainly at the junction of Raglan and Casuarina Creek (Figure 4.24). The preferential landward transport of lighter carbon-rich particles was also observed in the Winyah Bay South Carolina under conditions of low river discharge, where it was also attributed to a combination of tidally-controlled resuspension and hydrodynamic sorting (Goni *et al*., 2005). The Winyah Bay study also found that lower density particles had higher vascular plant contents on the basis of TOC:TN ratios and $\delta^{13}C$ signatures (Goni *et al*., 2005).

5.3.1.1. Oxic and sub-oxic processes inferred

There is a reasonable amount of semi-quantitative evidence for an important role of sub-oxic and especially oxic processes in organic matter degradation in the ZMR (and elsewhere in Keppel Bay), and it seems logical that reactive carbon that would likely be mineralised by oxic and sub-oxic processes as sediment is alternately eroded during ebb and flood tides and then deposited again during slack tides. The first line of the evidence was that CO_2 production continued for at least two days after all the dissolved oxygen was consumed in the bottle incubation experiment for sample 205 (and samples 198 and 199), suggesting that sub-oxic and/or anoxic diagenesis occurred at the termination of oxic diagenesis. Likewise the O_2:TCO_2 ratios were lower than 1:3 in sample 205, suggesting that more CO_2 was generated than could be accounted for by oxic mineralisation with complete nitrification (Figure 4.32). The core incubation studies also showed that, of the eight cores studied, the highest CO_2 fluxes were from the core taken from the ZMR (*i.e.* 41.2 mmol CO_2 m^{-2} d^{-1} in sample 205; Table 4.5). A CO_2 flux of this magnitude is indicative of oligotrophic conditions (<48 mmol CO_2 m^{-2} d^{-1}) in classification scheme of Eyre and Ferguson (2002). However, the core incubations assume a static sediment-water interface and thus probably underestimate the amount of organic matter degradation, and likewise trophic status, in this part of the estuary. This is because episodic re-suspension improves the opportunity for mixing between bacteria and labile organic matter in the sediment (Alongi and McKinnon, 2005). The predominantly mud and sandy-mud sediments found in the ZMR also share in common with most Keppel Bay sediments, displacement from the theoretical UCC weathering trend towards lower FeO + MgO compositions in A-CNK-FM diagrams (Figure 4.26c,d). However, the fact that the predominantly mud and sandy mud sediments found in this region have relatively low Fe(II):TOC and FeII:FeIII ratios in comparison to most Keppel Bay sediments (Figure 4.3b; Table 4.4) may suggest that oxic processes are relatively more important than sub-oxic processes in this region.

5.3.1.2. Relationships Between Suspended Sediment and Nutrients

Particulate nutrients dominated nutrient pools in the ZMR of Keppel Bay at the time of the dry season surveys (Figures 4.9 and 4.12), and linear relationships were found between chlorophyll corrected TPN and TPP and TSM (Figure 4.12a,b,d). The linear relationships between TPN and TPP and TSM are best explained by the re-suspension of bottom sediment and bound nutrients by the intense turbulence in the resuspension zone. Dissolved nutrient concentrations were also highest in the resuspension zone (Figures 4.3, 4.4, 4.9, 4.12); that is, with the exception of samples 1 and 2 from the Fitzroy River, which stood out on axis 2 of the water column PCA (Figure 4.1a; Table 4.1) on the basis of much higher NH_4^+ and NO_2^- concentrations than the rest of the data. Discharge from the Rockhampton wastewater treatment plants (WWTP) and meatworks probably accounted for the high concentrations of DIN as well as FRP and DON at these sites, under these dry season conditions (*i.e.* low river discharge). The analyses of longer term nutrient data along the Fitzroy Estuary suggested a source of DIN in the upper part of the estuary which is consistent with discharges from the (WWTP) and meatworks (Webster *et al*. 2005). In comparison, the dissolved nutrients in the resuspension zone were probably derived from the release of nutrients either from sediment or from algae (diatoms) washed from the mud banks and subsequently remineralised (P. Ford, in prep). As explained above, physical re-working and re-oxidation of the bottom sediment promotes the remineralisation of particulate organic matter (Aller, 1998; Aller and Blair, 2004; Aller *et al*., 1986) and nutrient release to the water column (see for example Ullman and Sandstrom, 1987; Walker, 1981).

As continual resuspension of the surface layer and high levels of TSM interfere with nutrient uptake by phytoplankton, there are strong numerical relationships between TSM and some dissolved nutrients in the resuspension zone, and some of the dissolved nutrient load is exported to Keppel Bay with the ebbing tide (P. Ford, in prep). For example, the relationship between FRP and TSM (samples 1 & 2 omitted) could be described with a logarithmic function of the form: FRP = 0.003 * ln TSM – 0.003 ($R^2 = 0.89$; Figure 4.12e). The shape of the FRP vs TSM relationship resembles a Langmuir isotherm for phosphorus adsorption which reflects the *phosphate buffer mechanism* of Froelich (1988), whereby the partially reversible adsorption of phosphate onto bottom and suspended sediment maintains phosphate concentrations in water columns, usually in a range from 0.019 to 0.043 mg L^{-1} for estuaries (see review of literature in Eyre, 1994). NOx was linearly correlated to TSM in the September 2003 (NOx = 0.00025 * TSM + 0.007; Figure 4.12f) when the highest levels of TSM were observed in Casuarina Creek. The large intercept in the sediment TN versus TOC cross plots (Figure 4.28b) may suggest that some of this NOx may have originally been NH_4 adsorbed onto clay particles, and subsequently nitrified in the water column. Nitrification is the oxidation of ammonium to nitrate and has been observed in the sediments and water column of a number of estuaries (Billen,1975). This process is often at its maximum in the resuspension zone because nitrifying bacteria occur attached to sediment particles (Owens, 1986; Abril *et al*., 2000). The high particle concentrations, together with the high water temperatures and well oxygenated waters bring about a rapid oxidation of any NH_4 produced, thus NOx is exported to Keppel Bay.

An alternative explanation for low NH_4 concentrations in the resuspension zone is that NH_4 was produced in Casuarina Creek, but was subject to rapid biological utilisation. Both heterotrophic bacteria and phytoplankton utilise NH_4, and indeed prefer it over NOx because of the energetic cost of reducing nitrate to ammonia (Kirchman, 1994; Kirchman 2000; Middleburg and Nieuwenhuize, 2000; Veuger *et al*., 2004). To complicate matters, a synthesis of studies has found that heterotrophic bacteria utilise DIN (including ammonia) and DON (especially dissolved free amino acids), while also simultaneously excreting NH_4 (Kirchman 2000; see also Palenik and

Morel, 1990). It is timely to mention that an equivalent transfer of DON to NH_4 (14. 1 mmol g^{-1} day^{-1}) was observed in the bottle incubation experiment undertaken during the *wet season* survey (and thus not formally reported here), on a sample collected near the mouth of the Fitzroy Estuary. This site was located not far from Stn F where DON was observed to decrease to zero in Redfield stoichiometric proportion to chlorophyll production in the passing water mass (Figure 4.18b). A zone of low DON concentrations was also observed near the same location near the mouth of Casuarina Creek during the September 2003 survey (Figure 4.4c). Based on the above evidence, it is possible that these phytoplankton were utilising NH_4 excreted by heterotrophic bacteria, inferring a tight coupling between organic matter breakdown and subsequent utilisation by phytoplankton (see for example Berman *et al*., 1999). However, it is also possible that phytoplankton were directly utilising components of the DON pool for their N nutrition (Berman and Bronk 2003; Zehr and Ward, 2002).

DON comprises a variety of compounds that can differ markedly in terms of their bioavailabilities and molecular weights: from highly bio-available (low TOC:TN) compounds like urea and amino acids, to largely refractory (high TOC:TN) poly-phenolic compounds (McCarthy *et al*., 1997; Seitzinger *et al*., 2002; Berman and Bronk, 2003). The ability of some algal species to utilise amino acids and urea has also been known for a long time (see review in Berman and Bronk, 2003). Indeed, it would seem unlikely that at least some algal species would not evolve mechanisms for DON acquisition in order to bypass the *microbial loop* of Azam *et al.* (1983). Studies on near-pristine streams and rivers in temperate South America have shown that nitrogen loss from forests unaffected by humans is mainly via DON (Lewis et al., 1999; Perakis and Hedin, 2002). Likewise, Harris (2001) found that DON was also the dominant form of N exported from forested Australian catchments. In the context of Keppel Bay, potential sources of DON at the times of the surveys were urban effluents (especially from the WWTP and meatworks; note high concentrations in the Fitzroy Estuary in Figure 4.4c), leachate from mangrove detritus and soils and exudates from phytoplankton. Notably, Smith (2004) measured DON fluxes ranging between 0.3 - 5.7 mmol m^{-2} d^{-1} from intertidal mud-bank sediments in the Fitzroy River. DOC concentrations are higher in both the Fitzroy estuary and Casuarina Creek relative to Keppel Bay. Since both areas are at higher salinity than Keppel Bay this reflects *in situ* generation by mineralisation of organic matter rather than remnant material left over from the previous flood. It is worth mentioning that iron may rapidly become a limiting factor for heterotrophic bacteria when DOC is in abundant supply (Kirchman *et al*., 2000). Clearly, a better definition of DON sources and reactivities is needed to better understand N cycling Australia's tropical coastal systems.

5.3.2. The Coastal Transitional Zone

In addition to the ZMR identified in the previous section, two other geographic areas with differing biogeochemical characteristics can be identified within Keppel Bay. They are a blue water zone (BWZ) characterised by primarily oceanic characteristics and a Coastal Transition Zone (CTZ) with properties intermediate between the ZMR and the BWZ. The CTZ represents the mixing zone between these two water bodies and reflects the wide tidal excursion which prevents any clear cut boundary developing between the two end members. The defining characteristics of the CTZ are discussed here. They include DOP concentrations and the phytoplankton speciation. DOP was found to dominate water column P-pools when TSM concentrations were less than ~20 mg L^{-1}, while DON was the dominant form of N when TSM was below 125 mg L^{-1} (Figures 4.10a,b, and 4.13). The transition from high TSM waters dominated by particulate and dissolved inorganic nutrients (*i.e.* in the resuspension zone), to low TSM waters dominated by organic nutrients was also marked by a transition in pigments indicative of a change in dominant phytoplankton assemblages from micro-phytoplankton to pico-phytoplankton (Oubelkheir *et al*., in prep). Interestingly, of all the water column variables in the PCA (Table 4.1), the relative numbers of these different phytoplankton groups were best correlated to %P as DOP (Figure 4.10c).

The coastal transitional zone (CTZ) was recognised on the basis of its near equal proportions of micro-phytoplankton and pico-phytoplankton by Oubelkheir *et al*., (in prep), and is shown here as that region beyond the ZMR where DOP-P percentages were in the range from 50 to 90% TP (Figure 4.10d). The transitional zone is also roughly coincident with the distribution of modern Fitzroy River sediments in Keppel Bay proper (Figure 4.24), in the region where TSM concentrations were in the range from 2 - 10 mg L^{-1} and the water was turquoise (rather than brown (ZMR)) or blue (BWZ; see below)) in colour (Figure 4.10d).

Fluctuations in general turbulence, P-concentrations and TN:TP ratios on tidal timescales (due to re-suspension and advection) may allow for the co-dominance of pico-phytoplankton and micro-phytoplankton in the CTZ. Because diatoms tend to sink at relatively high rates, they tend to flourish only in regions where they are actively resuspended by turbulence. In comparison, pico-phytoplankton are smaller and more buoyant so their losses due to sinking are much smaller and they can survive in regions of modest vertical mixing. It is also frequently observed that large phytoplankton out-compete smaller species in areas of high nutrient supply (Donald, 1997), while pico-phytoplankton (0.2 - 2 µm) biomass is usually highest in oligotrophic, and especially P-limited waters (Joint, 1986; Agawin *et al*., 2004). For example, Suttle and Harrison (1988) reported that the pico-cyanobacterium *Synechococcus* dominated over diatoms in laboratory cultures with high TN:TP ratios (TN:TP = 45), while diatoms dominated at lower TN:TP ratios. Similarly, Takamura and Nojiri (1994) identified a positive correlation between micro-phytoplankton biomass and the TN:TP ratio of lake waters. Our results would apparently support the co-dominance of micro-phytoplankton and pico-plankton in the CTZ, because TN:TP ratios ranged from 18-61 during the dry season surveys (Figure 4.5c and 4.11f), and fluctuations of 20 to 30 TN:TP units were observed over a tidal cycle (Figure 4.11f). The success of pico-plankton in nutrient depleted waters may in part rely on their ability to utilise numerous and sometimes *novel* organic P and N sources including cyanates and phosphonates (Fuller *et al*., 2005 and references therein), and in part on their different uptake efficiencies. For example, Donald *et al*., (1997) found that P-starved *Synechococcus* possessed a higher affinity system for inorganic-P uptake than the diatom *Thalassiosira weissflogii*, while *T. weissflogii* demonstrated faster P-uptake under P-replete conditions. As mentioned previously, several species of marine pico-plankton (including some *Synechococcus* spp.) can also fix nitrogen under dark conditions (Mitsui *et al*., 1986), and the activity of such organisms might account for the net uptake of N_2 as well as FRP in the core incubations undertaken in the CTZ (*i.e.* samples 196, 198, 200 and 204; Table 4.5).

Co-dominance of pico-phytoplankton and micro-phytoplankton has also been observed under *moderately iron-limited* and *iron-stressed* conditions (*sensu* Hutchins *et al*., 1998), and it has been repeatedly shown that large diatoms replace pico-plankton in iron fertilisation experiments conducted in areas of Fe-limitation (Cavender-Bares *et al*., 1999; Boyd *et al*, 2000; Gall *et al*., 2001; Hare *et al*., 2005). The conditions of iron limitation or iron stress are not unusual in coastal areas influenced by up-welling (Hutchins and Bruland, 1998), such as in the southern GBR region which includes Keppel Bay (Kleypas and Burrage, 1994). Iron-stressed coastal environments are poised on the verge of iron limitation: that is iron concentrations are sufficient to support pico- and nano-phytoplankton, as well as a reduced large diatom assemblage (Hutchins *et al*., 1998). In comparison, in moderately Fe-limited coastal environments, pico- and nano-plankton are slightly iron-stressed, while diatoms are iron limited (Hutchins *et al*., 1998). Another common feature of moderately Fe-limited coastal environments is high H_2SiO_4:NO_3 drawdown ratios (*i.e.* ~2-3; Hutchins *et al*., 1998); a phenomenon which might explain the lower than expected silicate concentrations at stations A and B in the CTZ during August 2004 (Figure 4.17c). However, there is abundant evidence that iron oxy-hydroxide reduction is an important process, especially in the CTZ (discussed below), and some of this iron would likely become available for use by phytoplankton. Recall that utilisation of iron by (iron-limited) unicellular heterotrophic bacteria was raised as a potential explanation for the correlation between N_2 flux and sediment ferric iron concentrations. If heterotrophic bacteria are indeed utilising this iron, then we may also speculate that these small cell sizes would be conducive to high rates of grazing (see citations in Alongi and McKinnon, 2005) and viral infection (Wilhelm and Suttle, 1999). This is because marine viruses infect heterotrophic bacteria at turnover rates of typically 20-50% of the population per day (Furman, 1999), while 5-10% of cyanobacteria are typically destroyed on a diurnal basis to maintain viral communities (Wilhelm and Suttle, 1999). Importantly, the *viral shunt* (Wilhelm and Suttle, 1999) and cell grazing can release a large number of iron-binding compounds of varying bioavailabilities to the water column (Poorvin *et al.*, 2004). It is also worth mentioning that NOx, FRP, SiO_4, DON and DOP concentrations were lower in Keppel Bay (*i.e.* below detection), than average concentrations from the representative data of Furnas and Brodie (1996) and Devlin *et al* (2001) (Figure 4.17a,b,c,e,f). The wider availability of iron may account for the greater utilisation of nutrients in Keppel Bay.

At station A, chlorophyll *a* concentrations were inversely proportional to silicate concentrations and the slope of the linear relationship was close to that of the Redfield stoichiometry (Figure 4.18a), assuming a chlorophyll:C ratio of 50. Nitrogen concentrations would have had to be 0.01 to 0.02 mg L^{-1} to support the silicate uptake inferred on the basis of Figure 4.18a, assuming Redfield stoichiometric proportions, or one half to one third of this if Si:N drawdown ratios were enhanced due to insufficient iron. Although dissolved inorganic N (and P) were not detected in water samples from this region during either of the dry season surveys, these nutrients may have been utilised immediately upon their release from plankton, detritus or dissolved organic matter during bacterial decomposition (Furnas *et al.,* 2005). As discussed previously, microbial recycling may occur in the water column (Furnas, 1995) or via a suite of reactions occurring in the underlying muddy sediment, which was derived from the modern Fitzroy River (see below; also Froelich *et al*., 1979). Again, nutrient release from bottom sediments can be enhanced by sediment re-suspension (see also Walker, 1981; Ullman and Sandstrom, 1987; Chongprasith, 1992 in Alongi and McKinnon, 2005). Nutrients may also be derived from local runoff or groundwater fluxes from Emu Park in the case of station A, from lysis of cells by viruses (Wilhelm and Suttle, 1999) or grazing, and from N-fixation.

5.3.2.1. Wide-spread Evidence for Sub-oxic Diagnesis

Alongi and McKinnon (2005) found a near 1:1 relationship between the flux of carbon to the seabed and organic carbon mineralisation rates in the coastal zone of the GBR shelf. If we assume the same relationship in Keppel Bay, carbon fluxes to the seafloor in the CTZ ranged from 9.8 to 21.3 mmol m^{-2} d^{-1} (sites 196, 198, 200 and 204; Table 4.5), and thus were indicative of oligotrophic conditions (*i.e.* <48 mmol CO_2 m^{-2} d^{-1}) in the classification scheme of Eyre and Ferguson (2002). O_2:TCO_2 flux ratios were less than 1:3 at all of the sites (Figure 4.32), again suggesting that more CO_2 was generated than could be accounted for by oxic mineralisation with complete nitrification. As previously suggested, the implication of this result is that anoxic and/or sub-oxic processes were also occurring in these sediments. Interestingly, CO_2 fluxes from the bottle incubation experiments (mainly from sediments in the CTZ) correlated to the Mn concentration of the sediment, although admittedly, with a large gap in the data sets in the intermediate Mn range (Figure 4.35a). Nonetheless, the samples with very high sediment Mn contents (196 and 204 in the CTZ) had very low or non-existent CO_2 fluxes, yet had O_2 consumption rates that were consistent with those of the other samples (Figure 4.34). This reaction pattern is indicative of chemical oxidation and might have been attributed to the re-oxidation of Mn^{2+} that was reduced in a previous redox oscillation (see review by Haese, 2000).

There is strong evidence for the occurrence of iron oxy-hydroxide reduction in micro-zones within surface sediments in the CTZ. Axis 2 of the sediment PCA explained 11.1% of the variance in the sediment data set and had high loadings in the CTZ (Figure 4.23), implying higher ferrous iron concentrations relative to TOC and FeIII in these sediments (see muddy sands and sands (+) in Table 4.3). Especially high FeII:TOC ratios coincided with the western beach fringe where high wave energy and sediment permeability presumably allows for extensive regeneration of Mn and Fe oxides. Ryan *et al*. (2005) also identified these fine sands as being, by far, the best sorted sediments in Keppel Bay. A substantial proportion of the muddy sand and sand (+) sediments found in the CTZ were also displaced away from the theoretical UCC weathering trend towards lower FeO + MgO compositions (Figure 4.26c,d). We speculate that these sediments are in the process of being stripped of iron through some combination of iron oxy-hydroxide reduction, biological uptake of FeII and release of biogenous iron and related compounds to the water column during resuspension. Further evidence for this process comes from the Fe:Al ratios. These are similar between all muds and sands suggesting that there is very little Fe-oxyhydroxide coating on sand grains with the ratio primarily controlled by the amount of mud present within the sediment (Table 4.4).

5.3.3. The Blue Water Zone

The *blue-water zone* (BWZ) of Keppel Bay is defined as the region where pico-phytoplankton (as inferred from HPLC analysis of particulate pigments) dominate phytoplankton assemblages (Figure 4.10c; Oubelkheir *et al*., in prep), and where DOP assumes >80-90% of the phosphorus pool (Figure 4.10d). Nano-phytoplankton (again based on particulate pigments) also increased in abundance over this region (Figure 4.5d), and slicks of *Trichodesmium*, a heterocystous cyanobacteria (which is included in the nano-phytoplankton grouping because of the size of individual cells despite being a filamentous species), were frequently observed (Figure 4.10d). The BWZ is roughly coincident with the distribution of the *relict sands*, as defined by the area of bottom sediments in Keppel Bay with factor loadings greater than zero on PCA axis 1 (Figure 4.24a), and where TSM levels in the overlying water were <1 mg L^{-1} (Figure 4.2c and 4.11a). Consequently, the light climate is very good in this region (Secchi disk depths > 3m). Oubelkheir *et al.* (in prep) found that TSM was strongly dominated by plankton in the BWZ on the basis of some measured water column optical properties. That organic particles (of various sizes) contribute almost exclusively to TSM in Keppel Bay proper would account for the large amount of observed variation in the relationship between TSM and turbidity in the samples with TSM concentrations <10 mg L^{-1} (September 2003; Figure 4.2c).

The increase in the abundance of cyanobacteria (including *Trichodesmium*) in the BWZ likely constitutes a *domain shift* in the terminology of Karl *et al*, (2001; but see also Karl *et al*., 1995). The pico-cyanobacterial genera *Synechococcus* and *Prochlorococcus* usually dominate primary production and phytoplankton biomass in GBR waters (Furnas *et al*., 2005), and diazotrophic *Trichodesmium* supply nitrogen to the GBR in amounts similar to the total amount entering from all the rivers in the GBRCA (Bell *et al*., 1999). Community dynamics are expected to shift towards phosphorus limitation (or iron limitation Lenes *et al*., 2001; Bell *et al*., 2005) in the presence of such large amounts of fixed N (Karl *et al*., 1995). Note that total P contents were at their lowest in Keppel Bay in the residual sands (Table 4.4; Figure 4.24e), and were strongly dominated (*i.e.* often >70%) by the less biologically available fractions such as Ca-P and rare-earth phosphates (*i.e.* residual-P; Figure 4.29e). It is noteworthy that some *Trichodesmium* have the capacity to utilise DOP (Mulholland *et al*., 2002), including species of this genera found in GBR waters (Bell *et al*., 2005). As with the pico-phytoplankton in Keppel Bay, utilisation of DOP may afford them a competitive advantage in areas where DIP is in short supply (Mulholland *et al*., 2002). *Trichodesmium* can also excrete up to 50% of the nitrogen they fix in the form of DON (Glibert and Bronk, 1994), and the uptake of DOP and release of DON by *Trichodesmium* may account for the progressive increase in DON:DOP ratios (and likewise TN:TP ratios) in the direction of Great Keppel Island (Figures 4.5b,c and 4.11f). Dissolved oxygen supersaturation was also observed in both surface and bottom waters over most of the area of the area where DON:DOP ratios exceeded 30, in September 2003 (Figure 4.6c,d). However, it should be noted that dissolved oxygen saturation levels are highly dependent on time of day and chlorophyll concentrations.

5.3.3.1. Benthic Processes

Carbon dioxide fluxes in the BWZ as determined from core incubations ranged from 8 to 31.2 mmol m^{-2} d^{-1} at the three sites where they were measured (sites 201-203; Table 4.5), and thus were indicative of oligotrophic conditions (*i.e.* <48 mmol CO_2 m^{-2} d^{-1}) in the classification scheme of Eyre and Ferguson (2002). Sites 201 and 203 were located near the boundary of the CTZ and BWZ (Figure 4.33b) and had correspondingly higher CO_2 fluxes (19.3 and 31.2 mmol m^{-2} d^{-1} respectively). Indeed, Site 203 was located in the nose of a channel that is currently being in-filled with fine sediment (Ryan et al., 2005), and presumably experiences higher sedimentation rates than the other sites. All of these stations (sites 201-203; Table 4.5) had positive N_2 fluxes. If these N_2 fluxes are indicative of denitrification, rather than anammox (raised as potentially important by C. Smith, personal communication), then these denitrification rates are in the low range, or lower, than those previously measured in GBR waters (*i.e.* 0.2 – 1.6 mmol N m^{-2} d^{-1} as compared to 1.3 – 13.7 mmol N m^{-2} d^{-1}; Alongi and McKinnon, 2005). Denitrification efficiencies ranged from 4.4 (site 203) to 128.9% at site 202. The greater than 100% denitrification efficiency at site 203 suggests that there is either preferential release of N over CO_2 from the sediment, or that an additional pool of N (not coupled to carbon) existed in the sediment.

The change in direction of N_2 fluxes in the BWZ (relative to CTZ) indicates a change in the dominant N-fixing assemblage: from predominantly heterotrophs in the CTZ capable of utilising N_2 under dark conditions, to an assemblage comprised mainly of light-requiring diazotrophic cyanobacteria of which *Trichodesmium* is the most obvious. It is also worth mentioning that the iron contents of the underlying sediments (residual sands or sands (-)) were roughly two thirds of those of the sands derived from the modern Fitzroy River (Table 4.4). These low iron levels are probably best explained by the winnowing-out of the mud fraction and by the reduction of iron oxyhydroxides and subsequent transfer of FeII to organisms. These features are likely related to the long residence times of these sediments in the marine environment (Anonymous, 1979). As with most GBR waters, the bulk of the phytoplankton N and P demand in Keppel Bay is probably met by microbial recycling in the water column (Furnas *et al*., 1995; Lourey *et al*., 2001), and this is probably also the case for iron.

The fact that all O_2:TCO_2 flux ratios were less than 1:3 in the BWZ of Keppel Bay (Figure 4.32a) is probably best explained by denitrification. The residual sands (sands -) underlying the BWZ had the lowest FeII:FeIII and FeII:TOC ratios in the data set (Table 4.4), and thus had negative loadings on axis 2 of the sediment PCA (Figure 4.30a). Lower FeII concentrations may explain the lesser importance of iron-oxyhydroxide reduction, based on these indicators. Note that the residual sands (sands -) occurred in the deepest waters, and were subject to the lowest shear velocities of all the sediments in Keppel Bay (Figure 4.31b,c).

6. Conclusions

6.1. SEDIMENT

- The chemistry of Keppel Bay sediments reflects the large size of the Fitzroy River Basin and the integration of the weathering products of a large number of rock types to give a composition similar to that of a partially weathered average continental crust.

- The best indicator of modern Fitzroy River sediments in Keppel Bay was an Al_2O_3:K_2O ratio of >4. The Al_2O_3:K_2O ratio reflects chemical changes that occur in sediment during weathering/fining of seddiment. As shown previously, Fitzroy River sediments occur in two distinct lobes in Keppel Bay. The first (western) lobe follows the coast northwards and becomes thin and discontinuous to the north of Keppel Sands. The second lobe extends in an east-ward direction from the estuary entrance toward Hummocky Island.

- Nutrient (TN and TP), TOC, Fe and the concentrations of most metals increased with the Al_2O_3:K_2O ratio. The most weathered, metal and nutrient-rich sediments occurred in Casuarina Creek and in the near shore region alongside Long Beach. The TOC, TN and TP concentrations of the muddy sediments were within the range of TOC, TN and TP measurements made on soils from the Fitzroy catchment. More than half the sediment-P was in forms that are considered less biologically available (*i.e.* was bound to Ca or were components of rare-earth minerals).

- Most sediment in Keppel Bay and Casuarina Creek had TOC:TN molar ratios and $\delta^{13}C$ signatures suggesting either a marine phytoplankton or bacterial source for the organic matter. Therefore, a significant component of the terrestrial organic matter is replaced by recently formed marine substances when Fitzroy River sediments meet the sea.

- The core incubation experiments found CO_2 decomposition rates at eight sites in Keppel Bay to range from 8 to 41.2 mmol m^2 d^{-1}. If the assumption is made that CO_2 decomposition are roughly proportional to productivity, than these measurements are in the oligotrophic range for coastal Australia. O_2/CO_2 flux ratios were consistently less than 1.3, suggesting that more CO_2 is generated than can be accounted for by oxic diagenesis alone.

- Keppel Bay sediments were depleted in Fe or Mg compared to average upper continental crust. This may be caused by the occurrence of iron-oxyhydroxide reduction in the sediments with subsequent loss of FeII (ultimately to biota). Ferrous iron was inversely proportional to TOC in the system TS+TOC+FeII in Keppel Bay, and together with FeII:TOC and FeII:FeIII ratios, this trend explained about 11% of the variance in the bottom sediment data. Notedly high FeII:TOC ratios were observed along the western shore, where high wave promoted sediment mixing and sub-oxic diagenesis. This process of repeated suspension and deposition elsewhere in Keppel Bay is also conducive to mineralization of organic matter by both oxic and suboxic processes.

- N_2-N fluxes ranged from -3.5 to 1.6 mmol m^2 d^{-1} and a strong correlation was found between N_2-N flux and the FeIII concentration of the sediment. The fact that most of the N_2-N fluxes were less than zero suggests that nitrogen-fixing organisms were using the di-nitrogen, while the correlation with FeIII suggests that these organisms are potentially iron limited. The nitrogen-fixing organisms are likely unicellular heterotrophic bacteria.

6.2. WATER COLUMN

- TSM concentrations were higher over the muddier substrates derived from the Fitzroy River. This is in part due to wave- or tide-driven resuspension, and in part to material being carried northward by prevailing currents and winds. Particularly high TSM concentrations were observed near the mouth of the Fitzroy Estuary and in Casuarina Creek, where the most weathered sediment was found to accumulate and current speeds were highest. TSM concentrations at a given location also varied substantially over the tidal cycle due to advection and to sediment resuspension/settling.

- Due to resuspension, particulate nutrients dominated nutrient pools when TSM concentrations were higher than 10-25 mg L^{-1} *i.e.* near the estuary mouth and in Casuarina Creek. Dissolved inorganic nutrient concentrations were also highest in this region because continual resuspension of the surface layer and high levels of TSM interfered with nutrient uptake by phytoplankton. The slopes of the conservative mixing lines (nutrient vs. salinity) were also steeper in Keppel Bay-Casuarina Creek than in GBR waters, due to the high levels of TSM in the near shore zone.

- Zones of elevated salinities were observed in Casuarina Creek and along the shallow western shore of Long Beach due to evaporation. A reverse salinity gradient was also apparent in the mixing diagrams: *i.e.* high salinity waters flowed out of Casuarina Creek and were a source of NOx, FRP, SiO_4 and DON to Keppel Bay. Most of the NOx, FRP and SiO_4 data adhered to linear relationships suggesting the conservative mixing of these nutrients outward into Keppel Bay. The nutrients were probably derived from the mineralisation of algae (washed from the mud banks) and sediment organic matter.

- Dissolved inorganic concentrations decreased to below detectable levels when TSM concentrations were <10-25 mg L^{-1}, marking a switch from light-limitation of photosynthesis to nutrient-limitation. This change occurred just to the north of Cattle Point.

- DON, DOP and NH_4 did not behave conservatively, and these concentrations dropped to below detectable limits at some of the 24 hour stations. High water temperatures and well oxygenated water potentially caused rapid oxidation of NH_4 to NOx in Casuarina Creek. The DON decrease at one station correlated with rising chlorophyll a concentrations and the slope of this relationship was close to the Redfield ratio. This suggests that phytoplankton were either directly utilising the DON or some form of rapid re-cycling was taking place; either way, a component of the DON pool was dynamic.

- DON:DOP and TN:TP molar ratios and the percentage of P in organic forms (%DOP-P) increased in the direction of Great Keppel Island. The change in this ratio was likely caused by the biological utilisation of part of the organic-P pool by pico-phytoplankton and nano-phytoplankton. The percentages of both these phytoplankton groups also increased in the direction of Great Keppel Island (pico-phytoplankton with %DOP-P and nano-phytoplankton with the TN:TP molar ratios) and this was matched with a parallel decrease in micro-phytoplankton.

6.3. INTEGRATED SEDIMENT-WATER COLUMN

- The nutrient dynamics in Keppel Bay under dry season conditions are a manifestation of the biogeochemical processes occurring in the water column and the sediments together with the inputs from (and losses to) the coastal creeks and the Fitzroy estuary and from the distant ocean. Under low flow conditions which prevail during the dry season little genuinely new material enters the system as the riverine flows are negligible and off shore nutrient concentrations approach very low oceanic values. Thus nutrient concentrations reflect the internal biogeochemical processes. These depend on the initial chemical characteristics of the sediment and the supply of oxidants to the sediments.

- Three distinct zones of physical, biogeochemical and ecological characteristics were identified in Keppel Bay and these reflect the influence of the hydrodynamic regime on the distribution of Fitzroy River sediment and relict sand deposits. The zones are:

    - *The Zone of Maximum Resupension (ZMR)* near the estuary mouth and in Casuarina Creek. This zone arises because of the large currents and asymmetric tides. Resuspension and entrainment of sediment in this high energy zone cause high levels of TSM in the water column and are conducive to hydrodynamic sorting of particles based on different densities and settling velocities. The large concentrations of suspended sediment cause light limitation of photosynthesis in this region, and therefore allows nutrient concentrations to build up in the water column. The mobile surface sediments also produce an efficient decomposition system for particulate organic matter and diatoms washed from the mud banks, characterised by repetitive redox oscillations. Consequently the region is a source of nutrients to Keppel Bay. Net N_2 fluxes were their most negative for the study in this region, and the FeIII concentrations were correspondingly high.

    - *The Coastal Transitional Zone (CTZ)* was characterised by turquoise coloured water, and was coincident with the western and eastern lobes of Fitzroy Estuary sediments in Keppel Bay proper. These sediments generally had mud contents >10%, and were subject to resuspension when current speeds were high. The resuspension caused variations in TSM and P concentrations and TN:TP molar ratios, in the order of 2-10 mg L^{-1} in the case of TSM and 18-61 in the case of TN:TP ratios. Variation in these parameters, and general turbulence, probably allowed for the co-dominance of pico-phytoplankton and micro-phytoplankton (mainly diatoms) that was observed in this region. The alternating resuspension/deposition cycles also promoted efficient decomposition by oxic and sub-oxic processes: the highest FeII:TOC and FeII:FeIII ratios were found in this zone. N_2 fluxes were all negative in the core incubations from these sediments, implying net nitrogen fixation in this zone.

    - *The Blue Water Zone (BWZ)* was characterised by water that was deep blue in colour, and coincided with the occurrence of the relict sand sediments in Keppel Bay. The mud contents of these sediments were low (<10%) and TSM concentrations did not exceed 2 mg L^{-1} at any time in the tidal cycle. The underlying sediments also had very low Fe and P concentrations and most of this P (>70%) was in biologically unavailable forms. Pico-phytoplankton dominated phytoplankton communities in this region, and nano-phytoplankton (mainly *Trichodesmium*) were found in higher abundance. These phytoplankton groups are frequently P-limited and are known to utilise components of the organic-P pool. Utilisation of organic-P might account for the observed increase of DON:DOP ratios. N_2 fluxes were all positive in the core incubations from these sediments, implying net denitrification in this zone. The bulk of the N and P demand in this zone is probably met by microbial cycling in the water column.

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Appendices

APPENDIX A. TABLE OF SAMPLE/STATION LOACTIONS, DATE/TIME SAMPLED & WATER DEPTHS AT TIME OF SAMPLING.

Sample number	Station	Decimal latitude	Decimal longitude	Date & time sampled	Water depth at time of sampling (m)
1		-23.3859	150.5619	5/09/2003 16:56	4.3
2		-23.4781	150.6275	5/09/2003 22:00	8.5
3		-23.5054	150.7682	6/09/2003 3:00	8.2
4		-23.5324	150.8299	6/09/2003 5:10	7.6
5		-23.5407	150.8954	6/09/2003 6:40	7.3
6		-23.5012	150.9528	6/09/2003 21:20	15.9
7		-23.4258	150.9885	6/09/2003 17:10	21.3
8		-23.4026	151.0429	6/09/2003 18:20	19.2
9		-23.4184	151.1563	6/09/2003 20:58	19.2
10		-23.4027	151.0460	7/09/2003 1:36	17.1
11		-23.4270	150.9906	7/09/2003 3:50	12.5
12		-23.5012	150.9528	7/09/2003 5:44	15.9
13		-23.5012	150.9528	7/09/2003 14:44	16.5
14		-23.4112	150.9678	7/09/2003 16:50	12.8
15		-23.3856	150.8978	7/09/2003 19:50	8.2
16		-23.3664	150.9676	7/09/2003 21:20	16.5
17		-23.3487	151.0148	7/09/2003 22:30	16.8
18		-23.3199	151.1169	8/09/2003 1:00	20.7
19		-23.3906	151.0287	8/09/2003 2:28	15.5
20		-23.4806	150.9635	8/09/2003 4:26	14.3
21		-23.5662	150.8616	8/09/2003 15:24	7.6
22		-23.5555	150.8224	8/09/2003 17:26	8.8
23		-23.6045	150.7939	8/09/2003 20:16	8.2
24		-23.5891	150.7410	8/09/2003 23:00	6.7
25		-23.6009	150.7139	9/09/2003 0:50	
26		-23.5708	150.7207	9/09/2003 1:40	0.5
27		-23.6045	150.7939	9/09/2003 3:22	1.5
28		-23.5555	150.8224	9/09/2003 4:30	5.8
29		-23.5662	150.8616	9/09/2003 5:40	4.6
30		-23.5018	150.9523	9/09/2003 17:32	17.1
31		-23.4452	150.9763	9/09/2003 18:50	15.9
32		-23.3651	150.9518	9/09/2003 21:16	15.2
33		-23.3534	150.8883	9/09/2003 22:32	7.9
34		-23.3449	150.8346	10/09/2003 0:46	6.1
35		-23.3216	150.8890	10/09/2003 2:50	8.5
36		-23.2618	150.8636	10/09/2003 3:48	7.6
37		-23.2098	150.8390	10/09/2003 5:14	7.6
38		-23.2623	150.8679	10/09/2003 14:40	11.6
39		-23.2593	150.9329	10/09/2003 18:28	17.1
40		-23.2627	150.9951	10/09/2003 20:36	19.1
41		-23.2464	151.0548	10/09/2003 21:44	24.2
42		-23.2427	151.0940	10/09/2003 23:24	24.1
43		-23.2212	151.0381	11/09/2003 0:28	21.2
44		-23.1710	150.8385	11/09/2003 6:00	5.9
45		-23.1520	150.7950	11/09/2003 15:32	8.8
46		-23.1438	150.8080	11/09/2003 16:40	8.8

Sample number	Station	Decimal latitude	Decimal longitude	Date & time sampled	Water depth at time of sampling (m)
47		-23.1247	150.8627	11/09/2003 17:20	15.1
48		-23.1051	150.9110	11/09/2003 19:20	18.3
49		-23.0821	150.9780	11/09/2003 20:38	25.9
50		-23.0710	151.0412	11/09/2003 23:02	26.2
51		-23.0855	150.9810	11/09/2003 0:00	24.4
52		-23.1100	150.9028	11/09/2003 0:00	15.2
53		-23.1217	150.8820	11/09/2003 0:00	14.8
54		-23.1296	150.8694	12/09/2003 4:30	10.4
55		-23.1338	150.8615	12/09/2003 4:40	9.5
56		-23.1430	150.8399	12/09/2003 5:10	8.5
57		-23.1487	150.8167	12/09/2003 5:40	6.7
58		-23.1518	150.8052	12/09/2003 6:00	7.3
59		-23.1994	150.8246	12/09/2003 16:12	8.8
60		-23.2564	150.8409	12/09/2003 17:30	8.5
61		-23.3152	150.8433	12/09/2003 17:58	7.9
62		-23.3666	150.8386	12/09/2003 20:10	8.2
63		-23.4216	150.8327	12/09/2003 21:38	6.1
64		-23.4030	150.8415	12/09/2003 23:06	6.4
65		-23.3756	150.8557	12/09/2003 23:50	7.9
66		-23.3462	150.8621	13/09/2003 0:34	8.8
67		-23.3176	150.8698	13/09/2003 1:12	9.1
68		-23.2713	150.8740	13/09/2003 2:14	9.1
69		-23.2493	150.8666	13/09/2003 2:56	7.6
70		-23.2325	150.8576	13/09/2003 3:30	6.4
71		-23.2198	150.8261	13/09/2003 4:22	6.1
72		-23.1976	150.8142	13/09/2003 5:04	6.3
81	A	-23.3061	150.8526	15/08/2004 10:20	7.9
82	A	-23.3061	150.8526	15/08/2004 11:15	7.3
83	A	-23.3061	150.8526	15/08/2004 12:15	6.7
84	A	-23.3061	150.8526	15/08/2004 13:15	6.1
85	A	-23.3061	150.8526	15/08/2004 14:15	5.8
86	A	-23.3061	150.8526	15/08/2004 15:15	6.1
87	A	-23.3061	150.8526	15/08/2004 16:15	6.6
88	A	-23.3061	150.8526	15/08/2004 17:15	7.0
89	A	-23.3061	150.8526	15/08/2004 18:15	7.6
90	A	-23.3061	150.8526	15/08/2004 19:15	8.5
91	A	-23.3061	150.8526	15/08/2004 20:15	9.1
92	A	-23.3061	150.8526	15/08/2004 21:15	9.1
93	B	-23.4169	150.8418	16/08/2004 9:15	6.1
94	B	-23.4169	150.8418	16/08/2004 10:15	5.8
95	B	-23.4169	150.8418	16/08/2004 11:15	5.5
96	B	-23.4169	150.8418	16/08/2004 12:15	4.7
97	B	-23.4169	150.8418	16/08/2004 13:15	4.0
98	B	-23.4169	150.8418	16/08/2004 14:05	3.4
99	B	-23.4169	150.8418	16/08/2004 15:00	3.4
100	B	-23.4169	150.8418	16/08/2004 16:00	3.2
101	B	-23.4169	150.8418	16/08/2004 17:00	3.7
102	B	-23.4169	150.8418	16/08/2004 18:00	4.4
103	B	-23.4169	150.8418	16/08/2004 19:00	5.3
104	B	-23.4169	150.8418	16/08/2004 20:00	6.1
105	B	-23.4169	150.8418	16/08/2004 21:00	7.3

Sample number	Station	Decimal latitude	Decimal longitude	Date & time sampled	Water depth at time of sampling (m)
106	C	-23.4179	151.0127	17/08/2004 9:20	15.2
107	C	-23.4179	151.0127	17/08/2004 10:00	14.9
108	C	-23.4179	151.0127	17/08/2004 11:00	14.6
109	C	-23.4179	151.0127	17/08/2004 12:00	14.0
110	C	-23.4179	151.0127	17/08/2004 13:00	13.1
111	C	-23.4179	151.0127	17/08/2004 14:00	12.8
112	C	-23.4179	151.0127	17/08/2004 15:00	12.2
113	C	-23.4179	151.0127	17/08/2004 16:00	12.2
114	C	-23.4179	151.0127	17/08/2004 17:00	12.8
115	C	-23.4179	151.0127	17/08/2004 18:00	13.1
116	C	-23.4179	151.0127	17/08/2004 19:00	14.0
117	C	-23.4179	151.0127	17/08/2004 20:00	14.6
118	C	-23.4179	151.0127	17/08/2004 21:00	15.2
119		-23.3444	151.0331	18/08/2004 7:10	17.1
120		-23.3414	150.9986	18/08/2004 7:55	16.3
121		-23.3345	150.9545	18/08/2004 8:30	13.4
122		-23.3175	150.9137	18/08/2004 9:30	14.8
123		-23.3002	150.8884	18/08/2004 10:10	11.0
124		-23.2904	150.8419	18/08/2004 11:05	7.3
125		-23.2277	150.9320	18/08/2004 12:25	15.2
126		-23.1832	150.8840	18/08/2004 13:45	7.3
127		-23.2329	150.8344	20/08/2004 8:05	7.3
128		-23.2812	150.8344	20/08/2004 9:05	4.6
129		-23.3995	150.8130	20/08/2004 10:35	4.3
130		-23.4018	150.8198	20/08/2004 10:55	5.2
131		-23.4026	150.8251	20/08/2004 11:15	5.8
132		-23.4532	150.8652	20/08/2004 12:15	3.8
133		-23.4437	150.9032	20/08/2004 13:00	4.7
134		-23.4002	150.9114	20/08/2004 13:45	9.3
135		-23.3166	150.8655	20/08/2004 14:45	8.2
136		-23.1690	150.8325	21/08/2004 7:35	6.1
137		-23.1391	150.8800	21/08/2004 9:55	13.4
138		-23.1193	150.9441	21/08/2004 10:55	18.3
139		-23.1213	151.0059	21/08/2004 11:55	22.9
140		-23.1374	151.0058	21/08/2004 14:05	26.2
141	D	-23.4006	150.9561	22/08/2004 10:45	10.2
142	D	-23.4006	150.9561	22/08/2004 11:45	10.8
143	D	-23.4006	150.9561	22/08/2004 12:45	11.0
144	D	-23.4006	150.9561	22/08/2004 13:45	11.1
145	D	-23.4006	150.9561	22/08/2004 14:45	10.8
146	D	-23.4006	150.9561	22/08/2004 15:45	10.4
147	D	-23.4006	150.9561	22/08/2004 16:45	10.1
148	D	-23.4006	150.9561	22/08/2004 17:45	9.6
149	D	-23.4006	150.9561	22/08/2004 18:45	9.6
151	D	-23.4006	150.9561	22/08/2004 19:45	
150	D	-23.4006	150.9561	22/08/2004 19:45	9.3
152	E	-23.4197	151.0062	23/08/2004 8:00	12.5
153	E	-23.4197	151.0062	23/08/2004 9:00	12.5
154	E	-23.4197	151.0062	23/08/2004 10:00	13.0
155	E	-23.4197	151.0062	23/08/2004 11:00	13.4
156	E	-23.4197	151.0062	23/08/2004 12:00	13.9

Sample number	Station	Decimal latitude	Decimal longitude	Date & time sampled	Water depth at time of sampling (m)
157	E	-23.4197	151.0062	23/08/2004 13:00	14.3
158	E	-23.4197	151.0062	23/08/2004 14:00	14.3
159	E	-23.4197	151.0062	23/08/2004 15:00	14.3
160	E	-23.4197	151.0062	23/08/2004 16:00	13.9
161	E	-23.4197	151.0062	23/08/2004 17:00	13.6
162		-23.4954	150.9551	24/08/2004 7:07	13.4
163	F	-23.5289	150.9346	24/08/2004 8:20	7.3
164	F	-23.5289	150.9346	24/08/2004 9:05	7.3
165	F	-23.5289	150.9346	24/08/2004 10:00	7.6
166	F	-23.5289	150.9346	24/08/2004 11:00	7.9
167	F	-23.5289	150.9346	24/08/2004 12:00	8.5
168	F	-23.5289	150.9346	24/08/2004 13:00	9.3
169	F	-23.5289	150.9346	24/08/2004 14:00	9.8
170	F	-23.5289	150.9346	24/08/2004 15:00	10.2
171	F	-23.5289	150.9346	24/08/2004 16:00	10.4
172	F	-23.5289	150.9346	24/08/2004 17:00	10.2
173	F	-23.5289	150.9346	24/08/2004 18:00	9.1
174	G	-23.5551	150.8321	25/08/2004 8:00	5.5
175	G	-23.5551	150.8321	25/08/2004 9:00	5.2
176	G	-23.5551	150.8321	25/08/2004 10:00	4.3
177	G	-23.5551	150.8321	25/08/2004 11:00	4.3
178	G	-23.5551	150.8321	25/08/2004 12:00	4.9
179	G	-23.5551	150.8321	25/08/2004 13:00	5.5
180	G	-23.5551	150.8321	25/08/2004 14:00	6.1
181	G	-23.5551	150.8321	25/08/2004 15:00	6.4
182	G	-23.5551	150.8321	25/08/2004 16:00	7.0
183	G	-23.5551	150.8321	25/08/2004 17:00	7.6
184	G	-23.5551	150.8321	25/08/2004 18:00	7.6
185	G	-23.5551	150.8321	25/08/2004 19:00	7.3
186		-23.5551	150.8321	25/08/2004 20:00	6.6
187		-23.5577	150.8111	25/08/2004 8:55	9.2
188		-23.5770	150.7977	25/08/2004 9:21	5.2
189		-23.5927	150.7949	25/08/2004 10:00	5.8
190		-23.6136	150.7663	25/08/2004 10:20	6.0
191		-23.5802	150.7083	25/08/2004 10:56	5.4
192		-23.5808	150.6964	25/08/2004 11:32	7.0
196		-23.4232	150.9333	31/08/2004 8:40	10
198		-23.3958	150.8457	31/08/2004 10:55	8.3
199		-23.3560	150.8539	31/08/2004 12:05	9
200		-23.3118	150.8440	31/08/2004 13:30	8.2
201		-23.2495	150.8605	31/08/2004 14:30	7.2
201		-23.2495	150.8605	31/08/2004 14:30	7.2
202		-23.2118	150.9325	1/09/2004 8:00	10.2
202		-23.2118	150.9325	1/09/2004 8:00	10.2
203		-23.3026	150.9909	1/09/2004 11:33	19
203		-23.3026	150.9909	1/09/2004 11:33	19
204		-23.3965	150.9725	1/09/2004 13:05	11
204		-23.3965	150.9725	1/09/2004 13:05	11
205		-23.5032	150.9519	1/09/2004 17:15	13.8
205		-23.5032	150.9519	1/09/2004 17:15	13.8

APPENDIX B. SURFACE AND BOTTOM WATER PROPERTIES AT KEPPEL BAY DURING SEPTEMBER 2003.

Ozestuaries #	Sample	GA #	Sample depth (m)	Water temperature (^{o}C)	Turbidity (NTU)	Conductivity (mS/cm)	PSU	Secchi depth (cm)	Dissolved oxygen (mg/L)
1272987	fk_01_0.5	1	0.5	19.9	102.5	40.5	29.1	55	6.64
1272989	fk_01_4.3	1	4.3	19.9	28.7	40.8	29.3		6.5
1272990	fk_01_2.6	1	2.6	19.8	28.9	40.7	29.3		6.4
1272993	fk_02_0.5	2	0.5	19.9	56.1	45.0	32.7	40	7.1
1272994	fk_02_6.6	2	6.6	19.7	38.1	45.0	32.9		7
1272995	fk_02_3.8	2	3.8	19.7	39.0	45.0	32.9		7
1272998	fk_03_0.5	3	0.5	20.3	134.3	49.6	36.1	15	
1272999	fk_03_0.75	3	0.75	19.6	136.5	48.8	36.1		7.1
1273000	fk_03_6.2	3	6.2	19.5	140.5	48.8	36.2		7.1
1273001	fk_03_2.9	3	2.9	19.5	145.0	49.1	36.4		7.1
1273004	fk_04_0.5	4	0.5	21.01	162.1*	36.2	25.0		
1273006	fk_05_0.5	5	0.5	20.3	150.1*	49.7	36.2	31.5	
1273007	fk_05_0.37	5	0.37	19.6	36.5	48.4	35.7		7.4
1273008	fk_05_6.5	5	6.5	19.6	44.5	48.4	35.7		7.4
1273009	fk_05_3.0	5	3	19.6	39.5	48.5	35.8		7.4
1273012	fk_06_0.5	6	0.5	20.1	17.9	49.4	36.1		
1273014	fk_07_0.5	7	0.5	20	17.4	49.1	36.0		
1273016	fk_08_0.5	8	0.5	20.1	6.3	49.4	36.1		
1273018	fk_09_0.5	9	0.4	20.7	67.4	49.5	36.0	1350	
1273019	fk_09_0.4	9	0.5	21.8	0.2	51.3	36.2		7
1273020	fk_09_2.2	9	2.2	20.7	0.2	50.0	36.1		7
1273021	fk_09_4.5	9	4.5	20.6	0.2	50.0	36.2		7
1273022	fk_09_6.5	9	6.5	20.6	0.2	50.0	36.2		6.9
1273023	fk_09_8.6	9	8.6	20.6	0.2	50.0	36.2		6.9
1273024	fk_09_12.5	9	12.5	20.6	0.2	50.0	36.2		6.8
1273025	fk_09_16.5	9	16.5	20.6	0.2	50.0	36.2		6.8
1273026	fk_09_19.4	9	19.4	20.6	0.2	50.0	36.2		6.8
1273029	fk_10_0.54	10	0.54	21.6	1.6	50.9	36.1	450	6.6
1273030	fk_10_2.8	10	2.8	20.9	2.3	50.0	35.9		6.6
1273031	fk_10_4.9	10	4.9	20.6	2.2	50.0	36.2		6.5

Ozestuaries #	Sample	GA #	Sample depth (m)	Water temperature (°C)	Turbidity (NTU)	Conductivity (mS/cm)	PSU	Secchi depth (cm)	Dissolved oxygen (mg/L)
1273032	fk_10_6.6	10	6.6	20.6	2.0	50.0	36.2		6.4
1273033	fk_10_8	10	8	20.6	2.5	50.0	36.2		6.4
1273034	fk_10_12.1	10	12.1	20.6	2.0	50.0	36.2		6.3
1273035	fk_10_16.3	10	16.3	20.6	2.6	50.0	36.2		6.2
1273036	fk_10_19.0	10	19	20.6	3.6	50.0	36.2		6.1
1273039	fk_11_0.5	11	0.5	20.8	3.7	50.0	36.0	210	6.9
1273040	fk_11_11.4	11	11.4	20.6	13.1	50.0	36.2		6.9
1273043	fk_12_0.5	12	0.5	20.4	44.2*	49.9	36.3		
1273045	fk_13_0.5	13	0.5	20.3	13.5*	49.7	36.2		
1273047	fk_14_0.5	14	0.5	20.3	24.9*	49.7	36.2		
1273049	fk_15_0.5	15	0.5	20.2	10*	49.5	36.1	330	
1273050	fk_15_0.55	15	0.55	21.1	1.8	50.3	36.0		7.3
1273051	fk_15_7.8	15	7.8	20.7	2.5	50.2	36.3		7.4
1273052	fk_15_4.8	15	4.8	20.7	2.1	50.2	36.3		7.7
1273055	fk_16_0.5	16	0.5	20.6	6.3*	50.1	36.3		
1273057	fk_17_0.5	17	0.5	20.5	6.4*	50.0	36.3		
1273059	fk_18_0.5	18	0.5	20.8	2.8*	50.1	36.1	2100	
1273060	fk_18_0.85	18	0.85	20.8	0.0	49.9	35.9		7.3
1273061	fk_18_21.6	18	21.6	20.6	0.1	49.7	35.9		7.3
1273062	fk_18_10.6	18	10.6	20.6	0.1	49.9	36.1		7.2
1273065	fk_19_0.5	19	0.5	20.9	8.8*	50.5	36.4		
1273067	fk_20_0.5	20	0.5	20.1	33*	49.7	36.4		
1273069	fk_21_0.5	21	0.5	20.3	98.5*	49.9	36.4	25	
1273070	fk_21_0.37	21	0.37	20.8	57.5	50.6	36.5		7.1
1273071	fk_21_6.5	21	6.5	20.8	153.0	50.7	36.6		6.9
1273074	fk_22_0.5	22	0.5	20.5	126.6*	50.1	36.4	22	
1273075	fk_22_0.8	22	0.8	21	70.0	50.7	36.4		7.3
1273076	fk_22_8.6	22	8.6	20.9	531.0	50.5	36.4		7.3
1273079	fk_23_0.5	23	0.5	20.4	46.1*	50.2	36.5	45	
1273080	fk_23_0.89	23	0.89	21.1	36.5	50.7	36.4		7.3
1273081	fk_23_8.5	23	8.5	20.8	295.0	50.3	36.3		7.1

Ozestuaries #	Sample	GA #	Sample depth (m)	Water temperature (^oC)	Turbidity (NTU)	Conductivity (mS/cm)	PSU	Secchi depth (cm)	Dissolved oxygen (mg/L)
1273084	fk_24_0.5	24	0.5	20.5	232*	50.5	36.7	21	
1273085	fk_24_0.3	24	0.3	21.04	151.5	51.0	36.7		7.1
1273086	fk_24_5.9	24	5.9	21	148.0	51.0	36.7		7
1273089	fk_25_0.5	25	0	25.67	248*	56.2	36.8		
1273091	fk_26_0.5	26	0	20.84	445*	58.6	43.1		
1273093	fk_27_0.5	27	0.5	20.77	125.7*	50.8	36.7		
1273095	fk_28_0.5	28	0.5	20.9	93.7*	50.7	36.5		
1273097	fk_29_0.5	29	0.5	20.9	115.7*	50.6	36.5		
1273099	fk_30_0.5	30	0.5	20.64	22.9*	50.0	36.2	85	
1273100	fk_30_0.53	30	0.53	21.14	15.0	50.2	35.9		7.16
1273101	fk_30_16.6	30	16.6	20.98	92.5	50.1	36.0		6.9
1273102	fk_30_8.8	30	8.8	21.01	31.0	50.1	35.9		7.06
1273105	fk_31_0.5	31	0.5	20.69	14.2*	49.9	36.1		
1273107	fk_32_0.5	32	0.5	20.56	15.1*	49.9	36.1	560	
1273108	fk_32_0.37	32	0.4	21	2.4	50.3	36.1		7.16
1273109	fk_32_13.1	32	13.1	20.98	2.0	50.2	36.1		7.08
1273110	fk_32_6.3	32	6.3	21.02	1.9	50.3	36.1		7.07
1273113	fk_33_0.5	33	0.5	21.11	3.6*	50.5	36.1		
1273115	fk_34_0.5	34	0.5	21.7	9.6*	55.2	39.4	330	
1273116	fk_34_0.62	34	0.62	22.2	1.9	52.5	36.9		7.17
1273117	fk_34_5.1	34	5.1	21.9	2.8	52.2	36.9		7.15
1273118	fk_34_2.2	34	2.2	21.97	2.1	52.2	36.8		7.12
1273121	fk_35_0.5	35	0.5	21.2	6.9*	50.8	36.3		
1273122	fk_35_0.46	35	0.46	21.66	0.9	51.2	36.3		7.45
1273123	fk_35_8	35	8	21.23	1.4	50.8	36.3		7.29
1273124	fk_35_4	35	4	21.23	1.4	50.7	36.2		7.3
1273127	fk_36_0.5	36	0.5	21.13	8.3*	50.4	36.1		
1273129	fk_37_0.5	37	0.5	21.01	19.1*	50.3	36.1		
1273131	fk_38_0.5	38	0.5	20.8	0.8*	50.2	36.4	900	
1273132	fk_38_0.4	38	0.4	21.28	0.4	50.8	36.3		
1273133	fk_38_10.8	38	10.8	21.22	0.5	50.8	36.3		

Ozestuaries #	Sample	GA #	Sample depth (m)	Water temperature (^{o}C)	Turbidity (NTU)	Conductivity (mS/cm)	PSU	Secchi depth (cm)	Dissolved oxygen (mg/L)
1273134	fk_38_3.9	38	3.9	21.21	0.6	50.8	36.3		
1273137	fk_39_0.5	39	0.5	20.59	0*	50.1	36.3		
1273139	fk_40_0.5	40	0.5	20.65	0*	50.2	36.3	1200	
1273140	fk_40_0.46	40	0.46	21.18	0.2	50.6	36.2		7.42
1273141	fk_40_17.9	40	17.9	20.98	0.2	50.4	36.2		7.35
1273142	fk_40_4	40	4	21.05	0.3	50.4	36.2		7.34
1273145	fk_41_0.5	41	0.5	20.22	1.9*	50.0	36.6		
1273147	fk_42_0.5	42	0.5	20.74	0.4*	50.0	36.0	1600	
1273148	fk_42_0.22	42	0.22	21.32	0.4	50.5	36.0		7.32
1273149	fk_42_15.5	42	15.5	20.84	0.2	50.1	36.1		7.32
1273150	fk_42_9.8	42	9.8	20.84	0.1	50.0	36.0		7.31
1273153	fk_43_0.5	43	0.5	20.93	0*	50.3	36.1		
1273155	fk_44_0.5	44	0.5	21.37	0*	51.0	36.4		
1273156	fk_44_2.1	44	2.1	21.77	0.7	51.6	36.5		7.33
1273157	fk_44_5.3	44	5.3	21.82	0.8	51.6	36.5		7.26
1273160	fk_45_0.5	45	0.5	21.46	1.9*	51.5	36.7	650	
1273161	fk_45_0.45	45	0.45	21.6	1.5	51.3	36.4		7.14
1273162	fk_45_7.9	45	7.9	21.59	1.1	51.3	36.4		7.14
1273163	fk_45_4.4	45	4.4	21.6	1.2	51.3	36.4		7.15
1273166	fk_46_0.5	46	0.5	21.02	0*	20.4	13.3	1070	
1273167	fk_46_10.1	46	10.1	21.53	0.9	51.1	36.3		
1273170	fk_47_0.5	47	0.5	20.77	0*	50.3	36.3		
1273172	fk_48_0.5	48	0.5	20.71	0*	50.2	36.2	1220	
1273173	fk_48_1.0	48	1	21.27	0.2	50.5	36.1		7.17
1273174	fk_48_18	48	18	21.1	0.1	50.2	36.0		7.13
1273175	fk_48_5.6	48	5.6	21.1	0.1	50.5	36.2		7.11
1273178	fk_49_0.5	49	0.5	20.74	0.0	50.1	36.2		
1273180	fk_50_0.5	50	0.5	20.98	0.5*	50.3	36.1	1500	
1273181	fk_50_0.57	50	0.57	21.72	0.4	51.1	36.2		7.14
1273182	fk_50_22.9	50	22.9	20.99	0.1	50.2	36.0		7.1
1273183	fk_50_10.2	50	10.2	21.01	0.1	50.3	36.1		7.1

Ozestuaries #	Sample	GA #	Sample depth (m)	Water temperature (^{o}C)	Turbidity (NTU)	Conductivity (mS/cm)	PSU	Secchi depth (cm)	Dissolved oxygen (mg/L)
1273192	fk_54_0.5	54	0.5	21.51	0.0	49.8	35.3		
1273202	fk_59_0.5	59	0.5	21.74		51.7	36.6		
1273205	fk_60_0.5	60	0.5	21.81		51.8	36.6	620	
1273208	fk_61_0.5	61	0.5	21.78		51.8	36.6	750	
1273211	fk_62_0.5	62	0.5	22.2		52.5	36.8	360	
1273214	fk_63_0.5	63	0.5	22.6		55.6	38.9	370	
1273215	fk_63_1.0	63	1	22.49		52.9	36.9		7.03
1273216	fk_63_5.4	63	5.4	22.38		52.9	37.0		7.09
1273219	fk_64_0.5	64	0.5	22.79		53.48	37.1	300	
1273222	fk_65_0.5	65	0.5	22.41		52.62	36.8	520	
1273225	fk_66_0.5	66	0.5	22.3		52.52	36.8		
1273228	fk_67_0.5	67	0.5	22.27		52.41	36.7	770	
1273231	fk_68_0.5	68	0.5	22.05		51.91	36.5	950	
1273234	fk_69_0.5	69	0.5	21.98		51.72	36.4	860	
1273237	fk_70_0.5	70	0.5	21.94		51.69	36.4	650	
1273240	fk_71_0.5	71	0.5	22.31		52.23	36.5	550	
1273243	fk_72_0.5	72	0.5	22.39	1.0	52.42	36.6		

APPENDIX C. SURFACE AND BOTTOM WATER SAMPLES FROM KEPPEL BAY TAKEN DURING SEPTEMBER 2003: NUTRIENTS AND TSM

Ozestuaries #	SAMPLE ID	GA #	Sample depth (m)	TSM (mg/L)	Total phosphorus (mg/L as P)	Total dissolved phosphorus (mg/L as P)	Filtered reactive phosphorus (mg/L as P)	Ammonia nitrogen (mg/L as N)	Nitrogen oxides (mg/L as N)	Nitrite nitrogen (mg/L as N)	Total dissolved nitrogen (mg/L as N)	Total nitrogen (mg/L as N)	Reactive silica (mg/L as Si)
1272987	fk_01_0.5	1	0.5	27.3	0.14	0.13	0.12	0.22	0.23	0.050	0.77	0.81	2.4
1272993	fk_02_0.5	2	0.5	51.1	0.075	0.056	0.048	0.023	0.21	0.035	0.45	0.49	1.3
1272998	fk_03_0.5	3	0.5	199.0	0.086	0.023	0.023	< 0.002	0.12	0.002	0.29	0.40	0.6
1273004	fk_04_0.5	4	0.5	62.1									
1273006	fk_05_0.5	5	0.5	66.0	0.037	0.014	0.006	< 0.002	0.013	0.001	0.12	0.18	1.4
1273012	fk_06_0.5	6	0.5	5.3	0.018	0.014	0.003	< 0.002	0.007	0.001	0.12	0.15	1.0
1273014	fk_07_0.5	7	0.5	3.7	0.015	0.012	< 0.002	< 0.002	< 0.002	< 0.001	0.11	0.11	0.052
1273016	fk_08_0.5	8	0.5	1.2	0.010	0.010	< 0.002	0.004	< 0.002	< 0.001	0.14	0.12	0.045
1273018	fk_09_0.5	9	0.4	0.3	0.011	0.010	< 0.002	0.003	< 0.002	< 0.001	0.13	0.11	0.032
1273026	fk_09_19.4	9	19.4	0.6	0.012	0.011	< 0.002	< 0.002	< 0.002	< 0.001	0.11	0.12	0.031
1273029	fk_10_0.54	10	0.54	0.8	0.009	0.009	< 0.002	< 0.002	< 0.002	< 0.001	0.11	0.11	0.050
1273036	fk_10_19.0	10	19	2.8	0.014	0.010	< 0.002	< 0.002	< 0.002	< 0.001	0.11	0.10	0.051
1273039	fk_11_0.5	11	0.5	3.4	0.012	0.010	< 0.002	< 0.002	< 0.002	< 0.001	0.10	0.11	0.047
1273040	fk_11_11.4	11	11.4	9.1	0.016	0.008	< 0.002	< 0.002	< 0.002	< 0.001	0.11	0.11	0.048
1273043	fk_12_0.5	12	0.5	45.5	0.041	0.018	0.009	0.002	0.023	0.002	0.15	0.19	0.22
1273045	fk_13_0.5	13	0.5	16.8	0.022	0.010	< 0.002	0.003	< 0.002	< 0.001	0.11	0.12	0.052
1273047	fk_14_0.5	14	0.5	7.2	0.013	0.011	< 0.002	0.002	< 0.002	< 0.001	0.11	0.11	0.056
1273049	fk_15_0.5	15	0.5	4.8	0.017	0.013	0.002	< 0.002	< 0.002	< 0.001	0.12	0.12	0.093
1273051	fk_15_7.8	15	7.8	1.8	0.015	0.014	0.003	< 0.002	< 0.002	< 0.001	0.12	0.12	0.10
1273055	fk_16_0.5	16	0.5	8.7	0.017	0.012	0.002	0.002	< 0.002	< 0.001	0.10	0.11	0.077
1273057	fk_17_0.5	17	0.5	1.6	0.009	0.013	< 0.002	0.002	< 0.002	< 0.001	0.12	0.12	0.053
1273059	fk_18_0.5	18	0.5	0.4	0.010	0.009	< 0.002	0.002	< 0.002	< 0.001	0.09	0.10	0.021
1273061	fk_18_21.6	18	21.6	0.3	0.010	0.011	< 0.002	0.003	< 0.002	< 0.001	0.11	0.11	0.016
1273065	fk_19_0.5	19	0.5	4.1	0.014	0.012	0.003	0.003	< 0.002	< 0.001	0.12	0.11	0.066
1273067	fk_20_0.5	20	0.5	33.9	0.023	0.015	0.006	0.003	0.012	0.001	0.13	0.17	0.18
1273069	fk_21_0.5	21	0.5	124.5	0.053	0.017	0.010	0.002	0.023	0.002	0.14	0.24	0.22
1273074	fk_22_0.5	22	0.5	161.8	0.062	0.019	0.012	0.003	0.035	0.001	0.16	0.26	0.28

Ozestuaries #	SAMPLE ID	GA #	Sample depth (m)	TSM (mg/L)	Total phosphorus (mg/L as P)	Total dissolved phosphorus (mg/L as P)	Filtered reactive phosphorus (mg/L as P)	Ammonia nitrogen (mg/L as N)	Nitrogen oxides (mg/L as N)	Nitrite nitrogen (mg/L as N)	Total dissolved nitrogen (mg/L as N)	Total nitrogen (mg/L as N)	Reactive silica (mg/L as Si)
1273076	fk_22_8.6	22	8.6	306.5	0.21	0.022	0.013	0.003	0.035	0.001	0.18	0.88	0.33
1273079	fk_23_0.5	23	0.5	82.5	0.047	0.023	0.015	< 0.002	0.039	0.002	0.18	0.22	0.33
1273084	fk_24_0.5	24	0.5	270.2	0.17	0.023	0.016	0.003	0.047	0.002	0.19	0.34	0.39
1273089	fk_25_0.5	25	0	326.2	0.24	0.028	0.017	0.003	0.052	0.002	0.19	0.44	0.42
1273091	fk_26_0.5	26	0	219.3	0.43	0.028	0.017	0.003	0.058	0.003	0.22	0.73	0.46
1273093	fk_27_0.5	27	0.5	241.4	0.056	0.017	0.016	0.002	0.044	0.002	0.16	0.26	0.37
1273095	fk_28_0.5	28	0.5	170.6	0.053	0.016	0.015	< 0.002	0.038	0.002	0.14	0.24	0.33
1273097	fk_29_0.5	29	0.5	159.9	0.054	0.015	0.014	< 0.002	0.035	0.001	0.15	0.24	0.32
1273099	fk_30_0.5	30	0.5	12.0	0.013	0.006	< 0.002	0.003	< 0.002	< 0.001	0.09	0.11	0.065
1273101	fk_30_16.6	30	16.6	49.2	0.044	0.010	0.005	0.003	0.013	0.002	0.18	0.20	0.13
1273105	fk_31_0.5	31	0.5	17.6	0.009	0.006	< 0.002	0.003	< 0.002	< 0.001	0.10	0.11	0.067
1273107	fk_32_0.5	32	0.5	3.8	0.006	0.005	0.002	< 0.002	< 0.002	< 0.001	0.12	0.10	0.068
1273109	fk_32_13.1	32	13.1	1.8	0.007	0.005	< 0.002	0.002	< 0.002	< 0.001	0.10	0.10	0.067
1273113	fk_33_0.5	33	0.5	2.3	0.006	0.005	< 0.002	< 0.002	< 0.002	< 0.001	0.10	0.09	0.08
1273115	fk_34_0.5	34	0.5	3.7	0.008	0.007	0.003	< 0.002	< 0.002	< 0.001	0.10	0.10	0.098
1273117	fk_34_5.1	34	5.1	2.0	0.018	0.011	0.007	< 0.002	< 0.002	< 0.001	0.14	0.17	0.10
1273121	fk_35_0.5	35	0.5	5.4	0.007	0.006	0.002	< 0.002	< 0.002	< 0.001	0.09	0.09	0.086
1273123	fk_35_8	35	8	1.2	0.008	0.006	0.003	< 0.002	< 0.002	< 0.001	0.12	0.10	0.086
1273127	fk_36_0.5	36	0.5	1.3	0.005	0.005	< 0.002	< 0.002	< 0.002	< 0.001	0.09	0.10	0.070
1273129	fk_37_0.5	37	0.5	3.8	0.006	0.005	< 0.002	< 0.002	< 0.002	< 0.001	0.09	0.09	0.065
1273131	fk_38_0.5	38	0.5	1.3	0.005	0.004	< 0.002	< 0.002	< 0.002	< 0.001	0.09	0.09	0.047
1273133	fk_38_10.8	38	10.8	0.3	0.005	0.004	< 0.002	< 0.002	< 0.002	< 0.001	0.09	0.09	0.053
1273137	fk_39_0.5	39	0.5	0.7	0.004	0.004	< 0.002	< 0.002	< 0.002	< 0.001	0.09	0.09	0.027
1273139	fk_40_0.5	40	0.5	1.2	0.004	0.003	< 0.002	< 0.002	< 0.002	< 0.001	0.10	0.09	0.027
1273141	fk_40_17.9	40	17.9	0.4	0.005	0.004	< 0.002	< 0.002	< 0.002	< 0.001	0.08	0.09	0.030
1273145	fk_41_0.5	41	0.5	0.6	0.004	0.004	< 0.002	< 0.002	< 0.002	< 0.001	0.10	0.09	0.021
1273147	fk_42_0.5	42	0.5	0.3	0.005	0.004	< 0.002	< 0.002	< 0.002	< 0.001	0.09	0.08	0.019
1273149	fk_42_15.5	42	15.5	0.5	0.005	0.003	< 0.002	< 0.002	< 0.002	< 0.001	0.10	0.09	0.018
1273153	fk_43_0.5	43	0.5	0.9	0.004	0.004	< 0.002	< 0.002	< 0.002	< 0.001	0.09	0.08	0.019
1273155	fk_44_0.5	44	0.5	0.8	0.006	0.004	< 0.002	< 0.002	< 0.002	< 0.001	0.10	0.12	0.044

Ozestuaries #	SAMPLE ID	GA #	Sample depth (m)	TSM (mg/L)	Total phosphorus (mg/L as P)	Total dissolved phosphorus (mg/L as P)	Filtered reactive phosphorus (mg/L as P)	Ammonia nitrogen (mg/L as N)	Nitrogen oxides (mg/L as N)	Nitrite nitrogen (mg/L as N)	Total dissolved nitrogen (mg/L as N)	Total nitrogen (mg/L as N)	Reactive silica (mg/L as Si)
1273157	fk_44_5.3	44	5.3	13.6	0.005	0.004	< 0.002	< 0.002	< 0.002	< 0.001	0.10	0.10	0.045
1273160	fk_45_0.5	45	0.5	1.6	0.006	0.005	< 0.002	< 0.002	< 0.002	< 0.001	0.09	0.09	0.065
1273166	fk_46_0.5	46	0.5		0.005	0.004	< 0.002	< 0.002	< 0.002	< 0.001	0.10	0.09	0.036
1273170	fk_47_0.5	47	0.5	1.0	0.004	0.003	< 0.002	< 0.002	< 0.002	< 0.001	0.09	0.09	0.019
1273172	fk_48_0.5	48	0.5	0.3	0.004	0.003	< 0.002	< 0.002	< 0.002	< 0.001	0.09	0.10	0.018
1273174	fk_48_18	48	18	0.2	0.005	0.004	< 0.002	< 0.002	< 0.002	< 0.001	0.09	0.11	0.021
1273178	fk_49_0.5	49	0.5	0.4	0.004	0.004	< 0.002	0.002	< 0.002	< 0.001	0.10	0.11	0.016
1273180	fk_50_0.5	50	0.5	0.3	0.005	0.004	< 0.002	< 0.002	< 0.002	< 0.001	0.09	0.10	0.016
1273182	fk_50_22.9	50	22.9	0.1	0.005	0.004	< 0.002	< 0.002	< 0.002	< 0.001	0.08	0.09	0.017
1273192	fk_54_0.5	54	0.5		0.015	NA	NA	NA	NA	NA	NA	0.36	NA
1273214	fk_63_0.5	63	0.5	14.0	0.009	0.008	0.004	< 0.002	< 0.002	< 0.001	0.10	0.10	0.070
1273216	fk_63_5.4	63	5.4	4.5	0.011	0.008	0.004	< 0.002	< 0.002	< 0.001	0.10	0.11	0.073

APPENDIX D. SURFACE AND BOTTOM WATER PROPERTIES AT KEPPEL BAY DURING AUGUST 2004.

OzEstuaries #	SAMPLE ID	GA consecutive sample	Sample depth	Water temperature (^{o}C)	Turbidity (NTU's)	Conductivity (mS cm^{-1})	PSU	Secchi depth (m)	DO (mg/L)	DO (%)
1440197	268/fk_1_81_0.5	81	0.5					5.75		
1440198	268/fk_1_82_0.5	82	0.5					4.39		
1440199	268/fk_1_83_0.5	83	0.5					4.75		
1440200	268/fk_1_84_0.5	84	0.5					4.75		
1440201	268/fk_1_85_0.5	85	0.5					4.9		
1440202	268/fk_1_86_0.5	86						6.2		
1440203	268/fk_1_87_0.5	87	0.5					4.05		
1440204	268/fk_2_94_0.5	94	0.5					4.25		
1440205	268/fk_2_95_0.5	95	0.5					3.9		
1440206	268/fk_2_96_0.5	96	0.5					4		
1440207	268/fk_2_97_0.5	97	0.5		1.05			4		
1440208	268/fk_2_97_3.6	97	3.6		0.9					
1440209	268/fk_2_98_0.5	98	0.5		1.485			3.4		
1440210	268/fk_2_98_3.0	98	3		2.38					
1440211	268/fk_2_99_0.5	99	0.5							
1440212	268/fk_2_100_0.5	100	0.5		1.7					
1440213	268/fk_2_100_2.8	100	2.8		1.595					
1440214	268/fk_2_101_0.5	101	0.5		3.3					
1440215	268/fk_2_101_3.3	101	3.3		3.57					
1440216	268/fk_2_102_0.5	102	0.5		1.1					
1440217	268/fk_2_102_4.0	102	4		0.95					
1440218	268/fk_2_103_0.5	103	0.5		0.99					
1440219	268/fk_2_103_4.9	103	4.9		1.905					
1440220	268/fk_2_104_0.5	104	0.5		1.235					
1440221	268/fk_2_104_5.7	104	5.7		1.28					
1440222	268/fk_2_105_0.5	105	0.5		1.455					
1440223	268/fk_2_105_6.9	105	6.9		1.505					

OzEstuaries #	SAMPLE ID	GA consecutive sample	Sample depth	Water temperature (^{o}C)	Turbidity (NTU's)	Conductivity (mS cm^{-1})	PSU	Secchi depth (m)	DO (mg/L)	DO (%)
1440224	268/fk_3_106_0.5	106	0.5		5.155					
1440225	268/fk_3_107_0.5	107	0.5		3.18					
1440226	268/fk_3_107_14.5	107	14.5		5.895			2.1		
1440227	268/fk_3_108_0.5	108	0.5		2.93			2		
1440228	268/fk_3_108_14.2	108	14.2		10.805			2		
1440229	268/fk_3_109_0.5	109	0.5		3.41					
1440230	268/fk_3_109_13.6	109	13.6		15.635					
1440231	268/fk_3_110_0.5	110	0.5		10.95					
1440232	268/fk_3_111_0.5	111	0.5		14.045					
1440233	268/fk_3_111_12.4	111	12.4		25					
1440234	268/fk_3_112_0.5	112	0.5		15.74					
1440235	268/fk_3_112_11.8	112	11.8		18.93					
1440236	268/fk_3_113_0.5	113	0.5		10.84					
1440237	268/fk_3_113_11.8	113	11.8		10.725					
1440238	268/fk_3_114_0.5	114	0.5		7.785					
1440239	268/fk_3_114_12.4	114	12.4		35.05					
1440240	268/fk_3_115_0.5	115	0.5		7.64					
1440241	268/fk_3_115_12.7	115	12.7		25.8					
1440242	268/fk_3_116_0.5	116	0.5		8.39					
1440243	268/fk_3_116_13.6	116	13.6		14.38					
1440244	268/fk_3_117_0.5	117	0.5		4.76					
1440245	268/fk_3_117_14.2	117	14.2		9.915					
1440246	268/fk_3_118_0.5	118	0.5		3.865					
1440247	268/fk_3_118_14.8	118	14.8		8.18					
1440248	268/fk_4_119_0.5	119	0.5		1.135			3.3		
1440249	268/fk_4_119_16.7	119	16.7		4.025					
1440250	268/fk_5_120_0.5	120	0.5	19.29	0.915	49	36.51			
1440251	268/fk_5_120_15.9	120	15.9		5.315					
1440252	268/fk_6_121_0.5	121	0.5	19.42	0.735	49.26	36.61	5.2		

OzEstuaries #	SAMPLE ID	GA consecutive sample	Sample depth	Water temperature (^oC)	Turbidity (NTU's)	Conductivity (mS cm^{-1})	PSU	Secchi depth (m)	DO (mg/L)	DO (%)
1440253	268/fk_6_121_13	121	13		7.525					
1440254	268/fk_7_122_0.5	122	0.5	19.54	0.205	49.3	36.54	10.2		
1440255	268/fk_7_122_14.4	122	14.4		0.32					
1440256	268/fk_8_123_0.5	123	0.5	19.6	0.21	49.38	36.55	10		
1440257	268/fk_8_123_10.6	123	10.6		0.245					
1440258	268/fk_9_124_0.5	124	0.5	19.66	0.145	49.55	36.64	7.3		
1440259	268/fk_9_124_6.9	124	6.9		0.011					
1440260	268/fk_10_125_0.5	125	0.5	20	0.025	49.54	36.34	15.2		
1440261	268/fk_10_125_14.8	125	14.8		0.09					
1440262	268/fk_11_126_0.5	126	0.5	20.02	0	49.5	36.29	7.7		
1440263	268/fk_11_126_6.9	126	7.3		0.005					
1440264	268/fk_12_127_0.5	127	0.5	18.95	0.595	48.69	36.55	4.4		
1440265	268/fk_12_127_6.9	127	6.9		0.685					
1440266	268/fk_13_128_0.5	128	0.5	18.69	0.46	48.54	36.65	5.1		
1440267	268/fk_13_128_4.2	128	4.2		0.555					
1440268	268/fk_14_129_0.5	129	0.5	18.58	3.56	49.11	37.23	1.6		
1440269	268/fk_14_129_3.9	129	3.9		6.025					
1440270	268/fk_15_130_0.5	130	0.5	18.67	0.61	49.04	37.09	4.6		
1440271	268/fk_15_130_4.8	130	4.8		1.765					
1440272	268/fk_16_131_0.5	131	0.5	18.93	0.935	49.16	36.96	4.4		
1440273	268/fk_16_131_5.4	131	5.4		0.94					
1440274	268/fk_17_132_0.5	132	0.5	19.28	1.285	49.58	37	3.9		
1440275	268/fk_17_132_3.4	132	3.4		1.37					
1440276	268/fk_18_133_0.5	133	0.5	19.5	4.105	49.99	37.15	1.6		
1440277	268/fk_18_133_4.3	133	4.3		12.685					
1440278	268/fk_19_134_0.5	134	0.5	19.42	5.9	49.28	36.63	1.3		
1440279	268/fk_19_134_8.9	134	8.9		32.75					
1440280	268/fk_20_135_0.5	135	0.5	19.38	0.88	49.33	36.7	4.35		
1440281	268/fk_20_135_7.8	135	7.8		0.935					

OzEstuaries #	SAMPLE ID	GA consecutive sample	Sample depth	Water temperature (^oC)	Turbidity (NTU's)	Conductivity (mS cm^{-1})	PSU	Secchi depth (m)	DO (mg/L)	DO (%)
1440282	268/fk_21_136_0.5	136	0.5	19.1	0.25	48.87	36.57	7.1		
1440283	268/fk_21_136_5.7	136	5.7		0.2					
1440284	268/fk_22_137_0.5	137	0.5	19.35	0.02	48.94	36.41	9.6		
1440285	268/fk_22_137_13	137	13		0.045					
1440286	268/fk_23_138_0.5	138	0.5	19.7	0.135	49.16	36.28	11.3		
1440287	268/fk_23_138_17.9	138	17.9		0.02					
1440288	268/fk_24_139_0.5	139	0.5	19.81	1.53	49.2	36.22	12.2		
1440289	268/fk_24_139_22.5	139	22.5		0.005					
1440290	268/fk_25_140_0.5	140	0.5	20.45		49.81	36.17	13.3		
1440291	268/fk_26_141_0.5	141	0.5	19.61	13.19	49.57	36.7	1.3		
1440292	268/fk_26_141_9.8	141	9.8		37.8					
1440293	268/fk_26_142_0.5	142	0.5	19.54	19.62	49.36	36.59	0.9		
1440294	268/fk_26_142_10.4	142	10.4		59.9					
1440295	268/fk_26_143_0.5	143	0.5	19.64	4.16	49.6	36.7	1.7		
1440296	268/fk_26_143_10.6	143	10.6		16.78					
1440297	268/fk_26_144_0.5	144	0.5	19.79	3.3	49.58	36.55	2		
1440298	268/fk_26_144_10.7	144	10.7		14.94					
1440299	268/fk_26_145_0.5	145	0.5	19.81	4.355	49.62	36.57	1.4		
1440300	268/fk_26_145_10.4	145	10.4		30					
1440301	268/fk_26_146_0.5	146	0.5	19.77	6.585	49.7	36.67	1		
1440302	268/fk_26_146_10	146	10		26.5					
1440303	268/fk_26_147_0.5	147	0.5	19.6	6.255	49.51	36.66			
1440304	268/fk_26_147_9.7	147	9.7		34.8					
1440305	268/fk_26_148_0.5	148	0.5	19.71	5.785	49.61	36.65			
1440306	268/fk_26_148_9.2	148	9.2		29.55					
1440307	268/fk_26_149_0.5	149	0.5	19.67	5.2					
1440308	268/fk_26_149_9.2	149	9.2		37.5					
1440309	268/fk_26_150_0.5	150	0.5		5.6					
1440310	268/fk_26_150_8.9	150	8.9		29					

OzEstuaries #	SAMPLE ID	GA consecutive sample	Sample depth	Water temperature (^oC)	Turbidity (NTU's)	Conductivity (mS cm^{-1})	PSU	Secchi depth (m)	DO (mg/L)	DO (%)
1440311	268/fk_28_152_0.5	152	0.5	19.36	5.405	49	36.45	1.1		
1440312	268/fk_28_152_12.1	152	12.1		11.91					
1440313	268/fk_28_153_0.5	153	0.5	19.5	2.615	49.14	36.44	1.4		
1440314	268/fk_28_153_12.1	153	12.1		8.83					
1440315	268/fk_28_154_0.5	154	0.5	19.71	2.995	49.26	36.36			
1440316	268/fk_28_154_12.6	154	12.6		7.78					
1440317	268/fk_28_155_0.5	155	0.5		2.8					
1440318	268/fk_28_155_13	155	13		8.205					
1440319	268/fk_28_156_0.5	156	0.5	19.74	2.77	49.45	36.49	2.5		
1440320	268/fk_28_156_13.5	156	13.5		6.32					
1440321	268/fk_28_157_0.5	157	0.5	19.92	2.115	49.55	36.42	2.5		
1440322	268/fk_28_157_13.9	157	13.9		3.575					
1440323	268/fk_28_158_0.5	158	0.5	19.91	1.61	49.54	36.42	3		
1440324	268/fk_28_158_13.9	158	13.9		2.5					
1440325	268/fk_28_159_0.5	159	0.5	19.88	1.705	49.5	36.41	2.9		
1440326	268/fk_28_159_13.9	159	13.9		2.2					
1440327	268/fk_28_160_0.5	160	0.5	19.83	1.7	49.45	36.41			
1440328	268/fk_28_160_13.5	160	13.5		2.945					
1440329	268/fk_28_161_0.5	161	0.5	19.87	1.6	49.51	36.43			
1440330	268/fk_29_162_0.5	162	0.5		11.67			0.6		
1440331	268/fk_29_162_13	162	13		50.45					
1440332	268/fk_30_163_0.5	163	0.5	19.34	46.65	49.8	37.13	0.15		
1440333	268/fk_30_163_6.9	163	6.9		65.1					
1440334	268/fk_30_164_0.5	164	0.5	19.44	34.9	49.84	37.08	0.3		
1440335	268/fk_30_164_6.9	164	6.9		55.15					
1440336	268/fk_30_165_0.5	165	0.5	19.81	20.8	50.24	37.08	0.4		
1440337	268/fk_30_165_7.2	165	7.2		45.35					
1440338	268/fk_30_166_0.5	166	0.5	20.05	25	50.47	37.06	0.4		
1440339	268/fk_30_166_7.5	166	7.5		76.7					

OzEstuaries #	SAMPLE ID	GA consecutive sample	Sample depth	Water temperature (^{o}C)	Turbidity (NTU's)	Conductivity (mS cm^{-1})	PSU	Secchi depth (m)	DO (mg/L)	DO (%)
1440340	268/fk_30_167_0.5	167	0.5	19.92	39	50.15	36.91			
1440341	268/fk_30_167_8.1	167	8.1		67.5			0.15		
1440342	268/fk_30_168_0.5	168	0.5	19.87	26.75	50.06	36.88	0.3		
1440343	268/fk_30_168_8.9	168	8.9		56.95					
1440344	268/fk_30_169_0.5	169	0.5	18.83	17.27	50.01	37.77			
1440345	268/fk_30_169_9.4	169	9.4		49.2					
1440346	268/fk_30_170_0.5	170	0.5	19.81	24.15	49.9	36.8	0.3		
1440347	268/fk_30_170_9.8	170	9.8		47.2					
1440348	268/fk_30_171_0.5	171	0.5	19.87	14	49.92	36.76			
1440349	268/fk_30_171_10	171	10.4		29.4			0.5		
1440350	268/fk_30_172_0.5	172	0.5	19.82	11.825	49.87	36.77			
1440351	268/fk_30_172_9.8	172	9.8		27.95					
1440352	268/fk_30_173_0.5	173	0.5	19.8	10.99	49.88	36.79			
1440353	268/fk_30_173_8.7	173	8.7		34.5					
1440354	268/fk_31_174_0.5	174	0.5		55			0.5		
1440355	268/fk_31_174_5.1	174	5.1		80					
1440356	268/fk_31_175_0.5	175	0.5		50			0.4		
1440357	268/fk_31_175_4.8	175	4.8		62.5					
1440358	268/fk_31_176_0.5	176	0.5		48			0.45		
1440359	268/fk_31_176_3.9	176	3.9		53					
1440360	268/fk_31_177_0.5	177	0.5		26			0.6		
1440361	268/fk_31_177_3.9	177	3.9		37.5					
1440362	268/fk_31_178_0.5	178	0.5		17			0.5		
1440363	268/fk_31_178_4.5	178	4.5		45					
1440364	268/fk_31_179_0.5	179	0.5		55			0.25		
1440365	268/fk_31_179_5.1	179	5.1		72					
1440366	268/fk_31_180_0.5	180	0.5		103					
1440367	268/fk_31_180_5.7	180	5.7		116					
1440368	268/fk_31_181_0.5	181	0.5		79					

OzEstuaries #	**SAMPLE ID**	**GA consecutive sample**	**Sample depth**	**Water temperature (^{o}C)**	**Turbidity (NTU's)**	**Conductivity (mS cm^{-1})**	**PSU**	**Secchi depth (m)**	**DO (mg/L)**	**DO (%)**
1440369	268/fk_31_181_6	181	6		81					
1440370	268/fk_31_182_0.5	182	0.5		75					
1440371	268/fk_31_182_6.6	182	6.6		83					
1440372	268/fk_31_183_0.5	183	0.5		65.8					
1440373	268/fk_31_183_7.2	183	7.2		68.5					
1440374	268/fk_31_184_0.5	184	0.5		51					
1440375	268/fk_31_184_7.2	184	7.2		91					
1440376	268/fk_31_185_0.5	185	0.5		40					
1440377	268/fk_31_185_6.9	185	6.9		130					
1440378	268/fk_31_186_0.5	186	0.5		60					
1440379	268/fk_31_186_6.2	186	6.2		120					
1440380	268/fk_32_187_0.5	187	0.5	19.3	37	49.86	37.22		7.46	100
1440381	268/fk_32_187_8.8	187	8.8	19.2	88	49.82	37.28		7.26	97.2
1440382	268/fk_33_188_0.5	188	0.5	19.2	47	49.84	37.29		7.42	99.2
1440383	268/fk_33_188_4.8	188	4.8	19.13	74	49.83	37.35		7.32	97.8
1440384	268/fk_34_189_0.5	189	0.5	19.26	37.37	50.01	37.38		7.46	100
1440385	268/fk_34_189_5.4	189	5.4	19.03	80	49.76	37.38		7.34	97.9
1440386	268/fk_35_190_0.5	190	0.5	19.13	87	49.88	37.39		7.38	98.9
1440387	268/fk_35_190_5.6	190	5.6	19.04	135	49.85	37.45		7.3	97.5
1440388	268/fk_36_191_0.5	191	0.5	19.18	109	50.18	37.6		7.33	98.1
1440389	268/fk_36_191_5.0	191	5	19.13	110	50.11	37.58		7.25	96.9
1440390	268/fk_37_192_0.5	192	0.5	19.28	82	50.4	37.69		7.29	98.4
1440391	268/fk_37_192_6.6	192	6.6	19.2	130	50.26	37.65		7.21	97.1
1440392	277/fk_vc01_196_0.5	196	0.5	21.2	18.3	50.76	36.3		6.89	100
1440393	277/fk_vc01_196_9.6	196	9.6	21.18	73.5	50.74	36.3		6.91	95.6
1440394	277/fk_vc03_198_0.5	198	0.5	21.3	1	51.12	36.51		7.28	101
1440395	277/fk_vc03_198_7.9	198	7.9	21.3	1.5	51.1	36.49		7.2	99.7
1440396	277/fk_vc04_199_0.5	199	0.5	21.26	0.5	51.1	36.52		7.18	101.1
1440397	277/fk_vc04_199_8.6	199	8.6	21.2	2.5	51.02	36.51		7.08	99.8

OzEstuaries #	SAMPLE ID	GA consecutive sample	Sample depth	Water temperature (^oC)	Turbidity (NTU's)	Conductivity (mS cm^{-1})	PSU	Secchi depth (m)	DO (mg/L)	DO (%)
1440398	277/fk_vc05_200_0.5	200	0.5	21.6	1	51.31	36.4		7.14	99.9
1440399	277/fk_vc05_200_7.8	200	7.8	21.54	1.9	51.34	36.48		7.08	99.4
1440400	277/fk_vc06_201_0.5	201	0.5	21.41	0.5	50.86	36.2		7.13	102
1440401	277/fk_vc06_201_6.8	201	6.8	21.25	0.5	50.86	36.34		7.2	100.3
1440402	277/fk_vc09_202_0.5	202		20.7	0.4	49.98	36.1		7.29	100.5
1440403	277/fk_vc09_202_9.8	202		20.94	0.5	50	35.91		7.3	101.1
1440404	277/fk_vc13_203_0.5	203		20.69	0	50.56	36.58		7.52	103.4
1440405	277/fk_vc13_203_18.6	203		20.78	0.5	50.45	36.41		7.37	101.9
1440406	277/fk_vc17_204_0.5	204		21.01	100	51.07	36.72		7.08	98.5
1440407	277/fk_vc17_204_10.6	204		21.19	135	50.91	36.43		6.99	97.3
1440408	277/fk_vc20_205_0.5	205		20.94	97.5	51.26	36.93		6.92	96.7
1440409	277/fk_vc20_205_13.4	205		21	150	51.29	36.9		6.76	94

APPENDIX E. SURFACE AND BOTTOM WATER SAMPLES FROM KEPPEL BAY TAKEN DURING AUGUST 2004: NUTRIENTS AND TSM.

OzEstuaries #	SAMPLE ID	GA #	Sample depth (m)	TSM (mg/L)	Total Phosphorus (mg/L)	Dissolved total phosphorus (mg/L as P)	Filtered Reactive Phosphorus (mg/L as P)	Ammonia Nitrogen (mg/L as P)	Nitrogen Oxides (mg/L as P)	Nitrite Nitrogen (mg/L as N)	Dissolved total Nitrogen (mg/L as N)	Total Nitrogen (mg/L as N)	Reactive Silica (mg/L as Si)
1440410	268/fk_1_81_0.5	81	7.4	0.79	0.011	0.01	<0.002	<0.002	< 0.002	< 0.001	0.11	0.14	0.034
1440411	268/fk_1_81_7.4	81	7.4	0.59									
1440412	268/fk_1_82_0.5	82	0.5	0.49	0.012	0.01	< 0.002	< 0.002	< 0.002	< 0.001	0.09	0.1	0.031
1440413	268/fk_1_82_6.9	82	6.9	0.99									
1440414	268/fk_1_83_0.5	83	0.5	0.69	0.011	0.008	< 0.002	< 0.002	< 0.002	< 0.001	0.09	0.09	0.031
1440415	268/fk_1_83_6.3	83	6.3	0.69	0.01	0.008	0.002	< 0.002	< 0.002	< 0.001	0.11	0.12	0.032
1440416	268/fk_1_84_0.5	84	0.5	0.89	0.008	0.008	< 0.002	< 0.002	< 0.002	< 0.001	0.1	0.11	0.041
1440417	268/fk_1_84_5.7	84	5.7	0.79									
1440418	268/fk_1_85_0.5	85	0.5	1.89	0.008	0.007	< 0.002	< 0.002	< 0.002	< 0.001	0.1	0.2	0.038
1440419	268/fk_1_85_5.4	85	5.4	1.59									
1440420	268/fk_1_86_0.5	86	0.5	0.89	0.008	0.006	< 0.002	< 0.002	< 0.002	< 0.001	0.09	0.11	0.039
1440421	268/fk_1_86_5.7	86	5.7	0.89									
1440422	268/fk_1_87_0.5	87	0.5	0.79	0.008	0.007	< 0.002	< 0.002	< 0.002	< 0.001	0.1	0.1	0.029
1440423	268/fk_1_87_6.2	87	6.2	0.89									
1440424	268/fk_1_88_0.5	88	0.5	1.09	0.008	0.006	< 0.002	< 0.002	< 0.002	< 0.001	0.1	0.14	0.028
1440425	268/fk_1_88_6.6	88	6.6	0.89	0.007	0.007	< 0.002	< 0.002	< 0.002	< 0.001	0.09	0.09	0.028
1440426	268/fk_1_89_0.5	89	0.5	1.09	0.009	0.008	< 0.002	< 0.002	< 0.002	< 0.001	0.09	0.13	0.037
1440427	268/fk_1_89_7.2	89	7.2	0.49									
1440428	268/fk_1_90_0.5	90	0.5	0.89	0.009	0.008	< 0.002	< 0.002	< 0.002	< 0.001	0.09	0.09	0.034
1440429	268/fk_1_90_8.1	90	8.1	2.09	0.011	0.007	< 0.002	< 0.002	< 0.002	< 0.001	0.1	0.13	0.035
1440430	268/fk_1_91_0.5	91	0.5	0.09	0.007	0.007	< 0.002	< 0.002	< 0.002	< 0.001	0.12	0.13	0.038
1440431	268/fk_1_91_8.7	91	8.7	0.19									
1440432	268/fk_1_92_0.5	92	0.5	0.19	0.007	0.006	< 0.002	< 0.002	< 0.002	< 0.001	0.11	0.13	0.04
1440433	268/fk_1_92_8.7	92	8.7	0.09	0.009	0.007	< 0.002	< 0.002	< 0.002	< 0.001	0.1	0.13	0.038
1440434	268/fk_2_93_0.5	93	0.5	0.99	0.012	0.008	0.002	< 0.002	< 0.002	< 0.001	0.14	0.15	0.098
1440435	268/fk_2_93_5.7	93	5.7	1.89	0.008	0.007	0.004	< 0.002	< 0.002	< 0.001	0.13	0.15	0.094
1440436	268/fk_2_94_0.5	94	0.5	1.29	0.008	0.008	< 0.002	< 0.002	< 0.002	< 0.001	0.14	0.14	0.097
1440437	268/fk_2_94_5.2	94	5.2	0.89	0.01	0.008	0.003	< 0.002	< 0.002	< 0.001	0.12	0.21	0.095

OzEstuaries #	SAMPLE ID	GA #	Sample depth (m)	TSM (mg/L)	Total Phosphorus (mg/L)	Dissolved total phosphorus (mg/L as P)	Filtered Reactive Phosphorus (mg/L as P)	Ammonia Nitrogen (mg/L as P)	Nitrogen Oxides (mg/L as P)	Nitrite Nitrogen (mg/L as N)	Dissolved total Nitrogen (mg/L as N)	Total Nitrogen (mg/L as N)	Reactive Silica (mg/L as Si)
1440438	268/fk_2_95_0.5	95	0.5	4.49	0.009	0.008	0.002	< 0.002	< 0.002	< 0.001	0.12	0.13	0.1
1440439	268/fk_2_95_5.1	95	5.1	1.09									
1440440	268/fk_2_96_0.5	96	0.5	1.39	0.008	0.008	0.003	< 0.002	< 0.002	< 0.001	0.12	0.13	0.099
1440441	268/fk_2_96_4.3	96	4.3	1.19	0.009	0.007	0.002	0.003	< 0.002	< 0.001	0.12	0.12	0.092
1440442	268/fk_2_97_0.5	97	0.5	0.99	0.01	0.008	< 0.002	< 0.002	< 0.002	< 0.001	0.12	0.12	0.096
1440443	268/fk_2_97_3.6	97	3.6	4.99	0.01	0.009	0.002	< 0.002	< 0.002	< 0.001	0.13	0.13	0.092
1440444	268/fk_2_98_0.5	98	0.5	1.295	0.009	0.009	0.002	< 0.002	< 0.002	< 0.001	0.13	0.14	0.096
1440445	268/fk_2_98_3.0	98	3	2.545	0.012	0.007	0.003	< 0.002	< 0.002	< 0.001	0.12	0.13	0.11
1440446	268/fk_2_99_0.5	99	0.5	1.99	0.009	0.008	0.002	< 0.002	< 0.002	< 0.001	0.11	0.12	0.094
1440447	268/fk_2_99_3.0	99	3	1.89	0.01	0.008	0.003	< 0.002	< 0.002	< 0.001	0.14	0.14	0.097
1440448	268/fk_2_100_0.5	100	0.5	1.99	0.011	0.01	< 0.002	< 0.002	< 0.002	< 0.001	0.12	0.12	0.094
1440449	268/fk_2_100_2.8	100	2.8	1.79									
1440450	268/fk_2_101_0.5	101	0.5	4.79	0.011	0.009	0.005	< 0.002	< 0.002	< 0.001	0.12	0.13	0.093
1440451	268/fk_2_101_3.3	101	3.3	4.79	0.01	0.009	0.002	< 0.002	< 0.002	< 0.001	0.13	0.14	0.097
1440452	268/fk_2_102_0.5	102	0.5	2.79	0.006	0.005	< 0.002	< 0.002	< 0.002	< 0.001	0.11	0.11	0.1
1440453	268/fk_2_102_4.0	102	4	1.49									
1440454	268/fk_2_103_0.5	103	0.5	1.29	0.005	0.005	0.002	< 0.002	< 0.002	< 0.001	0.1	0.1	0.11
1440455	268/fk_2_103_4.9	103	4.9	2.19	0.006	0.005	0.002	< 0.002	< 0.002	< 0.001	0.11	0.13	0.095
1440456	268/fk_2_104_0.5	104	0.5	1.59	0.006	0.005	0.002	< 0.002	< 0.002	< 0.001	0.11	0.12	0.1
1440457	268/fk_2_104_5.7	104	5.7	2.29									
1440458	268/fk_2_105_0.5	105	0.5	3.49	0.006	0.004	< 0.002	< 0.002	< 0.002	< 0.001	0.12	0.14	0.1
1440459	268/fk_2_105_6.9	105	6.9	2.19									
1440460	268/fk_3_106_0.5	106	0.5	3.59	0.005	0.004	< 0.002	< 0.002	< 0.002	< 0.001	0.12	0.13	0.041
1440461	268/fk_3_106_14.8	106	14.8	15.69	0.008	0.004	< 0.002	< 0.002	< 0.002	< 0.001	0.11	0.11	0.048
1440462	268/fk_3_107_0.5	107	0.5	5.49	0.005	0.004	< 0.002	0.002	< 0.002	< 0.001	0.1	0.11	0.044
1440463	268/fk_3_107_14.5	107	14.5	11.49									
1440464	268/fk_3_108_0.5	108	0.5	4.99	0.005	0.004	< 0.002	0.002	< 0.002	< 0.001	0.1	0.12	0.044
1440465	268/fk_3_108_14.2	108	14.2	10.39									
1440466	268/fk_3_109_0.5	109	0.5	4.69	0.006	0.004	< 0.002	< 0.002	< 0.002	0.001	0.1	0.1	0.054
1440467	268/fk_3_109_13.6	109	13.6	9.39	0.006	0.004	< 0.002	< 0.002	< 0.002	< 0.001	0.1	0.11	0.055

OzEstuaries #	SAMPLE ID	GA #	Sample depth (m)	TSM (mg/L)	Total Phosphorus (mg/L)	Dissolved total phosphorus (mg/L as P)	Filtered Reactive Phosphorus (mg/L as P)	Ammonia Nitrogen (mg/L as P)	Nitrogen Oxides (mg/L as P)	Nitrite Nitrogen (mg/L as N)	Dissolved total Nitrogen (mg/L as N)	Total Nitrogen (mg/L as N)	Reactive Silica (mg/L as Si)
1440468	268/fk_3_110_0.5	110	0.5	12.09	0.008	0.005	< 0.002	< 0.002	< 0.002	0.001	0.12	0.12	0.058
1440469	268/fk_3_110_12.7	110	12.7	21.89	0.01	0.004	< 0.002	< 0.002	< 0.002	0.001	0.12	0.12	0.057
1440470	268/fk_3_111_0.5	111	0.5	11.39	0.012	0.005	0.004	0.003	< 0.002	0.001	0.1	0.14	0.055
1440471	268/fk_3_111_12.4	111	12.4	59.69									
1440472	268/fk_3_112_0.5	112	0.5	18.99	0.01	0.003	< 0.002	< 0.002	< 0.002	0.001	0.1	0.12	0.046
1440473	268/fk_3_112_11.8	112	11.8	43.89									
1440474	268/fk_3_113_0.5	113	0.5	13.19	0.007	0.005	< 0.002	< 0.002	< 0.002	< 0.001	0.09	0.11	0.04
1440475	268/fk_3_113_11.8	113	11.8	20.296	0.006	0.005	< 0.002	< 0.002	< 0.002	< 0.001	0.11	0.12	0.044
1440476	268/fk_3_114_0.5	114	0.5	8.39	0.007	0.005	< 0.002	< 0.002	< 0.002	< 0.001	0.1	0.1	0.04
1440477	268/fk_3_114_12.4	114	12.4	18.978	0.012	0.005	< 0.002	< 0.002	< 0.002	< 0.001	0.09	0.12	0.039
1440478	268/fk_3_115_0.5	115	0.5	11.39	0.008	0.004	< 0.002	0.002	< 0.002	< 0.001	0.08	0.09	0.054
1440479	268/fk_3_115_12.7	115	12.7	20.59	0.01	0.005	< 0.002	0.008	0.002	0.001	0.12	0.12	0.052
1440480	268/fk_3_116_0.5	116	0.5	9.69	0.006	0.004	< 0.002	0.003	< 0.002	0.001	0.1	0.1	0.06
1440481	268/fk_3_116_13.6	116	13.6	15.29	0.008	0.004	0.002	< 0.002	< 0.002	0.001	0.1	0.11	0.056
1440482	268/fk_3_117_0.5	117	0.5	9.69	0.006	0.004	< 0.002	< 0.002	< 0.002	< 0.001	0.09	0.13	0.04
1440483	268/fk_3_117_14.2	117	14.2	11.39	0.006	0.004	< 0.002	< 0.002	< 0.002	< 0.001	0.1	0.11	0.041
1440484	268/fk_3_118_0.5	118	0.5	5.89	0.004	0.003	< 0.002	< 0.002	< 0.002	0.001	0.08	0.09	0.036
1440485	268/fk_3_118_14.8	118	14.8	9.59									
1440486	268/fk_4_119_0.5	119	0.5	2.69									
1440487	268/fk_4_119_16.7	119	16.7	4.79									
1440488	268/fk_6_121_0.5	121	0.5	2.09	0.007	0.003	< 0.002	0.002	< 0.002	0.001	0.12	0.17	0.064
1440489	268/fk_6_121_13	121	13	2.19									
1440490	268/fk_7_122_0.5	122	0.5	0.39									
1440491	268/fk_7_122_14.4	122	14.4	1.39									
1440492	268/fk_8_123_0.5	123	0.5	0.79	0.003	0.003	< 0.002	< 0.002	< 0.002	< 0.001	0.11	0.11	0.051
1440493	268/fk_8_123_10.6	123	10.6	0.89	0.003	0.003	< 0.002	0.005	< 0.002	0.001	0.1	0.11	0.055
1440494	268/fk_9_124_0.5	124	0.5	1.09									
1440495	268/fk_9_124_6.9	124	6.9	1.49									
1440496	268/fk_10_125_0.5	125	0.5	0.89	0.003	0.002	< 0.002	0.002	< 0.002	< 0.001	0.11	0.14	0.021
1440497	268/fk_10_125_14.8	125	14.8	1.19	0.003	0.002	< 0.002	< 0.002	< 0.002	< 0.001	0.1	0.14	0.021

OzEstuaries #	SAMPLE ID	GA #	Sample depth (m)	TSM (mg/L)	Total Phosphorus (mg/L)	Dissolved total phosphorus (mg/L as P)	Filtered Reactive Phosphorus (mg/L as P)	Ammonia Nitrogen (mg/L as P)	Nitrogen Oxides (mg/L as P)	Nitrite Nitrogen (mg/L as N)	Dissolved total Nitrogen (mg/L as N)	Total Nitrogen (mg/L as N)	Reactive Silica (mg/L as Si)
1440498	268/fk_11_126_0.5	126	0.5	0.49									
1440499	268/fk_11_126_6.9	126	7.3	0.89									
1440500	268/fk_12_127_0.5	127	0.5	0.59	0.007	0.005	< 0.002	< 0.002	< 0.002	0.001	0.1	0.11	0.034
1440501	268/fk_12_127_6.9	127	6.9	1.59									
1440502	268/fk_13_128_0.5	128	0.5	2.09									
1440503	268/fk_13_128_4.2	128	4.2	1.79									
1440504	268/fk_14_129_0.5	129	0.5	3.79	0.009	0.008	< 0.002	< 0.002	< 0.002	0.001	0.09	0.11	0.092
1440505	268/fk_14_129_3.9	129	3.9	8.79									
1440506	268/fk_15_130_0.5	130	0.5	0.79									
1440507	268/fk_15_130_4.8	130	4.8	3.19									
1440508	268/fk_16_131_0.5	131	0.5	1.69									
1440509	268/fk_16_131_5.4	131	5.4	0.89									
1440510	268/fk_17_132_0.5	132	0.5	1.19	0.009	0.007	< 0.002	< 0.002	< 0.002	0.001	0.11	0.12	0.11
1440511	268/fk_17_132_3.4	132	3.4	2.09									
1440512	268/fk_18_133_0.5	133	0.5	5.09	0.009	0.008	0.002	< 0.002	< 0.002	0.001	0.13	0.13	0.1
1440513	268/fk_18_133_4.3	133	4.3	16.79									
1440514	268/fk_19_134_0.5	134	0.5	9.79	0.009	0.005	0.003	< 0.002	0.003	0.001	0.16	0.18	0.086
1440515	268/fk_19_134_8.9	134	8.9	37.962									
1440516	268/fk_20_135_0.5	135	0.5	2.49									
1440517	268/fk_20_135_7.8	135	7.8	2.19									
1440518	268/fk_21_136_0.5	136	0.5	3.49	0.004	0.004	< 0.002	0.002	< 0.002	0.001	0.1	0.11	0.037
1440519	268/fk_22_137_0.5	137	0.5	1.69	0.006	0.013	< 0.002	< 0.002	< 0.002	0.001	0.21	0.11	0.021
1440520	268/fk_22_137_13	137	13	2.09									
1440521	268/fk_23_138_0.5	138	0.5	1.59									
1440522	268/fk_24_139_0.5	139	0.5	1.79	0.005	0.005	< 0.002	0.005	< 0.002	0.001	0.14	0.14	0.016
1440523	268/fk_26_141_0.5	141	0.5	12.79	0.014	0.007	0.003	0.003	0.004	0.001	0.12	0.14	0.084
1440524	268/fk_26_141_9.8	141	9.8	39.374									
1440525	268/fk_26_142_0.5	142	0.5	11.79	0.011	0.006	< 0.002	< 0.002	0.003	0.001	0.11	0.13	0.082
1440526	268/fk_26_142_10.4	142	10.4	50.937									
1440527	268/fk_26_143_0.5	143	0.5	4.59	0.008	0.007	0.003	0.008	< 0.002	< 0.001	0.11	0.12	0.055

OzEstuaries #	SAMPLE ID	GA #	Sample depth (m)	TSM (mg/L)	Total Phosphorus (mg/L)	Dissolved total phosphorus (mg/L as P)	Filtered Reactive Phosphorus (mg/L as P)	Ammonia Nitrogen (mg/L as P)	Nitrogen Oxides (mg/L as P)	Nitrite Nitrogen (mg/L as N)	Dissolved total Nitrogen (mg/L as N)	Total Nitrogen (mg/L as N)	Reactive Silica (mg/L as Si)
1440528	268/fk_26_143_10.6	143	10.6	23.79	0.013	0.006	0.003	0.009	0.003	< 0.001	0.11	0.14	0.066
1440529	268/fk_26_144_0.5	144	0.5	5.39	0.008	0.007	< 0.002	0.008	< 0.002	< 0.001	0.12	0.12	0.065
1440530	268/fk_26_144_10.7	144	10.7	37.732									
1440531	268/fk_26_145_0.5	145	0.5	4.59	0.01	0.006	0.003	< 0.002	< 0.002	< 0.001	0.08	0.1	0.066
1440532	268/fk_26_145_10.4	145	10.4	33.361	0.021	0.007	0.004	< 0.002	0.005	0.001	0.09	0.12	0.084
1440533	268/fk_26_146_0.5	146	0.5	7.59	0.012	0.009	0.005	< 0.002	0.004	< 0.001	0.1	0.1	0.094
1440534	268/fk_26_146_10	146	10	34.012									
1440535	268/fk_26_147_0.5	147	0.5	7.59	0.012	0.012	0.004	< 0.002	0.003	< 0.001	0.1	0.11	0.088
1440536	268/fk_26_147_9.7	147	9.7	28.939									
1440537	268/fk_26_148_0.5	148	0.5	6.29	0.008	0.014	0.01	0.006	0.003	0.002	0.14	0.12	0.088
1440538	268/fk_26_148_9.2	148	9.2	34.986	0.025	0.01	0.005	0.003	0.005	0.001	0.11	0.14	0.087
1440539	268/fk_26_149_0.5	149	0.5	7.09	0.009	0.008	0.003	< 0.002	0.003	< 0.001	0.11	0.12	0.079
1440540	268/fk_26_149_9.2	149	9.2	35.464	0.022	0.01	0.004	< 0.002	0.003	< 0.001	0.08	0.12	0.099
1440541	268/fk_26_150_0.5	150	0.5	14.79	0.01	0.008	0.003	< 0.002	0.003	< 0.001	0.09	0.09	0.085
1440542	268/fk_26_150_8.9	150	8.9	34.076									
1440543	268/fk_28_152_0.5	152	0.5	8.7	0.011	0.008	0.002	< 0.002	0.002	< 0.001	0.1	0.1	0.052
1440544	268/fk_28_152_12.1	152	12.1	10.8									
1440545	268/fk_28_153_0.5	153	0.5	4.8	0.009	0.005	< 0.002	< 0.002	< 0.002	< 0.001	0.11	0.11	0.049
1440546	268/fk_28_153_12.1	153	12.1	20.2									
1440547	268/fk_28_154_0.5	154	0.5	5.1	0.01	0.006	< 0.002	< 0.002	< 0.002	< 0.001	0.1	0.11	0.044
1440548	268/fk_28_154_12.6	154	12.6	10.8	0.011	0.008	< 0.002	< 0.002	< 0.002	< 0.001	0.12	0.12	0.051
1440549	268/fk_28_155_0.5	155	0.5	4.2	0.008	0.007	< 0.002	< 0.002	< 0.002	< 0.001	0.1	0.12	0.047
1440550	268/fk_28_155_13	155	13	15.5									
1440551	268/fk_28_156_0.5	156	0.5	4.6	0.008	0.008	0.002	< 0.002	< 0.002	< 0.001	0.08	0.1	0.051
1440552	268/fk_28_156_13.5	156	13.5	8.4	0.009	0.007	< 0.002	< 0.002	< 0.002	< 0.001	0.04	0.11	0.054
1440553	268/fk_28_157_0.5	157	0.5	4.2	0.009	0.007	0.002	0.002	< 0.002	< 0.001	0.07	0.12	0.051
1440554	268/fk_28_157_13.9	157	13.9	8.4									
1440555	268/fk_28_158_0.5	158	0.5	4.5	0.011	0.01	< 0.002	< 0.002	< 0.002	< 0.001	0.08	0.1	0.049
1440556	268/fk_28_158_13.9	158	13.9	5.2									
1440557	268/fk_28_159_0.5	159	0.5	3.3	0.009	0.008	< 0.002	< 0.002	< 0.002	< 0.001	0.11	0.11	0.05

OzEstuaries #	SAMPLE ID	GA #	Sample depth (m)	TSM (mg/L)	Total Phosphorus (mg/L)	Dissolved total phosphorus (mg/L as P)	Filtered Reactive Phosphorus (mg/L as P)	Ammonia Nitrogen (mg/L as P)	Nitrogen Oxides (mg/L as P)	Nitrite Nitrogen (mg/L as N)	Dissolved total Nitrogen (mg/L as N)	Total Nitrogen (mg/L as N)	Reactive Silica (mg/L as Si)
1440558	268/fk_28_159_13.9	159	13.9	5.4									
1440559	268/fk_28_160_0.5	160	0.5	3.5	0.007	0.007	0.002	< 0.002	< 0.002	< 0.001	0.09	0.14	0.048
1440560	268/fk_28_160_13.5	160	13.5	3.9	0.005	0.005	< 0.002	< 0.002	< 0.002	< 0.001	0.1	0.1	0.051
1440561	268/fk_28_161_0.5	161	0.5	2	0.006	0.004	< 0.002	< 0.002	< 0.002	< 0.001	0.07	0.1	0.046
1440562	268/fk_28_161_13.2	161	13.2	7.2									
1440563	268/fk_29_162_0.5	162	0.5	13.282									
1440564	268/fk_30_163_0.5	163	0.5	54.72	0.01	0.009	0.008	0.045	0.022	0.018	0.07	0.12	0.26
1440569	268/fk_30_163_6.9	163	6.9	78.095									
1440570	268/fk_30_164_0.5	164	0.5	36.8	0.024	0.01	0.011	< 0.002	0.019	0.003	0.05	0.14	0.22
1440571	268/fk_30_164_6.9	164	6.9	62.791									
1440572	268/fk_30_165_0.5	165	0.5	12.6	0.016	0.011	0.01	< 0.002	0.018	0.003	0.12	0.13	0.22
1440573	268/fk_30_165_7.2	165	7.2	56.364									
1440574	268/fk_30_166_0.5	166	0.5	28.041	0.021	0.01	0.009	< 0.002	0.018	0.003	0.05	0.15	0.23
1440575	268/fk_30_166_7.5	166	7.5	28.533	0.037	0.01	0.009	< 0.002	0.02	0.003	0.05	0.15	0.21
1440576	268/fk_30_167_0.5	167	0.5	41.497	0.023	0.01	0.009	< 0.002	0.017	0.003	0.1	0.12	0.18
1440577	268/fk_30_167_8.1	167	8.1	75									
1440578	268/fk_30_168_0.5	168	0.5	32.542	0.019	0.009	0.007	< 0.002	0.014	0.003	0.09	0.14	0.15
1440579	268/fk_30_168_8.9	168	8.9	63.75	0.03	0.01	0.009	< 0.002	0.018	0.003	0.11	0.14	0.2
1440580	268/fk_30_169_0.5	169	0.5	23.077	0.015	0.007	0.005	< 0.002	0.009	0.002	0.09	0.1	0.13
1440581	268/fk_30_169_9.4	169	9.4	58.312	0.031	0.011	0.009	< 0.002	0.021	0.004	0.1	0.15	0.2
1440582	268/fk_30_170_0.5	170	0.5	26.966	0.02	0.009	0.006	< 0.002	0.009	0.001	0.14	0.15	0.12
1440583	268/fk_30_170_9.8	170	9.8	58.992	0.037	0.015	0.009	< 0.002	0.017	0.003	0.19	0.21	0.19
1440584	268/fk_30_171_0.5	171	0.5	16.905	0.017	0.011	0.007	< 0.002	0.007	0.002	0.13	0.15	0.12
1440585	268/fk_30_171_10	171	10.4	59.344									
1440586	268/fk_30_172_0.5	172	0.5	14.5	0.015	0.009	0.005	< 0.002	0.007	0.001	0.13	0.17	0.12
1440587	268/fk_30_172_9.8	172	9.8	21.818	0.017	0.011	0.006	< 0.002	0.007	< 0.001	0.13	0.16	0.12
1440588	268/fk_30_173_0.5	173	0.5	13.7	0.015	0.008	0.006	< 0.002	0.009	0.002	0.12	0.14	0.13
1440589	268/fk_30_173_8.7	173	8.7	34.519									
1440590	268/fk_31_174_0.5	174	0.5	46.652	0.033	0.016	0.012	< 0.002	0.028	0.003	0.19	0.2	0.25
1440596	268/fk_31_174_5.1	174	5.1	83.266									

OzEstuaries #	SAMPLE ID	GA #	Sample depth (m)	TSM (mg/L)	Total Phosphorus (mg/L)	Dissolved total phosphorus (mg/L as P)	Filtered Reactive Phosphorus (mg/L as P)	Ammonia Nitrogen (mg/L as P)	Nitrogen Oxides (mg/L as P)	Nitrite Nitrogen (mg/L as N)	Dissolved total Nitrogen (mg/L as N)	Total Nitrogen (mg/L as N)	Reactive Silica (mg/L as Si)
1440597	268/fk_31_175_0.5	175	0.5	56.309	0.043	0.016	0.012	0.003	0.029	0.003	0.17	0.2	0.27
1440598	268/fk_31_175_4.8	175	4.8	68.983									
1440599	268/fk_31_176_0.5	176	0.5	46.928	0.037	0.017	0.012	< 0.002	0.026	0.003	0.17	0.2	0.27
1440600	268/fk_31_176_3.9	176	3.9	78	0.045	0.015	0.012	< 0.002	0.023	0.002	0.17	0.22	0.27
1440601	268/fk_31_177_0.5	177	0.5	19.722	0.026	0.017	0.015	0.002	0.028	0.003	0.18	0.19	0.27
1440602	268/fk_31_177_3.9	177	3.9	46.349	0.036	0.014	0.012	< 0.002	0.028	0.003	0.17	0.21	0.28
1440603	268/fk_31_178_0.5	178	0.5	27.8	0.028	0.015	0.012	< 0.002	0.026	0.003	0.17	0.18	0.27
1440604	268/fk_31_178_4.5	178	4.5	41.977									
1440605	268/fk_31_179_0.5	179	0.5	53.521	0.043	0.018	0.012	< 0.002	0.028	0.003	0.19	0.25	0.26
1440606	268/fk_31_179_5.1	179	5.1	86.719									
1440607	268/fk_31_180_0.5	180	0.5	139.77	0.058	0.015	0.012	< 0.002	0.025	0.003	0.17	0.25	0.24
1440608	268/fk_31_180_5.7	180	5.7	135.64									
1440609	268/fk_31_181_0.5	181	0.5	89.381	0.044	0.015	0.01	< 0.002	0.024	0.003	0.19	0.23	0.23
1440610	268/fk_31_181_6	181	6	93.176									
1440611	268/fk_31_182_0.5	182	0.5	89.778	0.045	0.013	0.011	< 0.002	0.023	0.004	0.18	0.23	0.22
1440612	268/fk_31_182_6.6	182	6.6	99.813									
1440613	268/fk_31_183_0.5	183	0.5	71.485	0.044	0.014	0.01	< 0.002	0.02	0.003	0.17	0.24	0.22
1440614	268/fk_31_183_7.2	183	7.2	85.905									
1440615	268/fk_31_184_0.5	184	0.5	60.43	0.036	0.015	0.009	< 0.002	0.02	0.003	0.17	0.19	0.23
1440616	268/fk_31_184_7.2	184	7.2	142.44									
1440617	268/fk_31_185_0.5	185	0.5	45.526	0.029	0.011	0.011	< 0.002	0.016	0.002	0.15	0.17	0.23
1440618	268/fk_31_185_6.9	185	6.9	152.97									
1440619	268/fk_31_186_0.5	186	0.5	76.289	0.036	0.012	0.01	< 0.002	0.021	0.003	0.17	0.2	0.23
1440620	268/fk_31_186_6.2	186	6.2	150.93									
1440621	268/fk_32_187_0.5	187	0.5	33.944	0.027	0.016	0.013	< 0.002	0.028	0.003	0.16	0.17	0.29
1440622	268/fk_33_188_0.5	188	0.5	37.143	0.038	0.014	0.012	< 0.002	0.03	0.003	0.15	0.24	0.31
1440623	268/fk_34_189_0.5	189	0.5	24.6	0.026	0.017	0.014	< 0.002	0.033	0.003	0.16	0.18	0.32
1440624	268/fk_35_190_0.5	190	0.5	84.576	0.056	0.018	0.015	< 0.002	0.037	0.004	0.16	0.26	0.35
1440625	268/fk_36_191_0.5	191	0.5	91.481	0.054	0.016	0.015	< 0.002	0.043	0.004	0.18	0.25	0.39
1440626	268/fk_37_192_0.5	192	0.5	87.107	0.051	0.018	0.016	< 0.002	0.047	0.006	0.21	0.27	0.4

APPENDIX F. BOTTOM SEDIMENT SAMPLES FROM KEPPEL BAY: WET BULK DENSITY AND MINERALOGY.

OzEstauries #	SAMPLE ID	GA #	Wet bulk density	Albite (%)	Anorthite (%)	Greigite (%)	Halloysite (%)	Kaolinite (%)	Microcline (%)	Orthoclase (%)	Quartz (%)	Sanidine (%)	Bulk carbonate (%)
1272991	fk_01_ss	1	2.2	3.20%	1.60%	0.00%	0.30%	0.90%	0.60%	5.40%	85.60%	0.00%	1
1272996	fk_02_ss	2	2.2	2.50%	0.80%	0.00%	0.00%	0.20%	0.20%	6.30%	88.00%	0.20%	1
1273002	fk_03_ss	3	2.4	3.30%	0.00%	0.00%	0.00%	0.10%	1.10%	4.40%	87.20%	0.50%	1
1273010	fk_05_ss	5	1.5	9.20%	1.20%	0.00%	1.70%	6.50%	0.00%	7.80%	63.90%	3.50%	2
1273027	fk_09_ss	9	2.1	2.30%	0.90%	2.20%	0.00%	0.50%	0.40%	4.90%	60.00%	0.00%	41
1273037	fk_10_ss	10	1.8	11.10%	5.80%	1.70%	0.50%	0.70%	0.70%	7.60%	60.20%	0.10%	13
1273041	fk_11_ss	11	2.1	9.40%	3.30%	2.20%	0.00%	0.30%	0.50%	12.50%	59.30%	1.30%	12
1273053	fk_15_ss	15	1.6	9.30%	1.20%	2.50%	0.40%	0.80%	0.00%	12.90%	42.00%	0.00%	25
1273063	fk_18_ss	18	2.0	4.20%	1.20%	0.60%	0.00%	0.20%	1.80%	6.50%	77.70%	0.00%	10
1273072	fk_21_ss	21	1.7	12.00%	2.60%	0.00%	3.00%	2.80%	0.00%	5.00%	61.90%	0.00%	3
1273077	fk_22_ss	22	2.0	5.60%	0.60%	0.00%	0.20%	0.20%	1.20%	5.20%	78.60%	1.40%	7
1273082	fk_23_ss	23	1.4	12.60%	5.50%	0.00%	1.20%	3.00%	0.00%	4.70%	63.40%	0.20%	3
1273087	fk_24_ss	24	1.7	5.30%	1.10%	0.10%	0.50%	1.60%	0.50%	4.30%	63.90%	0.00%	11
1273266	fk_26_ss	26	1.6	16.70%	5.80%	0.00%	3.30%	3.00%	0.00%	8.80%	55.20%	2.30%	3
1273103	fk_30_ss	30	2.3	5.40%	0.00%	0.40%	0.00%	0.40%	0.00%	5.40%	64.80%	0.00%	22
1273111	fk_32_ss	32	1.8	6.80%	0.00%	1.30%	1.50%	1.10%	0.00%	10.10%	66.40%	0.00%	17
1273119	fk_34_ss	34	1.6	12.70%	10.90%	2.20%	0.80%	1.30%	0.20%	8.30%	53.10%	0.30%	9
1273125	fk_35_ss	35	2.1	3.30%	1.20%	2.20%	0.00%	0.20%	1.70%	5.60%	68.00%	0.10%	24
1273135	fk_38_ss	38	2.3	4.70%	2.60%	2.80%	0.00%	0.40%	0.00%	11.20%	58.10%	2.30%	16
1273143	fk_40_ss	40	2.2	3.00%	0.70%	0.10%	0.00%	0.00%	1.40%	2.50%	88.10%	1.90%	3
1273151	fk_42_ss	42	2.0	7.60%	1.70%	1.10%	0.00%	0.10%	0.40%	6.20%	75.50%	0.70%	12
1273158	fk_44_ss	44	2.2	4.70%	0.90%	1.40%	1.00%	1.20%	0.00%	3.50%	76.80%	0.00%	5
1273164	fk_45_ss	45	2.0	7.90%	0.80%	2.10%	0.10%	0.40%	0.00%	6.10%	56.40%	0.00%	25
1273168	fk_46_ss	46	2.1	6.80%	0.00%	0.90%	0.80%	1.10%	0.00%	3.10%	75.90%	0.40%	14
1273176	fk_48_ss	48	2.1	2.50%	0.00%	0.20%	0.00%	0.30%	0.60%	3.80%	88.70%	0.50%	5
1273184	fk_50_ss	50	2.1	5.90%	0.30%	1.70%	0.00%	0.40%	0.00%	3.80%	74.40%	0.00%	21
1273186	fk_51_ss	51	2.1	4.20%	1.60%	0.60%	0.00%	0.70%	1.50%	3.50%	83.30%	1.10%	7
1273188	fk_52_ss	52	2.2	1.50%	0.00%	0.30%	0.00%	0.10%	1.00%	0.00%	88.30%	3.50%	5
1273190	fk_53_ss	53	2.1	0.80%	0.00%	0.00%	0.00%	0.20%	3.70%	0.80%	90.00%	0.10%	3
1273194	fk_55_ss	55	2.0	2.60%	0.00%	0.90%	0.00%	0.40%	3.00%	4.30%	79.30%	1.10%	7

OzEstauries #	SAMPLE ID	GA #	Wet bulk density	Albite (%)	Anorthite (%)	Greigite (%)	Halloysite (%)	Kaolinite (%)	Microcline (%)	Orthoclase (%)	Quartz (%)	Sanidine (%)	Bulk carbonate (%)
1273196	fk_56_ss	56	2.2	5.00%	0.00%	0.30%	0.00%	0.10%	5.00%	4.60%	75.00%	1.70%	7
1273198	fk_57_ss	57	2.3	3.70%	0.60%	0.00%	0.00%	0.10%	2.30%	4.80%	83.20%	0.00%	8
1273200	fk_58_ss	58	2.1	4.30%	1.30%	0.50%	0.60%	0.80%	1.90%	3.80%	71.80%	0.00%	16
1273203	fk_59_ss	59	2.0	4.40%	2.10%	1.10%	0.70%	0.30%	1.20%	5.80%	67.40%	0.00%	16
1273206	fk_60_ss	60	2.0	1.40%	0.80%	0.30%	0.00%	0.10%	1.10%	3.30%	84.70%	0.00%	9
1273209	fk_61_ss	61	2.0	5.80%	2.10%	0.50%	0.60%	0.70%	1.50%	4.60%	73.40%	1.40%	14
1273212	fk_62_ss	62	1.9	12.60%	2.30%	1.80%	2.00%	1.20%	0.30%	5.40%	52.80%	0.50%	22
1273217	fk_63_ss	63	1.6	14.80%	0.00%	0.00%	2.50%	4.80%	0.00%	4.90%	58.20%	1.30%	2
1273220	fk_64_ss	64	1.7	15.90%	1.80%	0.90%	0.90%	1.10%	6.10%	2.40%	49.60%	0.00%	12
1273223	fk_65_ss	65	1.8	11.70%	3.80%	0.00%	2.50%	1.80%	1.70%	5.10%	60.60%	0.20%	17
1273226	fk_66_ss	66	1.9	10.20%	4.00%	0.00%	0.70%	0.90%	0.10%	6.30%	50.80%	0.40%	27
1273229	fk_67_ss	67	2.2										10
1273232	fk_68_ss	68	2.2	3.50%	0.00%	0.00%	0.00%	0.30%	0.00%	6.40%	74.70%	0.80%	17
1273235	fk_69_ss	69	2.2	6.80%	1.40%	0.00%	0.00%	0.30%	1.00%	5.60%	73.60%	1.60%	13
1273238	fk_70_ss	70	2.1	4.70%	2.70%	0.00%	0.10%	0.80%	0.00%	8.40%	78.30%	2.00%	6
1273241	fk_71_ss	71	1.8	11.10%	0.00%	0.00%	0.50%	0.90%	0.00%	10.20%	59.60%	1.60%	16
1273243	fk_72_ss	72	2.0	8.80%	2.90%	0.00%	0.10%	0.50%	0.00%	11.90%	49.80%	2.60%	23
1440102	268/fk_1_85_A	85	1.9	0.80%	0.20%	0.00%	0.00%	0.20%	0.00%	0.00%	89.40%	0.00%	6.01
1440103	268/fk_2_98_A	98	1.9	3.30%	0.30%	0.00%	0.00%	0.60%	0.00%	1.80%	66.70%	0.00%	12.1
1440104	268/fk_3_110_A	110	1.6	2.80%	2.00%	0.00%	0.00%	0.60%	0.60%	4.40%	74.10%	0.00%	11.09
1440105	268/fk_4_119_A	119	1.7	1.90%	1.60%	0.00%	0.00%	1.00%	4.00%	3.20%	78.40%	0.00%	10.07
1440106	268/fk_5_120_A	120	1.8	3.50%	0.30%	0.00%	0.00%	0.60%	3.60%	4.00%	68.50%	0.00%	13.11
1440107	268/fk_6_121_A	121	1.8	2.80%	0.20%	0.00%	0.00%	2.80%	5.00%	4.40%	71.40%	0.00%	14.13
1440108	268/fk_7_122_A	122	1.8	1.00%	3.00%	0.00%	0.00%	0.20%	1.20%	3.00%	68.80%	0.00%	19.2
1440109	268/fk_8_123_A	123	1.8	1.90%	1.00%	0.00%	0.00%	0.20%	3.60%	3.00%	83.50%	0.00%	8.55
1440110	268/fk_9_124_A	124	1.6	3.90%	5.10%	0.00%	0.00%	0.80%	5.20%	4.00%	69.10%	0.00%	6.01
1440111	268/fk_10_125_A	125	1.9	1.40%	0.30%	0.00%	0.00%	0.40%	4.60%	1.20%	90.60%	0.00%	2.97
1440112	268/fk_11_126_A	126	1.9	0.90%	0.60%	0.00%	0.00%	0.20%	3.40%	1.40%	92.60%	0.00%	3.47
1440113	268/fk_12_127_A	127	1.9	2.10%	0.10%	0.00%	0.00%	1.00%	7.20%	1.00%	74.80%	0.00%	9.56
1440114	268/fk_13_128_A	128	1.8	2.10%	1.00%	0.00%	0.00%	0.40%	4.00%	11.40%	75.30%	0.00%	7.03
1440115	268/fk_14_129_A	129	1.4	3.60%	2.10%	0.00%	0.00%	2.00%	2.40%	10.80%	59.60%	0.00%	6.01

OzEstauries #	SAMPLE ID	GA #	Wet bulk density	Albite (%)	Anorthite (%)	Greigite (%)	Halloysite (%)	Kaolinite (%)	Microcline (%)	Orthoclase (%)	Quartz (%)	Sanidine (%)	Bulk carbonate (%)
1440116	268/fk_15_130_A	130	1.8	3.30%	0.00%	0.00%	0.00%	1.60%	3.00%	13.20%	66.50%	2.40%	9.06
1440117	268/fk_16_131_A	131	1.7	3.00%	0.00%	0.00%	0.00%	0.60%	2.40%	7.40%	70.90%	0.80%	10.07
1440118	268/fk_17_132_A	132	1.9	2.30%	2.80%	0.00%	0.00%	0.20%	3.40%	11.20%	76.40%	1.80%	5
1440119	268/fk_18_133_A	133	1.8	2.60%	2.70%	0.00%	0.00%	0.40%	5.60%	10.80%	73.40%	2.00%	4.49
1440120	268/fk_19_134_A	134	1.6	3.50%	0.00%	0.00%	0.00%	1.40%	4.20%	12.00%	54.20%	0.00%	19.2
1440121	268/fk_20_135_A	135	1.8	0.50%	0.00%	0.00%	0.00%	0.20%	1.00%	8.60%	88.50%	4.00%	5.5
1440122	268/fk_21_136_A	136	1.8	1.10%	0.00%	0.00%	0.00%	0.40%	3.00%	11.20%	86.00%	0.00%	3.98
1440123	268/fk_22_137_A	137	1.9	0.60%	0.00%	0.00%	0.00%	0.20%	1.80%	9.60%	83.30%	0.00%	12.1
1440124	268/fk_23_138_A	138	1.9	0.60%	0.00%	0.00%	0.00%	0.20%	1.60%	13.60%	87.00%	0.60%	5.5
1440125	268/fk_24_139_A	139	1.9	0.90%	0.00%	0.00%	0.00%	0.20%	1.20%	12.20%	85.20%	0.20%	7.03
1440126	268/fk_25_140_A	140	1.7	1.30%	0.00%	0.00%	0.00%	1.20%	2.60%	13.60%	79.50%	0.00%	10.07
1440127	268/fk_26_141_A	141	1.9	1.50%	0.50%	0.00%	0.20%	1.00%	1.80%	13.60%	74.80%	1.00%	9.56
1440128	268/fk_27_151_A	151	1.7	2.30%	2.60%	0.00%	0.20%	0.40%	5.20%	14.00%	71.70%	2.40%	3.98
1440129	268/fk_29_162_A	162	2.0	3.60%	0.00%	0.00%	0.00%	1.60%	2.40%	6.60%	67.90%	0.00%	12.1
1440135	268/fk_30_165_A	165	1.5	2.50%	1.50%	0.00%	0.40%	2.00%	2.60%	12.00%	73.50%	0.20%	2.97
1441011	268/fk_31_183_A	183	2.1	0.80%	0.10%	0.00%	0.00%	1.20%	1.60%	11.20%	87.20%	0.00%	1.95
1440141	268/fk_32_187_A	187	1.6	1.50%	0.70%	0.00%	0.60%	1.60%	2.00%	11.40%	79.70%	0.00%	1.95
1440142	268/fk_33_188_A	188	2.0	1.30%	0.00%	0.00%	0.00%	0.80%	4.00%	16.20%	83.20%	0.00%	0.94
1440143	268/fk_34_189_A	189	1.7	2.50%	2.00%	0.00%	1.60%	2.20%	2.20%	16.60%	72.40%	0.40%	0
1440144	268/fk_35_190_A	190	1.8	2.60%	0.00%	0.00%	1.40%	2.60%	3.40%	7.20%	43.50%	0.00%	19.2
1440145	268/fk_36_191_A	191	1.9	2.70%	0.00%	0.00%	0.20%	1.20%	1.00%	19.20%	80.50%	0.00%	0
1440146	268/fk_37_192_A	192	1.4	3.30%	4.30%	0.00%	4.80%	4.40%	3.60%	19.00%	58.10%	2.40%	0
1440147	268/fk_38_193_A	193	1.8	2.00%	0.00%	0.00%	0.00%	1.00%	2.20%	12.60%	58.80%	0.00%	22.25
1440148	268/fk_39_194_A	194	2.0	3.00%	0.00%	0.00%	0.00%	0.00%	4.00%	10.00%	64.00%	0.00%	21.74
1440149	268/fk_40_195_A	195	2.0	1.20%	0.00%	0.00%	0.00%	0.40%	1.60%	16.00%	80.30%	0.00%	10.07
1440150	277/fk_vc01_196	196	2.1	2.00%	0.10%	0.00%	0.00%	0.80%	4.20%	14.80%	75.50%	0.00%	9.56
1440163	277/fk_vc02_197	197	1.9	1.60%	0.90%	0.00%	0.00%	0.40%	3.20%	13.80%	81.80%	0.60%	3.47
1440164	277/fk_vc03_198	198	1.9	3.00%	1.70%	0.00%	0.00%	1.20%	5.80%	13.20%	60.70%	0.00%	14.13
1440177	277/fk_vc04_199	199	1.8	3.70%	1.00%	0.00%	0.00%	1.60%	2.40%	15.20%	51.30%	0.00%	24.78
1440178	277/fk_vc05_200	200	2.1	2.40%	0.00%	0.00%	0.00%	1.00%	4.60%	16.60%	71.60%	0.00%	10.07
1440179	277/fk_vc06_201	201	2.1	1.40%	0.90%	0.00%	0.20%	0.60%	3.00%	19.60%	79.50%	0.00%	7.03

OzEstauries #	SAMPLE ID	GA #	Wet bulk density	Albite (%)	Anorthite (%)	Greigite (%)	Halloysite (%)	Kaolinite (%)	Microcline (%)	Orthoclase (%)	Quartz (%)	Sanidine (%)	Bulk carbonate (%)
1440193	277/fk_vc09_202	202	1.7	1.00%	0.30%	0.00%	0.00%	0.20%	2.00%	18.60%	81.60%	0.00%	8.04
1440194	277/fk_vc13_203	203	1.6	2.70%	0.00%	0.00%	0.00%	0.80%	2.80%	16.40%	66.80%	0.00%	18.19
1440195	277/fk_vc17_204	204	1.6	2.00%	2.20%	0.00%	0.20%	1.00%	1.20%	19.80%	72.50%	0.00%	5
1440196	277/fk_vc20_205	205	1.5	3.00%	2.10%	0.00%	1.20%	1.20%	1.80%	19.60%	67.10%	0.00%	3.98
1438740	KB32A	32a	2.0	2.20%	0.80%	0.00%	0.40%	0.20%	2.80%	14.80%	76.80%	1.80%	4
1438741	KB33A	33a	1.9	2.20%	2.70%	0.00%	0.00%	0.40%	4.80%	17.80%	69.90%	0.80%	5
1438742	KB34A	34a	1.8	4.20%	1.10%	0.00%	0.00%	0.20%	5.00%	17.20%	57.00%	0.20%	14.1
1438743	KB35A	35a	1.7	4.00%	0.80%	0.00%	0.00%	0.80%	0.00%	15.20%	61.50%	0.00%	10.6
1438744	KB36A	36a	1.8	1.80%	2.80%	0.00%	3.80%	3.40%	2.00%	14.40%	62.30%	1.80%	7
1438745	KB37A	37a	1.9	1.70%	1.70%	0.00%	0.00%	0.80%	4.20%	13.40%	71.90%	1.20%	6
1438746	KB38A	38a	1.8	3.30%	2.30%	0.00%	0.00%	1.00%	3.00%	13.60%	59.30%	1.60%	12.1
1438747	KB39A	39a	1.8	1.90%	1.40%	0.00%	0.00%	0.80%	3.60%	12.40%	74.90%	0.40%	4.5
1438748	KB40A	40a	1.7	3.50%	0.00%	0.00%	0.00%	0.20%	3.20%	17.80%	61.20%	1.40%	14.1
1438749	KB41A	41a	1.7	2.90%	0.60%	0.00%	0.00%	0.20%	6.80%	11.40%	77.30%	0.80%	3
1438750	KB42A	42a	1.9	1.90%	1.40%	0.00%	0.00%	1.00%	1.00%	14.40%	76.60%	0.00%	5
1438751	KB43A	43a	1.9	1.50%	0.00%	0.00%	0.20%	1.00%	3.40%	11.00%	80.50%	0.00%	8.5
1438752	KB44A	44a	1.7	0.90%	3.30%	0.00%	0.00%	0.20%	2.00%	10.80%	75.20%	3.40%	6
1438708	CC01A	cc1a	1.8	0.50%	0.30%	0.00%	0.00%	0.20%	6.20%	0.00%	92.50%	0.00%	2
1438712	CC02A	cc2a	1.7	0.70%	0.90%	0.00%	0.00%	0.20%	7.00%	0.40%	86.50%	2.40%	5
1438715	CC03A	cc3a	1.7	1.30%	0.00%	0.00%	0.00%	0.80%	4.60%	8.20%	69.40%	0.00%	26.3
1438718	CC04A	cc4a	1.8	5.00%	2.00%	0.00%	0.00%	0.20%	1.80%	13.40%	78.70%	0.80%	7
1438721	CC05A	cc5a	1.8	4.40%	2.60%	0.00%	0.00%	0.80%	4.20%	14.20%	76.50%	0.00%	8
1438722	CC05A2	cc5a2	1.7	2.30%	0.00%	0.00%	0.00%	0.60%	1.80%	18.20%	65.60%	0.00%	16.2
1438725	CC06A	cc6a	1.9	3.40%	0.10%	0.00%	0.00%	0.60%	3.40%	16.40%	66.80%	0.00%	11.1
1438729	CC07A	cc7a	1.8	2.10%	2.20%	0.00%	0.00%	0.20%	2.00%	18.80%	69.60%	0.20%	6
1438732	CC08A	cc8a	1.8	1.50%	1.60%	0.00%	0.00%	0.20%	4.80%	16.80%	68.80%	0.00%	10.1

APPENDIX G. BOTTOM SEDIMENT SAMPLES FROM KEPPEL BAY: MAJOR ELEMENT OXIDE DATA CONVERTED TO MMOL G^{-1}.

OzEstuaries #	SAMPLE ID	GA #	Al	Ca	Cl	Cr	Cu	totFe	Fe III	Fe II	K	Mg	Mn	Na	Ni	Si	S	Ti	Zn
1272991	fk_01_ss	1	0.64	0.07	0.07	0.001	0.0001	0.15	0.15	0.00	0.14	0.08	0.01	0.24	0.00	15.4	0.01	0.02	0.0001
1272996	fk_02_ss	2	0.38	0.04	0.05	0.000	0.0000	0.08	0.08	0.00	0.13	0.03	0.00	0.18	0.00	15.9	0.01	0.01	0.0000
1273002	fk_03_ss	3	0.40	0.04	0.07	0.000	0.0000	0.09	0.02	0.07	0.14	0.04	0.01	0.22	0.00	15.8	0.01	0.01	0.0000
1273010	fk_05_ss	5	3.35	0.20	0.30	0.002	0.0004	0.87	0.71	0.16	0.40	0.46	0.01	0.65	0.00	9.5	0.11	0.11	0.0012
1273027	fk_09_ss	9	0.53	3.57	0.21	0.000	0.0001	0.20	0.18	0.02	0.12	0.27	0.01	0.35	0.00	9.1	0.04	0.02	0.0001
1273037	fk_10_ss	10	1.52	1.28	0.20	0.001	0.0001	0.36	0.23	0.14	0.29	0.29	0.01	0.60	0.00	11.5	0.03	0.07	0.0004
1273041	fk_11_ss	11	0.97	1.08	0.15	0.000	0.0001	0.21	0.10	0.11	0.26	0.20	0.01	0.49	0.00	13.1	0.02	0.04	0.0002
1273053	fk_15_ss	15	1.78	2.43	0.15	0.001	0.0002	0.44	0.33	0.11	0.26	0.30	0.01	0.53	0.00	8.9	0.03	0.08	0.0006
1273063	fk_18_ss	18	0.44	0.99	0.09	0.000	0.0000	0.13	0.13	0.00	0.15	0.14	0.01	0.24	0.00	14.2	0.01	0.01	0.0000
1273072	fk_21_ss	21	2.95	0.27	0.23	0.001	0.0005	0.79	0.64	0.14	0.34	0.40	0.01	0.63	0.00	10.3	0.04	0.11	0.0011
1273077	fk_22_ss	22	0.74	0.63	0.12	0.000	0.0001	0.23	0.22	0.01	0.18	0.09	0.03	0.32	0.00	14.3	0.04	0.02	0.0002
1273082	fk_23_ss	23	3.19	0.32	0.27	0.002	0.0006	0.84	0.70	0.14	0.35	0.43	0.01	0.70	0.00	9.6	0.05	0.12	0.0012
1273087	fk_24_ss	24	1.95	1.03	0.13	0.001	0.0003	0.69	0.59	0.10	0.23	0.26	0.03	0.40	0.00	10.7	0.12	0.10	0.0006
1273266	fk_26_ss	26	2.98	0.35	0.21	0.002	0.0005	0.77	0.66	0.10	0.36	0.39	0.01	0.71	0.00	10.1	0.06	0.12	0.0011
1273103	fk_30_ss	30	0.64	2.15	0.12	0.001	0.0001	0.22	0.22	0.00	0.14	0.11	0.03	0.30	0.00	11.7	0.03	0.04	0.0002
1273111	fk_32_ss	32	1.28	1.54	0.16	0.001	0.0001	0.36	0.24	0.13	0.24	0.29	0.01	0.42	0.00	11.3	0.03	0.05	0.0004
1273119	fk_34_ss	34	2.41	0.99	0.25	0.001	0.0003	0.57	0.43	0.13	0.33	0.36	0.01	0.76	0.00	10.4	0.06	0.11	0.0008
1273125	fk_35_ss	35	0.43	2.14	0.14	0.000	0.0001	0.20	0.20	0.00	0.12	0.20	0.01	0.27	0.00	11.7	0.02	0.02	0.0001
1273135	fk_38_ss	38	0.70	1.48	0.15	0.000	0.0001	0.21	0.21	0.00	0.20	0.21	0.01	0.35	0.00	12.7	0.02	0.04	0.0002
1273143	fk_40_ss	40	0.45	0.30	0.12	0.000	0.0000	0.09	0.09	0.00	0.15	0.08	0.01	0.25	0.00	15.3	0.01	0.01	0.0000
1273151	fk_42_ss	42	0.60	1.09	0.15	0.000	0.0000	0.11	0.11	0.00	0.20	0.14	0.00	0.34	0.00	13.8	0.02	0.02	0.0001
1273158	fk_44_ss	44	0.49	0.45	0.13	0.000	0.0000	0.14	0.14	0.00	0.17	0.10	0.01	0.25	0.00	15.0	0.01	0.02	0.0000
1273164	fk_45_ss	45	0.80	2.32	0.16	0.000	0.0000	0.23	0.16	0.07	0.16	0.20	0.01	0.38	0.00	10.9	0.03	0.04	0.0003
1273168	fk_46_ss	46	1.05	1.23	0.14	0.001	0.0001	0.27	0.14	0.14	0.20	0.20	0.00	0.34	0.00	12.4	0.02	0.06	0.0003
1273176	fk_48_ss	48	0.25	0.40	0.13	0.000	0.0000	0.07	0.07	0.00	0.09	0.08	0.00	0.18	0.00	15.6	0.01	0.03	0.0000
1273184	fk_50_ss	50	0.42	1.84	0.12	0.000	0.0000	0.11	0.11	0.00	0.13	0.17	0.00	0.25	0.00	12.5	0.02	0.02	0.0000
1273186	fk_51_ss	51	0.50	0.60	0.12	0.000	0.0001	0.09	0.09	0.00	0.17	0.10	0.00	0.28	0.00	14.8	0.01	0.02	0.0001
1273188	fk_52_ss	52	0.23	0.43	0.13	0.001	0.0000	0.07	0.07	0.00	0.08	0.08	0.00	0.18	0.00	15.3	0.01	0.04	0.0000
1273190	fk_53_ss	53	0.20	0.38	0.14	0.000	0.0000	0.06	0.06	0.00	0.06	0.07	0.00	0.18	0.00	15.7	0.01	0.03	0.0000

OzEstuaries #	SAMPLE ID	GA #	Al	Ca	Cl	Cr	Cu	totFe	Fe III	Fe II	K	Mg	Mn	Na	Ni	Si	S	Ti	Zn
1273194	fk_55_ss	55	0.38	0.65	0.11	0.000	0.0000	0.06	0.06	0.00	0.13	0.11	0.00	0.21	0.00	14.9	0.01	0.02	0.0000
1273196	fk_56_ss	56	0.63	0.67	0.16	0.000	0.0000	0.15	0.15	0.00	0.20	0.14	0.01	0.32	0.00	14.4	0.01	0.02	0.0001
1273198	fk_57_ss	57	0.57	0.67	0.14	0.000	0.0001	0.15	0.01	0.15	0.18	0.12	0.01	0.28	0.00	14.4	0.01	0.03	0.0001
1273200	fk_58_ss	58	0.80	1.53	0.17	0.001	0.0000	0.23	0.14	0.09	0.17	0.17	0.00	0.32	0.00	12.4	0.02	0.05	0.0002
1273203	fk_59_ss	59	0.76	1.45	0.16	0.001	0.0000	0.24	0.14	0.11	0.18	0.17	0.01	0.33	0.00	12.4	0.02	0.07	0.0003
1273206	fk_60_ss	60	0.30	0.87	0.11	0.000	0.0000	0.18	0.17	0.01	0.09	0.09	0.01	0.18	0.00	14.5	0.01	0.03	0.0000
1273209	fk_61_ss	61	0.94	1.11	0.12	0.001	0.0001	0.33	0.27	0.06	0.20	0.20	0.01	0.36	0.00	12.7	0.02	0.06	0.0003
1273212	fk_62_ss	62	1.50	2.09	0.11	0.001	0.0001	0.41	0.32	0.09	0.25	0.27	0.01	0.51	0.00	10.2	0.03	0.08	0.0006
1273217	fk_63_ss	63	3.46	0.33	0.52	0.002	0.0006	0.92	0.79	0.13	0.38	0.51	0.01	0.93	0.00	8.7	0.06	0.12	0.0013
1273220	fk_64_ss	64	1.76	1.22	0.15	0.001	0.0002	0.43	0.34	0.09	0.28	0.27	0.01	0.61	0.00	11.1	0.03	0.10	0.0006
1273223	fk_65_ss	65	1.74	1.52	0.14	0.001	0.0003	0.46	0.39	0.07	0.27	0.29	0.01	0.53	0.00	10.5	0.02	0.08	0.0006
1273226	fk_66_ss	66	1.58	2.59	0.17	0.001	0.0001	0.43	0.33	0.11	0.25	0.29	0.01	0.55	0.00	9.2	0.03	0.08	0.0006
1273229	fk_67_ss	67	0.75	0.88	0.12	0.001	0.0000	0.25	0.17	0.07	0.20	0.17	0.01	0.34	0.00	13.6	0.01	0.06	0.0002
1273232	fk_68_ss	68	0.49	1.49	0.11	0.001	0.0000	0.27	0.19	0.08	0.13	0.21	0.01	0.26	0.00	12.9	0.02	0.05	0.0001
1273235	fk_69_ss	69	0.50	1.16	0.11	0.000	0.0000	0.15	0.12	0.03	0.15	0.15	0.01	0.28	0.00	13.6	0.02	0.02	0.0001
1273238	fk_70_ss	70	0.70	0.51	0.12	0.000	0.0000	0.18	0.14	0.04	0.19	0.14	0.01	0.33	0.00	14.5	0.01	0.03	0.0001
1273241	fk_71_ss	71	1.31	1.56	0.14	0.001	0.0002	0.34	0.21	0.13	0.24	0.24	0.01	0.46	0.00	11.2	0.03	0.07	0.0004
1273243	fk_72_ss	72	1.08	2.08	0.13	0.001	0.0002	0.29	0.18	0.11	0.22	0.22	0.01	0.46	0.00	10.9	0.02	0.05	0.0003
1440102	268/fk_1_85_A	85	0.51	0.68	0.06	0.000	0.0001	0.21	0.20	0.01	0.15	0.13	0.01	0.21	0.00	14.3	0.01	0.04	0.0001
1440103	268/fk_2_98_A	98	1.73	1.47	0.13	0.002	0.0005	0.42	0.33	0.09	0.27	0.28	0.01	0.64	0.00	10.5	0.03	0.11	0.0005
1440104	268/fk_3_110_A	110	1.15	1.33	0.12	0.001	0.0003	0.27	0.18	0.09	0.25	0.23	0.01	0.48	0.00	11.8	0.03	0.07	0.0003
1440105	268/fk_4_119_A	119	1.05	1.25	0.11	0.001	0.0001	0.25	0.19	0.06	0.22	0.21	0.00	0.39	0.00	12.2	0.02	0.05	0.0003
1440106	268/fk_5_120_A	120	1.44	1.57	0.16	0.001	0.0002	0.36	0.28	0.08	0.26	0.29	0.01	0.47	0.00	10.8	0.03	0.07	0.0004
1440107	268/fk_6_121_A	121	1.30	1.55	0.14	0.001	0.0002	0.33	0.27	0.06	0.24	0.25	0.01	0.41	0.00	11.1	0.02	0.06	0.0004
1440108	268/fk_7_122_A	122	1.10	2.27	0.13	0.001	0.0002	0.37	0.30	0.08	0.20	0.28	0.01	0.37	0.00	10.2	0.03	0.06	0.0004
1440109	268/fk_8_123_A	123	0.57	1.11	0.06	0.001	0.0001	0.30	0.25	0.05	0.15	0.20	0.01	0.22	0.00	13.1	0.01	0.05	0.0002
1440110	268/fk_9_124_A	124	1.78	0.92	0.17	0.001	0.0004	0.41	0.33	0.08	0.32	0.30	0.01	0.64	0.00	11.5	0.03	0.06	0.0005
1440111	268/fk_10_125_A	125	0.41	0.32	0.06	0.000	0.0001	0.08	0.08	0.01	0.15	0.06	0.00	0.17	0.00	15.2	0.01	0.01	0.0000
1440112	268/fk_11_126_A	126	0.35	0.45	0.07	0.000	0.0001	0.09	0.03	0.05	0.12	0.07	0.01	0.16	0.00	15.1	0.01	0.01	0.0000
1440113	268/fk_12_127_A	127	1.06	1.27	0.13	0.001	0.0002	0.29	0.24	0.06	0.21	0.21	0.01	0.40	0.00	12.1	0.02	0.07	0.0004
1440114	268/fk_13_128_A	128	1.07	0.88	0.12	0.001	0.0002	0.25	0.21	0.04	0.29	0.22	0.01	0.49	0.00	13.0	0.02	0.04	0.0003
1440115	268/fk_14_129_A	129	2.32	0.88	0.24	0.002	0.0005	0.57	0.48	0.09	0.31	0.35	0.01	0.78	0.00	10.2	0.06	0.11	0.0008

OzEstuaries #	SAMPLE ID	GA #	Al	Ca	Cl	Cr	Cu	totFe	Fe III	Fe II	K	Mg	Mn	Na	Ni	Si	S	Ti	Zn
1440116	268/fk_15_130_A	130	1.53	1.21	0.12	0.002	0.0003	0.41	0.34	0.07	0.26	0.25	0.01	0.49	0.00	11.5	0.03	0.10	0.0006
1440117	268/fk_16_131_A	131	1.28	1.29	0.10	0.002	0.0002	0.38	0.36	0.02	0.24	0.21	0.01	0.49	0.00	11.6	0.02	0.12	0.0005
1440118	268/fk_17_132_A	132	1.11	0.68	0.09	0.000	0.0002	0.22	0.17	0.05	0.26	0.16	0.01	0.49	0.00	13.5	0.01	0.06	0.0002
1440119	268/fk_18_133_A	133	1.20	0.66	0.13	0.001	0.0001	0.27	0.20	0.07	0.28	0.18	0.01	0.56	0.00	13.1	0.02	0.11	0.0003
1440120	268/fk_19_134_A	134	1.85	1.95	0.15	0.001	0.0003	0.50	0.43	0.07	0.27	0.36	0.02	0.56	0.00	9.4	0.04	0.09	0.0007
1440121	268/fk_20_135_A	135	0.48	0.57	0.09	0.000	0.0002	0.19	0.18	0.01	0.15	0.12	0.01	0.22	0.00	14.3	0.01	0.02	0.0001
1440122	268/fk_21_136_A	136	0.57	0.50	0.10	0.000	0.0002	0.16	0.09	0.06	0.18	0.12	0.01	0.25	0.00	14.6	0.01	0.03	0.0001
1440123	268/fk_22_137_A	137	0.21	1.30	0.04	0.000	0.0000	0.06	0.04	0.03	0.07	0.12	0.00	0.09	0.00	13.8	0.02	0.02	0.0000
1440124	268/fk_23_138_A	138	0.35	0.66	0.05	0.000	0.0000	0.09	0.06	0.03	0.12	0.10	0.00	0.13	0.00	14.8	0.01	0.02	0.0000
1440125	268/fk_24_139_A	139	0.48	0.80	0.08	0.000	0.0001	0.09	0.08	0.01	0.16	0.11	0.00	0.21	0.00	14.2	0.01	0.02	0.0000
1440126	268/fk_25_140_A	140	0.57	1.09	0.09	0.000	0.0000	0.11	0.10	0.01	0.17	0.15	0.00	0.26	0.00	13.5	0.02	0.02	0.0001
1440127	268/fk_26_141_A	141	1.45	1.07	0.11	0.001	0.0003	0.40	0.32	0.08	0.23	0.25	0.01	0.40	0.00	11.8	0.03	0.09	0.0005
1440128	268/fk_27_151_A	151	1.75	0.61	0.14	0.002	0.0003	0.45	0.36	0.09	0.29	0.27	0.01	0.51	0.00	12.1	0.03	0.10	0.0006
1440129	268/fk_29_162_A	162	1.48	1.38	0.14	0.002	0.0003	0.39	0.30	0.09	0.23	0.24	0.02	0.48	0.00	11.1	0.07	0.06	0.0004
1440135	268/fk_30_165_A	165	2.06	0.46	0.30	0.001	0.0005	0.51	0.44	0.07	0.30	0.29	0.01	0.64	0.00	11.6	0.06	0.09	0.0007
1441011	268/fk_31_183_A	183	0.53	0.24	0.10	0.000	0.0001	0.15	0.14	0.01	0.16	0.07	0.02	0.27	0.00	14.9	0.01	0.02	0.0001
1440141	268/fk_32_187_A	187	1.82	0.30	0.20	0.001	0.0004	0.48	0.42	0.06	0.27	0.24	0.01	0.51	0.00	12.4	0.04	0.07	0.0007
1440142	268/fk_33_188_A	188	0.52	0.13	0.10	0.000	0.0001	0.24	0.16	0.08	0.17	0.06	0.04	0.25	0.00	15.0	0.01	0.01	0.0001
1440143	268/fk_34_189_A	189	2.48	0.25	0.27	0.002	0.0003	0.62	0.54	0.08	0.35	0.34	0.01	0.67	0.00	11.2	0.07	0.10	0.0009
1440144	268/fk_35_190_A	190	2.09	2.22	0.21	0.001	0.0004	0.78	0.72	0.07	0.26	0.29	0.02	0.52	0.00	7.9	0.24	0.08	0.0009
1440145	268/fk_36_191_A	191	0.95	0.15	0.07	0.000	0.0002	0.28	0.22	0.07	0.22	0.07	0.01	0.38	0.00	14.4	0.05	0.02	0.0001
1440146	268/fk_37_192_A	192	3.49	0.10	0.27	0.002	0.0007	0.86	0.81	0.06	0.39	0.39	0.01	0.72	0.00	9.4	0.26	0.13	0.0015
1440147	268/fk_38_193_A	193	0.88	2.49	0.13	0.001	0.0004	0.34	0.29	0.05	0.19	0.26	0.01	0.40	0.00	10.2	0.03	0.06	0.0003
1440148	268/fk_39_194_A	194	0.91	2.38	0.12	0.001	0.0004	0.28	0.24	0.04	0.16	0.21	0.01	0.29	0.00	10.3	0.02	0.05	0.0003
1440149	268/fk_40_195_A	195	0.39	1.18	0.09	0.000	0.0002	0.14	0.14	0.01	0.12	0.10	0.01	0.18	0.00	13.7	0.01	0.02	0.0000
1440150	277/fk_vc01_196	196	0.81	1.20	0.08	0.001	0.0002	0.24	0.19	0.05	0.18	0.16	0.01	0.29	0.00	12.7	0.02	0.06	0.0004
1440163	277/fk_vc02_197	197	0.65	0.50	0.10	0.000	0.0002	0.18	0.17	0.01	0.19	0.12	0.01	0.29	0.00	14.5	0.01	0.02	0.0001
1440164	277/fk_vc03_198	198	1.49	1.78	0.18	0.001	0.0004	0.38	0.30	0.08	0.25	0.25	0.01	0.54	0.00	10.6	0.02	0.09	0.0006
1440177	277/fk_vc04_199	199	1.44	2.67	0.15	0.001	0.0003	0.42	0.35	0.07	0.23	0.27	0.01	0.53	0.00	9.0	0.02	0.09	0.0006
1440178	277/fk_vc05_200	200	0.84	1.26	0.13	0.001	0.0001	0.27	0.22	0.05	0.21	0.18	0.01	0.39	0.00	12.5	0.02	0.05	0.0003
1440179	277/fk_vc06_201	201	0.54	0.84	0.06	0.000	0.0000	0.16	0.14	0.03	0.15	0.13	0.01	0.23	0.00	14.2	0.01	0.04	0.0000
1440193	277/fk_vc09_202	202	0.52	0.87	0.04	0.000	0.0001	0.11	0.10	0.01	0.17	0.13	0.01	0.18	0.00	14.1	0.03	0.02	0.0001

OzEstuaries #	SAMPLE ID	GA #	Al	Ca	Cl	Cr	Cu	totFe	Fe III	Fe II	K	Mg	Mn	Na	Ni	Si	S	Ti	Zn
1440194	277/fk_vc13_203	203	0.92	1.93	0.16	0.001	0.0002	0.30	0.20	0.10	0.22	0.27	0.02	0.37	0.00	11.1	0.02	0.03	0.0002
1440195	277/fk_vc17_204	204	1.48	0.66	0.14	0.002	0.0003	0.46	0.34	0.11	0.25	0.24	0.01	0.47	0.00	12.2	0.03	0.17	0.0005
1440196	277/fk_vc20_205	205	2.25	0.57	0.27	0.002	0.0004	0.59	0.48	0.11	0.31	0.35	0.01	0.65	0.00	11.0	0.05	0.12	0.0009
1438740	KB32A	32a	1.01	0.57	0.10	0.001	0.0003	0.24	0.16	0.07	0.24	0.16	0.01	0.42	0.00	13.8	0.01	0.09	0.0002
1438741	KB33A	33a	1.14	0.81	0.08	0.001	0.0003	0.22	0.16	0.06	0.29	0.17	0.01	0.48	0.00	13.3	0.01	0.06	0.0002
1438742	KB34A	34a	1.45	1.64	0.14	0.001	0.0002	0.31	0.24	0.07	0.28	0.26	0.01	0.64	0.00	11.0	0.02	0.08	0.0004
1438743	KB35A	35a	2.15	1.32	0.24	0.002	0.0003	0.54	0.46	0.08	0.31	0.37	0.01	0.65	0.00	10.0	0.04	0.10	0.0007
1438744	KB36A	36a	1.88	1.00	0.29	0.002	0.0004	0.46	0.38	0.08	0.29	0.29	0.01	0.62	0.00	11.1	0.04	0.10	0.0007
1438745	KB37A	37a	1.52	0.89	0.14	0.001	0.0003	0.43	0.36	0.07	0.26	0.26	0.01	0.43	0.00	12.0	0.03	0.08	0.0007
1438746	KB38A	38a	1.75	1.59	0.16	0.001	0.0004	0.46	0.38	0.08	0.27	0.29	0.01	0.53	0.00	10.3	0.03	0.09	0.0007
1438747	KB39A	39a	1.07	0.74	0.06	0.000	0.0002	0.23	0.18	0.05	0.27	0.18	0.01	0.40	0.00	13.5	0.01	0.04	0.0002
1438748	KB40A	40a	1.16	1.70	0.10	0.000	0.0004	0.24	0.18	0.05	0.31	0.25	0.01	0.48	0.00	11.3	0.02	0.04	0.0002
1438749	KB41A	41a	0.99	0.46	0.06	0.001	0.0002	0.19	0.14	0.05	0.27	0.14	0.01	0.40	0.00	13.9	0.01	0.05	0.0002
1438750	KB42A	42a	1.06	0.83	0.06	0.000	0.0002	0.21	0.15	0.06	0.27	0.16	0.01	0.45	0.00	13.3	0.01	0.06	0.0002
1438751	KB43A	43a	0.72	0.95	0.05	0.000	0.0002	0.16	0.12	0.04	0.21	0.11	0.01	0.28	0.00	13.6	0.01	0.04	0.0001
1438752	KB44A	44a	1.22	0.86	0.06	0.003	0.0002	0.41	0.26	0.15	0.28	0.21	0.01	0.49	0.00	12.5	0.01	0.24	0.0005
1438708	CC01A	cc1a	0.28	0.22	0.05	0.000	0.0000	0.08	0.03	0.05	0.10	0.06	0.00	0.11	0.00	15.7	0.01	0.01	0.0000
1438712	CC02A	cc2a	0.49	0.64	0.03	0.000	0.0001	0.11	0.10	0.01	0.18	0.09	0.00	0.15	0.00	14.6	0.01	0.02	0.0001
1438715	CC03A	cc3a	0.33	2.82	0.02	0.000	0.0000	0.13	0.10	0.03	0.11	0.12	0.01	0.13	0.00	11.0	0.01	0.01	0.0002
1438718	CC04A	cc4a	0.79	0.89	0.06	0.001	0.0002	0.20	0.16	0.05	0.22	0.18	0.01	0.30	0.00	13.5	0.01	0.05	0.0002
1438721	CC05A	cc5a	0.79	0.98	0.07	0.000	0.0001	0.20	0.16	0.03	0.23	0.19	0.01	0.31	0.00	13.2	0.01	0.03	0.0002
1438722	CC05A2	cc5a2	0.86	1.89	0.08	0.000	0.0002	0.23	0.19	0.04	0.25	0.27	0.01	0.34	0.00	11.6	0.02	0.03	0.0002
1438725	CC06A	cc6a	1.11	1.39	0.09	0.000	0.0001	0.21	0.15	0.06	0.26	0.19	0.01	0.49	0.00	12.1	0.02	0.05	0.0002
1438729	CC07A	cc7a	1.16	0.88	0.11	0.001	0.0001	0.26	0.17	0.09	0.29	0.19	0.01	0.55	0.00	12.9	0.02	0.09	0.0003
1438732	CC08A	cc8a	0.96	1.35	0.08	0.000	0.0001	0.22	0.18	0.04	0.28	0.21	0.01	0.40	0.00	12.3	0.02	0.03	0.0002

APPENDIX H. BOTTOM SEDIMENT SAMPLES FROM KEPPEL BAY: %MUD AND NUTRIENTS

OzEstuaries #	SAMPLE ID	GA #	%Mud	TOC (mmol/g)	TN (mmol/g)	XRF P (mmol/g)	QLD digest TP (mmol/g)	MAFRI digest TP (mmol/g)	Org P (mmol/g)	Apatite P (mmol/g)	NAP (mmol/g)	Residual inorg P (mmol/g)
1272991	fk_01_ss	1	7.8	0.051	0.010	0.006	0.005					
1272996	fk_02_ss	2	0.1	0.006	0.002	0.004	0.004					
1273002	fk_03_ss	3	0.2	0.006	0.000	0.005	0.004	0.003	0.001	0.001	0.000	0.000
1273010	fk_05_ss	5	82.4	0.452	0.066	0.017	0.015					
1273027	fk_09_ss	9	8.6	0.063	0.018	0.010	0.009					
1273037	fk_10_ss	10	22.4	0.160	0.027	0.010	0.009	0.009	0.002	0.006	0.000	0.001
1273041	fk_11_ss	11	2.7	0.030	0.010	0.007	0.006	0.005	0.001	0.004	0.000	0.000
1273053	fk_15_ss	15	48.4	0.234	0.040	0.011	0.010	0.010	0.002	0.006	0.000	0.001
1273063	fk_18_ss	18	0.3	0.018	0.008	0.006	0.005					
1273072	fk_21_ss	21	74.8	0.478	0.062	0.015	0.013	0.014	0.004	0.006	0.003	0.002
1273077	fk_22_ss	22	2.3	0.060	0.011	0.008	0.006					
1273082	fk_23_ss	23	91.8	0.501	0.066	0.018	0.014	0.014	0.004	0.007	0.002	0.000
1273087	fk_24_ss	24	56.2	0.392	0.033	0.013	0.011					
1273266	fk_26_ss	26	96.2	0.425	0.053	0.016	0.014	0.015	0.003	0.008	0.002	0.002
1273103	fk_30_ss	30	3.9	0.047	0.011	0.009	0.007					
1273111	fk_32_ss	32	23.3	0.154	0.026	0.013	0.012	0.013	0.003	0.008	0.000	0.002
1273119	fk_34_ss	34	82.4	0.253	0.041	0.013	0.001					
1273125	fk_35_ss	35	0.9	0.020	0.008	0.010	0.009					
1273135	fk_38_ss	38	1.7	0.019	0.010	0.009	0.007					
1273143	fk_40_ss	40	0.5	0.018	0.006	0.005	0.004					
1273151	fk_42_ss	42	0.9	0.029	0.009	0.005	0.005	0.004	0.001	0.002	0.000	0.001
1273158	fk_44_ss	44	0.3	0.019	0.006	0.006	0.006					
1273164	fk_45_ss	45	13.0	0.057	0.015	0.008	0.006					
1273168	fk_46_ss	46	9.0	0.102	0.019	0.008	0.007	0.006	0.002	0.003	0.000	0.001
1273176	fk_48_ss	48	3.2	0.012	0.005	0.004	0.003	0.003	0.001	0.001	0.000	0.001
1273184	fk_50_ss	50	0.7	0.023	0.008	0.006	0.005					
1273186	fk_51_ss	51	0.4	0.015	0.006	0.005	0.004					
1273188	fk_52_ss	52	0.3	0.014	0.005	0.004	0.003	0.002	0.000	0.001	0.000	0.000
1273190	fk_53_ss	53	0.2	0.013	0.005	0.004	0.003	0.003	0.000	0.001	0.000	0.001

OzEstuaries #	SAMPLE ID	GA #	%Mud	TOC (mmol/g)	TN (mmol/g)	XRF P (mmol/g)	QLD digest TP (mmol/g)	MAFRI digest TP (mmol/g)	Org P (mmol/g)	Apatite P (mmol/g)	NAP (mmol/g)	Residual inorg P (mmol/g)
1273194	fk_55_ss	55	0.2	0.012	0.005	0.004	0.004	0.003	0.000	0.002	0.000	0.000
1273196	fk_56_ss	56	3.1	0.025	0.009	0.007	0.006	0.005	0.001	0.003	0.000	0.001
1273198	fk_57_ss	57	1.0	0.019	0.007	0.006	0.006					
1273200	fk_58_ss	58	15.3	0.068	0.014	0.007	0.006					
1273203	fk_59_ss	59	9.7	0.035	0.011	0.008	0.006					
1273206	fk_60_ss	60	2.1	0.014	0.005	0.007	0.006					
1273209	fk_61_ss	61	10.6	0.065	0.014	0.010	0.009					
1273212	fk_62_ss	62	34.3	0.140	0.025	0.010	0.009					
1273217	fk_63_ss	63	96.1	0.579	0.082	0.019	0.016	0.018	0.004	0.007	0.003	0.004
1273220	fk_64_ss	64	46.7	0.176	0.029	0.012	0.009					
1273223	fk_65_ss	65	46.6	0.182	0.032	0.012	0.010	0.011	0.002	0.006	0.000	0.002
1273226	fk_66_ss	66	37.9	0.151	0.028	0.011	0.010					
1273229	fk_67_ss	67	1.6	0.025	0.008	0.008	0.007	0.007	0.002	0.004	0.000	0.001
1273232	fk_68_ss	68	0.9	0.018	0.007	0.010	0.009					
1273235	fk_69_ss	69	0.1	0.010	0.005	0.007	0.006					
1273238	fk_70_ss	70	2.9	0.030	0.010	0.008	0.006	0.006	0.002	0.003	0.000	0.001
1273241	fk_71_ss	71	27.4	0.131	0.022	0.009	0.008	0.008	0.002	0.004	0.000	0.001
1273243	fk_72_ss	72	16.4	0.077	0.016	0.009	0.007					
1440102	268/fk_1_85_A	85	2.0	0.031	0.007	0.008	0.0070968					
1440103	268/fk_2_98_A	98	52.8	0.132	0.026	0.011	0.0091935					
1440104	268/fk_3_110_A	110	5.3	0.094	0.016	0.009	0.0079032					
1440105	268/fk_4_119_A	119	14.0	0.087	0.021	0.009	0.0074194					
1440106	268/fk_5_120_A	120	18.5	0.137	0.032	0.012	0.01					
1440107	268/fk_6_121_A	121	16.9	0.125	0.028	0.011	0.0096774					
1440108	268/fk_7_122_A	122	17.1	0.096	0.025	0.012	0.0103226					
1440109	268/fk_8_123_A	123	1.1	0.017	0.007	0.010	0.0095161					
1440110	268/fk_9_124_A	124	1.5	0.136	0.032	0.012	0.0098387					
1440111	268/fk_10_125_A	125	0.1	0.023	0.005	0.005	0.0037097					
1440112	268/fk_11_126_A	126	0.0	0.035	0.005	0.005	0.0043548					
1440113	268/fk_12_127_A	127	10.4	0.068	0.016	0.009	0.0074194					
1440114	268/fk_13_128_A	128	0.7	0.027	0.009	0.008	0.0069355					

OzEstuaries #	SAMPLE ID	GA #	%Mud	TOC (mmol/g)	TN (mmol/g)	XRF P (mmol/g)	QLD digest TP (mmol/g)	MAFRI digest TP (mmol/g)	Org P (mmol/g)	Apatite P (mmol/g)	NAP (mmol/g)	Residual inorg P (mmol/g)
1440115	268/fk_14_129_A	129	54.0	0.243	0.053	0.015	0.0117742					
1440116	268/fk_15_130_A	130	27.7	0.117	0.025	0.012	0.008871					
1440117	268/fk_16_131_A	131	31.4	0.071	0.019	0.011	0.0093548					
1440118	268/fk_17_132_A	132	12.4	0.050	0.010	0.007	0.0066129					
1440119	268/fk_18_133_A	133	2.7	0.029	0.009	0.008	0.0074194					
1440120	268/fk_19_134_A	134	4.2	0.188	0.041	0.016	0.0133871					
1440121	268/fk_20_135_A	135	0.8	0.025	0.007	0.008	0.0077419					
1440122	268/fk_21_136_A	136	0.3	0.025	0.006	0.007	0.0072581					
1440123	268/fk_22_137_A	137	1.2	0.019	0.005	0.005	0.0043548					
1440124	268/fk_23_138_A	138	0.5	0.027	0.005	0.005	0.0041935					
1440125	268/fk_24_139_A	139	0.9	0.031	0.008	0.005	0.0041935					
1440126	268/fk_25_140_A	140	1.2	0.042	0.011	0.007	0.0056452					
1440127	268/fk_26_141_A	141	21.7	0.130	0.026	0.012	0.0091935					
1440128	268/fk_27_151_A	151	47.5	0.166	0.032	0.012	0.0095161					
1440129	268/fk_29_162_A	162	26.7	0.158	0.023	0.011	0.0098387					
1440135	268/fk_30_165_A	165	33.4	0.220	0.035	0.013	0.0112903					
1441011	268/fk_31_183_A	183	1.1	0.033	0.007	0.007	0.0059677					
1440141	268/fk_32_187_A	187	33.5	0.200	0.035	0.013	0.0106452					
1440142	268/fk_33_188_A	188	1.1	0.032	0.006	0.011	0.0093548					
1440143	268/fk_34_189_A	189	47.2	0.255	0.040	0.015	0.0120968					
1440144	268/fk_35_190_A	190	42.3	0.393	0.037	0.015	0.0133871					
1440145	268/fk_36_191_A	191	4.8	0.245	0.018	0.011	0.0098387					
1440146	268/fk_37_192_A	192	79.1	0.500	0.040	0.014	0.0114516					
1440147	268/fk_38_193_A	193	10.4	0.063	0.017	0.013	0.0103226					
1440148	268/fk_39_194_A	194	7.5	0.090	0.021	0.010	0.008871					
1440149	268/fk_40_195_A	195	19.5	0.032	0.007	0.007	0.0058065					
1440150	277/fk_vc01_196	196	4.8	0.056	0.012	0.011	0.008871					
1440163	277/fk_vc02_197	197	0.4	0.069	0.005	0.007	0.0053226					
1440164	277/fk_vc03_198	198	38.3	0.011	0.023	0.011	0.0082258					
1440177	277/fk_vc04_199	199	27.6	0.211	0.028	0.011	0.008871					
1440178	277/fk_vc05_200	200	6.3	0.037	0.010	0.008	0.0070968					

OzEstuaries #	SAMPLE ID	GA #	%Mud	TOC (mmol/g)	TN (mmol/g)	XRF P (mmol/g)	QLD digest TP (mmol/g)	MAFRI digest TP (mmol/g)	Org P (mmol/g)	Apatite P (mmol/g)	NAP (mmol/g)	Residual inorg P (mmol/g)
1440179	277/fk_vc06_201	201	0.1	0.019	0.005	0.008	0.0054839					
1440193	277/fk_vc09_202	202	1.8	0.027	0.005	0.006	0.0040323					
1440194	277/fk_vc13_203	203	4.6	0.086	0.024	0.014	0.0108065					
1440195	277/fk_vc17_204	204	29.7	0.163	0.026	0.012	0.0093548					
1440196	277/fk_vc20_205	205	69.0	0.220	0.041	0.014	0.0091935					
1438740	KB32A	32a	3.0	0.028	0.008	0.008	0.0054839					
1438741	KB33A	33a	2.9	0.022	0.006	0.007	0.0048387					
1438742	KB34A	34a	31.8	0.055	0.015	0.010	0.0070968					
1438743	KB35A	35a	37.9	0.201	0.043	0.014	0.0109677					
1438744	KB36A	36a	47.9	0.156	0.029	0.012	0.0082258					
1438745	KB37A	37a	25.7	0.124	0.003	0.011	0.0085484					
1438746	KB38A	38a	40.7	0.155	0.031	0.012	0.008871					
1438747	KB39A	39a	2.2	0.029	0.008	0.007	0.0053226					
1438748	KB40A	40a	1.5	0.027	0.008	0.009	0.0079032					
1438749	KB41A	41a	1.3	0.034	0.006	0.007	0.0051613					
1438750	KB42A	42a	1.6	0.019	0.006	0.007	0.0059677					
1438751	KB43A	43a	0.5	0.025	0.004	0.006	0.0048387					
1438752	KB44A	44a	2.5	0.020	0.008	0.010	0.0077419					
1438708	CC01A	cc1a	0.0	0.017	0.002	0.005	0.003					
1438712	CC02A	cc2a	0.0	0.016	0.005	0.005	0.0037097					
1438715	CC03A	cc3a	0.0	0.009	0.005	0.006	0.0045161					
1438718	CC04A	cc4a	0.4	0.014	0.005	0.007	0.0062903					
1438721	CC05A	cc5a	0.4	0.021	0.008	0.008	0.0064516					
1438722	CC05A2	cc5a2	0.5	0.030	0.007	0.010	0.0075806					
1438725	CC06A	cc6a	2.1	0.023	0.006	0.007	0.0054839					
1438729	CC07A	cc7a	1.5	0.035	0.008	0.008	0.006129					
1438732	CC08A	cc8a	0.6	0.043	0.010	0.009	0.0069355					