DEVELOPING A MONITORING PROGRAM FOR SIX KEY ESTUARIES IN NORTH-WEST TASMANIA

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August 2008

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Summary

Given the economic, social and environmental importance of estuaries in NW Tasmania there is a need for baseline and ongoing assessment of estuarine condition. With an appropriate monitoring program, managers can use the information gathered to underpin better management decisions, targeting any problem areas and thereby maintain or improve the condition of estuaries in the region.

We implemented a monitoring program developed by Crawford and White (2006), which was designed to assess the current condition of six key estuaries in NW Tasmania: Port Sorell, the Leven, Inglis, Black, Montagu and Arthur River estuaries. This study considered a range of water quality and ecological indictors commonly used to monitor estuaries. These included: salinity, temperature, dissolved oxygen, turbidity, pH, nutrients (nitrate + nitrite, dissolved reactive phosphorus and ammonia), silica molybdate reactive and chlorophyll *a* for the water column; chlorophyll *a* and macroinvertebrate community structure amongst the sediments. Baseline data were collected from each estuary and showed that water quality varied significantly between estuaries, and over seasons. Generally estuaries with lower water quality had the greatest degree of urban development and catchment disturbance.

In terms of water quality the Arthur River recorded the lowest levels of nutrients and chlorophyll *a* over the sampling period; however, bottom water dissolved oxygen levels were disturbingly low over the summer/autumn period. Whether this is a natural phenomenon or due to human activities in the catchment is not known. The Black River, which has high conservation significance (Edgar *et al.,* 1999), remains in good condition ecologically; however, nitrate levels appear to be on the increase. The Leven, Inglis, Montagu and Port Sorell estuaries showed signs of reduced water quality, particularly in the upper estuary during winter and spring when catchment input was greatest. During summer and autumn, the upper regions of the Leven, Inglis and Montagu River estuaries recorded chlorophyll *a* levels two-four times above recommended guidelines. The Montagu River estuary had significantly elevated nitrate and phosphate levels, well above acceptable levels for most of the year.

In NW Tasmanian estuaries that enter Bass Strait the impact of high nutrient levels is significantly reduced by the large tidal range (2-3m). It was most notable in the lower regions of these estuaries, where nutrients and phytoplankton levels were found at more diluted levels. The high rates of tidal exchange effectively flush the lower reaches of these estuaries, washing nutrients and phytoplankton out to sea.

Despite several of the estuaries showing signs of reduced water quality, the macroinvertebrate communities were relatively healthy. Macroinvertebrate community assemblages varied between estuaries; however whether these differences are more related to geomorphological characteristics of estuaries rather than water quality will require further investigation.

The monitoring program tested in this study has provided valuable baseline information on the condition of NW Tasmanian estuaries. Using these results, we have prepared a monitoring program for future assessment which is restricted to essential indicators of ecosystem health and at a reduced number of sites, in order to minimise costs. We recommend that community and stakeholders are included in the monitoring program to encourage participation, education and awareness raising amongst the general population, thus creating a sense of ownership and responsibility towards their estuary. However, to be most effective a collaborative monitoring program would require a dedicated coordinator to manage the program, analyse results and report to stakeholders.

Table of Contents

Introduction

Estuaries are typically defined as the interface between marine and freshwater systems. They are generally semi-enclosed or periodically closed water bodies that receive sediment, water and nutrients derived from land and sea (Edgar *et al.*, 1999; Heap *et al.*, 2001). As a consequence, anthropogenic activities within a catchment can have significant impacts on the integrity of the estuarine ecosystem and environment (Edgar *et al.*, 1999). Land usage (e.g., agriculture, forestry and urban development) and water quantity (e.g., abstraction for irrigation and domestic water supply) within a catchment have been shown to alter water quality in estuaries (e.g., increased turbidity and nutrient loads, decreased oxygen levels) (Krasnicki, 2002; Kennish, 2002).

There are 38 estuaries in the Cradle Coast Region (Crawford and White, 2006) all varying in environmental condition. Studies by Edgar *et al.* (1999), Murphy *et al.* (2003), Hirst *et al.* (2005, 2007) confirm that some estuaries in North West Tasmania have degraded water quality, particularly those that are surrounded by urban centres and/or those that have catchments which have been modified by anthropogenic activities. This is of concern as these estuaries are important on economic (aquaculture, shipping and tourism), social (fishing, swimming, bird watching, boating or just living beside), and environmental scales.

Despite the economic, environmental and social importance of estuaries in NW Tasmania, they have received little attention and are often overlooked. This is limited by the lack of recognition of the importance of these systems, leading to minimal funding and resources available for environmental assessment. Recognising this problem, NRM Cradle Coast partnered with and provided funds to the Tasmanian Aquaculture and Fisheries Institute (TAFI) to develop a monitoring program for NW Tasmanian estuaries and to collect baseline data.

The first step in this process was to document the relevant information on estuaries in the Cradle Coast region, including climate and geology, water quality data and identified threats, biophysical characteristics, extent of human activities and impacts, groups reliant on estuaries and coastal waters (such as marine farmers, tourism), areas of international or special significance, sensitive habitats and threatened species, and level of monitoring already conducted. Because of insufficient funding to monitor all estuaries in the region, six estuaries were selected for monitoring. This information is available in a report prepared by Crawford and White (2006) in “Establishing key estuaries and coastal waters for monitoring”, available at http://eprints.utas.edu.au/view/authors/Crawford,_C.html.
This process did not seek to rank any estuary as being of more ‘value’ than any other; it was merely to identify estuaries where implementing a monitoring program was likely to be most successful in the first instance.

A monitoring program for the six estuaries was prepared and based on a recommended set of indicators for monitoring the condition of coastal, estuarine and marine environments around Tasmania. This indicator set was developed by the Tasmanian Coastal, Estuarine and Marine Indicators Working Group as the 'Tasmanian NRM Estuarine, Coastal and Marine Resource Condition Indicator Compendium' available at http://www.environment.tas.gov.au/index.aspx?base=410. A summarised; working version of this compendium was produced by Crawford (2006) is available at http://eprints.utas.edu.au/view/authors/Crawford,_CM.html.

Project aims

The main aims of this monitoring program were to:

1. Provide baseline data on the condition of the six key estuaries selected by Crawford and White (2006),
2. Evaluate the efficacy of the indicator variables and
3. Develop an affordable and effective monitoring program for the six key estuaries

Methods

Sampling Sites

Of the 38 estuaries in the Cradle Coast region, six key estuaries were chosen for this study - Port Sorell, Leven River, Inglis River, Black River, Montagu River and the Arthur River estuaries (Fig 1). Estuaries were selected by establishing a number of key parameters and ranking each estuary accordingly (see report by Crawford and White, 2006). This selection of estuaries was approved by stakeholders at a public meeting in Burnie on October 2006. The parameters included:

- Biophysical representativeness of the region
- Levels of monitoring already conducted
- Extent of human activity
- Stakeholder interest (marine farming, industry, tourism etc)
- Areas of international or special significance
- Presence of threatened species or sensitive habitats.

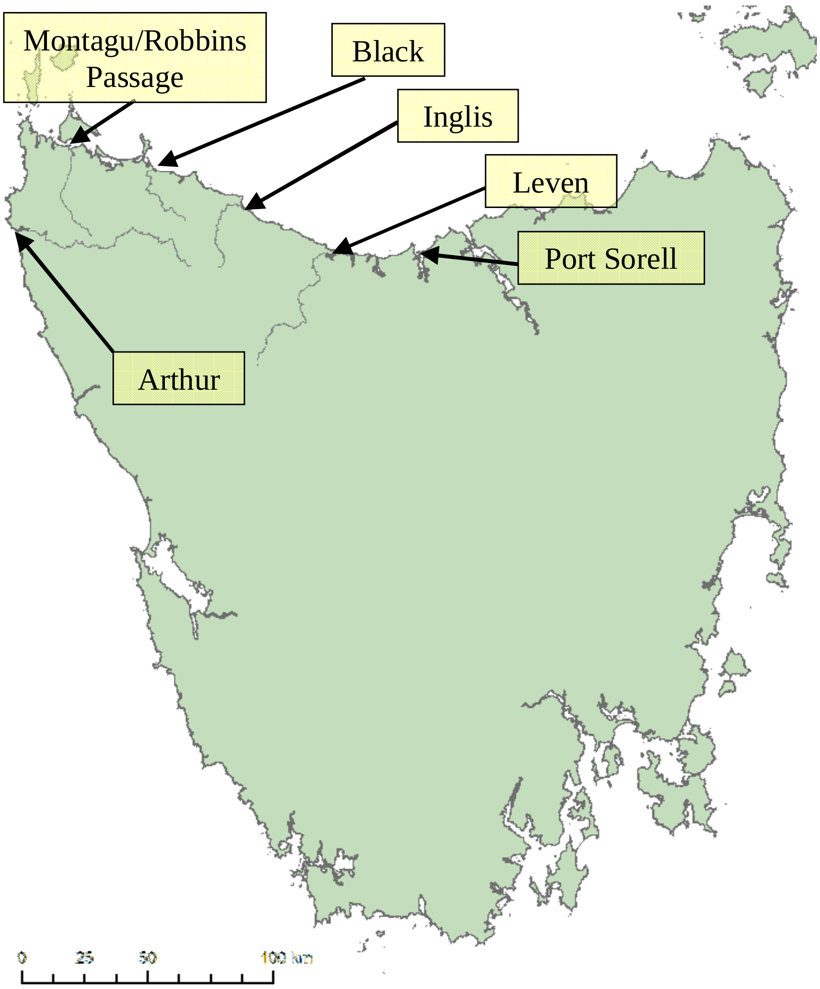


Fig. 1. The six estuaries currently monitored in the Cradle Coast region.

Sites within each estuary were selected to represent upper, middle and lower reaches. To determine the boundaries of these zones preliminary physico-chemical surveys of each estuary were conducted. Between one and three sites were chosen for each zone in each estuary. Some sites within Port Sorell, Black River, Montagu River and the Arthur River estuaries were chosen to be the same as those used by Murphy *et al.* (2003) and Hirst *et al.* (2005) to enable comparisons over time, as some data were already available for these estuaries (Hirst *et al.* 2005, 2007).

Field Sampling

Of the six estuaries, three (Port Sorell, Leven River, Inglis River) were visited on a monthly basis from November 2006 to March 2008. The Montagu River and the Arthur River estuaries were visited on a bimonthly basis from November 2006 - October 2007 and the Black River from February 2007 – December 2007. Sampling was conducted from a small boat or by wading if sites became inaccessible by boat. All sampling was conducted at low tide when estuaries are influenced to a greater extent by freshwater flows (Hirst *et al.*, 2005).

Physico-chemical parameters measured at each site at low tide were:

- Salinity,
- Temperature (ºC),
- Dissolved oxygen (% saturation),
- pH,
- Turbidity (NTU),
- Dissolved nutrients – ammonia, nitrate + nitrite (NOx), reactive phosphorus(mg/L),
- Silica (mg/L),

Ecological parameters monitored were:

- Water column chlorophyll *a* and benthic chlorophyll *a* and
- Macroinvertebrates (sampled once only during autumn and spring).

Results obtained for benthic chlorophyll *a* will not be presented in this report but will be made publicly available in a subsequent report.

Water quality measurements were taken mid channel. Salinity, temperature and dissolved oxygen were measured from the surface to the bottom at 1 m intervals. Where the bottom did not fall exactly on a 1 m interval the true depth was recorded. During the course of the study, salinity and temperature were recorded with a WTW LF196 and WTW Cond 315i instruments. Dissolved oxygen was measured with a TPS WP-82Y meter. Salinity and dissolved oxygen were not recorded on occasions due to equipment failure.

Turbidity, pH, nutrients and water column chlorophyll *a* measurements were all sampled in surface waters (<30cm). Three turbidity readings were taken at each site using a *HACH* 2100P Turbidimeter and averaged. The pH meter (Hanna HI 98127) was recalibrated every month prior to field sampling. Nutrients were sampled using standard protocols set by Analytical Services Tasmania (AST) and Eriksen (2006) and analysed by AST.

In the field, water column chlorophyll *a* samples were collected using a 1 L plastic container covered with alfoil to reduce photo-degradation and stored in an esky containing ice packs. Samples were filtered through Whatman GF/F 45mm diameter filter paper within a day of collection and immediately frozen.

Benthic chlorophyll *a* samples were collected using a 35mL syringe with the end removed and marked 3cm from the end point. At each site three mud samples were collected at the low tide mark (0m), each containing approximately 3cm of sediment. After completing a field sampling day all benthic chlorophyll *a* samples were immediately frozen.

Benthic Macroinvertebrates

To determine the diversity and abundance of estuarine invertebrate fauna in the sediments, macroinvertebrate samples were collected at each site within each estuary during autumn and spring of 2007. All sampling was undertaken at low tide using similar methods to Hirst *et al.* (2005). At each site five sediment cores (diameter = 150mm, depth = 100mm) were taken along a line at 0.0, 0.1, 0.2, 0.3, and 0.5m depths. The core samples were sieved through a 1mm sieve in the field and the remaining contents were fixed in 10% formalin. In the laboratory macroinvertebrates were identified to species level where possible and counted.

Laboratory Analyses

Water column chlorophyll a

Chlorophyll *a* analyses were conducted using standard techniques at the Tasmanian Aquaculture and Fisheries Institute. The concentration of chlorophyll a was calculated using the equation

$$\text{Total Chlorophyll a} = 11.0(\text{Abs}_{665}-\text{Abs}_{750})\frac{v}{Vp}$$

where V is the volume filtered (L), v is the volume of acetone (mL) and p is the path length (cm). The amount of phaeophytin, a natural degradation product of chlorophyll *a* was also calculated and found to be negligible. Therefore results for chlorophyll *a* are presented without a correction for phaeophytin.

Statistics

Invertebrate community composition

To determine broad scale trends in macroinvertebrate communities within and between estuaries and to reduce the inherent spatial variability within each site, replicates at each site were pooled. Similarity in macroinvertebrate composition between sites and estuaries was represented using non-metric multidimensional scaling (MDS) ordination using the PRIMER software package. Stress values <0.20 are considered to provide a reasonable representation of the original similarity data matrix. The position of invertebrate communities collected from upper, middle and lower regions and the six estuaries was superimposed onto MDS ordination plots to aid interpretation.

Water quality data

The data on water column variables are presented as continuous line graphs to assist presentation and interpretation of the results. However, these samples were only collected monthly and are not continuous data.

Relationships between measured water quality indicators were tested statistically using Principal Component Analysis (PCA). A PCA is used to reduce many variables to a smaller number that adequately summarise the original information. A PCA can also reveal patterns between variables that could not be found by analysing each variable separately (Quinn and Keough, 2002).

Results

Port Sorell

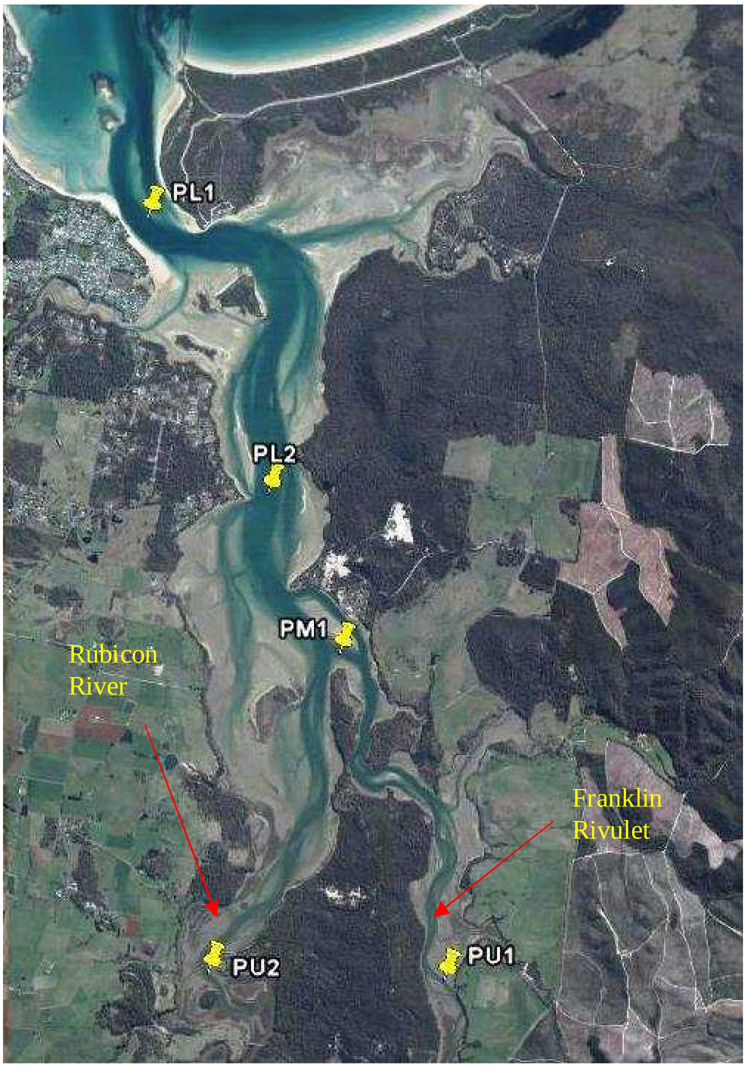


Fig. 2. Google Earth image of Port Sorell estuary showing fixed sampling sites. Note: P= Port Sorell, L=Lower, M=Middle, U=upper and 1, 2 are site numbers.

Catchment and estuary description

The Greater Rubicon catchment covers an area of approximately 610km^2 and incorporates a number of waterways which drain into the Port Sorell estuary. The two main river systems draining into the estuary are the Rubicon River (Site PU2, Fig 2) and the Franklin Rivulet (Site PU1, Fig 2). There are also a number of smaller catchments on each side of the estuary which have intermittent flows. These include Little Branches Creek, Marshalls Creek, Little Browns Creek, Panatana Rivulet and Greens River (Krasnicki, 2002).

The Port Sorell estuary has a large tidal range of approximately two to three metres. Much of the estuary is very shallow, <2 m, however deeper water (up to 8 m) is found in the channels at the mouth of the estuary. Above site PL2 (Fig 2) the estuary is dominated by mud flats with sediment particles derived from the upper catchment. The lower estuary is chiefly marine and contains extensive seagrass beds and sand flats. Habitat mapping is yet to be conducted in the Port Sorell estuary.

Classification and conservation significance

Port Sorell is described as an open marine inlet with a strong freshwater influence (Edgar *et al.* 1999). Edgar *et al.* (1999) classified the conservation significance of estuaries around Tasmania by examining their physical attributes, the degree of human development and assessing the diversity of invertebrate fauna and conservation status of identified taxa. Due to the high population density and associated human induced changes, the Port Sorell estuary was considered to be Class D, degraded and of low conservation significance (Edgar *et al.* 1999).

Although the Port Sorell estuary has been classified as low conservation significance, it is very important to the community and has substantial stakeholder interest. Residents use the estuary for swimming, fishing, boating and living beside. The Port Sorell estuary also currently holds three marine farm lease areas for Pacific Oysters (*Crassostrea* gigas).

The estuary shares its eastern border with the Narawntapu National Park, which contains unique coastal heath lands and extensive saltmarsh and lagoon areas important to a variety of bird species (Crawford and White, 2006). The estuary is also an important breeding habitat for fish and a designated shark nursery. DPIWE (2001) listed forty-two species of fish found to inhabit the estuary including the Australian grayling (*Prototroctes maraena*), which is listed as vulnerable under the *Tasmanian Threatened Species Act 1995*. The waters and coastline of the Port Sorell estuary also contain important habitat for bird species, several of which are also listed as vulnerable or endangered under the *Tasmanian Threatened Species Act 1995*.

Current land use

Port Sorell is one of the fastest growing municipalities in the North West region of Tasmania. The Port Sorell township is undergoing rapid urbanisation, particularly by people seeking a life style change. A number of smaller townships are also developing along the foreshores of the estuary, which are placing enormous pressure on coastal vegetation.

Since European settlement the upper catchment has seen rapid changes and development. The basalt soils are extremely fertile, enabling intensive agriculture, mainly cropping and grazing. There has also been a steady increase in water abstraction for irrigation, stock and domestic supply and other uses either by directly pumping water out of the river or by constructing instream water storages on its tributaries. In 2007 the total licensed water abstraction totalled 16, 531 ML (Waterways Monitoring Report: Rubicon catchment, 2007).

Forestry operations are also active in the upper catchment. Since European settlement much of the original forest has been cleared for agriculture. More recently remnant native forests have been cleared for forestry plantations of fast growing eucalypt species and Radiata Pine. There is anecdotal evidence to suggest that an increase in farming and forestry during the 1990's has led to the increase in siltation of the Port Sorell estuary. However, further research is needed to explore the changes in current water and land management practices and their effects on estuarine processes.

Salinity, Dissolved Oxygen and Temperature

Salinity in the Port Sorell estuary ranged between 6 recorded at site PU1 in August 2007 and 39.7 at site PU2 in December 2006 (Fig 3). A reduction in salinity from marine conditions (<35) was recorded from May 2007 to Dec 2007 in the upper estuary. However, in the lower estuary only a significant flood event in August 2007 reduced salinity below 35 (See graph PL1, Fig 3).

During summer and autumn of 2006/2007 and 2007/2008 the upper sites PU1 and PU2 tended towards hyper-salinity (>35). During 1999 and 2000, Murphy *et al.* (2003) reported similar findings. Hyper-salinity exists where there is little or no freshwater entering the estuary and evaporation rates are high. 2006 and 2007 have been two of the driest years on record, which resulted in very poor flows in the Rubicon River (Fig 3) and the Franklin Rivulet. During the summer/autumn of 2007/2008 the Rubicon River ceased flowing and the Franklin Rivulet dried up completely (pers. obs.).

There was little or no difference in salinity between surface and bottom waters (Fig 3). The shallowness of the estuary coupled with the large tidal range (2-3m) ensures that the water column within the estuary remains homogenous.

Dissolved oxygen (DO) concentrations ranged between 77.9 % saturation recorded in the bottom water at site PU2 during October 2007 and 106.0% recorded in the surface water at site PL1 during March 2007 (Fig 4). There was little or no difference in DO concentrations between surface and bottom waters (Fig 4). DO levels obtained during this study were generally above the acceptable range (>80% sat) recommended by ANZECC (2000) guidelines. Only site PU2 recorded DO levels slightly below recommended levels (Fig 4). A DO gradient existed with levels increasing towards the mouth of the estuary (Fig 4). This suggests that the upper estuary has greater biological oxygen demand.

Temperature within the estuary ranged between 5.8 ºC at site PU1 in June 2007 and 24.2 ºC at the same site in January 2008 (Fig 5). During winter a temperature gradient existed between the upper and lower reaches of the estuary with cooler temperatures in the upper reaches due to freshwater inputs (Fig 5). The lower section of the estuary was dominated by marine water, which resulted in less temperature variation over a calendar year. There was little or no difference in temperature between surface and bottom water.

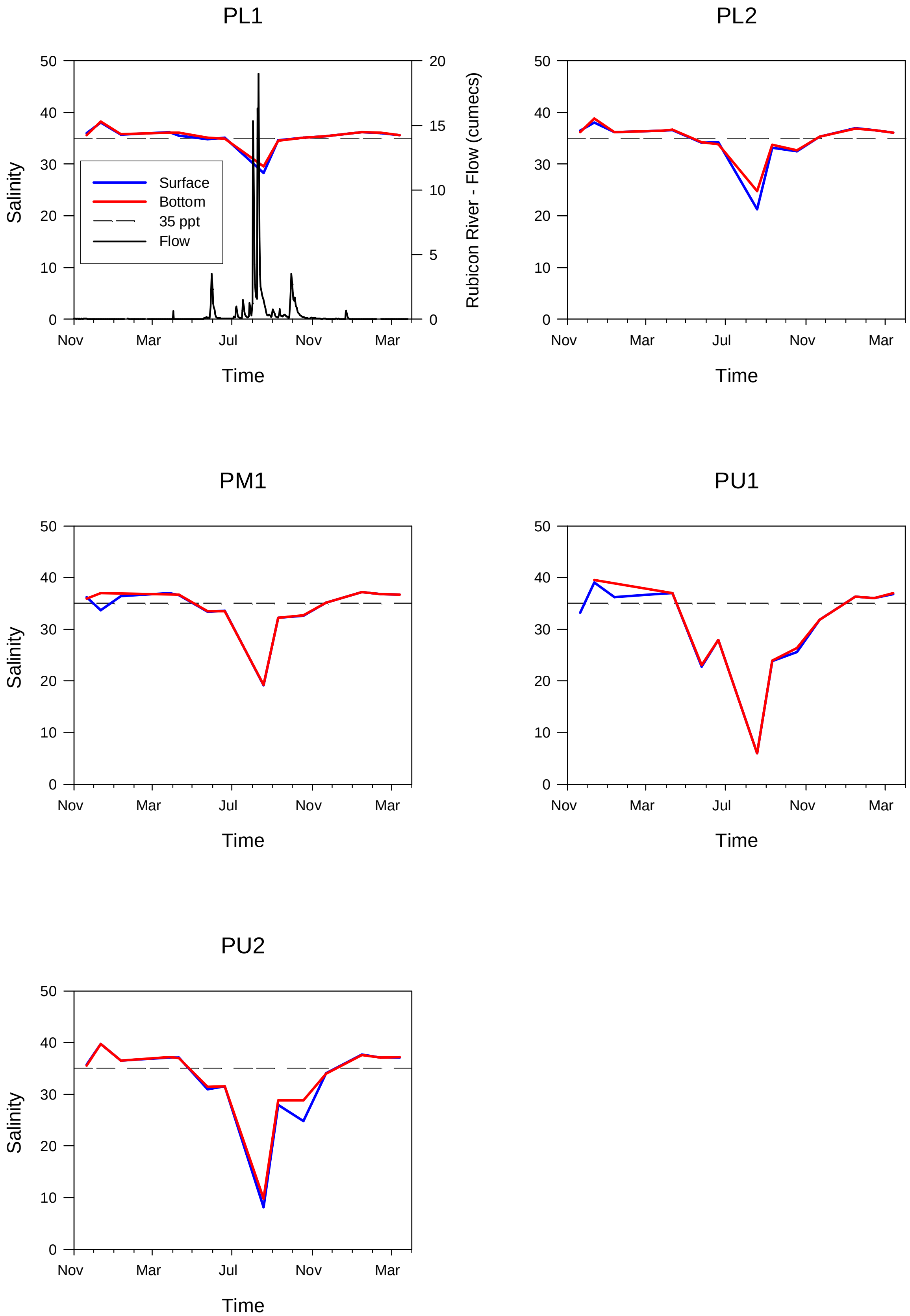


Fig. 3. Salinity data recorded for surface and bottom waters at each site within the Port Sorell estuary from November 2006 to March 2008. Note: the Rubicon River flow data presented in graph PL1 does not apply to site PU1.

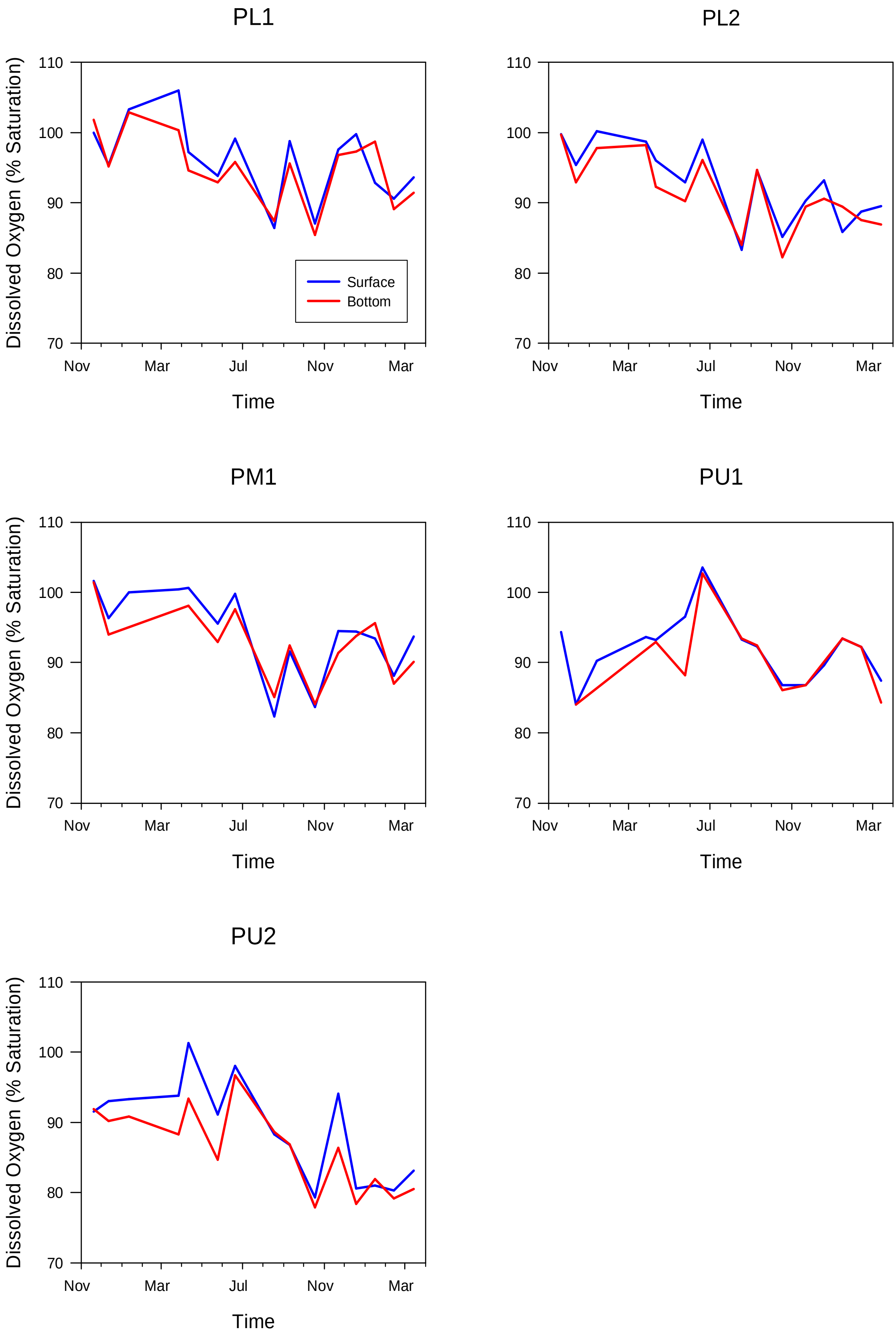


Fig. 4. Dissolved oxygen data recorded for surface and bottom waters at each monitoring site within the Port Sorell estuary from November 2006 to March 2008.

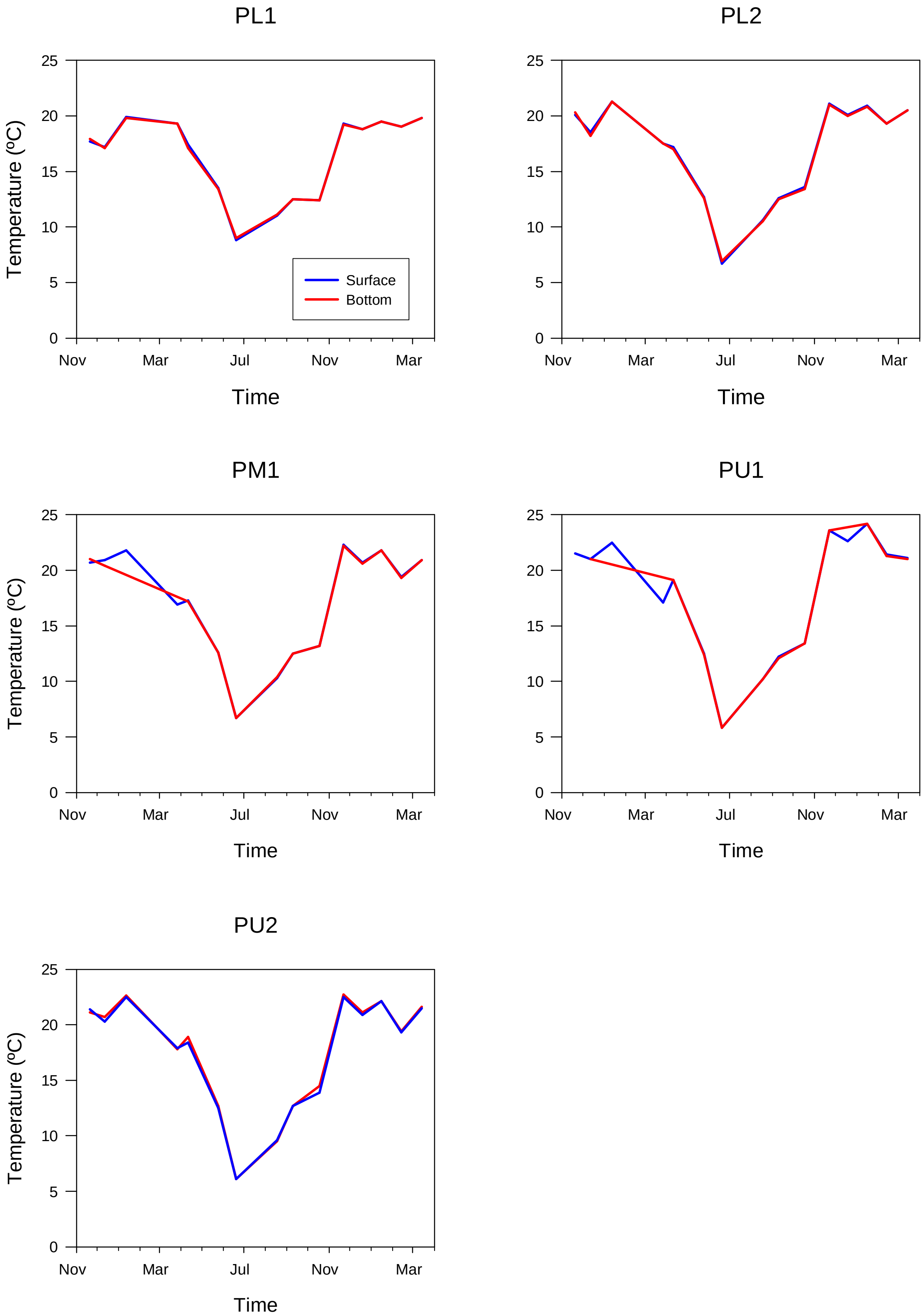


Fig. 5. Temperature data recorded for surface and bottom waters at each site within the Port Sorell estuary from November 2006 to March 2008.

Turbidity and pH

Average turbidity for sites PU1 and PU2 regularly exceeded ANZECC (2000) guidelines and fell into the high to very high categories from the recommended draft indicator levels set by Murphy *et al.* (2003) (see Appendix 1). Site PU1 had a minimum turbidity of 4.1 NTU and a maximum of 77.0 NTU. The average during the sixteen month sampling period was 13.5 NTU. Site PU2 showed similar results with a minimum turbidity reading of 3.7 NTU, a maximum of 104 NTU and an average of 17.0 NTU. The maximums at these sites coincided with a localised thunderstorm event during the February 2007 sampling period (Fig 6), which resulted in sediment from adjacent mud flats washing into the estuary. Murphy *et al.* (2003) also recorded high turbidity levels during winter flood events, similar to those recorded in this study.

A strong turbidity gradient exists in the Port Sorell estuary with turbidity increasing from the lower estuary towards the upper estuary (Fig 6). The upper estuary is shallow and contains large quantities of loosely packed sediment derived from the upper catchment. The sediment suspends during flood, tide, wind and rain events increasing turbidity in the upper estuary.

Levels of pH were within the expected range of a marine dominated estuary (7.0-8.5, ANZECC guidelines 2000). A pH gradient existed in the estuary with higher values recorded at the seaward end (Fig 6).

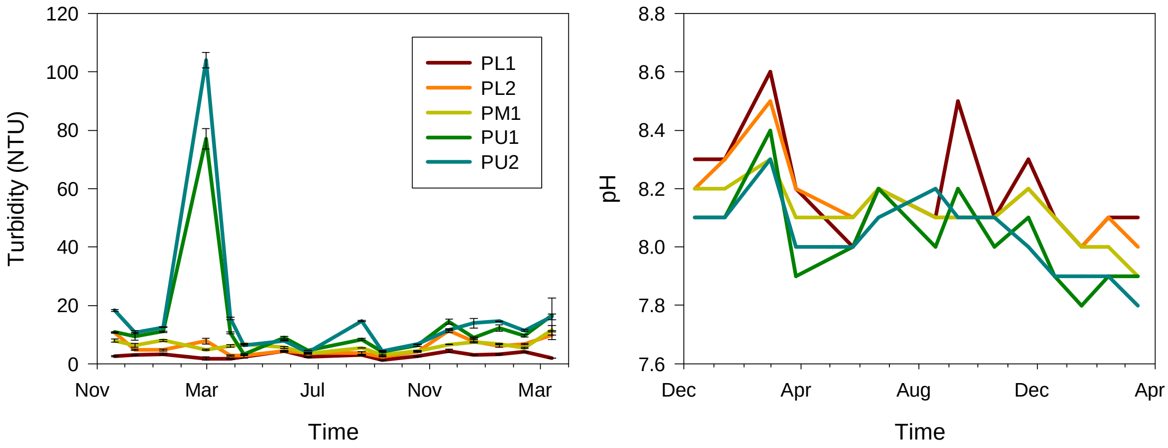


Fig. 6. Turbidity and pH measurements recorded for each monitoring site within the Port Sorell estuary from November 2006 to March 2008. Error bars indicate the standard deviation from the mean.

Nutrients, silica and chlorophyll *a*

Ammonia levels in the Port Sorell estuary were high in the upper estuary (Sites PM1, PU1 and PU2) from November 2006 – May 2007 (Fig 7). Levels were up to five times higher than the recommended ammonia levels set by ANZECC guidelines (0.015mg/L).

The levels of nitrate recorded were generally very low except during flood events (Fig 7). In the upper reaches of the estuary, elevated levels of nitrate were recorded from

May to August 2007 coinciding with winter rainfall (Fig 7). The flood event in August 2007 caused a flush of freshwater that extended to the mouth of the estuary. Nitrate levels exceeded ANZECC guidelines although at more diluted levels in the lower estuary.

Phosphate concentrations were generally low throughout the sampling period ranging from <0.002mg/L to 0.016mg/L (Fig 7). Maximum values were recorded in February 2007 when a severe thunderstorm event washed large quantities of sediment into the estuary from the surrounding mud flats, possibly releasing phosphate contained in the sediment.

Concentrations of phosphate did exceed trigger values set by ANZECC (2000) guidelines (0.005 mg/L); however were within the medium levels set by Murphy *et al.* (2003). Interestingly, the levels of phosphate were not significantly elevated during the August 2007 flood event, which supports Murphy *et al.* (2003) assumption that the Port Sorell catchment contains naturally low phosphate levels.

Silica levels were low throughout the sampling period. The highest levels of silica were recorded during the August flood event indicating that siliceous material is derived from the catchment (Fig 7).

Chlorophyll *a* levels were generally low during the sampling period with a total average of 1.96µg/L across all sampling sites within the Port Sorell estuary. Concentrations of chlorophyll *a* displayed a seasonal pattern, being lowest from April to November and highest levels during summer and early autumn (Fig 7). Levels of chlorophyll *a* were consistently highest at site PU2 with an average of 3.4µg/L and a peak of 16.9µg/L in February 2007. This peak in chlorophyll *a* may be confounded by a localised thunderstorm event washing sediment from exposed mudflats into the estuary. These sediments contain high levels of microphytobenthos, which would have contributed substantially to the total chlorophyll *a* measured.

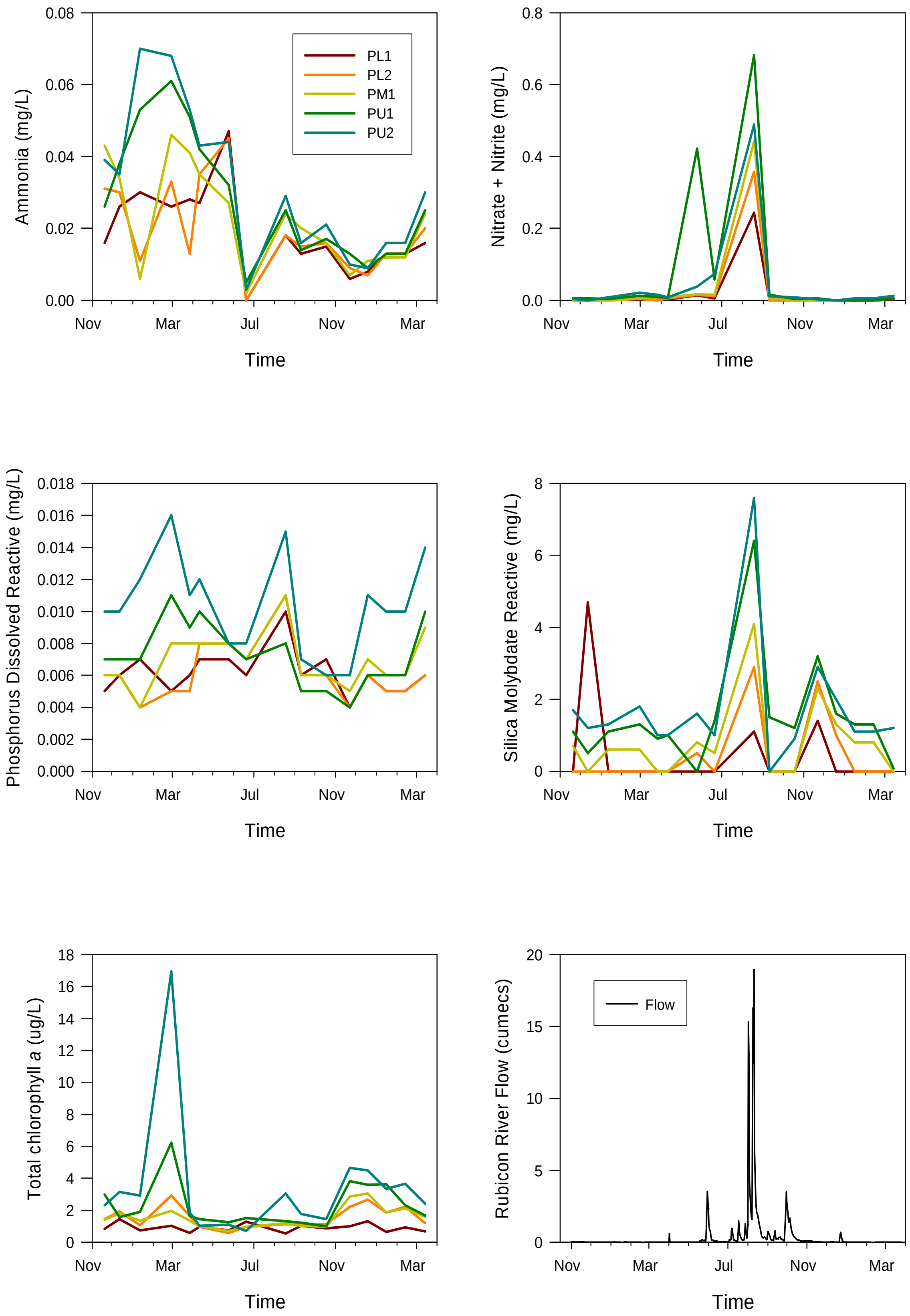


Fig. 7. Concentrations of ammonia, nitrate + nitrite, phosphorus dissolved reactive, silica molybdate reactive and total chlorophyll *a* recorded at each site from November 2006 to March 2008.

Leven River

Fig. 8. A Google earth image of the Leven River estuary showing fixed sampling sites.

Catchment and estuary description

The Leven River has a catchment area of approximately 700km^2 and a total length of 102km. The Leven River originates at the northern edge of Cradle Mountain Lake St Clair National Park and drains into Bass Strait at Ulverstone. The general topography of the catchment comprises hills, mountain ranges and tiers of varying altitude (200-1300m) with Black Bluff (1339m) the highest peak in the catchment (Pinto 2002). Several water courses discharge into the Leven River estuary with the largest being Gawler River entering slightly upstream of site LM1 (Fig 8).

The estuary is quite extensive with an approximate length of 10km (Pinto 2002). Like all estuaries that flow into Bass Strait, the Leven estuary has a large tidal range of 2-3m. It is generally narrow with clearly defined river banks above site LM2 (Fig 8). Below site LM2 heading seaward to the township of Ulverstone the Leven River widens out, exposing extensive mud and sand flats at low tide (Fig 8). A breakwall has been built at the mouth of the estuary to maintain an open channel.

The estuary is generally shallow, <3m; however deeper holes have formed in the upper estuary with maximum depths ~ 5m at sites LU2 and LU3 (Fig 8). Heading seaward from site LU2 the estuary becomes progressively shallower with the average depth <2m at low tide. Benthic habitat mapping is yet to be conducted in the Leven River estuary.

Classification and conservation significance

The estuary has been classified as a large wave dominated mesotidal river estuary and was found to be most similar to the Duck Bay and Mersey estuaries on the basis of physical attributes (Edgar *et al.* 1999). As a result of the high population density and the proportion of the catchment affected by human impact, the Leven estuary is considered to be of a severely degraded nature (Class E) and of low conservation significance.

Although the Leven estuary has been classified as low conservation significance a number of common, vulnerable and endangered water birds nest in the Leven estuary. It is home to many fish species, some of which are listed under the *Tasmanian Threatened Species Act 1995* (Pinto 2002). The estuary also contains areas of seagrass which are utilised by several fish species.

Current land use

The upper most region of the catchment falls in the Cradle Mountain Lake St-Clair national park and supports native forest and button grass plains. Immediately below this point the highly productive basalt soils have been utilised for forestry. A state reserve is also present within the upper catchment, which incorporates limestone caves and the Leven Canyon (Pinto, 2002).

Given the productive soils of the middle and lower regions of the catchment, much of the area has been cleared for agricultural purposes. The main agricultural development is intensive cropping with some grazing of sheep and cattle.

The township of Ulverstone (population ~ 9500 people) is situated either side of the mouth of the Leven estuary. The Leven estuary below site LM1 (Fig 8) has been heavily modified by the construction of extensive retaining walls for bank stabilisation.

Salinity, Dissolved Oxygen and Temperature

The water column in the Leven estuary was generally well mixed in the lower estuary; however stratification in salinity and dissolved oxygen developed in the upper estuary during summer and autumn (Fig 9). The upper estuary is generally narrow (<30m wide), and deep (~ 2 - 5m) and contains a series of rock bars and ledges above site LM2, which restricts water movement on an out going tide. These physical attributes coupled with low freshwater flows during summer and autumn lead to the formation of a halocline in the upper sites.

The highest salinity recorded at low tide in the Leven estuary was 35.3 in the bottom water at site LL1 in April 2007 (Fig 10). The lowest salinity reading was <0.1 for both surface and bottom waters during the flood event of August 2007 from sites LU3 to LM2 (Fig 10). During winter the upper sites LU3 – LU1 experienced freshwater flows with little or no intrusion of oceanic water (Fig 10).

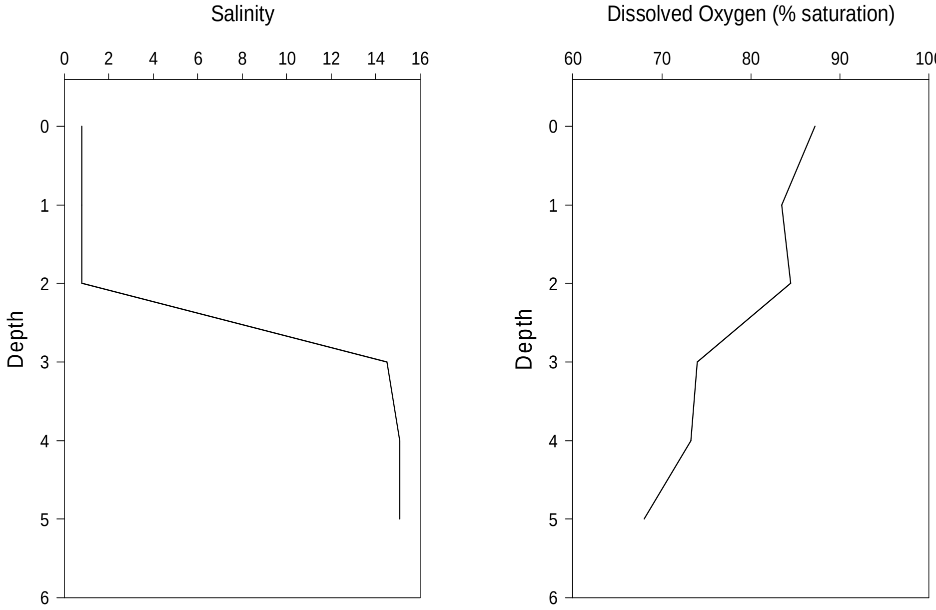


Fig. 9. A water column profile at site LU3 during November 2006 showing changes in salinity and dissolved oxygen with depth.

Dissolved oxygen (DO) concentrations ranged from 67.9 % saturation in the bottom waters at site LU1 in January 2007 to 115.4 % saturation in the surface waters at site LL1 in February 2007 (Fig 11). DO concentrations in the surface waters at sites LL1, LM1 and LM2 were generally stable over all seasons ranging between ~ 80 – 115% saturation. DO concentrations differed by less than 10% between surface and bottom waters at these sites (Fig 11).

The upper sites LU1, LU2 and LU3 had high DO concentrations in both surface and bottom waters over winter and spring; however during summer and autumn the bottom water recorded low DO levels (Fig 11) dipping below 80% saturation, the acceptable level recommended by ANZECC (2000) guidelines. There was a larger difference in DO concentrations between surface and bottom waters (~ 20% difference, Fig 11) indicating that the upper section of the Leven River estuary experiences reduced flushing during summer and autumn and may experience reduced water quality as a result.

During June 2007 a minimum temperature of 4.2 ºC was recorded in the bottom water at site LU3 and the maximum temperature of 25.1 ºC was recorded at site LU2 in February 2007 (Fig 12). The lower sites, LL1 and LM1, had less variation in temperature (~15 ºC) over seasons reflecting the marine nature of the water. The middle and upper sites displayed greater temperature variation (~20 ºC) over seasons reflecting the riverine nature of the upper estuary. Temperature was relatively homogenous between surface and bottom waters at all sites and over all seasons (Fig 12).

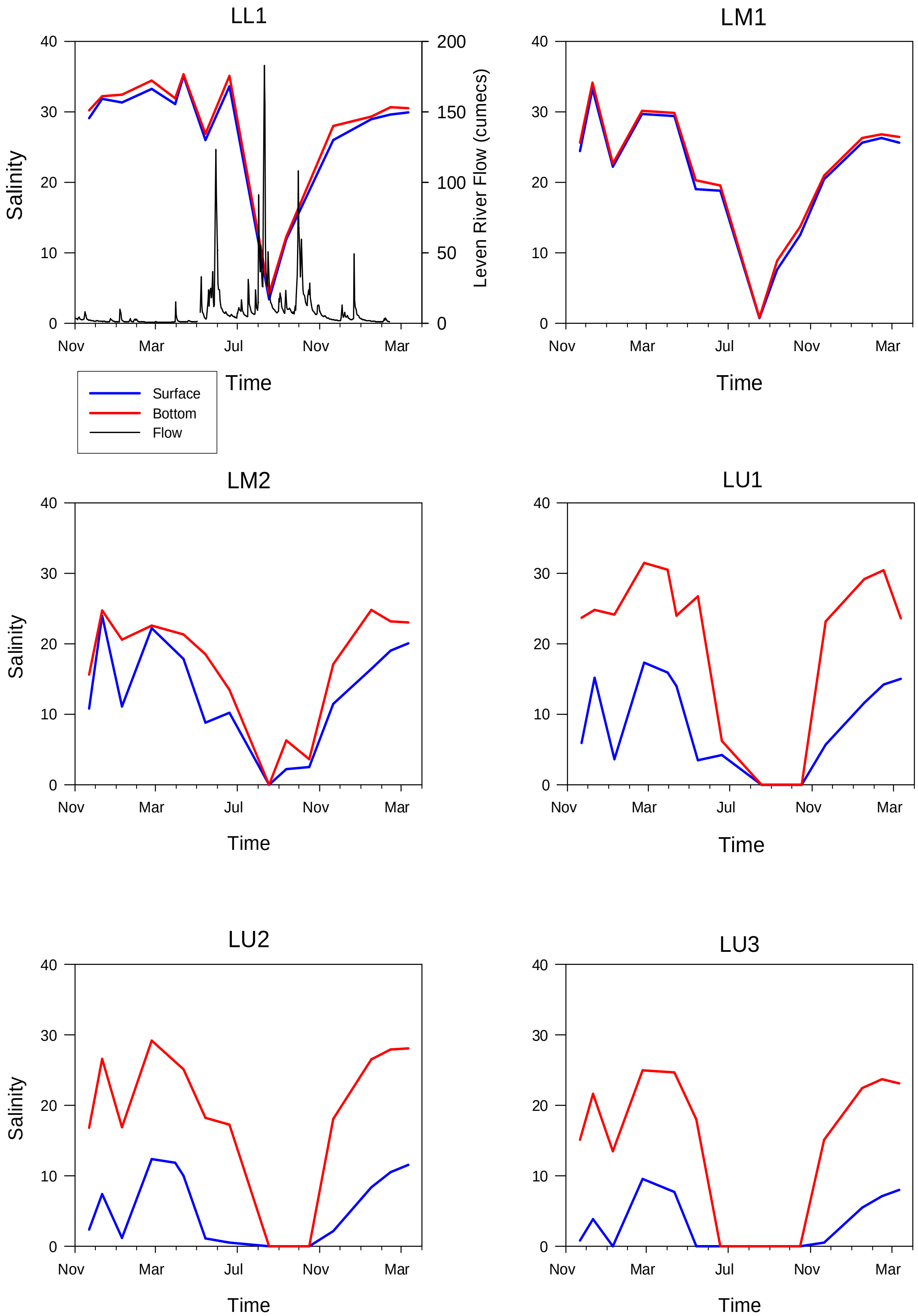


Fig. 10. Salinity data recorded for surface and bottom waters at each site within the Leven River estuary from November 2006 to March 2008.

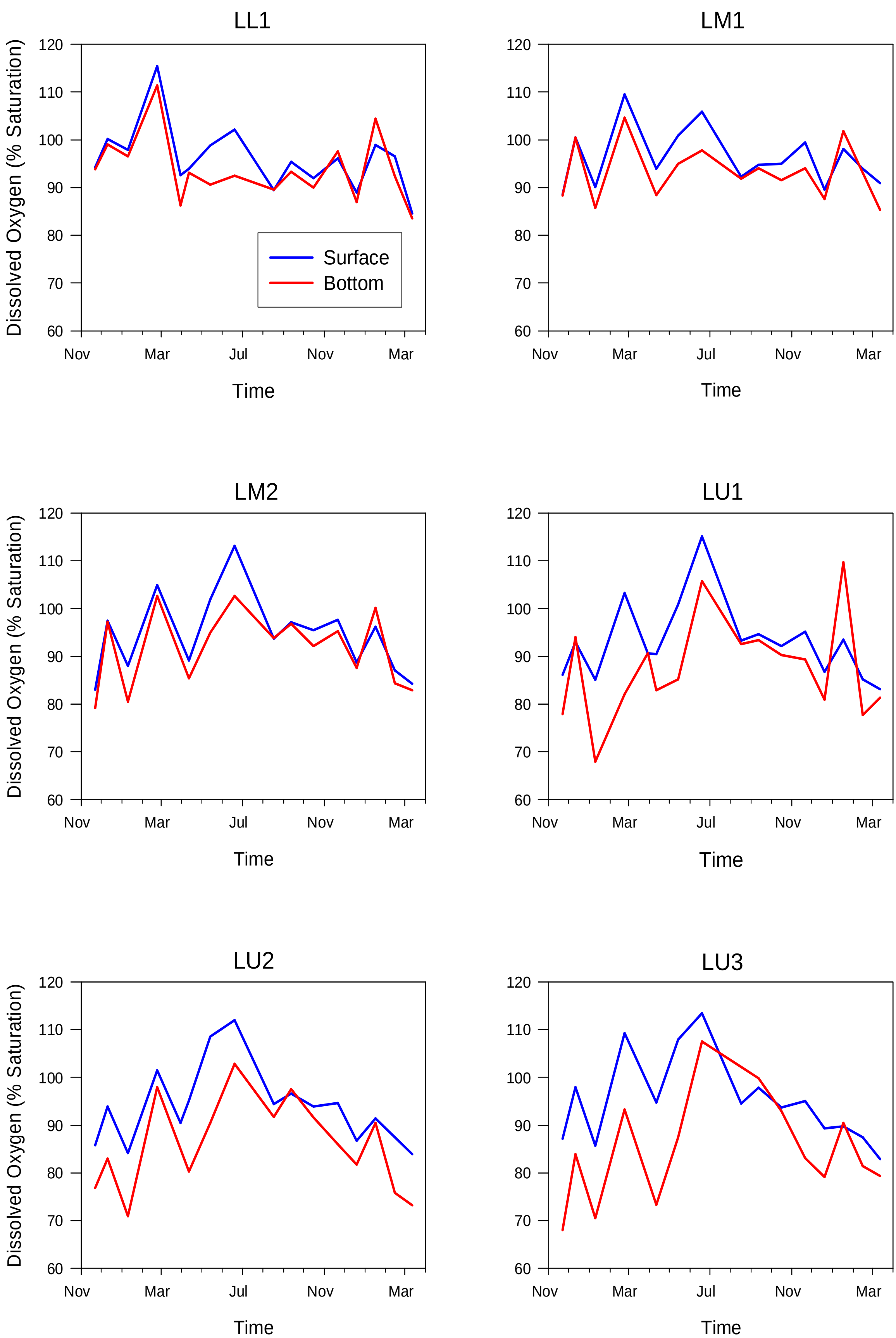


Fig. 11. Dissolved oxygen data recorded for surface and bottom waters at each monitoring site within the Leven River estuary from November 2006 to March 2008.

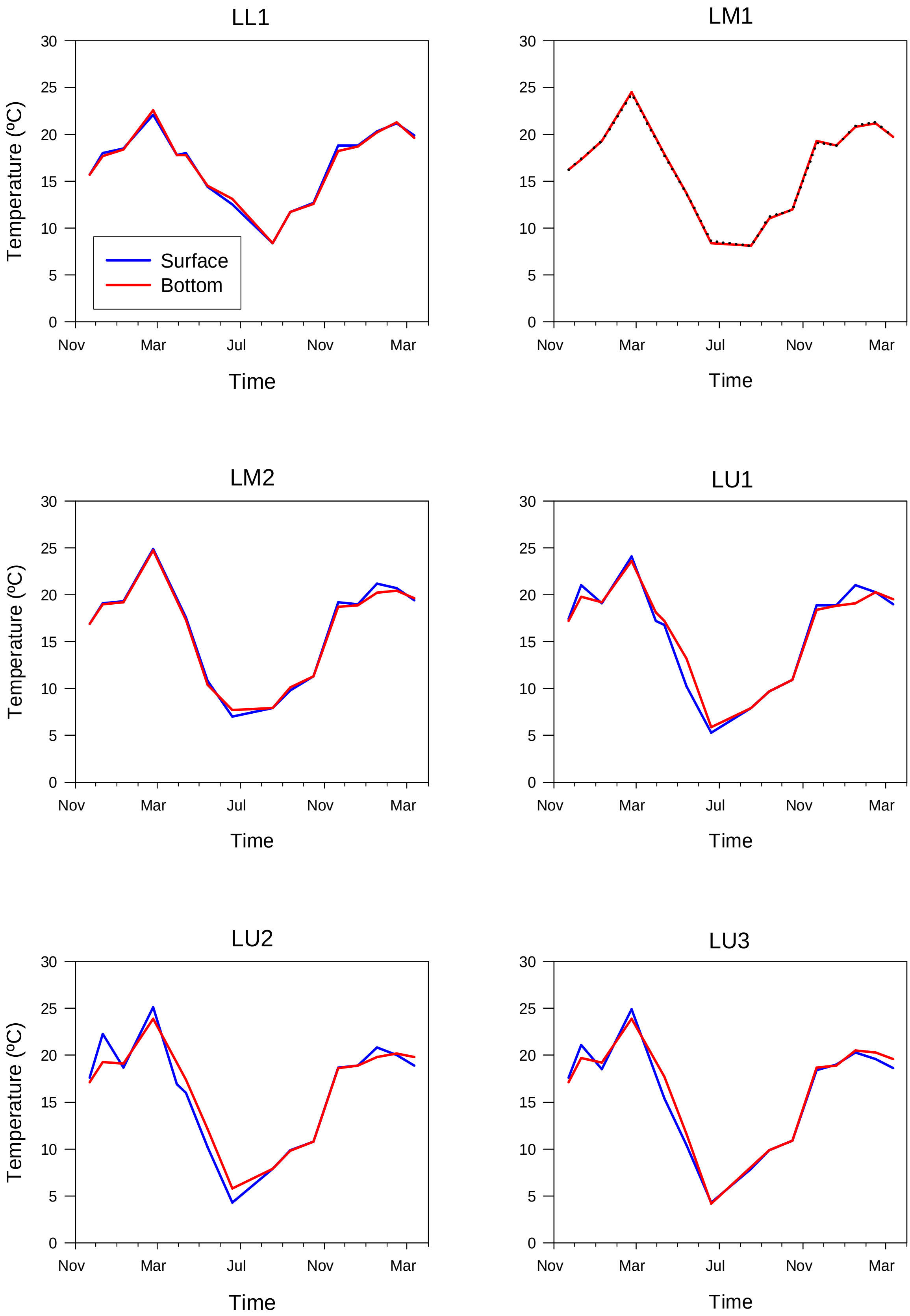


Fig. 12. Temperature data recorded for surface and bottom waters at each site within the Leven River estuary from November 2006 to March 2008.

Turbidity and pH

During the course of this study turbidity levels in the Leven River estuary were generally low. The lowest average turbidity was 1.17 NTU at site LL1 during April 2007 and the maximum was 7.67 NTU at the same site during March 2007 (Fig 13). The maximum turbidity reading was recorded during a severe wind storm event causing resuspension of sediments. Throughout the study turbidity was generally higher at the lower end of the estuary. This pattern occurred even during the large rainfall event of August 2007.

PH levels ranged from 6.9 recorded at Site LM1 in August 2007 to 8.6 recorded at LU3 during the May 2007 sampling round (Fig 13). There were no discernable gradients in pH levels in the Leven River estuary. Generally pH levels were lower in the upper estuary; however during high freshwater inputs of winter 2007 the gradients were less clear. There was a significant fall in pH values during the August 2007 flood event at all sites in the estuary indicating that the freshwater from the upper catchment is generally more acidic.

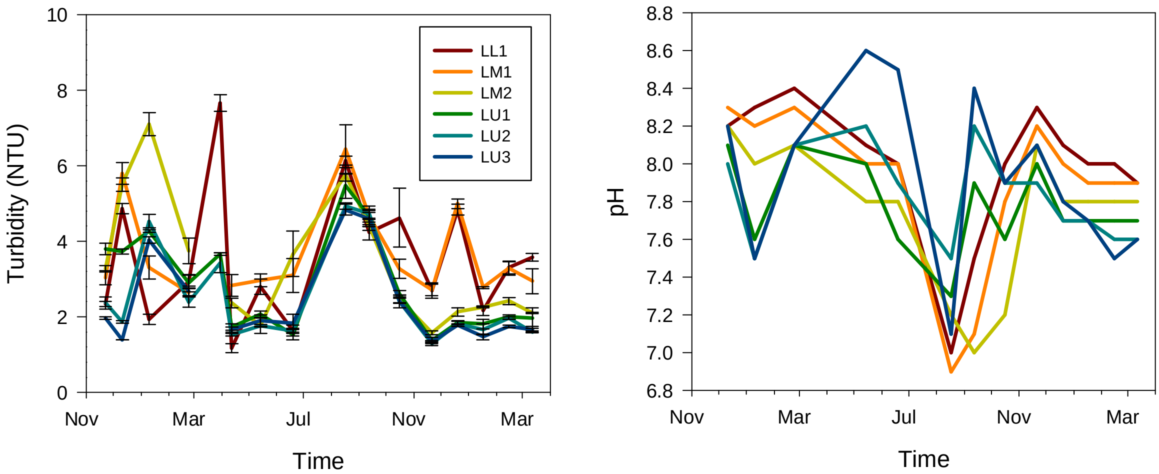


Fig. 13. Turbidity and pH measurements recorded for each monitoring site within the Leven River estuary from November 2006 to March 2008. Error bars indicate the standard deviation from the mean.

Nutrients, silica and chlorophyll *a*

Nutrient levels in the Leven River estuary were generally high with the exception of phosphate, which was low throughout the sampling period. A strong estuarine gradient in phosphate concentrations existed with higher levels found in the lower estuary (Fig 14). The source of phosphate in the lower estuary was probably from the intrusion of oceanic water from Bass Strait.

Ammonia levels in the Leven River estuary exceeded ANZECC guidelines (0.015 mg/L) on most sampling occasions. Ammonia levels were highest during autumn of 2007 especially in the lower section of the estuary. Interestingly ammonia levels dropped appreciatively during the August 2007 flood event highlighting the importance of regular flushing of estuaries. Post August 2007, ammonia increased but did not reach levels experienced in autumn 2007. In contrast to Port Sorell, ammonia concentrations were generally highest at the estuary entrance and declined with distance upstream. These high levels suggest a point source of ammonia into the lower estuary.

Nitrate levels were generally high with a large spike recorded during the August 2007 flood event (Fig 14) indicating that nitrogen loading in the estuary is largely catchment derived. Generally levels of nitrate were highest in the upper estuary; however during the August 2007 flood event the lower sites recorded the highest nitrate levels. It is possible that during flood events, contributions of nutrients from the Gawler River, small tributaries and possibly storm water runoff may affect the water quality of the lower estuary. Further research is required to determine the source and fate of nutrients at the lower end of this estuary.

Silica levels were low throughout the sampling period. They were higher in the upper estuary indicating that silica is catchment derived.

Chlorophyll *a* levels displayed a very strong seasonal pattern with highest levels recorded during late spring to early autumn and low levels during winter. Chlorophyll *a* levels in the Leven estuary were the highest recorded of the six estuaries sampled in this study with a peak of 17.58µg/L recorded at site LU1 during January 2007 (Fig 14). ANZECC guidelines (2000) recommend that chlorophyll *a* levels should not exceed 4µg/L in South East Australian estuaries. During late spring, summer and autumn of 2007 and 2008 the Leven River estuary exceeded ANZECC (2000) guidelines on numerous occasions.

As this is the first water quality assessment of the Leven estuary, it is difficult to determine whether high chlorophyll *a* levels occur naturally or are the result of human activities. Continuous monitoring is recommended to determine the cause of phytoplankton blooms and whether current levels are of concern for the health of the upper estuary.

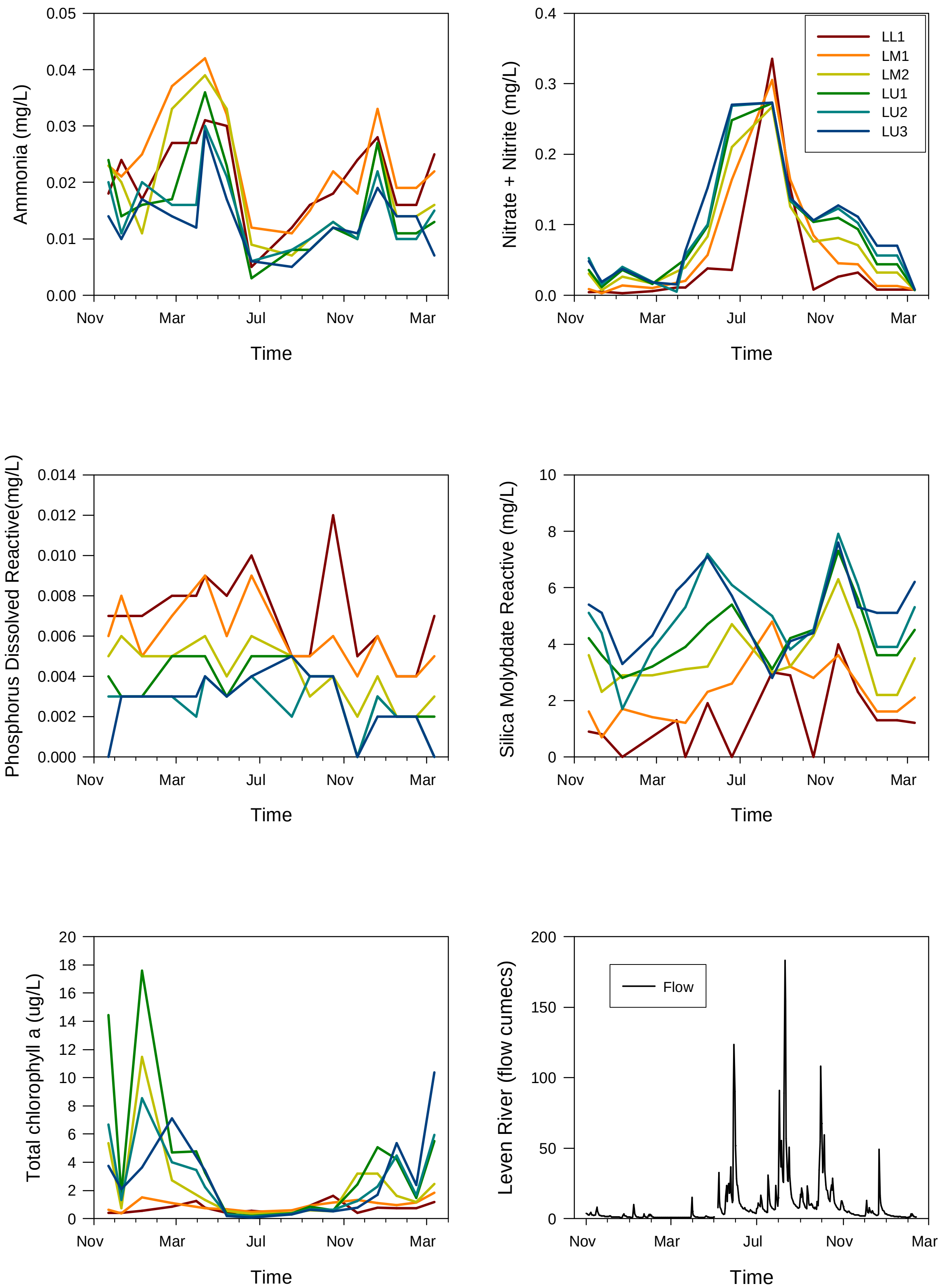


Fig. 14. Concentrations of ammonia, nitrate + nitrite, phosphate dissolved reactive, silica molybdate reactive and total chlorophyll *a* recorded at each monitoring site of the Leven River estuary from November 2006 to March 2008.

Inglis River

Fig. 15. A Google earth image of the Inglis River estuary showing fixed sampling sites

Catchment and estuary description

The Inglis River has a total catchment area of 615 km^2 and is drained by two major rivers, the Inglis and Flowerdale rivers, both of which join before flowing into Bass Strait at Wynyard. During summer the estuary proper is approximately 5-6 km long, reaching the old weir at Pump Station Road (Fig 15). A series of creeks and tributaries drain into the estuary, the most notable are Big Creek, which enters the estuary between sites IM1 and IU1 and Camp Creek situated below site IL1 at the Wynyard Yacht Club (Fig 15).

The tidal range of the estuary is approximately 2-3m. Above Site IM1 (Fig 15) the estuary is generally narrow with clearly defined river banks. Below site IM1 the estuary widens out exposing mud and sand flats at low tide (Fig 15). A breakwall has been built at the mouth of the estuary to maintain an open channel to Bass Strait.

The estuary is generally shallow <2m; however at site IU1 deeper holes have formed with a maximum depth of ~ 4m. Much of the upper estuary contains silt, cobble and bedrock material which makes navigation by boat difficult during summer. The lower estuary is mainly silt, sand and cobble.

Classification and conservation significance

The Inglis River has been described as a large mesotidal river dominated estuary (Edgar *et al.* 1999). Edgar *et al.* (1999) classified the Inglis River estuary as being severely degraded (Class E) and of low conservation significance. This classification was given as a result of the high population density, most notably the township of Wynyard located either side of the estuary and the proportion of the catchment affected by human impact.

Despite the low conservation classification, the estuary is home to a number of vulnerable and endangered species including the Australian Grayling (*Prototroctes maraena*). The endemic freshwater lobster is also thought to occur in the lower reaches of the Inglis River with occasional migrations into the tidal limits (Crawford and White, 2006).

Current land use

The uppermost reaches of the Inglis Flowerdale catchment is relatively steep and has retained substantial native forests that buffer these rivers from land-use activities. However, much of the middle and lower reaches have been converted into forestry plantations or cleared for agriculture. The heaviest agricultural activity is concentrated in the area between Takone, Yolla and Wynyard, and as a result many of the smaller streams draining this region are significantly modified, with little or no riparian vegetation (Waterways Monitoring Report: Inglis catchment, 2007).

The majority of the township of Wynyard extends along the eastern edge of the estuary. The western shore is predominantly farm land although there is some residential development at Site IM1. A golf course also occurs on the western side of the estuary below site IM1. A small wharf area exists at Site IL1 (Fig 15) and a breakwall has been built below site IL1 to allow easier passage of larger vessels.

Salinity, Dissolved Oxygen and Temperature

At site IL1, salinity differed little between surface and bottom waters. Bottom water salinity at site IL1 also tended to be lower than sites IM1 and IU1 for much of the year (Fig 16). This is attributed to marine water being trapped in deep holes located at these upper sites. Sites IM1 and IU1 had similar salinity patterns, with bottom waters close to marine except during heavy rainfall periods in winter. The uppermost site IU2 showed a strong freshwater influence with salinity <0.1 in winter/spring and brackish water for the remainder of the year.

At all sites dissolved oxygen (DO) concentrations were generally above recommended levels (80%) set by ANZECC (2000) guidelines. The exception was site IU1, which had reduced DO levels in the bottom water during summer and autumn (Fig 17). Site IU1 is deep (~4m) and tends to stratify when freshwater flows are low. At sites within the Inglis estuary, DO levels were higher on the surface than on the bottom on most sampling occasions.

At site IL1 the surface and bottom waters were homogenous with little or no difference in temperature; however, at sites IM1 and IU1 a temperature gradient with depth occurred. Surface temperatures were higher than on the bottom during summer, but lower in winter; with a maximum difference of ~ 5-6 ºC recorded during June 2007 (Fig 18). Temperature differences during winter were attributed to the temperature differences between freshwater flowing down the Inglis River and oceanic water entering the estuary from Bass Strait.

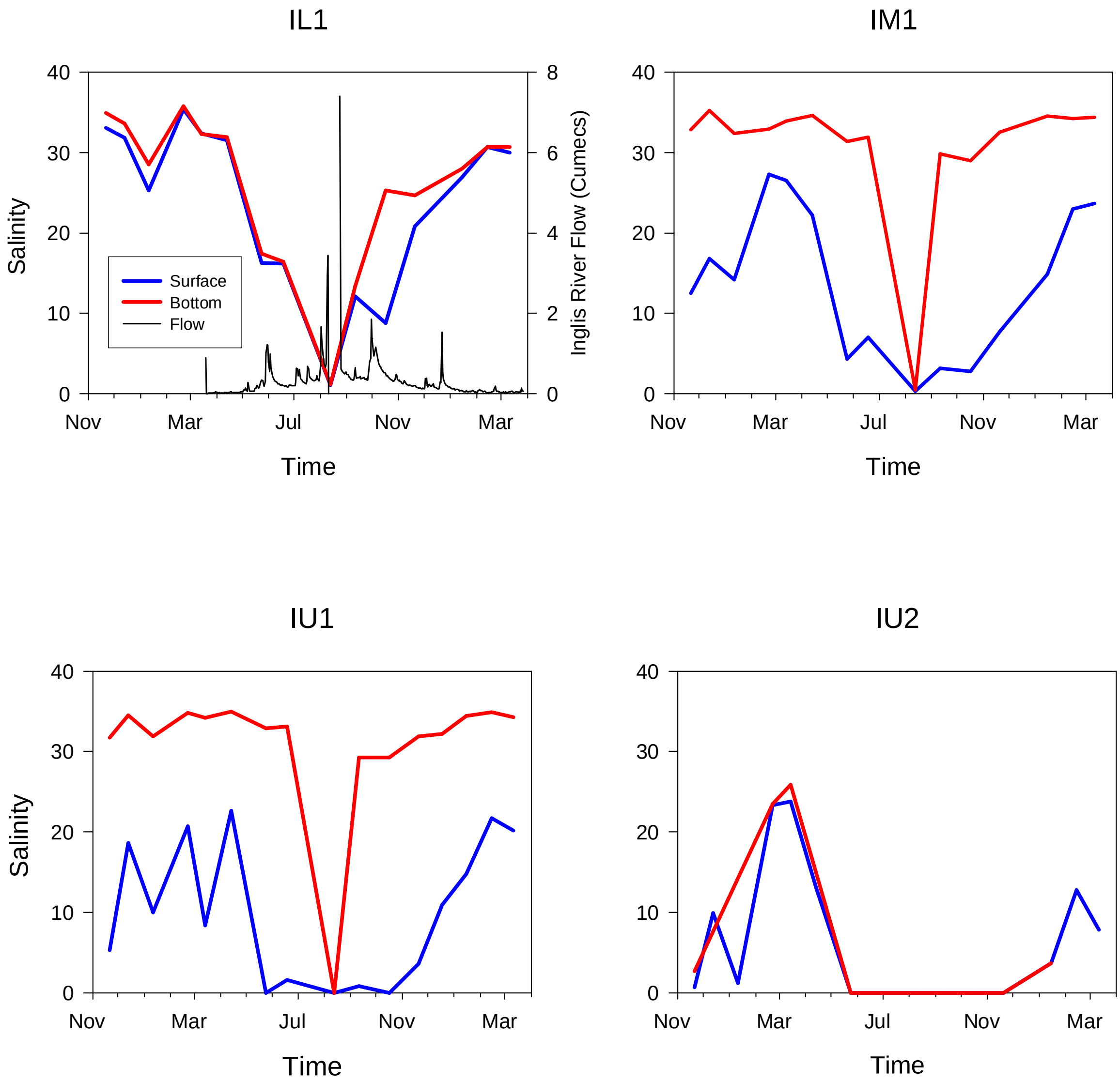


Fig. 16. Salinity data recorded for surface and bottom waters at each monitoring site within the Inglis River estuary from November 2006 to March 2008.

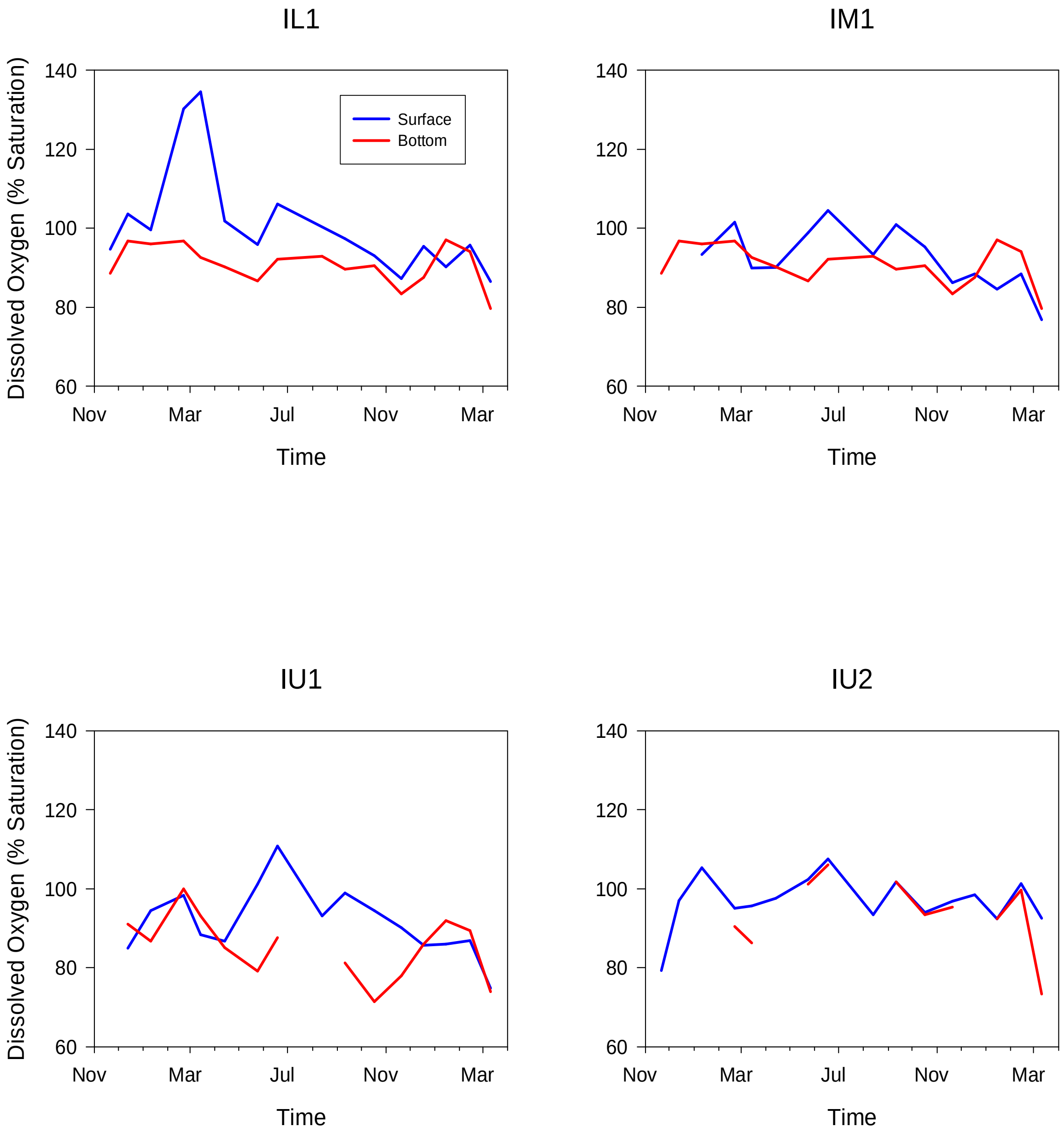


Fig. 17. Dissolved oxygen data recorded for surface and bottom waters at each monitoring site within the Inglis River estuary from November 2006 to March 2008.

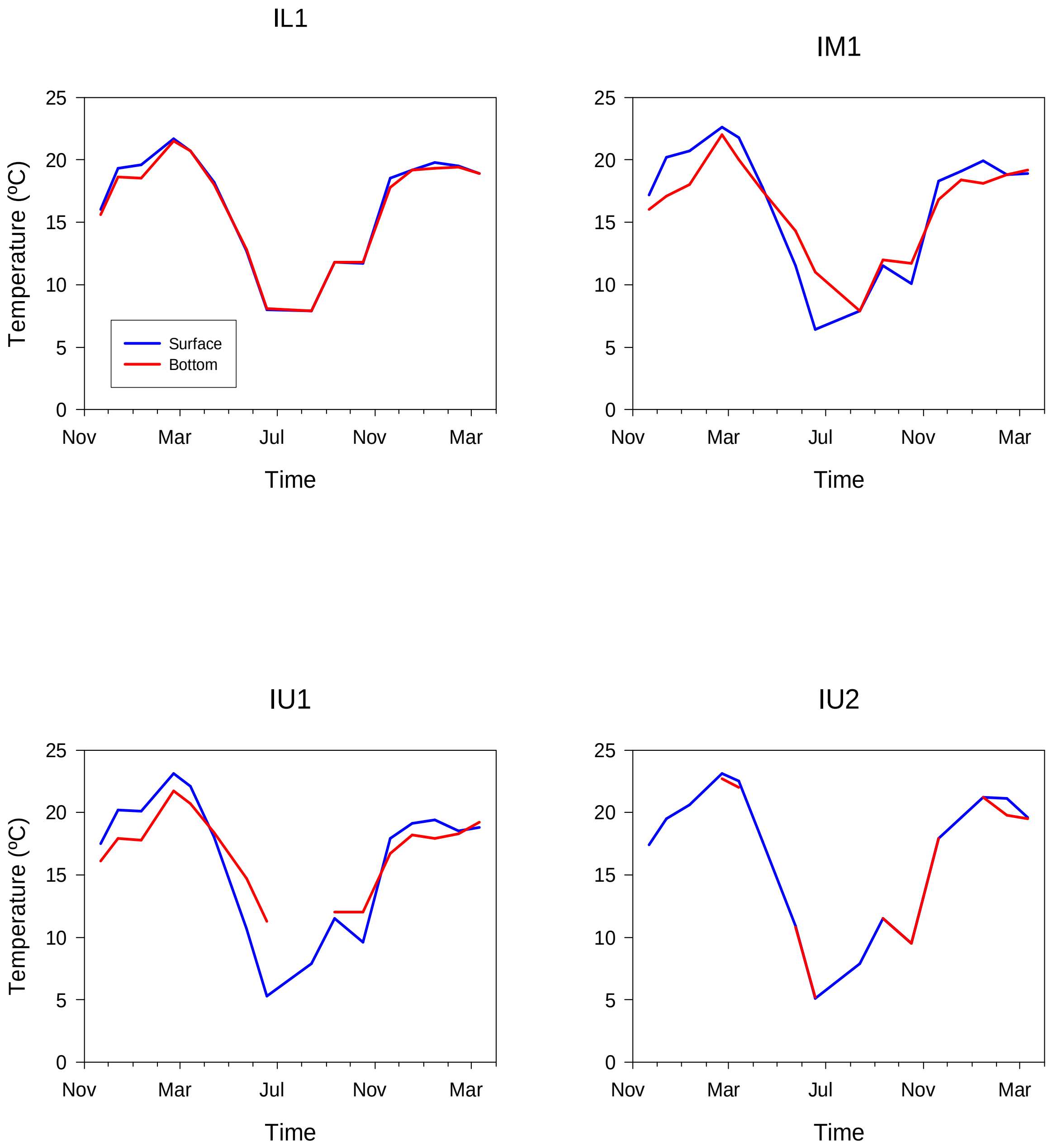


Fig. 18. Temperature data recorded for surface and bottom waters at each sampling site within the Inglis River estuary from November 2006 to March 2008.

Turbidity and pH

Turbidity in the Inglis River estuary was generally low (<5 NTU) except during high freshwater flows over winter. Turbidity peaked at 18.27 NTU at site IL1 during the August 2007 flood event (Fig 19). Generally the upper sites recorded the highest turbidity during moderate to high freshwater inputs. During low freshwater input, the trend reversed with the lower sites recording higher turbidity.

The pH levels in the Inglis River estuary ranged from 7.2 – 8.7. The lower sites IL1 and IM1 generally had higher pH levels than the upper sites over summer and autumn; however during winter and spring of 2007 the pattern reversed (Fig 19). The freshwater coming down the estuary is probably more alkaline than the salt water entering the estuary. Another factor that could be contributing to lower pH in the lower estuary during winter and spring is the influence of Big Creek and Camp Creek.

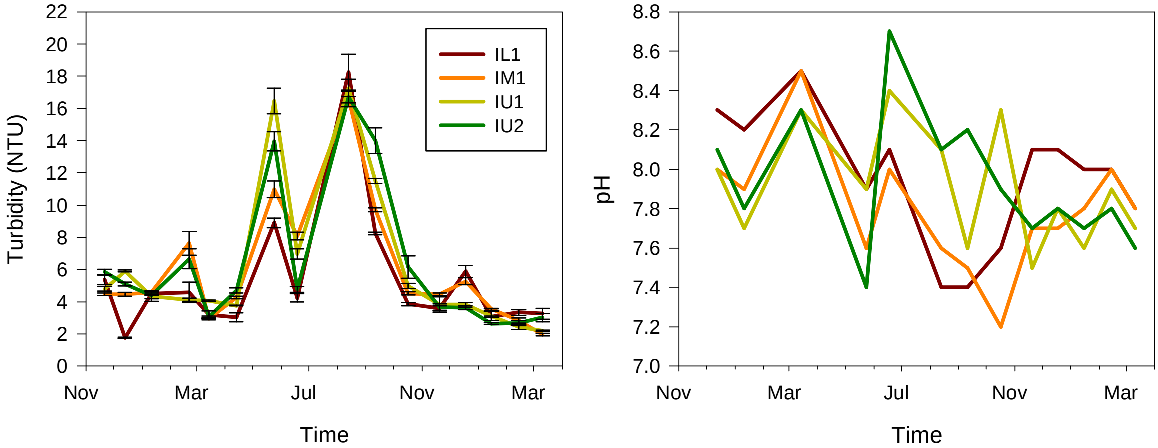


Fig. 19. Turbidity and pH measurements recorded for each monitoring site within the Inglis River estuary from November 2006 to March 2008. Error bars indicate the standard deviation from the mean.

Nutrients, silica and chlorophyll *a*

Nutrient levels in the Inglis River estuary were generally high to very high, particularly ammonia and nitrate. Ammonia concentrations of 0.08mg/L (Fig 20) were the highest recorded for any of the six estuaries monitored in this study. These levels are about five times higher than that recommended by ANZECC (2000) guidelines (Appendix 1). Lowest ammonia levels were recorded during August 2007 when large volumes of freshwater flushed out the estuary reducing the amount of ammonia in the water column. The middle and upper sites, particularly IM1, tended to have higher ammonia concentrations than the lower site.

Levels of nitrate also showed seasonal variation with the highest levels recorded during winter and spring when freshwater inputs were greatest. Nitrate levels peaked at 0.664mg/L at site IM1 during August 2007 (Fig 20) which is considerably higher than 0.015mg/L recommended by ANZECC (2000) guidelines. A strong gradient occurred with the upper sites having higher levels of nitrate. As no previous research has been conducted on the Inglis River estuary, further work is recommended to determine the source of nitrate and the effects on the ecology of the estuary.

Phosphorus concentrations were generally low throughout the sampling period ranging from <0.002mg/L to a maximum of 0.013mg/L (Fig 20) recorded at site IM1 in February 2007. There was also one very high reading of 0.055mg/L at site IM1 in December 2006. The reason for this high concentration of phosphate is unknown. Levels of phosphorus were consistently highest at Site IL1 indicating a marine input of phosphates.

Silica concentrations ranged from <0.5mg/L to 10mg/L (Fig 20). The peak of 10mg/L was the highest recorded in all six estuaries sampled. There was a strong longitudinal gradient with the upper sites having higher concentrations of silica. Concentrations were slightly higher over winter and spring when compared to summer and autumn.

Chlorophyll *a* levels were low over winter and moderate to high over spring, summer and autumn. Peaks occurred in December 2006 at site IU2 (12.4µg/L) and at site IM1 (10.5µg/L) during April 2007. A small peak of 5.9µg/L at site IU2 was also recorded in September 2007 (Fig 20). The highest peaks are two to three times the recommended values set by ANZECC (2000) guidelines (Appendix 1). A strong estuarine gradient existed with highest concentrations recorded in the upper estuary. Further study is required to determine the cause of the high levels of phytoplankton and whether current levels are of concern for the health of the estuary.

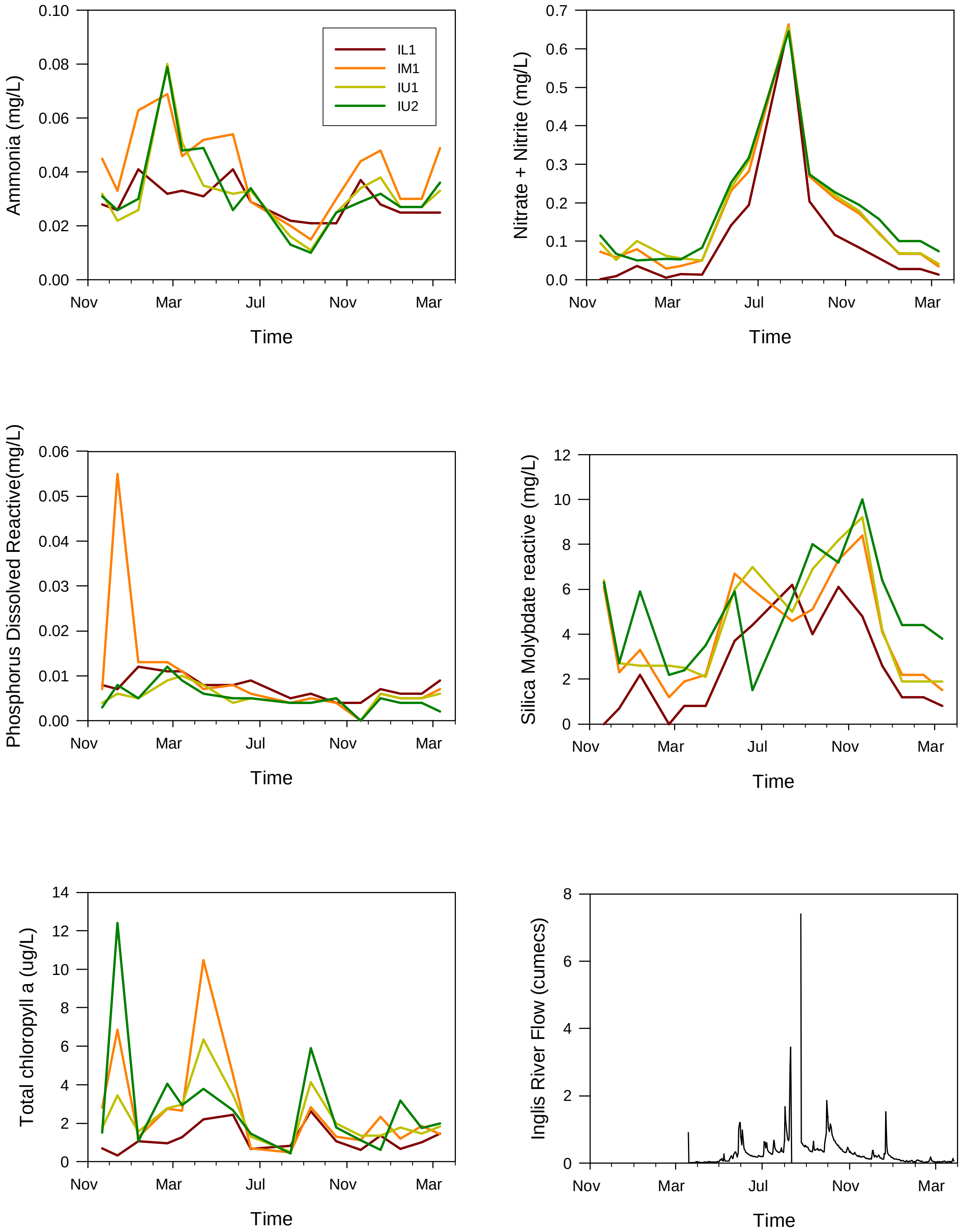


Fig. 20. Concentrations of ammonia, nitrate + nitrite, phosphorus dissolved reactive, silica molybdate reactive and total chlorophyll *a* recorded at each monitoring site of the Inglis River estuary from November 2006 to March 2008.

Black River

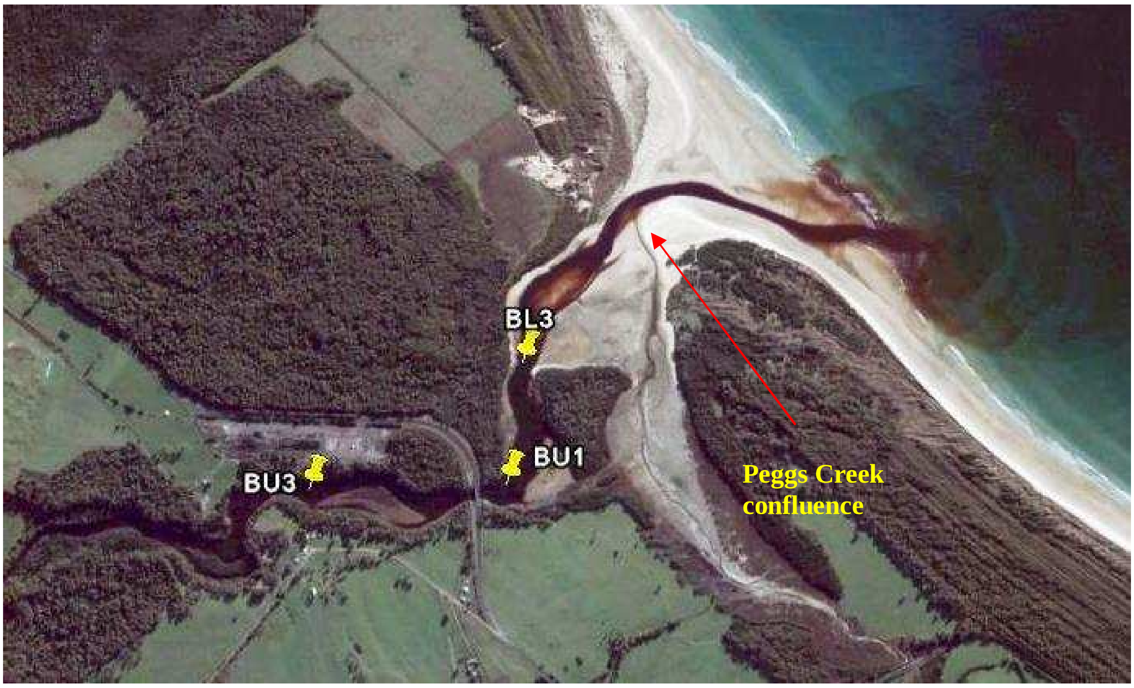


Fig. 21. A Google earth image of the Black River estuary showing fixed sampling sites.

Catchment and estuary description

The Black River has a total catchment area of approximately 320 km^2 and is drained by two main rivers, the Black River (55km) and the Dip River (35km). The estuary enters Bass Strait at the small township of Black River, east of Stanley.

The upper catchment is generally low relief with most of the catchment area below 250m; however, the eastern side of the Dip Range is ~500m. Although the catchment is low relief, much of the upper catchment contains steep gulleys making the Black River a fast draining system. It is also relatively narrow, increasing the velocity of the river. The effect this has on the estuary is profound where flood events continually alter river channels and sand bars in the lower estuary.

The estuary proper is short, with an approximate length of 3-4km. The only major creek system draining into the Estuary is Peggs Creek, entering the estuary below site BL3 (Fig 21). The water entering the estuary from the upper catchment contains high humic (tannin) concentrations, giving the water a distinct brown/black colour. This is displayed spectacularly in Fig 21 where the Black River water contrasts with oceanic water of Bass Strait.

The tidal range of the estuary is approximately 2-3m. The average depth at low tide ranges between 0.5 – 4m. Much of the upper estuary is shallow, <2m deep and has an instream habitat of mostly cobble (Fig 22). Depositional banks are composed of mostly silt and organic material derived from the catchment. Site BU1 (Fig 21) is the deepest location in the estuary with a maximum depth of 4m at low tide. Below this point the estuary widens out and is generally shallow, <2m deep and composed of low profile reef, hard sand and sand (Fig 21 and 22).

Because the condition of this estuary was monitored over previous years (Murphy *et al.* 2003; Hirst *et al.* 2005; Hirst *et al.* 2007) and as the budget was limited, this estuary was monitored every second month and at a reduced number of sites.

Fig 22. A SEAMAP Tasmania image showing the benthic habitat for the Black River estuary.

Classification and conservation significance

The Black River estuary is described as a meso-tidal river dominated estuary with a permanent opening to the sea. Edgar *et al.* (1999) assessed the conservation significance of the Black River estuary and gave it a rating of Class A, critical conservation significance. The significance of this estuary was attributed largely to it being the least impacted estuary of its type, with a relatively low proportion of agricultural land in the catchment and low population density.

Current land use

In comparison to the majority of river systems located on the North West coast of Tasmania, the Black River is the least modified catchment. Less than 20 % has been cleared for agriculture and much of the riparian zone is left intact. The majority of agriculture, mainly grazing and cropping occur in the coastal region adjacent to the Black River estuary (Waterways Monitoring Report: Black - Detention catchment 2007). The upper catchment has seen rapid development and expansion of forestry activities including forestry plantations.

The estuary is also becoming increasingly popular for recreational activities. A camping ground is located near the mouth on the eastern side of the estuary. It is used by people from the region and tourists for camping and fishing.

Salinity, Dissolved Oxygen and Temperature

Stratification occurred during summer and autumn at sites BL3 and BU1 with large differences in surface and bottom water salinities, to a maximum difference of 31.8 at site BL3 during May 2007 (Fig 23). Both sites are deep (~ 2 - 4m) with rock and sand bars between and below these sampling points, trapping oceanic water on an outgoing tide. Very low salinity persisted at site BU3 from May to October during high riverine input (Fig 23).

Dissolved Oxygen (DO) concentrations were generally above recommended levels (80%) determined by ANZECC (2000) guidelines. Lower than recommended levels were recorded at sites BU1 and BU3 during March 2007 (Fig 24). Generally there was little difference between surface and bottom water DO. Site BU1 displayed the largest difference in DO levels, ~ 20%, between surface and bottom waters. Site BU1 is the deepest section in the estuary and has the propensity to stratify during periods of low freshwater flow.

Temperature was relatively homogenous by depth at all sites throughout the sampling period (Fig 25). Site BU1 did display a temperature gradient with depth during August 2007, which was attributed to the differences in temperature between the freshwater flowing down the Black River and the saltwater entering from Bass Strait.

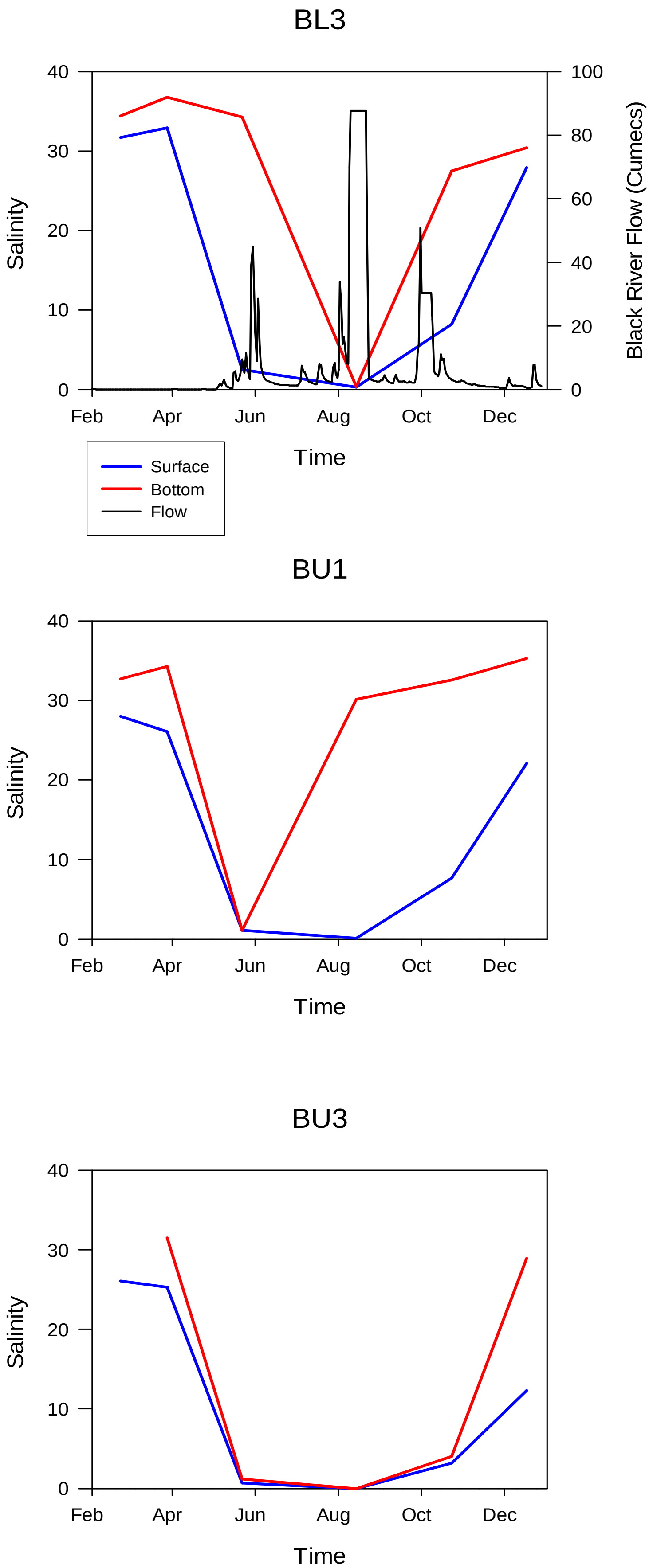


Fig. 23. Salinity data recorded for surface and bottom waters at each monitoring site within the Black River estuary from February 2007 to December 2007.

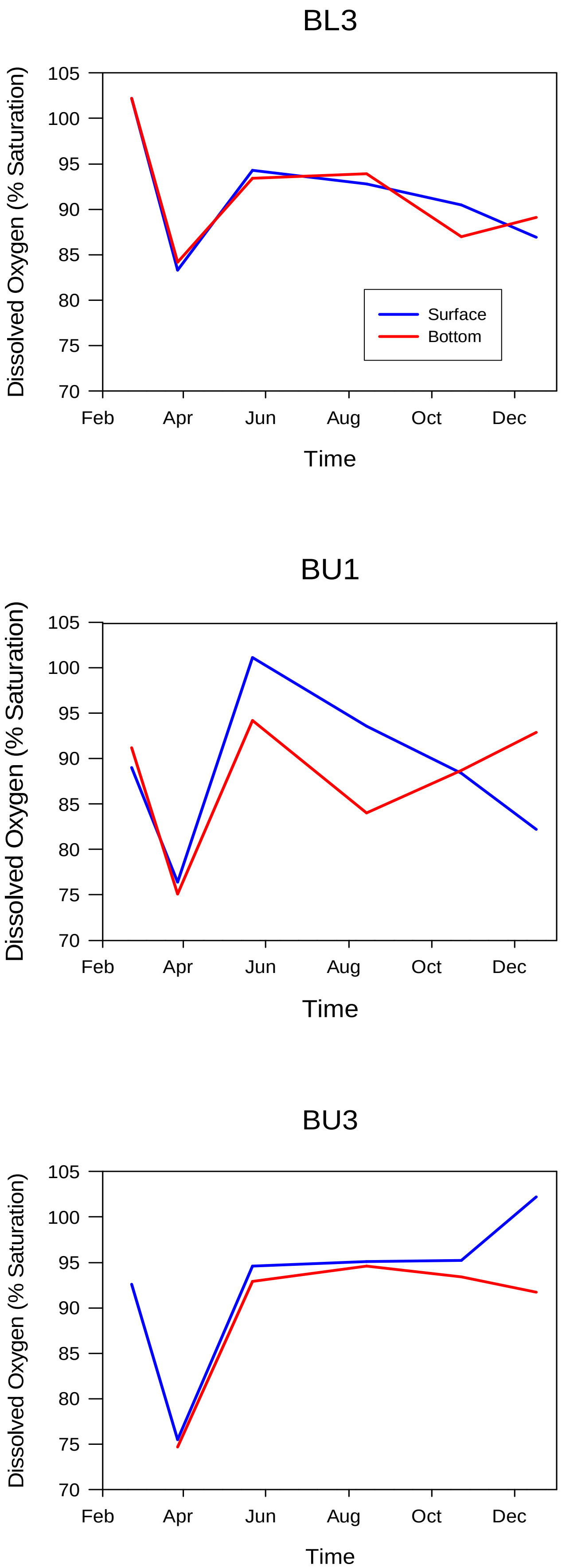


Fig. 24. Dissolved oxygen data recorded for surface and bottom waters at each monitoring site within the Black River estuary from February 2007 to December 2007.

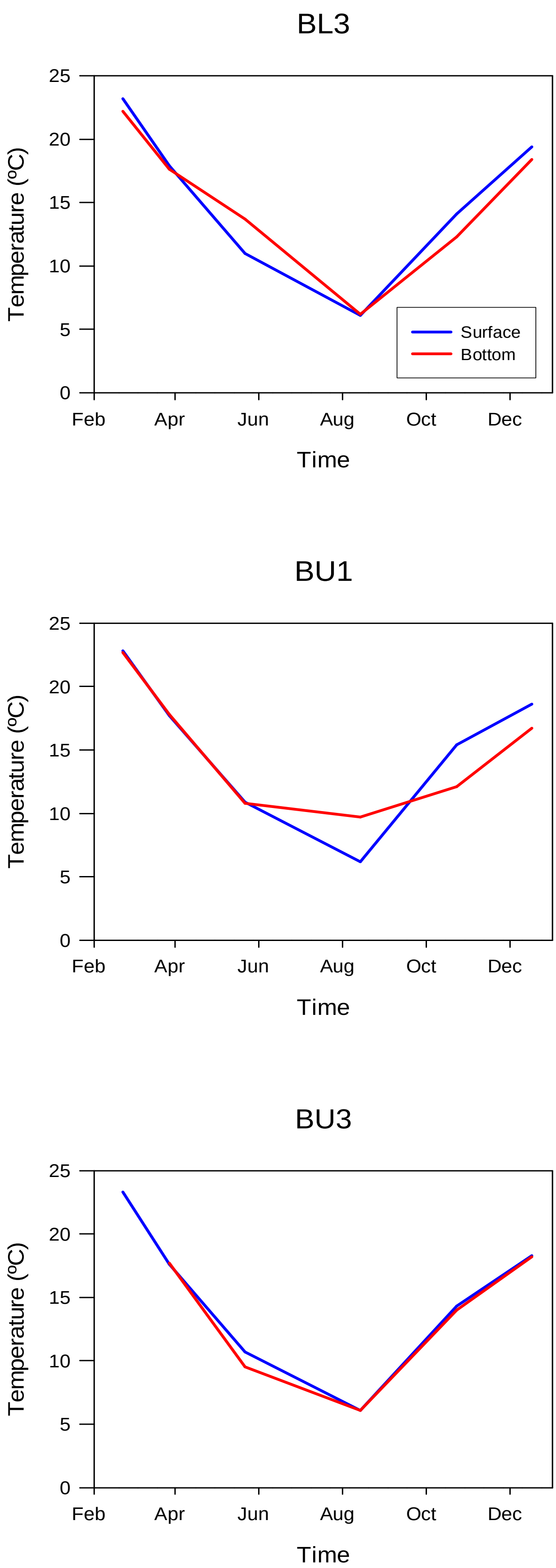


Fig. 25. Temperature data recorded for surface and bottom waters at each sampling site within the Black River estuary from February 2007 to December 2007.

Turbidity and pH

Turbidity levels in the Black River estuary were generally low (< 6 NTU), with the lowest average turbidity of 1.95 NTU recorded at sites BL3 and BU1 during December 2007. The maximum turbidity was 12.33 NTU at site BU1 during May 2007 (Fig 26), coinciding with a moderate flood event. A turbidity gradient existed, with the upper estuary generally having higher turbidity.

PH values were relatively low during winter and spring with a minimum of 5.5, when freshwater input was greatest (Fig 26). PH data for the upper catchment from the Water Information Services of Tasmania (WIST) showed that pH can attain levels as low as 4.0. The acidic water is most likely derived from humic material in the upper catchment; however acid sulphate soils may also be present. A pH gradient occurred in the Black River estuary, increasing towards the mouth of the estuary.

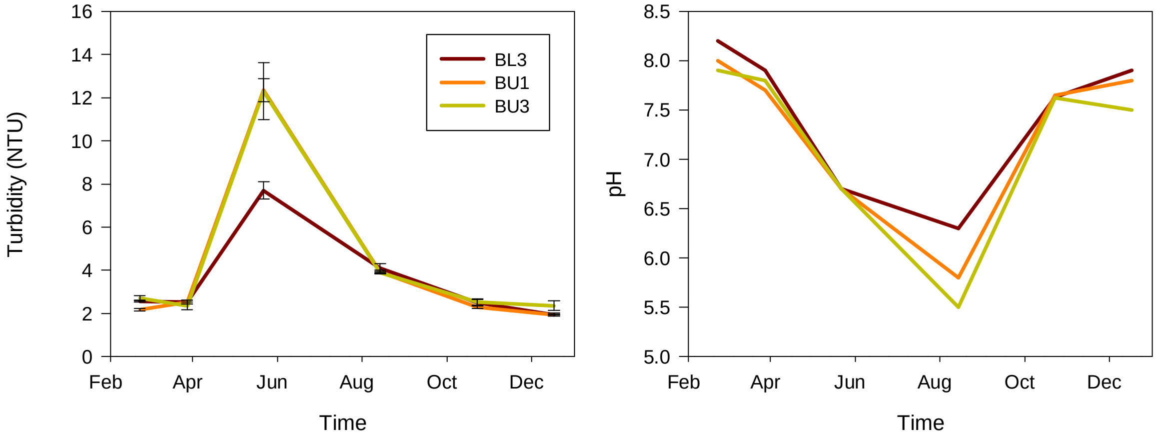


Fig. 26. Turbidity and pH measurements recorded for each monitoring site within the Black River estuary from February 2007 to December 2007. Error bars indicate the standard deviation from the mean.

Nutrients, silica and chlorophyll a

Using Murphy *et al.* (2003) draft indicator levels (Appendix 1, Table 2) concentrations of most nutrients were low, although nitrate was medium to very high on most sampling occasions. The peak nitrate concentration of 0.275 mg/L was recorded at site BU3 during March 2007 and a second peak of 0.205 mg/L occurred at the same site during the August 2007 flood event (Fig 27). Interestingly the March 2007 sample was taken when the Black River had very low base flows; in all other estuaries nitrate levels peaked with the August 2007 flood event. Reasons for this high value in March are not known. The elevated levels of nitrate observed in the Black River estuary require further investigation to determine whether they are natural or relate to anthropogenic input.

Levels of ammonia in the Black River estuary were up to twice that recommended (0.015mg/L) by ANZECC guidelines; however the levels are comparable or below levels recorded for other estuaries in the North West region of Tasmania. There was little difference in ammonia concentrations between upper and lower sites. Lowest levels of ammonia were recorded during the August 2007 flood event when large volumes of freshwater flushed the estuary (Fig 27).

Phosphate concentrations were very low throughout the sampling period ranging from 0.003mg/L to 0.006mg/L (Fig 27). Levels of phosphate were mostly higher in the upper estuary although differences between sites were always within 0.001 – 0.002 mg/L.

Silica concentrations were generally low ranging from 0.8mg/L to 7.8mg/L (Fig 27). Levels were higher over winter and spring when rainfall was greatest indicating that silica is derived from the upper catchment.

Chlorophyll *a* levels declined progressively during the study period from a high of over 5µg/L at all sites in February 2007 to <1µg/L in winter and spring (Fig 27). Previous studies of the Black River (Murphy *et al.*, 2003; Hirst *et al.*, 2005) have indicated that the upper estuary generally has higher concentrations of phytoplankton. Levels detected in this study were the highest that have been recorded from the estuary and may have resulted from reduced flushing during drought conditions.

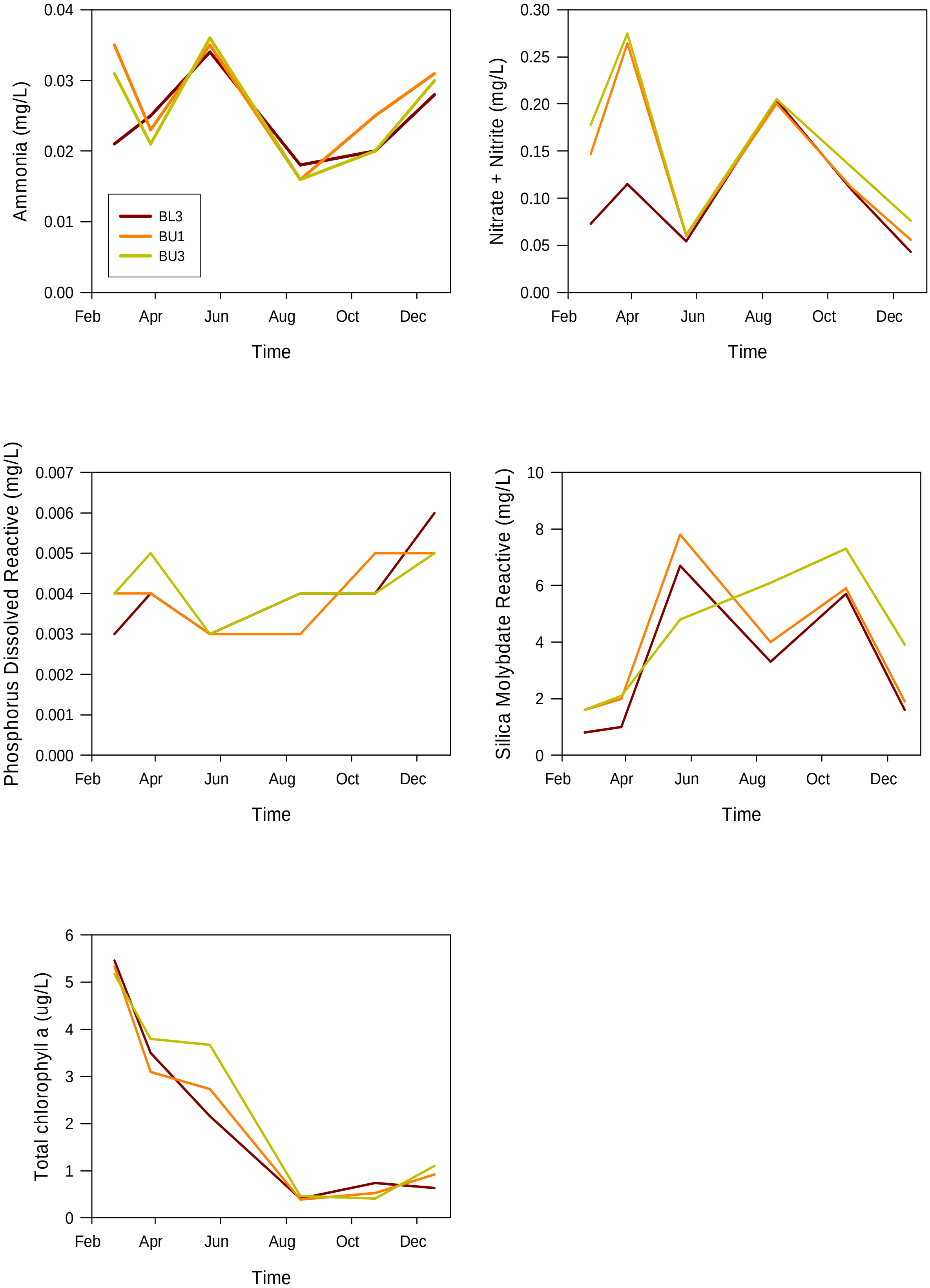


Fig. 27. Concentrations of ammonia, nitrate + nitrite, phosphorus dissolved reactive, silica molybdate reactive and total chlorophyll *a* recorded at each monitoring site of the Black River estuary from February 2007 to December 2007.

Montagu River

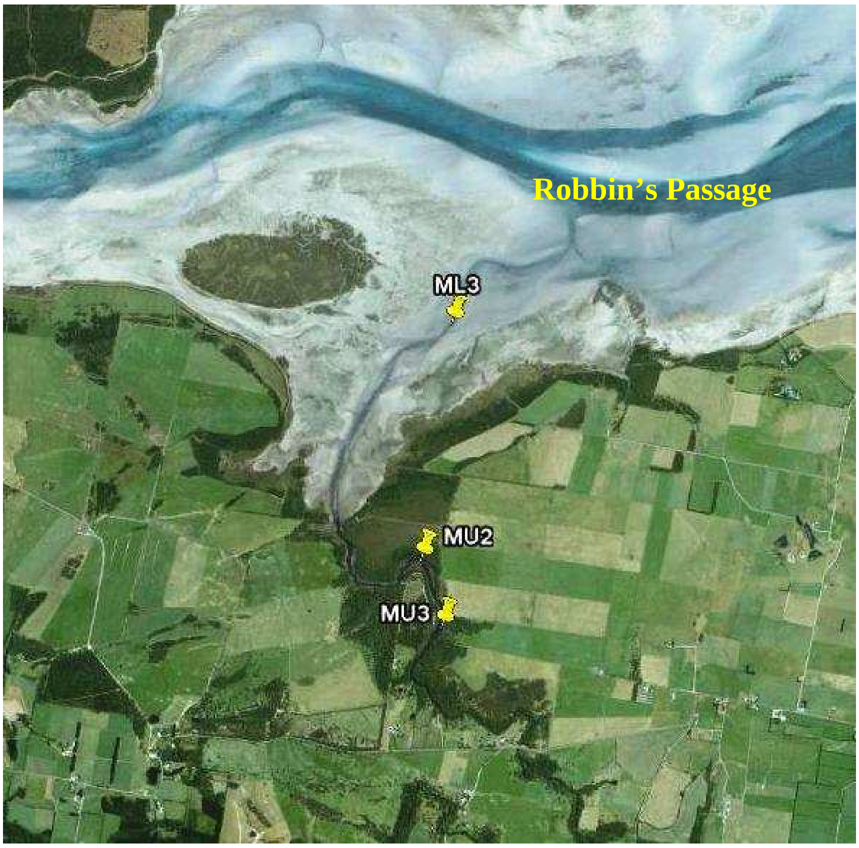


Fig. 28. A Google earth image of the Montagu River estuary and Robbins Passage showing fixed sampling sites.

Catchment and estuary description

The Montagu River catchment is ~ 323 km^2 in area, and ranges in elevation between sea level and 200m. This region of Tasmania receives high annual rainfall of approximately 1200mm. The Montagu River drains through areas of intensive agriculture and forestry before entering Bass Strait west of Smithton.

The upper reaches of the Montagu River estuary are relatively short, approximately 2-3km long. The instream habitat of the upper estuary is comprised of cobble substrate with some depositional banks containing silt (Fig 29). Much of the riparian zone of the estuary remains intact and is lined by thick forests of *Melaleuca* and scrub *Eucalyptus* trees. The bed slope in the upper estuary is steep and contains a series of rock bars and ledges making navigation by boat difficult.

The estuary widens at the mouth depositing large quantities of silt into the lower estuary (Fig 28, Fig 29). During periods of high rainfall the lower estuary extends into Robbins Passage with a range exceeding 3.5km from the mouth (Hirst *et al.*, 2005). At low tide the estuary across all sites is very shallow with an average depth of 0.5 – 1.5m. The shallowness and shape of the estuary has led to the development of a complex wetland system containing large areas of sand and seagrass (Fig 29). There are no major creek systems entering the estuary.

Because the condition of this estuary was monitored over the previous two years (Hirst et al 2005, Hirst et al 2007) and as the budget was limited, this estuary was monitored every second month and at a reduced number of sites.

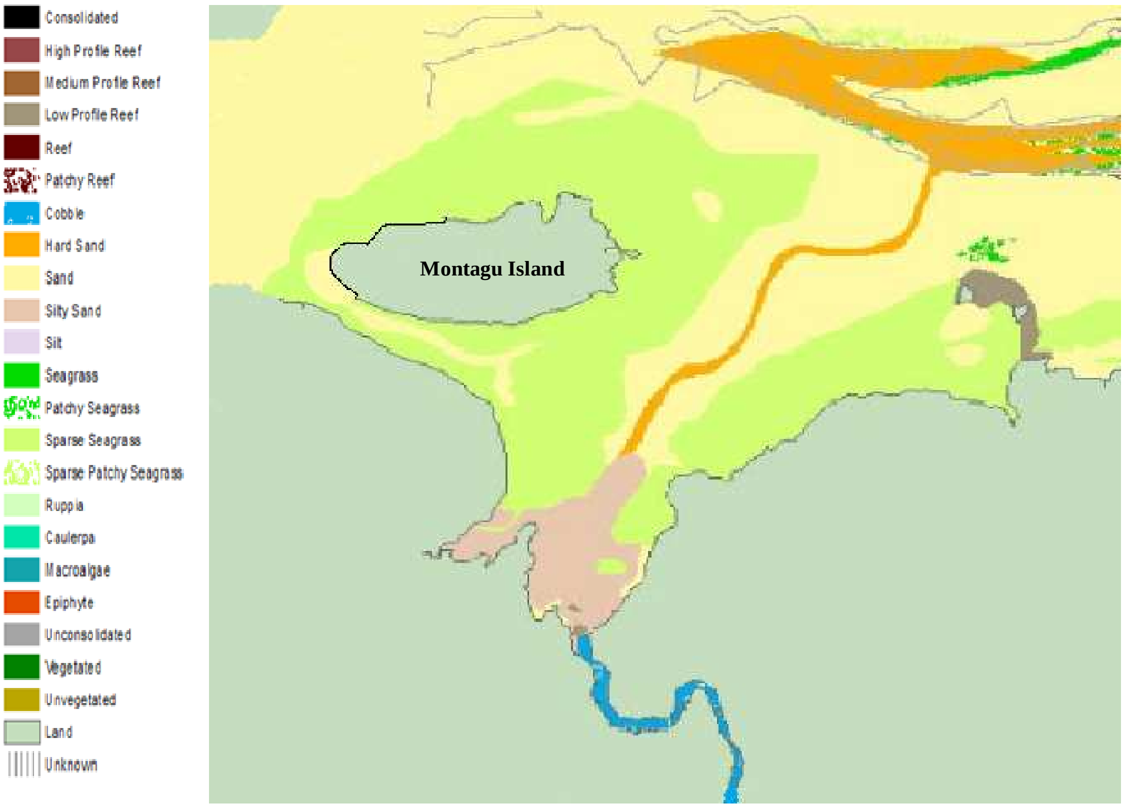


Fig 29. A SEAMAP Tasmania image showing the benthic habitat for the Montagu River estuary.

Classification and conservation significance

The Montagu River estuary is described as a mesotidal river dominated estuary with a freshwater influence extending into Robbins Passage. Despite the important wetland incorporating much of the lower estuary Edgar *et al*. (1999) assessed the conservation significance of the Montagu River estuary as Class C, moderate conservation significance. The lower than expected classification of this estuary was due to agricultural development in the upper catchment.

The Montagu Estuary/Robbins Passage wetlands and salt marshes provide breeding, roosting and feeding habitat for the largest density and diversity of shorebirds found in Tasmania (CCNRM, 2005). This area is home to the endangered little tern and the vulnerable hooded plover. Also white bellied sea eagles have active nesting sites along the riparian zone of the Montagu River estuary (pers. obs.).

Current land use

Much of the catchment was once a complex wetland system comprised of Blackwood and Melaleuca forests. Currently the upper catchment contains only remnants of this vegetation type. Most of the middle and lower catchment has been cleared for agriculture, comprising intense dairy farming and forestry plantation. The main river and tributaries in the middle and lower catchment have been straightened and channelled to allow for better drainage. This has led to poor water quality in the Montagu River (Waterways Monitoring Report: Montagu catchment, 2007).

Much of the estuary has remained unchanged; however some dairying does occur on the eastern side while the western side is comprised of small hobby farms. Some thinning of riparian vegetation has occurred on the eastern side; however, the banks still contain native vegetation. The lower estuary contains five Pacific oyster (*Crassostrea gigas*) leases.

Salinity, Dissolved Oxygen and Temperature

Surface salinities were affected by riverine input at all sites, especially during winter when freshwater flow was highest. All sites had <0.1 salinity throughout the water column during the August 2007 flood event (Fig 30). The freshwater incursion during the flood event extended beyond our lowest sampling site ML3 and the freshwater (noted by the brown colour) was seen to extend well into Robbins Passage.

During summer when freshwater flow was low, large differences in surface and bottom water salinities existed at sites MU2 and MU3. Differences in salinity by depth were not observed at site ML3 indicating that that the lower estuary is generally well mixed (Fig 30).

Dissolved Oxygen (DO) concentrations showed seasonal variation with lowest concentrations observed from May – August 2007. The lowest DO level recorded in the estuary was 67.8 % saturation in the bottom water at site MU3 during May 2007 (Fig 31). Lower DO levels (~ 70 – 75 %) persisted throughout winter when freshwater inputs were greatest. An estuarine gradient existed with DO levels increasing towards the mouth.

Temperature was similar at all sites and by depth throughout the sampling period (Fig 32). The shallowness of the estuary coupled with the large tidal range (2-3m) ensures that the water column within the estuary remains homogenous in temperature.

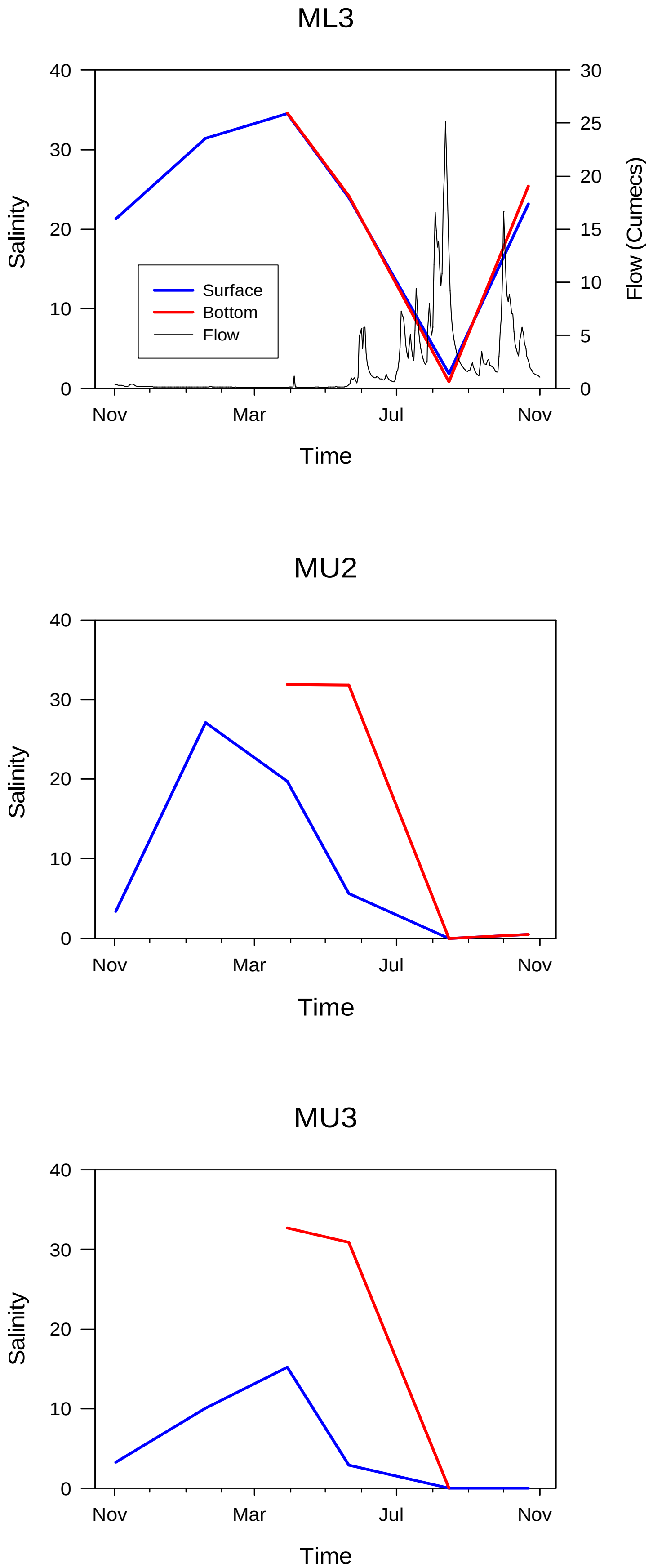


Fig. 30. Salinity data recorded for surface and bottom waters at each monitoring site within the Montagu River estuary from November 2006 to October 2007.

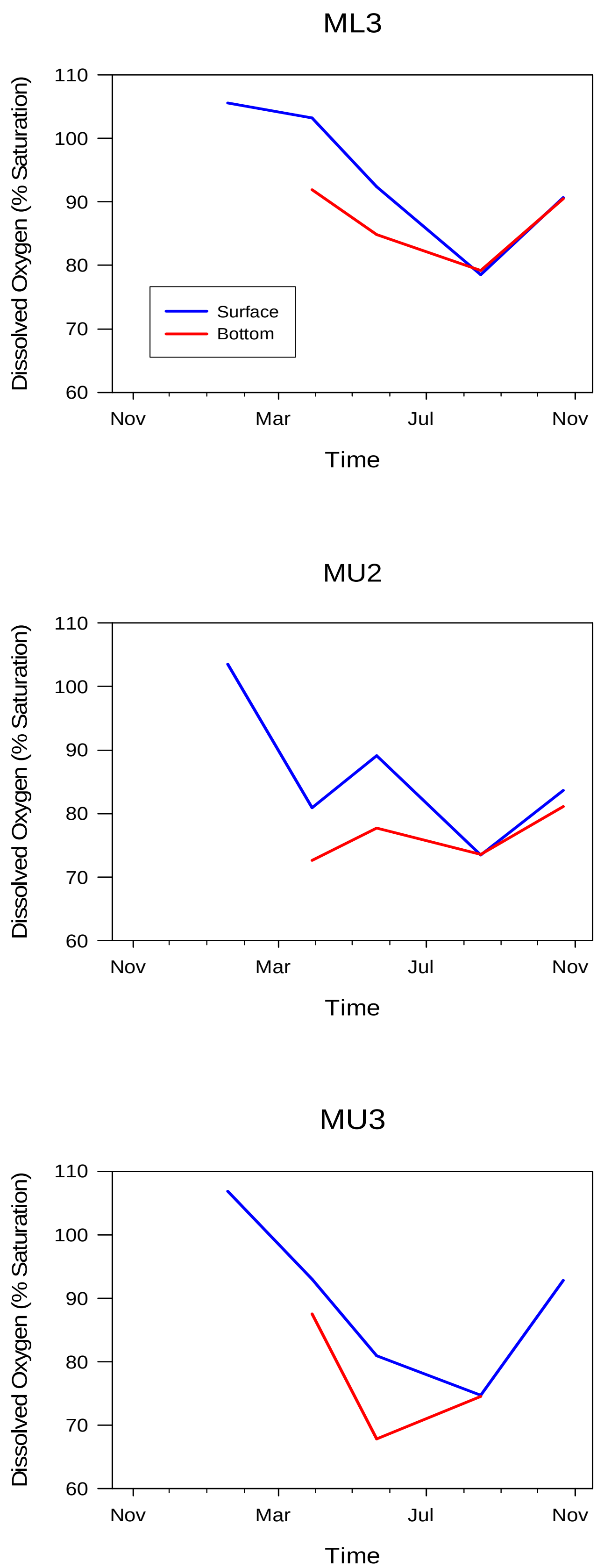


Fig. 31. Dissolved oxygen data recorded for surface and bottom waters at each monitoring site within the Montagu River estuary from November 2006 to October 2007.

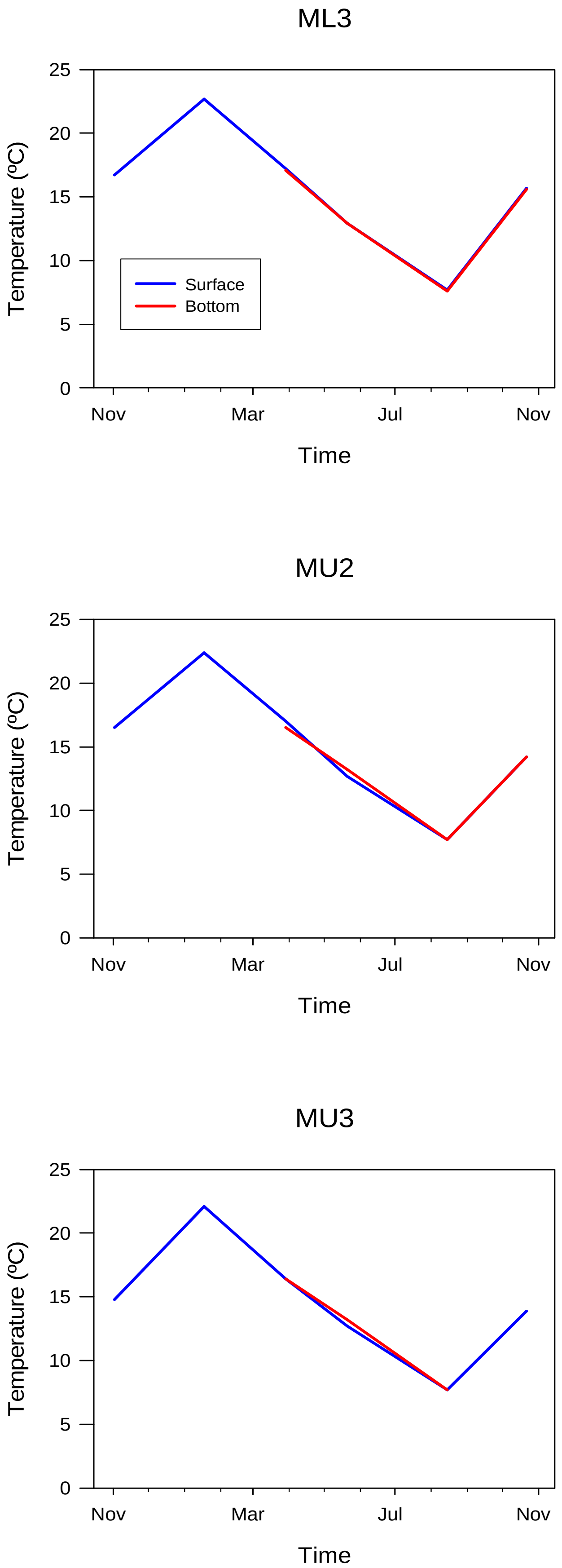


Fig. 32. Temperature data recorded for surface and bottom waters at each sampling site within the Montagu River estuary from November 2006 to October 2007.

Turbidity and pH

Average turbidity in the Montagu River estuary was generally medium to high (5 - 25 NTU) during all sampling events. The upper estuary generally had higher turbidity except during the August 2007 flood event where it was highest in the lower estuary (Fig 33). This was partly due to sediment washing down from the upper catchment but also from freshwater entering the lower estuary at high velocity causing a resuspension of sediments. Wave action caused by strong wind events also disturbs sediments in the lower estuary.

PH in the Montagu River estuary ranged from 7.0 – 8.2 which is within acceptable range set by ANZECC (2000) guidelines. During the August 2007 flood event lower pH was recorded at all sites (Fig 33).

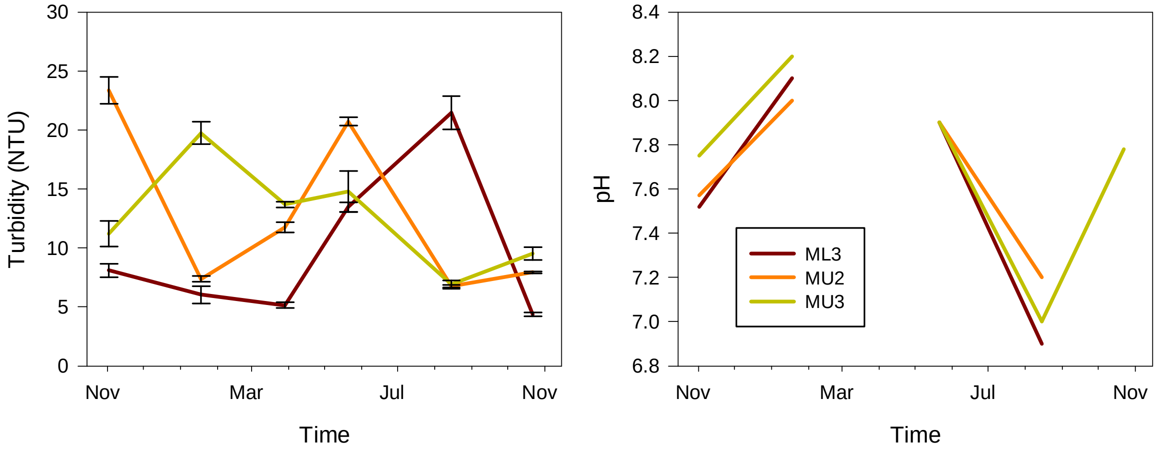


Fig. 33. Turbidity and pH measurements recorded at each monitoring site within the Montagu River estuary from November 2006 to October 2007. Error bars indicate the standard deviation from the mean.

Nutrients, silica and chlorophyll a

Nutrient levels within the Montagu River estuary are among the highest recorded for the six estuaries monitored in this study. Ammonia concentrations were generally higher than other NW Tasmanian estuaries and peaked at 0.058 mg/L during May 2007. Levels of ammonia were higher during winter/spring and lowest in autumn (Fig 34), which differs to other estuaries monitored where lowest levels occurred during winter and spring. Water entering the estuary from the catchment may contain elevated levels of ammonia.

Nitrate levels in the Montagu River estuary were the highest recorded in this study peaking at 0.914 mg/L at site MU2 during the August 2007 flood event. The levels of nitrate were highest during winter, spring and early summer when riverine inputs were greatest (Fig 34). A nitrate gradient occurred with concentrations decreasing towards Robbins Passage.

Phosphate levels were also very high peaking at 0.083 mg/L at sites ML3 and MU2 during the August 2007 flood event (Fig 34). Phosphate levels were highest in the upper estuary on most sampling occasions, which differed to the Leven, Inglis and

Arthur River estuaries where higher levels occurred in the lower estuary. This indicates that phosphate in the Montagu River estuary is likely catchment derived.

Silica levels were comparable to other estuaries within the region. Concentrations were higher over winter, spring and early summer (Fig 34) indicating that silica is sourced from the upper catchment

Chlorophyll *a* levels ranged from 1.3 – 9.6 µg/L and were generally highest during summer and autumn (Fig 34). Chlorophyll *a* levels in the Montagu River estuary are considered high by ANZECC (2000) guidelines (4 µg/L) and by Murphy *et al.* (2003) draft indicator levels (Appendix 1). Given the high levels of nutrients in the estuary, chlorophyll *a* could attain much higher levels.

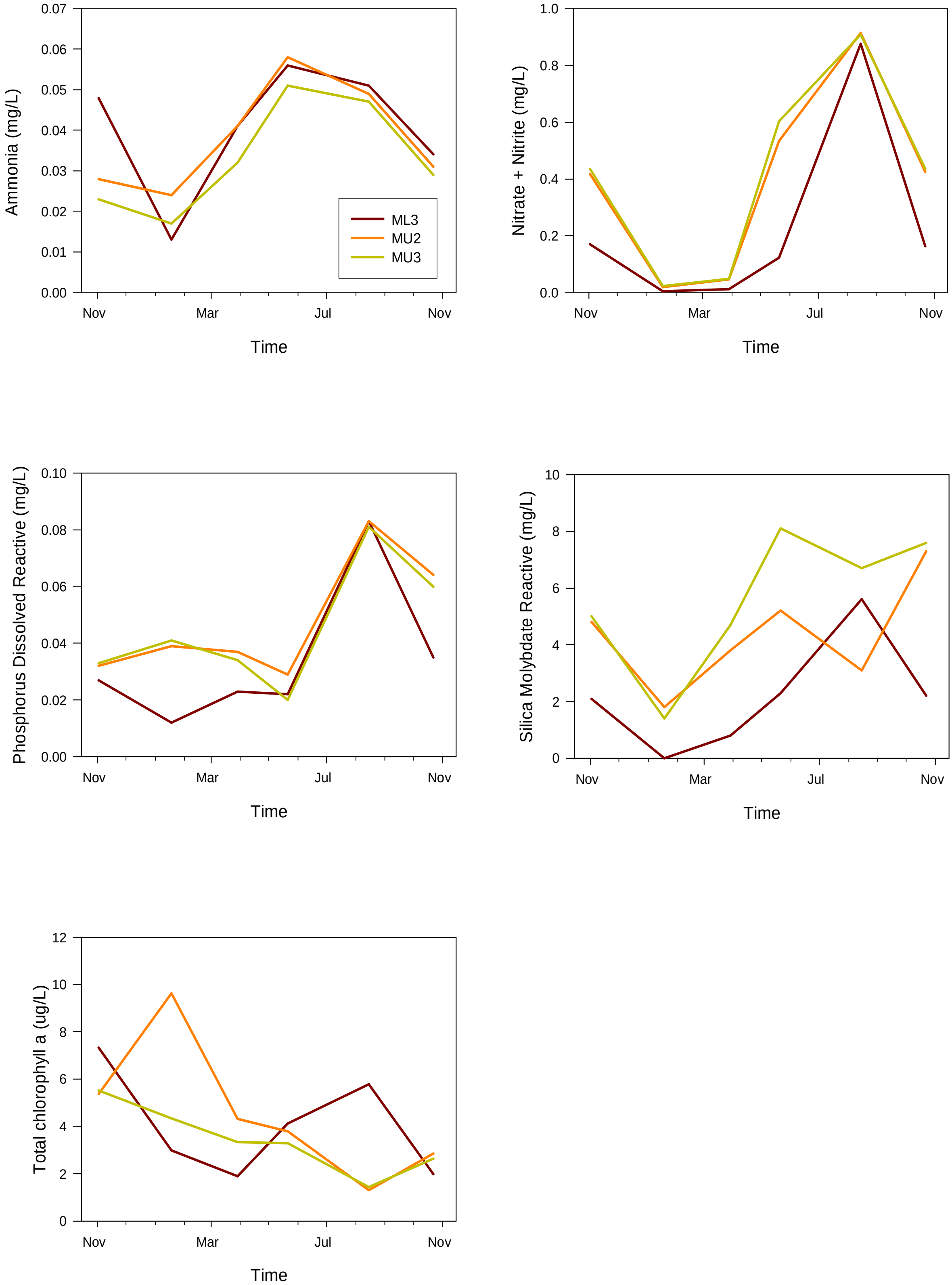


Fig. 34. Concentrations of ammonia, nitrate + nitrite, phosphorus dissolved reactive, silica molybdate reactive and total chlorophyll *a* recorded at each monitoring site of the Montagu River estuary from November 2006 to October 2007.

Arthur River

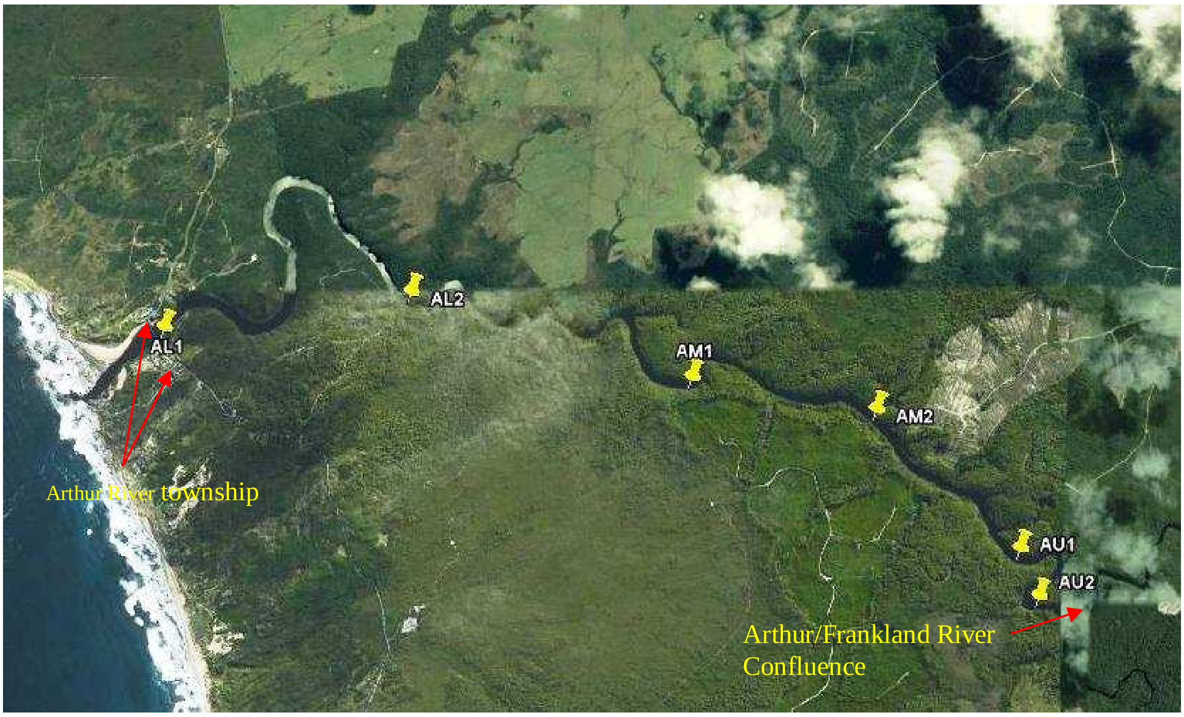


Fig. 35. A Google earth image of the Arthur River estuary showing fixed sampling sites.

Catchment and estuary description

The Arthur River catchment, located on the west coast of Tasmania, covers an area of approximately 2,500 km^2. The catchment drains westward through the small coastal township of Arthur River and into the ocean. The total length of the Arthur River is about 180 km, originating near Waratah in the foothills of Mt Bischoff at an altitude of 800m above sea level. The annual average rainfall ranges from about 1000 mm at the Arthur River township to 2200 mm at Waratah.

The length of the Arthur River estuary is relatively long with site AU2 approximately 13km upstream of the Arthur River Township. The estuary is thought to extend beyond this point to the first set of rapids above the Arthur/Frankland River confluence (Fig 35). The riparian zone of the upper catchment and estuary is heavily vegetated and in relatively pristine condition. The riparian vegetation becomes more open as the river approaches the mouth.

The tidal range of the Arthur River is small, generally <1m, compared to 2-3m in Bass Strait. During low flows and stable weather patterns (late summer and autumn) a sand barrier can form across the mouth reducing water movement in and out of the estuary. The estuary is very deep with most monitoring sites recording depths between 7 - 18m. Much of the estuary is formed on silt and sand although there are areas of bedrock at sites AU2 (Fig 35). Benthic habitat mapping is yet to be conducted in the Arthur River estuary.

Because the condition of this estuary was monitored previously (Murphy *et al.*, 2003) and as the budget was limited, this estuary was monitored every second month.

Classification and conservation significance

The Arthur River estuary has been described as a large microtidal river dominated estuary. Edgar *et al*. (1999) assessed the conservation significance of the Arthur River estuary as Class B (high conservation significance). The river supports populations of the Australian Grayling, *Prototroctes maraena*, which is listed as vulnerable under the *Tasmanian Threatened Species Act 1995*. White bellied sea-eagles, which are also listed as vulnerable, occur along the Arthur River estuary (pers. obs.).

Current land use

The Arthur River catchment is used extensively for all forms of forestry production. Small pockets of beef cattle farming occur along the northern boundary of the estuary and in the uppermost catchment near Waratah. In the past the upper catchment was subject to substantial mining activities at Balfour and Mt Bischoff. During flood events, seepage from old tailing dams can impact on water quality (Waterways Monitoring Report: Arthur catchment, 2007).

The Arthur River estuary provides natural scenery for tourists and supports two boat cruise companies. Recreational fishing also draws people to this estuary from outside the Cradle Coast region.

Salinity, Dissolved Oxygen and Temperature

During late summer and early autumn the Arthur River estuary became vertically stratified (layered) in salinity, temperature and dissolved oxygen (Fig 36). Stratification occurred at all sites except for site AL1 where a relatively homogenous profile existed.

Figure 36 demonstrates the typical depth profile of water chemistry in the Arthur River during summer and autumn. The depth of the halocline is ~2m where there is a sharp increase in salinity and a decrease in both dissolved oxygen (DO) and temperature (Fig 36). The depth of the halocline varies by site and by month and is dependent on the strength of freshwater flows and tidal influence. Generally below the 2-3m depth zone the water becomes highly anoxic. Site AU2 recorded a minimum DO concentration of 8.6 % saturation in the bottom water (Fig 36, 38).

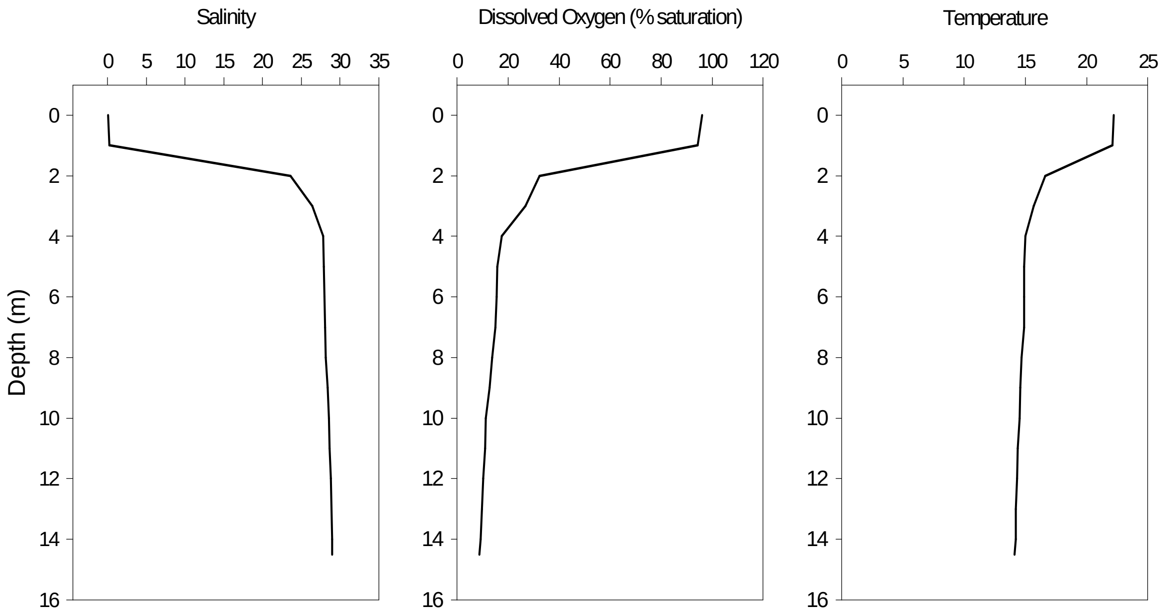


Fig. 36. A water column profile at site AU2 during January 2007 showing changes in salinity, dissolved oxygen and temperature with depth.

Low salinity, <0.01salinity, persisted throughout winter and spring at sites AU2, AU1, AM2 and AM1 (Fig 37). During the August 2007 flood event the entire estuary ran fresh at all sites and at all depths, with the exception of site AL2 where a pocket of saline water remained on the bottom. Maximum salinities were close to marine in the bottom water at sites AL2 and AM1 during March 2007 (Fig 37).

Dissolved Oxygen (DO) concentrations in the surface waters were generally above recommended levels (80%) set by ANZECC (2000) guidelines. However during summer and autumn the bottom waters were anoxic at all sites (Fig 38). Further research is required to determine the cause of the low DO concentrations and whether current levels pose an ecological risk to the estuary. During summer and autumn there were large temperature differences recorded between the surface and bottom waters at all sites with a maximum difference of 8.1 ºC (Fig 39). During periods of high freshwater flows the water column was relatively homogenous.

Given the stratified nature of the estuary, water quality in the surface waters will be unrepresentative of the conditions at depths > 2 - 4m. If feasible, future monitoring of water quality should incorporate characterisation of water quality parameters in bottom water.

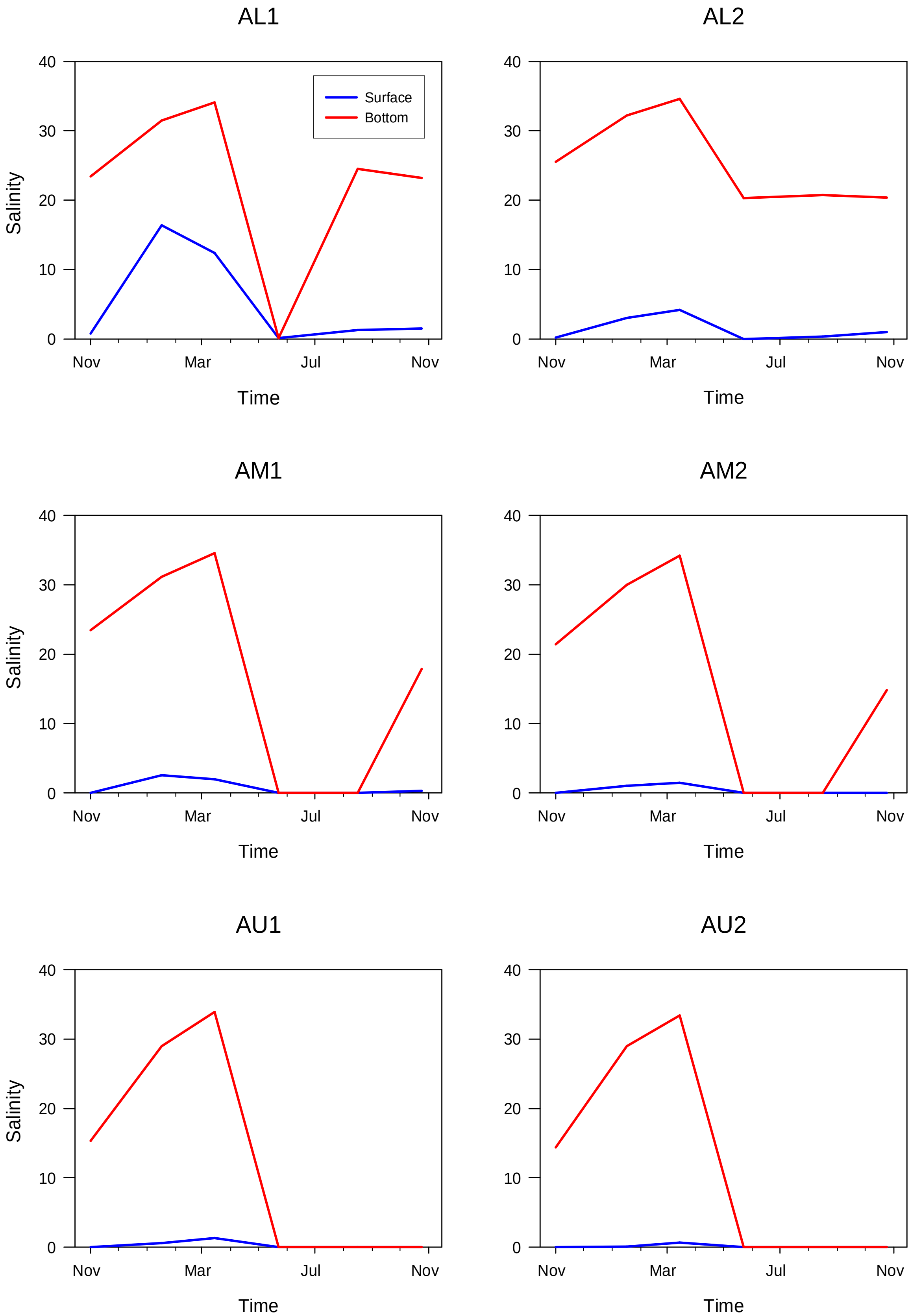


Fig. 37. Salinity data recorded for surface and bottom waters at each monitoring site within the Arthur River estuary from November 2006 to October 2007.

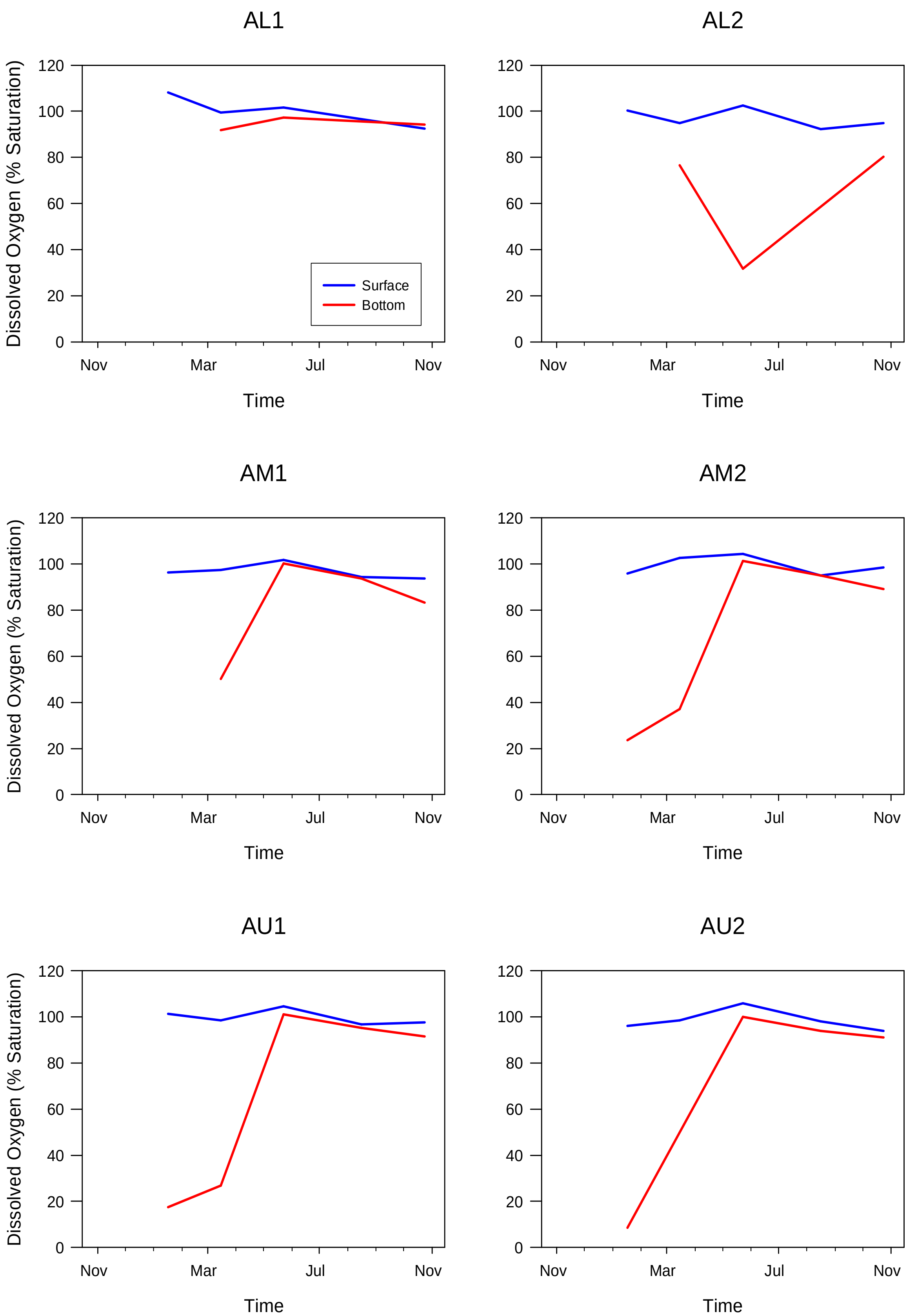


Fig. 38. Dissolved oxygen (% saturation) data recorded for surface and bottom waters at each monitoring site within the Arthur River estuary from November 2006 to October 2007.

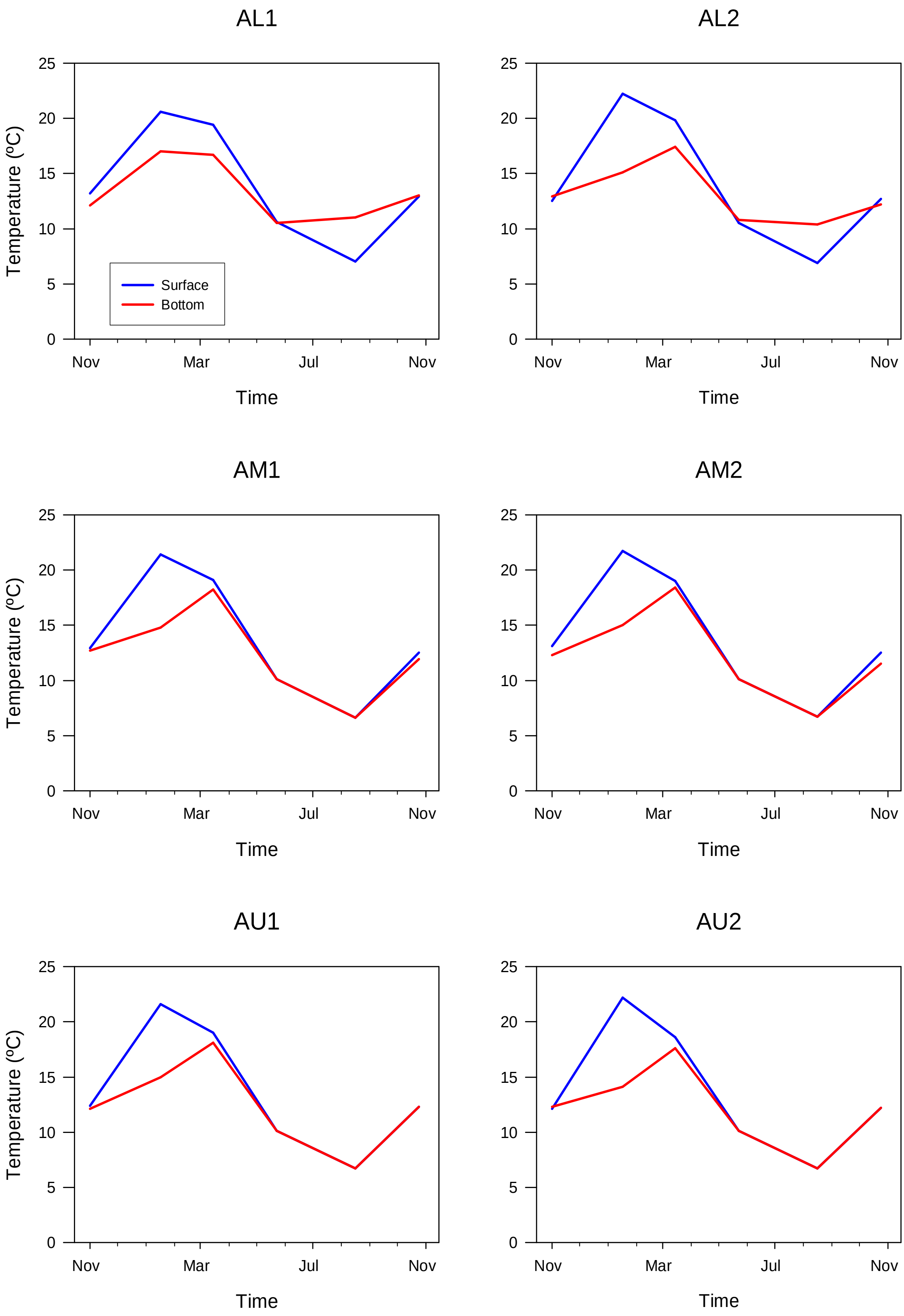


Fig. 39. Temperature (ºC) data recorded for surface and bottom waters at each sampling site within the Arthur River estuary from November 2006 to October 2007.

Turbidity and pH

Turbidity levels in the Arthur River estuary were generally low < 6 NTU except during high flow events where turbidity levels exceeded 10 NTU (Fig 40). A turbidity gradient existed in the estuary with the upper and middle estuary generally having higher turbidity.

PH ranged from 5.5 to 8.4 with lower pH levels coinciding with large rainfall events (Fig-40). The acidic water is most likely derived from humic material contained in the upper catchment.

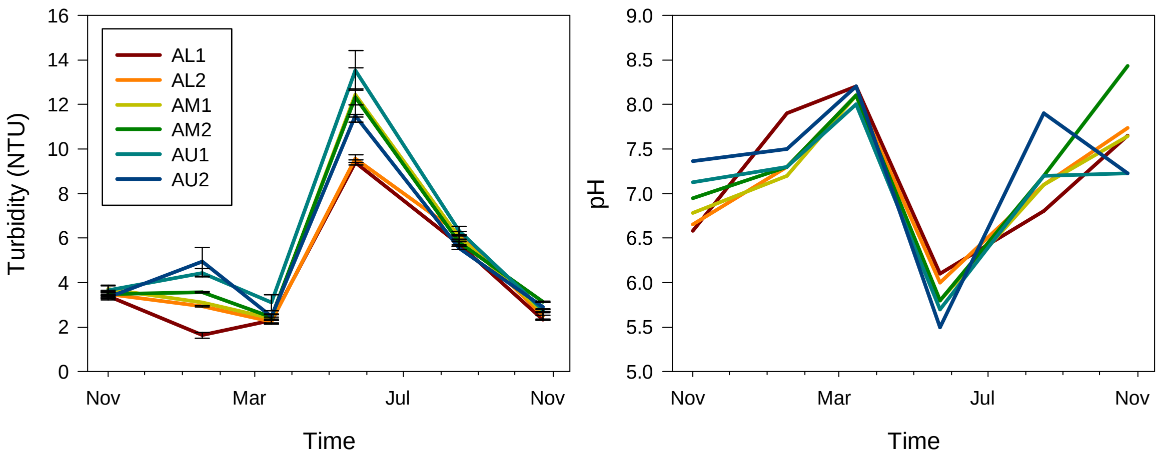


Fig. 40. Turbidity and pH measurements recorded for each monitoring site within the Arthur River estuary from November 2006 to October 2007. Error bars indicate the standard deviation from the mean.

Nutrients, silica and chlorophyll *a*

The Arthur River estuary had low nutrient levels in surface waters throughout the year. Nitrate levels were highest at all sites during the August 2007 flood event, peaking at 0.106mg/L (Fig 41). However, they were significantly lower than other estuaries monitored during the same flood event.

Concentrations of ammonia ranged between 0.005 – 0.030 mg/L (Fig 41) and were up to twice that recommended by ANZECC (2000) guidelines (0.015mg/L). However, ammonia concentrations in the Arthur River estuary were the lowest recorded for all NW Tasmanian estuaries surveyed in this study. No estuarine gradient existed and no seasonal pattern was detected in ammonia concentrations.

Phosphate concentrations were very low throughout the sampling period ranging from <0.002mg/L to 0.004mg/L (Fig 41) suggesting that phosphorus levels are naturally low in the catchment. No phosphate gradient in the Arthur River estuary was discernable.

Silica concentrations ranged from <0.5mg/L to 7.9mg/L (Fig 41). Silica levels varied considerably over seasons and the upper sites generally had higher silica levels than the lower sites (Fig 41). Silica is therefore most likely derived from the upper catchment.

Chlorophyll *a* concentrations were low throughout the sampling period peaking at 1.59µg/L at site AL1 during March 2007 (Fig 41). Sites AL1, AU1 and AU2 consistently had the highest levels of chlorophyll *a* with the exception of the May and August 2007 sampling rounds where site AM1 recorded the highest levels of chlorophyll *a* (Fig 41).

The levels of ammonia, nitrate, phosphorus and chlorophyll *a* detected in the Arthur River estuary were on average the lowest of the six estuaries monitored in this study. In contrast, the dissolved oxygen levels in bottom waters over summer and autumn were the lowest recorded and are likely to have impacted on the benthic fauna of the estuary.

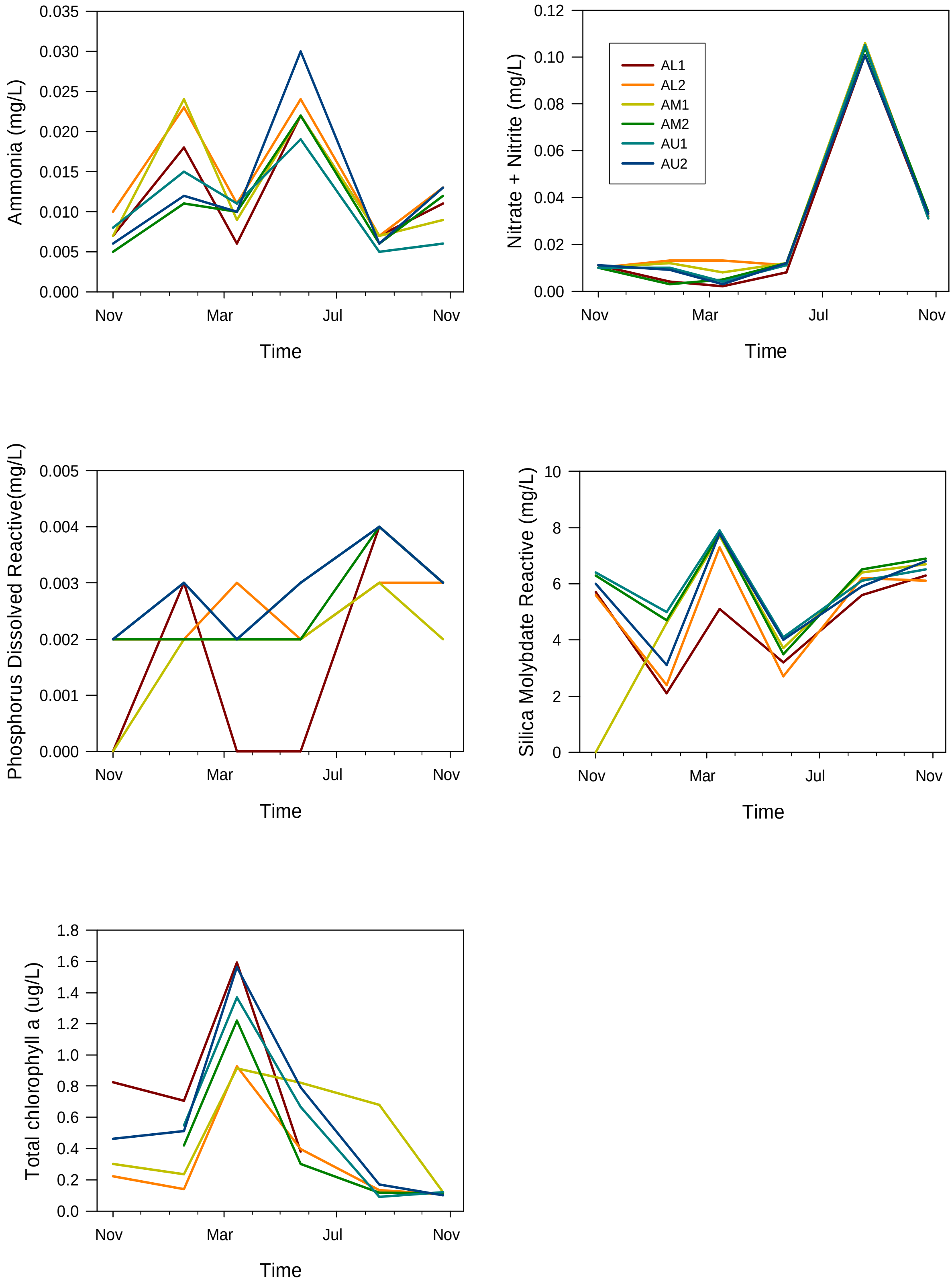


Fig. 41. Concentrations of ammonia, nitrate + nitrite, phosphorus dissolved reactive, silica molybdate reactive and total chlorophyll *a* recorded at each monitoring site of the Arthur River estuary from November 2006 to October 2007.

Macroinvertebrates

Patterns in macroinvertebrate communities of estuaries in NW Tasmania were analysed using non-metric multidimensional scaling (MDS) ordination. MDS is a standard analytical technique commonly used by ecologists to compare macroinvertebrate communities from different sites. This technique is described in texts on statistical methods for biological sciences (e.g. Quinn and Keogh, 2002) and in reports and publications from TAFI on macroinvertebrate fauna, available at http://www.tafi.org.au/. MDS takes into account the similarity/dissimilarity of the species composition and abundance of each species between sites and displays these differences graphically. The more different sites are with respect to species composition and abundance, the further apart they are on an MDS plot.

The nMDS revealed two interesting patterns in macroinvertebrate community structure. First there was a separation between estuaries, and secondly, a downstream gradient conveying changes in community structure from marine to estuarine environments (left to right across plot) was particularly evident amongst the mesotidal river estuaries (see Fig 42). The stress value of 0.16 indicates that this is a reasonable representation of the original similarity data matrix.

In general, macroinvertebrate communities collected from the Arthur River and Port Sorell estuaries clustered at either end of the ordination plot (Fig 42), indicating the marine nature of Port Sorell and the brackish system of the Arthur River. There was no distinction between macroinvertebrate communities in the upper, middle and lower sites within the Arthur River estuary; however communities found in the upper sites of the Port Sorell estuary appear to differ from the mid and lower sites (Fig 42). The Leven, Inglis, Black and Montagu River estuaries shared the most similarities in macroinvertebrate communities, except for the lower Leven River sample in spring, which was inadvertently sampled higher in the intertidal zone. The results for Lower Leven 1 (LL1) have been omitted from Figs. 44 and 45 for this reason.

Macroinvertebrate assemblages exhibited an estuarine gradient for the Leven, Inglis and Montagu River estuaries; however a gradient was not present in the Black River. For estuaries where a gradient existed, the upper and mid sites clustered together and showed some similarity to Arthur River macroinvertebrate communities (Fig 42). The lower sites; however, grouped with Port Sorell indicating the marine nature of these sites. An exception to this pattern was site LM1, which was similar to the marine communities of Port Sorell (Fig 42). Considering the marine nature of the invertebrate community, LM1 should be reclassified as a lower site.

To aid interpretation of the Black River data, an MDS ordination was plotted, displaying the date of sampling (spring and autumn) (Fig 43). The plot indicates that macroinvertebrate communities in the Black River estuary changed between sampling dates from estuarine in spring to one dominated by marine communities in autumn. Site LM2 of the Leven River also recorded a similar community shift (Fig 43). The change occurred due to the introduction of marine species into these sites rather than the disappearance of estuarine species. The Arthur River communities also tended to separate out by seasons, although they remained unique to that estuary. Port Sorell, the

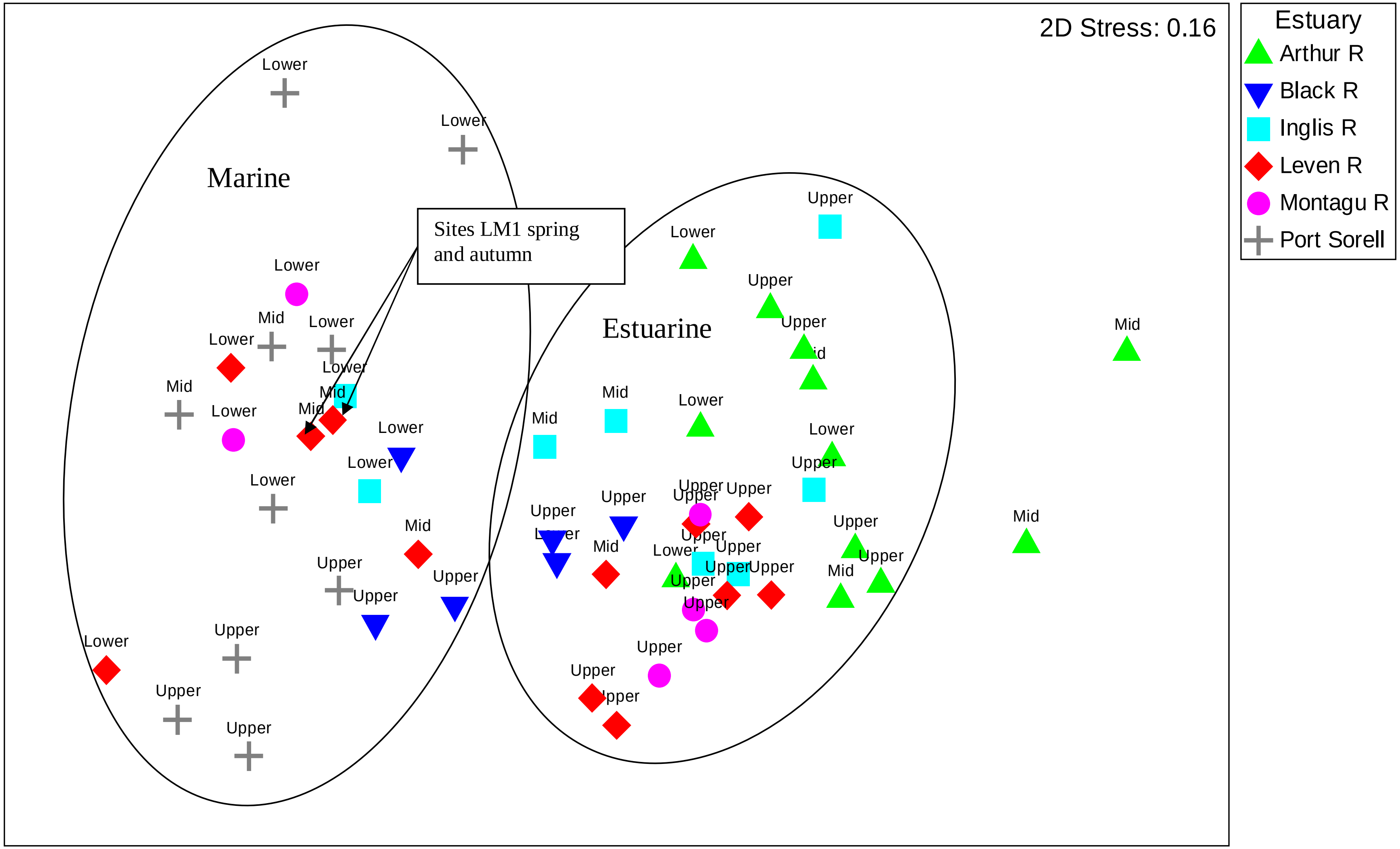


Fig. 42. MDS ordination of macroinvertebrate assemblages from all sites within the six estuaries monitored in north-western Tasmania.

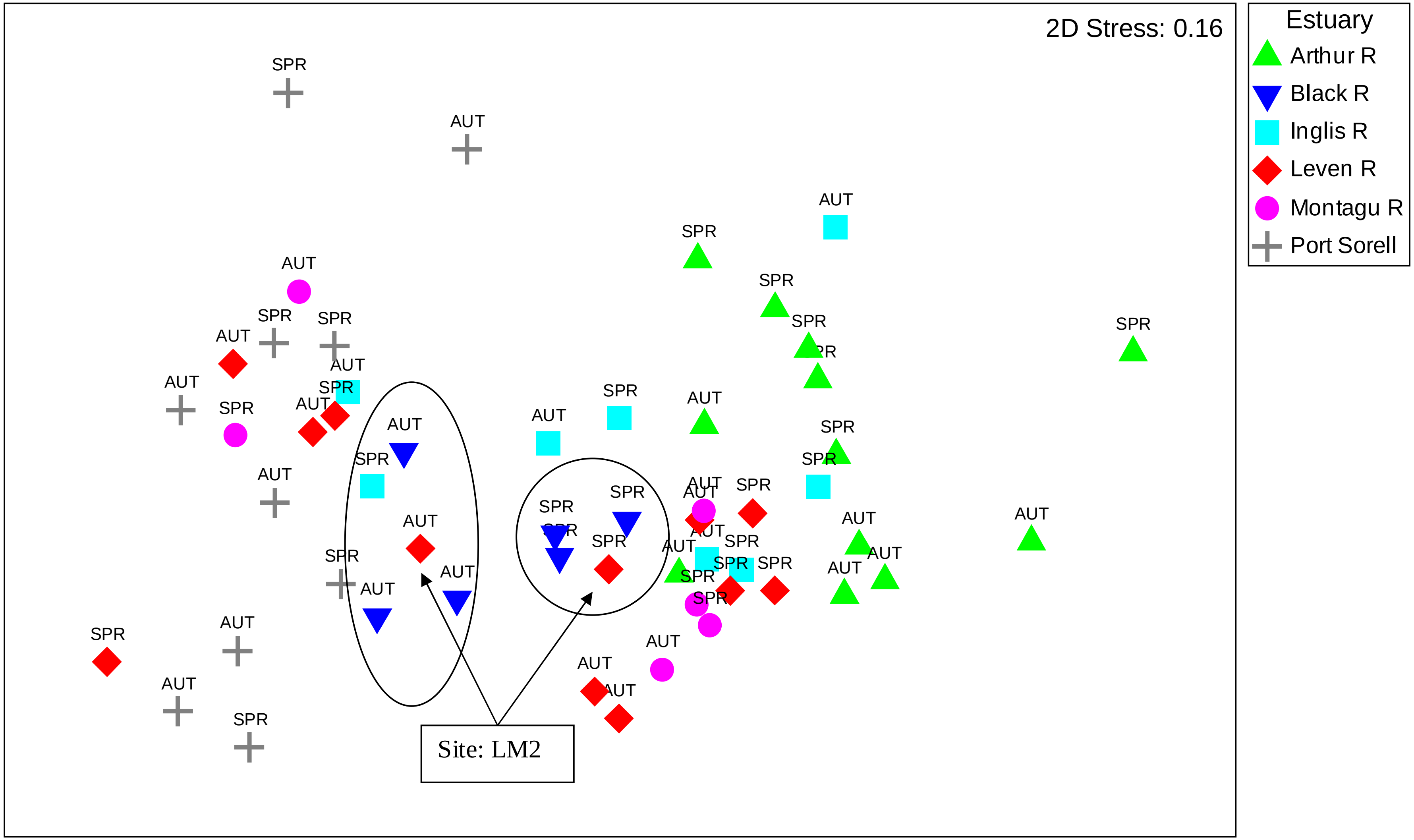


Fig. 43. MDS ordination of macroinvertebrate assemblages of spring and autumn from all sites within the six estuaries monitored in north-western Tasmania. Note the separation of Black River estuary communities during spring and autumn.

Leven, Inglis and the Montagu River estuaries showed little variation in macroinvertebrate assemblages over seasons (Fig 43).

High numbers of oligochaete worms separated the Arthur River benthos from the other estuaries surveyed. In addition, the Arthur River contained the most species of insects, which were absent in Port Sorell (see Appendix 2). Port Sorell was distinguished from the other estuaries by the presence of coastal/marine species not found elsewhere (refer to Appendix 2). By comparison the Leven, Inglis, Black and Montagu River estuaries supported a combination of estuarine and marine invertebrates.

The number of species per core generally decreased with distance up the estuary in autumn, indicating a more stable marine environment at the estuarine mouth (Fig 44). This trend, however, was not apparent in the Arthur River estuary where the tidal range is much lower. It also was not evident in the spring sampling round where in many of the estuaries there was a general tendency towards an increased number of species in the middle and upper estuary compared with the autumn sampling.

The number of animals per core was overall lower in autumn than in spring, especially in the upper regions and most noticeably in the Black and Montagu estuaries (Fig 45). The reduction in the number of macroinvertebrates during autumn is due mainly to the seasonality of the amphipod *Paracorophium sp.* The abundance of this species is greater in spring than in autumn (Hirst *et al.* 2005). Port Sorell consistently showed relatively low faunal abundance across all sites, whereas the Arthur River estuary was variable between sites and between seasons.

An introduced mollusc species *Musculista senhousia* (Asian bag mussel) was discovered in the Port Sorell estuary. This species is known to occur in Georges Bay, Tamar estuary and the Mersey River at Devonport. Only one individual was found in Port Sorell (so further sampling is required to assess the extent of the population); however, given the size of our macroinvertebrate survey, it is likely that a larger population exists. The effect of this introduced species on the ecology of Port Sorell is unknown. The level of impact will be determined by how successful the species can colonise and dominate benthic communities. The presence of high numbers of predators, such as crabs and skates may aid in reducing potential impacts.

The community patterns displayed in the MDS ordination plots reflect in part the geomorphological characteristics of each of the estuaries surveyed. For example Port Sorell is characterised as an open marine inlet and was represented by a marine/coastal macroinvertebrate community. The Arthur River was the only microtidal river dominated estuary surveyed in this study and showed macroinvertebrate assemblages that were tolerant of brackish conditions and low dissolved oxygen levels. The four mesotidal, river dominated estuaries (the Leven, Inglis, Black and Montagu River estuaries) were most similar in macroinvertebrate communities, with the majority showing a strong estuarine gradient in community structure.

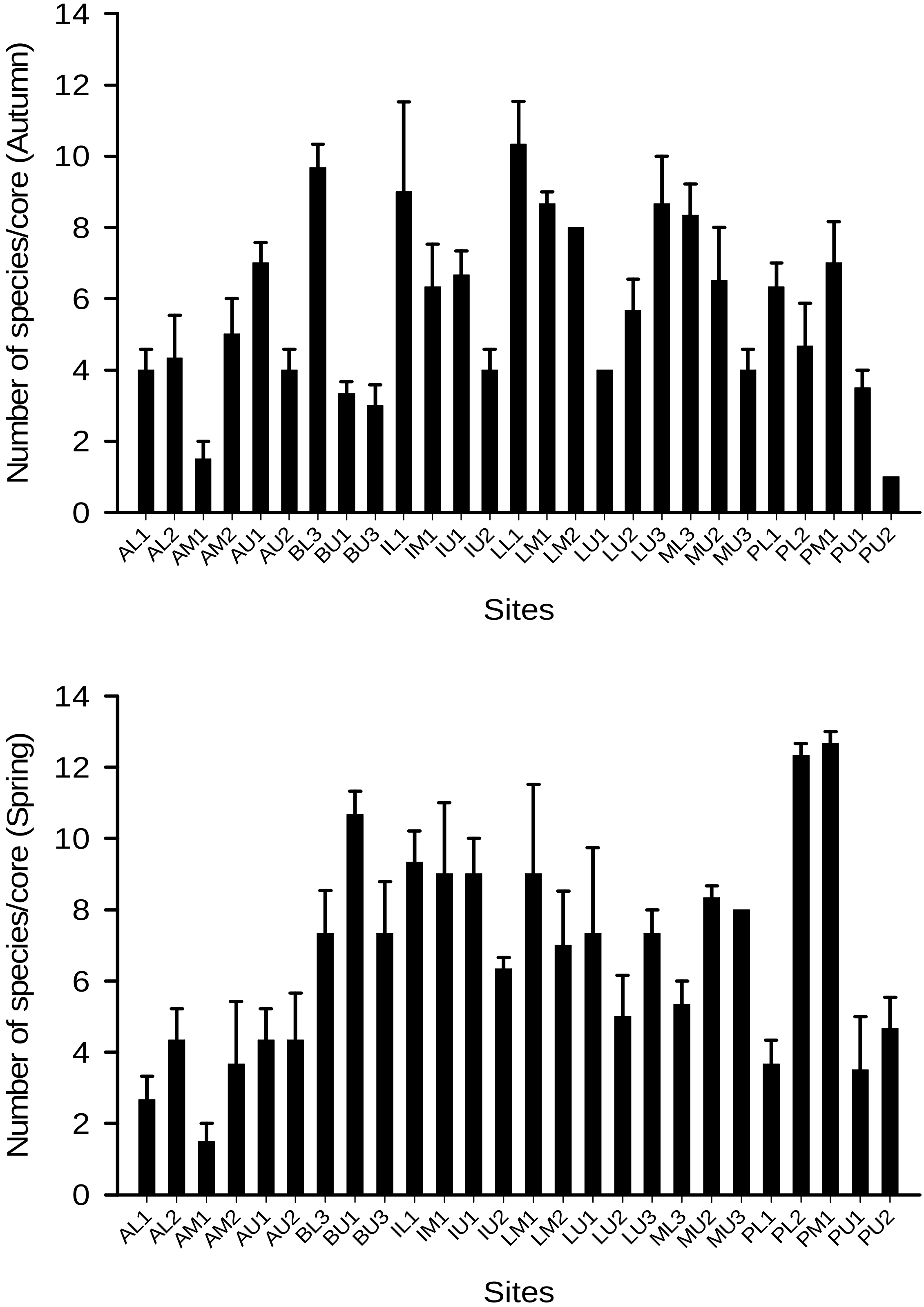
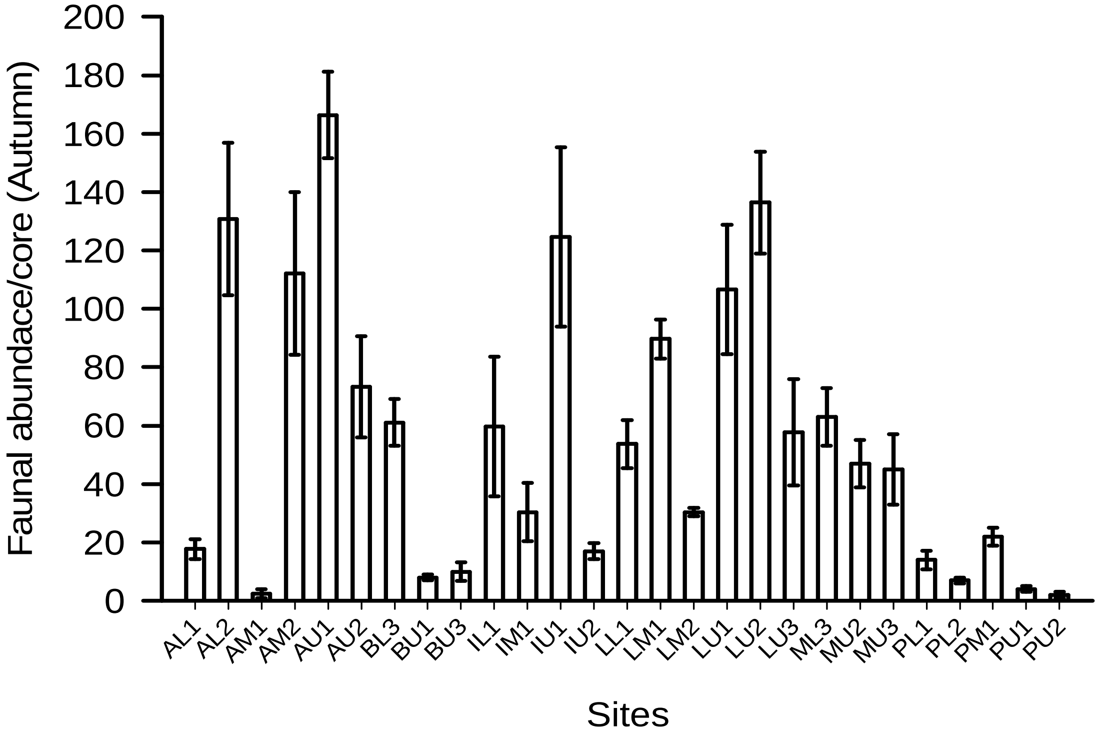


Fig. 44. Number of species per core at each site in each estuary sampled during autumn and spring.



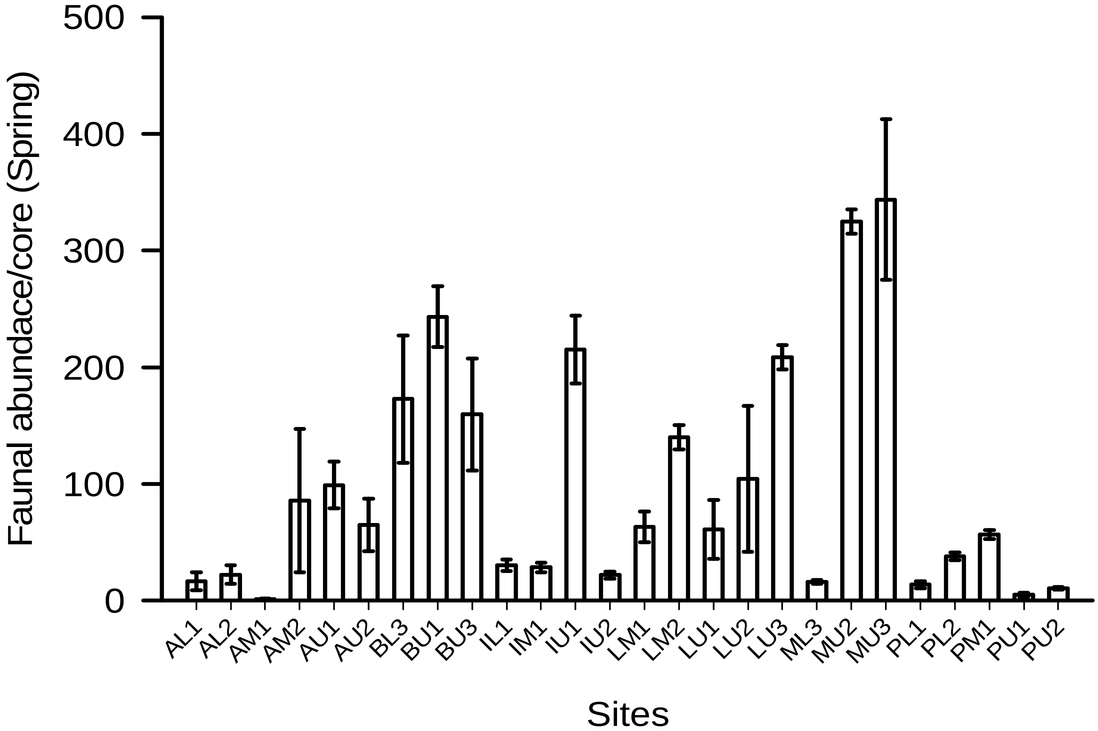


Fig. 45. Total abundance of fauna per core at each site in each estuary in autumn and spring.

Summary of results by estuary, season and region

The data on the condition of estuaries in north-western Tasmania collected by Murphy *et al.* (2003), Hirst *et al.* (2005), Hirst *et al.* (2007) and from this project have been pooled to provide a summary of condition indicators for the representative estuaries in the region. All four sets of data have been collected by staff of the Tasmanian Aquaculture and Fisheries Institute and hence sampling methods and equipment have been consistent across projects.

The data are presented as 'box and whisker' plots where the median (middle of the data) for all sites in the estuary over time is shown by the line across the inside of the box, the top and bottom edges of the box are 80th and 20th percentiles (i.e.80% or 20% of all data occur at or below this value) and the error bars indicate the 10th and 90th percentiles. The dots indicate maximum and minimum values; however maximum values for some estuaries exceeded the scale provided.

The Inglis and Black estuaries have the highest median nitrate values over the sampling period, however high nitrates are most frequent in the Montagu estuary, as shown by the 80th percentile (Fig 46). By contrast, Port Sorell had very low nitrate concentrations The ANZECC guidelines default trigger value for nitrates of 15µg/L was exceeded by all estuaries sampled except Port Sorell.

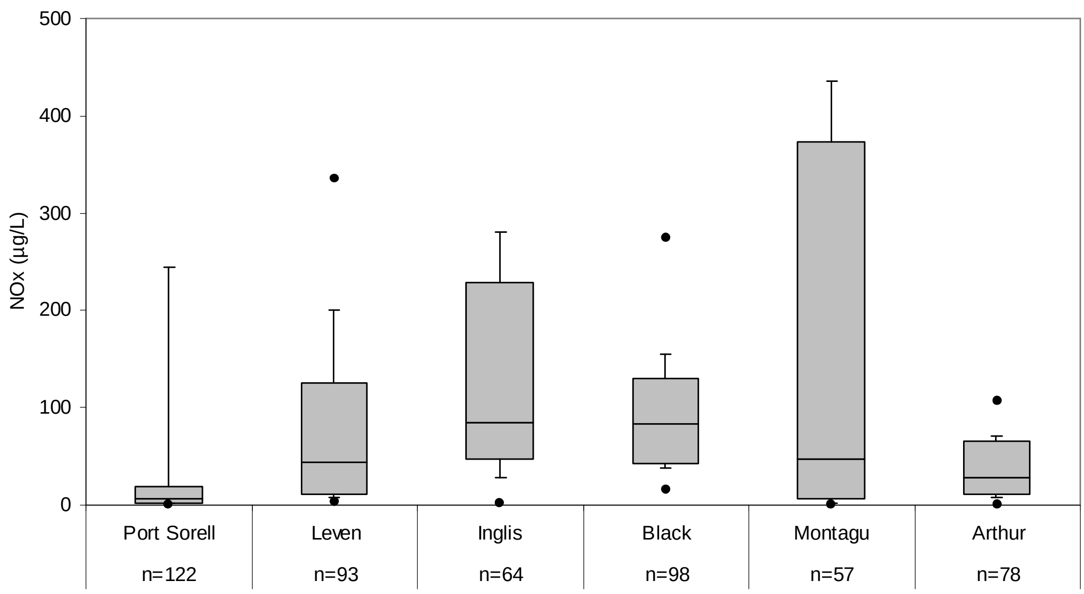


Fig. 46. Box and whisker plot showing median, 20th and 80th percentiles for nitrate + nitrite (NOx) for six north-western Tasmanian estuaries. N is the number of data points used in the analysis.

Median values for ammonia were highest in the Inglis and similar for other estuaries. Again, ANZECC guidelines default trigger value of 15µg/L was exceeded by all estuaries except the Arthur River (Fig 47).

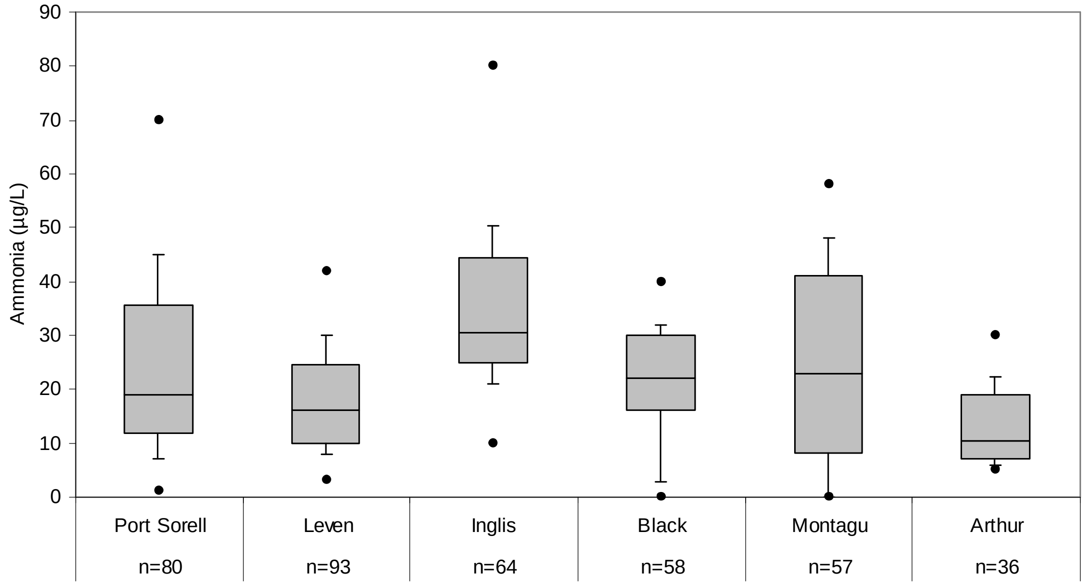


Fig. 47. Box and whisker plot showing median, 20th and 80th percentiles for ammonium for six north-western Tasmanian estuaries. N is the number of data points used in the analysis.

The values for dissolved reactive phosphorous are clearly much higher in the Montagu than the other estuaries and exceed ANZECC guidelines of 5 µg/L (Fig 48). The lowest concentrations were again in the Arthur estuary. Median values for phosphates in the Port Sorell and Inglis estuaries marginally exceeded ANZECC guidelines.

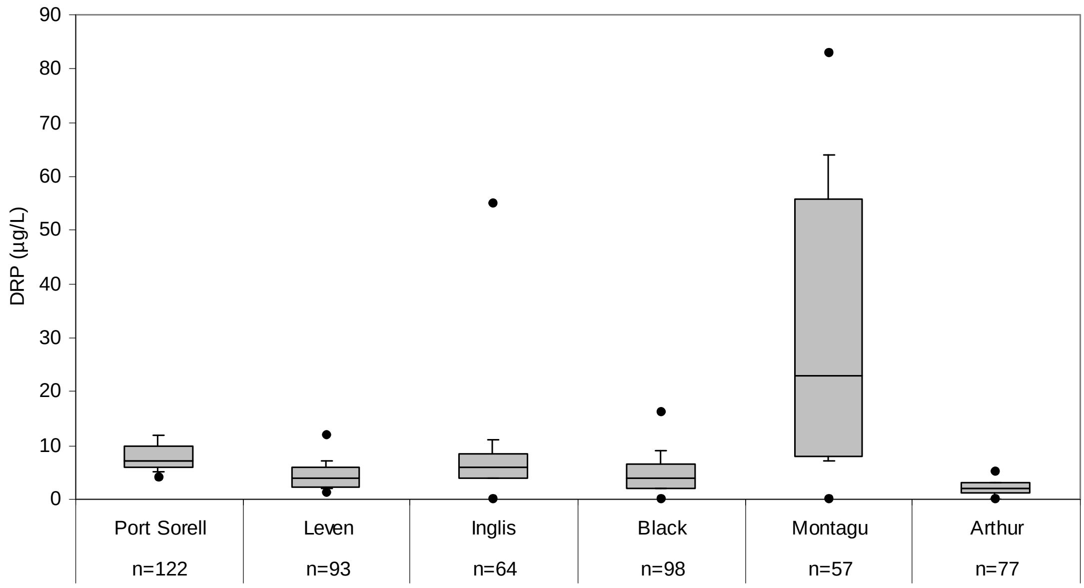


Fig. 48. Box and whisker plot showing median, 20th and 80th percentiles for dissolved reactive phosphorous (DRP) for six north-western Tasmanian estuaries. N is the number of data points used in the analysis.

In contrast, chlorophyll *a* concentrations were relatively low across all estuaries and were below the ANZECC guideline value of 4µg/L, with the exception of the Montagu (Fig 49).

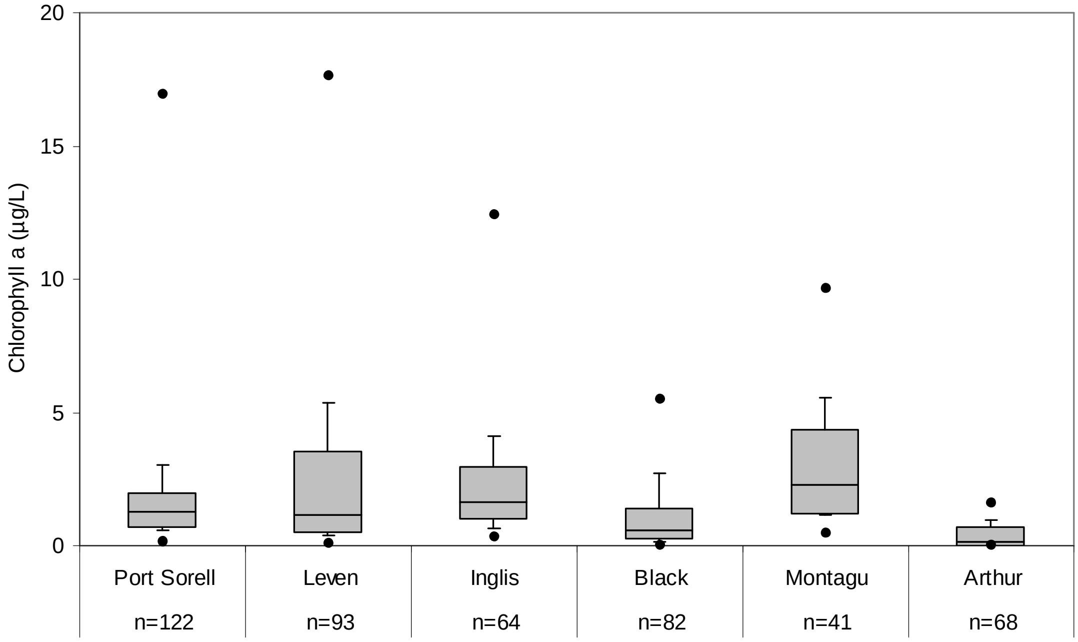


Fig. 49. Box and whisker plot showing median, 20th and 80th percentiles for chlorophyll a for six north-western Tasmanian estuaries. N is the number of data points used in the analysis.

Similarly turbidity values were below ANZECC guidelines trigger value of 10 NTU, except at Port Sorell and Montagu where they were just above (Fig50).

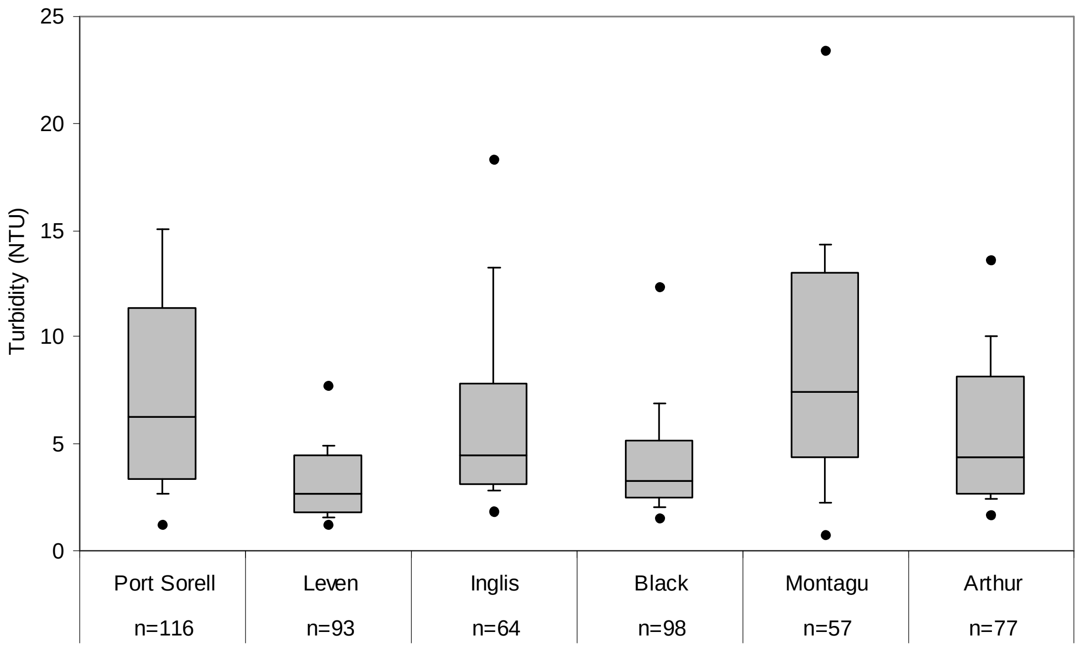


Fig. 50. Box and whisker plot showing median, 20th and 80th percentiles for turbidity for six north-western Tasmanian estuaries. N is the number of data points used in the analysis.

Bottom water dissolved oxygen levels in each estuary, pooled for all sites over time, were within ANZECC guidelines of 80-110% saturation in the Port Sorell, Leven, Inglis and Black estuaries, but not in the Montagu where the lower trigger value of 80% saturation was exceeded on a few occasions (Fig 51). In the Arthur estuary bottom water dissolved oxygen levels were clearly the lowest and regularly exceeded the guidelines. It is not known whether these are natural occurrences or due to human activities in the catchment.

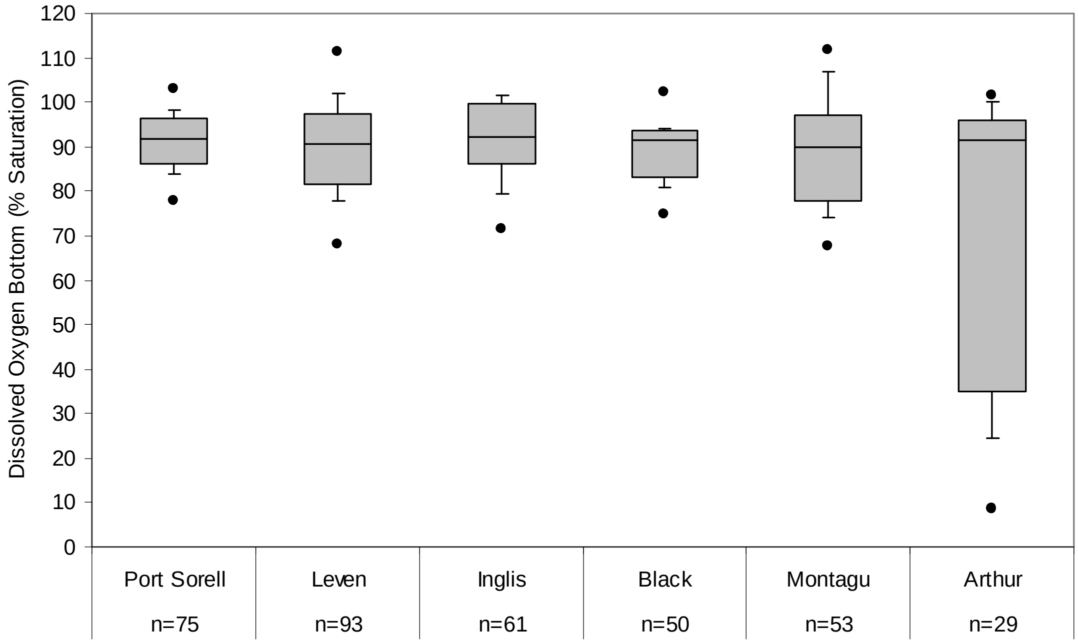


Fig. 51. Box and whisker plot showing median, and 20th and 80th percentiles for dissolved oxygen in six north-western Tasmanian estuaries. N is the number of data points used in the analysis.

pH was within the guidelines of 7.0-8.5, except for low (more acidic) results in the Black and the Arthur River estuaries (Fig 52).

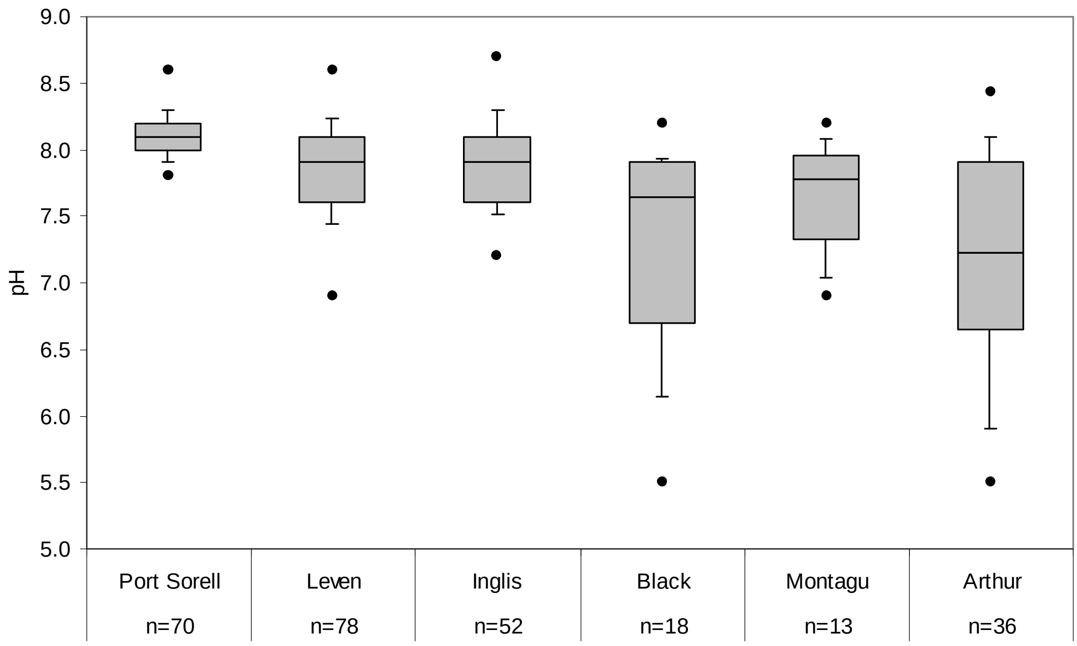


Fig. 52. Box and whisker plot showing median, and 20th and 80th percentiles for pH in six north-western Tasmanian estuaries. N is the number of data points used in the analysis.

Discussion

Water Quality

ANZECC Water Quality Guidelines (2000) have been used widely around Australia to assess water quality in rivers, and to a lesser extent in estuaries. They provide a number of steps for assessing water quality and recommend collecting a minimum of 24 months baseline data for setting trigger values. Trigger levels, which are a threshold value above or below which there is a risk of adverse ecological effects (generally the 20^{th} or 80^{th} percentile of the baseline data), have been set for water quality parameters in different regions of Australia

However, the use of $20^{th}/80^{th}$ percentiles assumes that the site/catchment/estuary is in good condition and is the baseline for future assessments. This is problematic if the estuary is already degraded. Also, water quality information does not necessarily provide information on the ecological health of the estuary. For example, high nutrient levels may not be a problem if they flushed out to sea and diluted.

Although water quality trigger values as described by ANZECC guidelines (2000) have been used widely around Australia, their value for measuring estuarine condition is currently being questioned by several State Governments. For example, the NSW Department of Environment and Conservation found that water quality alone was not sufficient to determine the condition of coastal lagoons and a range of indicators including ecological ones, were necessary (Scanes *et al*. 2007). Additionally, no data from Tasmania were used in setting the ANZECC guideline trigger values for rivers and estuaries in south-eastern Australia. Thus although we use these ANZECC trigger values to assess the results from north-western Tasmanian estuaries, these values must be used with caution until we have sufficient data to develop trigger values which are specific to these estuaries.

A combination of water quality and ecological indicators of estuarine health suggest that although some north-western Tasmanian estuaries, most notably the Montagu, are receiving high nutrient loads from upstream catchment activities, the impact on these estuaries is moderated by the relatively rapid flushing rates, primarily due to the high tidal range and relatively high seasonal freshwater flows in the region.

High nutrient concentrations, way above ANZECC guideline trigger values, were most frequent in the Montagu estuary, presumably due in part to the intensive dairy farming occurring in the catchment. In particular, phosphorous concentrations were much higher than other estuaries in the region. Nitrate and ammonium values in most estuaries would have triggered the default ANZECC guidelines, including the relatively “less impacted” Black and Arthur River estuaries. This suggests naturally high levels of inorganic nitrogen in north-western Tasmanian estuaries. Southern Tasmanian estuaries receive an influx of nitrate rich Southern Ocean waters, especially during winter (CSIRO 2000), resulting in naturally high nitrate concentrations. These nutrient rich waters may periodically extend to Bass Strait; however, the comparatively low nitrate concentrations in Port Sorell compared with the Montagu, suggest some input of nitrates from the Montagu catchment. Historical records for the Black estuary indicate that nutrient levels, particularly nitrate, appear to be on the increase. The concentrations of nitrate recorded in the estuary exceeded those at the stream gauging station in the upper catchment, suggesting that nutrient loading is occurring between these two points. Further research is required to determine the source and associated impacts, if any, on the ecology of the Black River estuary

Similarly, high ammonium concentrations, well above ANZECC guidelines, in all estuaries except the Arthur suggest land-based inputs. The relatively high values in the Inglis, particularly at the upper and middle estuary sites and in the lower section of the Leven are of concern and we suggest that potential sources of these high ammonia levels should be investigated.

Turbidity levels were generally low, although very high values were recorded during flood events, especially at Port Sorell and Montagu estuaries. Although dissolved oxygen levels were overall within accepted limits, it is the occasional very low values that are of most concern because of the significant effect that these low values can have on the fauna. This is especially a concern in the Arthur estuary, which was significantly stratified during summer and autumn, and bottom water dissolved oxygen dropped to below 20% saturation. Such low levels would be expected to affect the fauna of the sediment and bottom waters, which is evident in the MDS plot where the Arthur estuary fauna are differentiated from fauna in all other estuaries. Reasons for these low DO values are likely to be linked to the geomorphology of the estuary (deep, narrow, low tidal range, low freshwater flow during summer and autumn, slow flushing). However, the impact of upstream activities on dissolved oxygen levels is not known and we suggest further research should be conducted to assess whether these low values are a natural occurrence or due to human activities in the catchment.

Another indicator for water quality in the Port Sorell and Montagu River estuaries comes from the Tasmanian Shellfish Quality Assurance Program (TSQAP). They collect data on water temperature, salinity and faecal coliform bacteria from around oyster leases and have developed a correlation between these indicators and rainfall. Closure of harvesting occurs if the salinity levels drop below a predetermined point, which has been correlated with unacceptable levels of coliform bacteria. During 2007, the oyster leases in Port Sorell were closed for 151 days (DHHS, 2008a) and the Montagu River lease for 116 days (DHHS, 2008b), indicating reduced water quality from the catchment.

The lower regions of these estuaries are in relatively good condition, containing nutrient and phytoplankton levels at more diluted levels. NW Tasmanian estuaries that enter Bass Strait have a large tidal range (2-3m), resulting in high rates of tidal exchange, effectively flushing the lower reaches of the estuary every 12 hours (Hirst *et al*. 2005). CEE (1999) reported that in the Duck Bay estuary, ~ 90 % of water is exchanged at each tidal cycle, flushing nutrients and phytoplankton populations out to sea. However, increased levels of phytoplankton in the upper reaches of the Leven, Inglis and Montagu River estuaries during summer and autumn indicate that flushing is not as rapid and that the residence time of nutrients and phytoplankton populations may be higher as a result.

The other characteristic that defines NW Tasmanian estuaries, which aids in maintaining estuarine health, is the strong seasonal river flow. Although the majority of nutrients entering estuaries in NW Tasmania are sourced from their respective catchments, the fast flowing rivers aid in flushing these estuaries. With drought conditions becoming more prevalent and with increasing demand on freshwater resources for agriculture, forestry and human consumption, the water column of the upper reaches of these estuaries may see a decline in water quality and a subsequent decline in ecological health if the seasonal flows are substantially reduced.

Ecological indicators

Chlorophyll *a*, which is commonly monitored along with water quality parameters, is an indicator of ecological health because it is a general measure of primary production (microalgal production) in an estuary. In north-western Tasmanian estuaries chlorophyll *a* concentrations were generally low, although some periodic peaks, maximum 17.6µg/L in upper Leven, were recorded. Nevertheless, these peaks were still relatively low compared to peaks in other estuaries around Tasmania, for example a maximum of 87.9µg/L in Ansons Bay (Murphy *et al*., 2003). These low chlorophyll *a* concentrations are most likely due to the high flushing rates resulting from high tidal ranges in all estuaries emptying into Bass Strait. High tannin levels, resulting in low light penetration, especially in estuaries in the far north west, are also likely to limit the rate of photosynthesis, and hence production of chlorophyll *a*. Also, high nutrient levels were most common during winter/spring, the wetter, colder months of the year when primary production is slowest because of low water temperatures. The frequency of high chlorophyll *a* values showed a general trend with level of human activity in the catchment – highest in the Montagu, followed by the Inglis, relatively low in the Black and lowest in the Arthur.

Macroinvertebrates in estuarine sediments were also sampled as an indicator of ecosystem health. The current sampling has provided a baseline survey and current condition of existing communities. It's envisaged that macroinvertebrates in Tasmanian estuaries can be used in a similar manner to the AUSRIVAS program where they are used in conjunction with water quality data to determine the 'health' of rivers around Tasmania. The macroinvertebrate communities sampled in this study appeared to be in good health despite lower water quality in some of the estuaries. The composition of the infaunal community appeared to be more related to tidal range and salinity than activity levels in the catchment; however, further data are required to examine these relationships.

Similarly, Hirst *et al.* (2005) and Hirst *et al.* (2007) who compared estuaries that were impacted in terms of water quality (Montagu and Duck) with less impacted estuaries (Black and Detention) found that reduced water quality (high nutrient concentrations) and changing salinity did not appear to affect macroinvertebrate communities. The reason given for not detecting change in macroinvertebrate communities is that they are extremely stable over seasons despite significant variations in water quality. This effectively reduces the power of detecting minor disturbances in estuaries, but may provide greater certainty in detecting moderate to major impacts (Hirst *et al.* 2007). Although we did not detect changes in the overall ecology in NW Tasmanian estuaries, the long term effects of high nutrient loads may be detrimental. There are signs that the upper regions of estuaries in catchments of intensive agriculture, such as the Montagu, are undergoing changes in the benthic environment. Hirst *et al.* (2007) reported higher microphytobenthos and sediment carbon and nitrogen in the upper estuary.

Developing an Estuarine Monitoring Program for North Western Tasmania

Due to the dynamic nature of estuaries, there is no single indicator that can describe the state of an estuary (Crawford and White 2005). Estuaries in north-western Tasmania are highly seasonal such that catchment processes dominate in winter/spring and marine processes in summer/autumn. Further complicating the dynamics of estuaries are flood events, which can occur at any time of the year. Thus, the monitoring program must measure a number of indicators over all seasons, and if possible, during and after flood events.

A major issue when designing monitoring programs is the cost associated with collecting and processing some indicators (nutrients, chlorophyll *a* and macroinvertebrates). These and other indicators require scientific expertise not always available. Costs may be reduced in the long term by using automatic monitoring systems permanently moored in estuaries; however the cost is likely to remain high for nutrients. Thus, a monitoring program is often a compromise between the number of samples required for a comprehensive statistical assessment and resources available to the program (Crawford and White 2005).

To determine the health of estuaries in NW Tasmania, we collected baseline information on a number of water quality and ecological indicators across all seasons, including a moderate flood event. This baseline study offered an opportunity to assess the performance of a range of indicator variables.

Principal Component Analysis – water quality indicators

Principal Component Analysis (PCA) was used to examine for relationships between water quality indicators. It is a statistical method that examines correlations between large numbers of variables by grouping them into "principal components", such that variables within each component are more highly correlated than with variables in other components (Hirst *et al.* 2005). The relationships between large numbers of variables can often be adequately summarised by only a small number of components. A PCA may also reveal patterns between variables that could not be found by analysing each variable independently (Quinn and Keough 2002). If a strong relationship exists between two or more variables, then it may be possible to infer trends in water quality from a single variable, reducing the cost to the monitoring program.

Spearman's Rank Correlation was also used to test the direction (positive or negative correlation) and strength of the relationship between two variables. It uses the Spearman Rank Correlation coefficients (values), which fall between -1 and +1. In ecological studies coefficient values > -0.5 and 0.5 are considered to be a strong correlation. Table 2 displays the Spearman's Rank Correlations coefficients between water quality indicators collected in this study.

In this study the most coherent relationships between water quality indicator variables were found when the data was split into seasons: 1) winter/spring (high river flows) and 2) summer/autumn (low river flows). The first two principal components explained 53% of the total variation in spring and winter (Table 1). The first principal component explained variation in surface salinity (-ve correlated with PC1), silica molybdate reactive (+ve), surface temperature (-ve), pH (-ve) and NOx (+ve) (Table 1 and Fig 48 a). The second principal component explained variation in nutrients (NOx, P, and NH_4 all +ve correlated with PC2), turbidity (+ve), surface dissolved oxygen (-ve) and chlorophyll *a* (+ve) (Table 1). These results are indicative of a strong downstream estuarine gradient present in these meso-tidal river dominated estuaries (Hirst and Kilpatrick, 2007).

A much less clear picture is evident for the summer/autumn data (Fig. 48b). The first two components of the PCA explained only 46% of the variation (Table 1), indicating that relationships were weaker over this sampling period. Surface salinity, turbidity, phosphate, and ammonia were positively correlated with the first principal component, and negatively with silica molybdate reactive (Table 1). On the second component surface dissolved oxygen, surface temperature and pH were positively correlated and negatively with NOx (Figure 48b). A much less clear signal was evident for nutrients on the second principal component.

Table 1: The component loadings for principal components analysis during winter/spring and summer/autumn displaying in bold each water quality indicator variables that contribute most to the total variance.

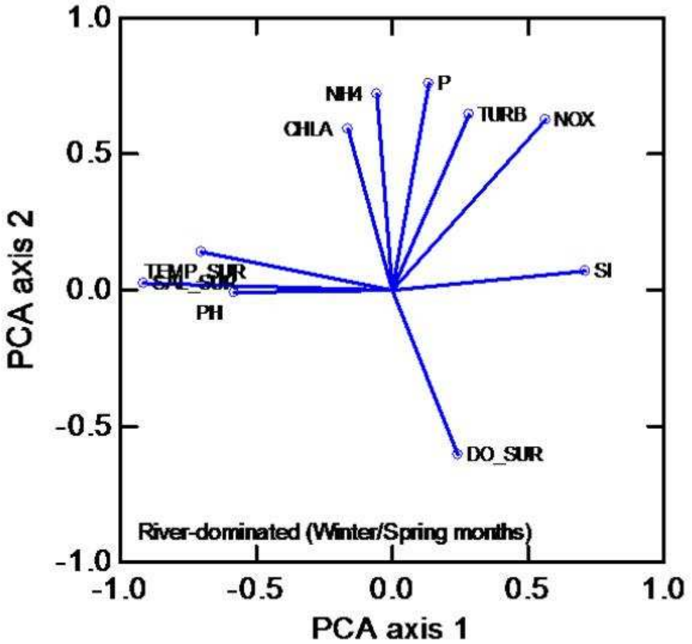
Winter/Spring	**PC 1**	**PC 2**
Surface salinity (SAL_SUR)	**-0.914**	0.025
Silica Molybdate Reactive (SI)	**0.71**	0.07
Surface Temperature (TEMP_SUR)	**-0.703**	0.14
PH	**-0.581**	-0.008
Nitrate + Nitrite (NOX)	**0.565**	**0.626**
Dissolved Reactive Phosphorus (P)	0.135	**0.759**
Ammonia (NH4)	-0.056	**0.72**
Turbidity (TURB)	0.282	**0.645**
Surface dissolved oxygen (DO_SUR)	0.242	**-0.605**
Chlorophyll *a* (CHLA)	-0.163	**0.592**
Total % variance explained	29.5	23.7
Summer/Autumn	**PC 1**	**PC 2**
Surface salinity (SAL_SUR)	**0.853**	0.061
Silica molybdate reactive (SI)	**-0.808**	-0.02
Turbidity (TURB)	**0.642**	0.082
Dissolved reactive phosphorus (P)	**0.598**	0.262
Ammonia (NH4)	**0.561**	-0.076
Surface dissolved oxygen (DO_SUR)	-0.075	**0.88**
Nitrate + Nitrite (NOX)	0.018	**-0.619**
Surface Temperature (TEMP_SUR)	0.022	**0.567**
PH	0.473	**0.536**
Chlorophyll *a* (CHLA)	-0.113	-0.261
Total % variance explained	29.1	17.1

Silica molybdate reactive (Si) was negatively correlated with salinity over both seasons (Table 1) indicating that silica levels are higher in the upper estuary and, hence, probably catchment derived. Silica is important in phytoplankton growth, particularly diatoms which incorporate this element into their exoskeleton. However, silica did not correlate strongly with chlorophyll *a* or with other nutrient indicators over both seasons (Table 2).

During winter and spring chlorophyll *a* was not strongly correlated with any other indicators (Table 2). The lack of correlation is not surprising, considering that the highest nutrient concentrations are observed during winter and spring when temperatures, and hence productivity, are at their lowest. By comparison chlorophyll *a* was more strongly correlated with nutrient levels, particularly phosphate during summer and autumn (Table 2).

The PCA showed that: 1) most of the indicator variables are inter-related and 2) observed patterns occur along two principal gradients, one describing downstream changes along an estuarine gradient, the other, variation primarily in nutrient levels. Silica was negatively correlated with salinity and found in higher concentrations in the upper estuaries. As silica showed little or no relationship with other indicators it may describe an aspect of water quality that other indicators do not measure. In the event that costs need to be reduced in a monitoring program we suggest that silica is omitted as an indicator. Notably, silica is not correlated with diminishing water quality (e.g. high nutrient levels, chlorophyll *a* or turbidity). Dissolved nitrate, phosphate and ammonia are more correlated to chlorophyll *a* during summer and autumn and are therefore likely to be more useful as water quality indicators.

a)



b)

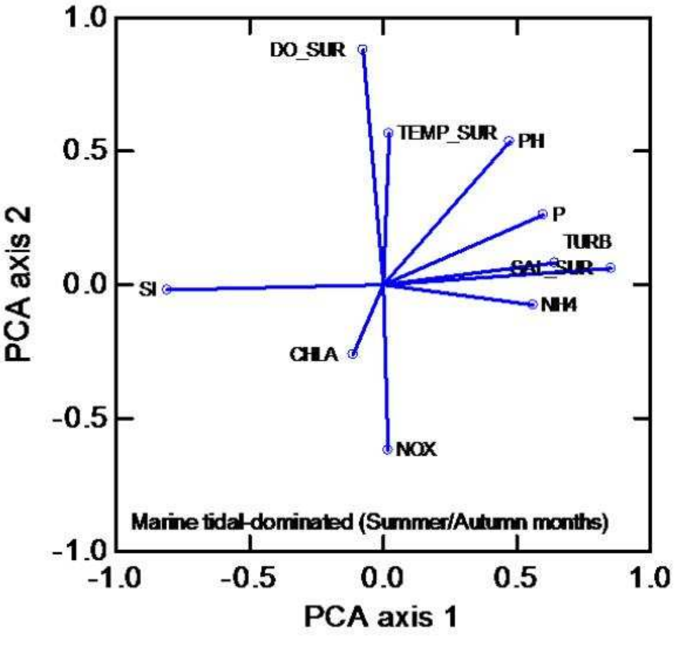


Fig 48. Vector plots displaying correlations between indicator variables and Principal Components 1 and 2 for a) winter/spring, and b) summer/autumn water quality data.

Table 2: Spearman rank correlations during winter/spring and summer/autumn displaying in bold strongest correlations (>0.5) between water quality indicators.

Winter/Spring										
	TEMP_SUR	SAL_SUR	DO	PH	TURB	NH_4	NOX	P	SI	CHLA
TEMP_SUR	1									
SAL_SUR	**0.951**	1								
DO	**0.538**	**0.614**	1							
PH	-0.308	-0.221	-0.182	1						
TURB	-0.28	-0.326	-0.273	**0.621**	1					
NH_4	0.309	0.351	0.473	0.107	0.072	1				
NOX	-0.162	-0.132	-0.085	-0.122	-0.086	-0.254	1			
P	0.229	0.278	0.216	-0.213	-0.286	-0.094	0.349	1		
SI	**-0.552**	**-0.51**	-0.498	-0.016	-0.116	-0.32	0.177	0.121	1	
CHLA	0.006	-0.003	0.4	-0.236	-0.069	0.321	0.208	0.31	0.048	1
Summer/Autumn										
	TEMP_SUR	SAL_SUR	DO	PH	TURB	NH_4	NOX	P	SI	CHLA
TEMP_SUR	1									
SAL_SUR	**0.715**	1								
DO	-0.019	-0.037	1							
PH	0.446	0.194	-0.026	1						
TURB	0.372	0.392	0.121	**0.536**	1					
NH_4	0.195	0.263	0.357	**0.557**	**0.549**	1				
NOX	0.236	0.079	0.405	-0.007	-0.025	0.104	1			
P	0.127	0.174	0.138	-0.027	0.254	0.237	0.277	1		
SI	0.015	-0.043	-0.319	-0.27	-0.13	-0.294	-0.151	0.435	1	
CHLA	0.124	0.154	0.477	0.037	0.369	0.447	0.492	**0.645**	-0.157	1

Biological indicators

Biological indicators are included into monitoring programs because they provide information on whether stressors to a system, such as increased pollutants are impacting on the natural flora and fauna (Crawford and White, 2005). When developing monitoring programs it has unfortunately become a trend for managers to monitor stressors and infer outcomes to the ecology of estuaries rather than recognising the distinction between stressors and outcomes (Scanes *et al.*, 2007). The ANZECC (2000) guidelines also stress the importance for a broader approach to aquatic ecosystem management, which should consider all changes, not just those affecting water quality. Similarly, The European Union Water Framework Directive for water quality has shifted from targets based on chemistry to include those related to the ecological structure of natural systems. The ecological quality status of coastal and transitional waters is now assessed on biological, hydromorphological and physico-chemical elements; with the biological elements considered being phytoplankton, macroalgae, benthos and fishes (Muxika, 2007).

Given the reduced water quality in some of the NW Tasmanian estuaries it would have been easy to infer that the ecology of these systems was also affected. However, in this study the macroinvertebrate communities in all estuaries surveyed appeared to be in reasonable to good health. Hirst *et al.* (2007) found macroinvertebrate communities in the Duck and Montagu River estuaries were generally healthy despite reduced water quality and were comparable to the Black and Detention River estuaries which have better water quality. They also found that macroinvertebrates were remarkably stable over seasons and resilient to minor disturbances. Macroinvertebrates are therefore unlikely to be useful indicators for minor disturbances; however they may provide greater certainty in the detection of moderate and major disturbances (Hirst *et al.* 2007). Chlorophyll *a* values also were generally low, indicating a healthy system, although periodic peaks did occur.

The macroinvertebrate survey conducted in this study has been designed to be repeated in the future and provides an opportunity to test statistically any changes in species diversity and abundance over time. We suggest a macroinvertebrate survey be conducted every 2-5 years. Monitoring seagrass distribution and abundance has also been suggested as a biological indicator (Scanes *et al.* 2007). In this study seagrass was observed to occur in the lower regions of the Leven, Inglis and Montagu River and Port Sorell estuaries. We recommend that benthic habitat mapping be conducted in these estuaries and incorporate a seagrass survey. The survey should be repeated every 5 years to determine change over time. By using both water quality and biological indicators, scientists and managers can link water quality to ecological integrity and derive a measure of the ‘health’ or ‘condition’ of an estuary.

Community and Stakeholder monitoring

Community and stakeholder based monitoring is important because it encourages participation, education and awareness raising amongst the general population (Crawford and White, 2005), creating a sense of ownership and responsibility towards their estuary. Community groups and stakeholders are also important because they are able to collect water quality data that may be missed by a time-scheduled expertise based monitoring program, such as collecting data during and after flood events or recording mass mortality events. An important caveat is that community and stakeholder based monitoring programs work in conjunction with, but do not replace monitoring requirements of industry and governments or replace expertise-based monitoring where required.

Incorporating community and stakeholder groups into a monitoring program requires coordination of activities to maximise the value and usefulness of the data collected. We recommend that a regional coordinator is employed, who would be responsible for coordinating monitoring activities between all stakeholders. The outcome of a monitoring program involving the different user groups will be a better understanding of the condition of estuaries and coastal waters by a wider group of stakeholders, which will underpin improved management (Crawford and White, 2006).

Indicators for community and stakeholder monitoring in NW Tasmania

Once fully trained, community members and stakeholders can collect data on the following indicators of estuarine health:

1. Contextual information

Date, time, tide (high or low), surface water conditions, and weather should be recorded at each time of sampling. All sampling should be conducted at low tide or on an ebbing tide approaching low water.

2. Estuarine Processors

Salinity, temperature, and pH can be measured using hand held field probes, preferably just below the surface and on the bottom. Given the difficulty of sampling estuaries in NW Tasmania, most will only be able to measure water quality in surface waters.

Salinity depth profiles i.e. measuring salinity over 1m intervals through the water column at several sites within an estuary is very useful in understanding water movement through the estuary. The ability to measure salinity over depth is dependent on access to a boat and the length of cable between the probe and the field meter.

Turbidity can be measured using a turbidity meter or a Secchi disk. The turbidity meter is easy to use and maintain although it does require calibrating every 2-3 months to ensure greater accuracy. Secchi discs can not be used in shallow water.

3. Chemical

Dissolved oxygen (DO) can be measured using a field probe in the same fashion as the salinity probe. The most relevant measure of DO is in bottom waters because the breakdown of organic matter accumulating on the bottom can strip DO from surrounding waters, resulting in anoxic conditions which may not be detected at the surface. DO probes can be temperamental and difficult to maintain for any length of time; therefore they must be calibrated regularly and require an annual service by an accredited instrument repairer.

Nutrient samples can be collected by the community provided that they are given sufficient training and sampling protocols are strictly adhered to. All samples will need to be analysed in the laboratory by an accredited service provider, such as Analytical Services Tasmania. They are relatively expensive approximately $40/sample for measurement of dissolved NOx, ammonia and phosphorus.

4. Biological indicators

Chlorophyll a samples can be collected by community groups provided they receive training and follow standard protocols. They will also have to be analysed by AST at a cost of approximately $50/sample. However, this cost is reduced if the samples are filtered before sending to AST (see further information in Crawford 2006).

Note: field probes such as fluorometers which measure chlorophyll *a* now exist. These probes are expensive but cheaper versions are starting to become available. However, they require some expertise, regular maintenance and annual servicing by an accredited instrument repairer.

Community groups, being on site, can monitor for algal blooms, introduced pest species, fish kills and other mass mortalities when they occur. This information is not part of a regular monitoring program but is extremely valuable to the assessment of the condition of an estuary and highlights changes occurring. A manual for the assessment of the health of Georges Bay: Community monitoring was produced by TAFI in 2007 (Crawford and Cahill 2007, available at http://eprints.utas.edu.au/6821/), which provides details of methods for community monitoring.

Skill- based monitoring

Expertise based monitoring will be required for the following indicators:

- Macroinvertebrates (collection and analysis) and
- Benthic habitat mapping of seagrass distribution and abundance.

Monitoring Program

From the baseline data collected thus far we have recommended a program for future monitoring of the six estuaries in the region. We have reduced the number of sites and indicators monitored to only those that we consider essential, so that costs are minimised (Tables 3 and 4). As more data becomes available it is likely that the monitoring program can be further refined. Where possible we have recommended sites that can be easily accessed by land; however some sites can only be reached by boat, for example the mud flats in the Upper Port Sorell estuary are too dangerous to wade.

However, if any site monitored shows signs of degradation we recommend that additional monitoring be conducted to determine the extent of the poor condition and the cause of the problem.

Table 3. The recommended indicators of estuarine health

Basic measures of ecosystem condition	**Frequency of sampling**
Temperature	Monthly (or every 2 months if limited resources)
Salinity	Monthly (or every 2 months if limited resources)
Dissolved oxygen (especially bottom waters)	Monthly (or every 2 months if limited resources)
Turbidity	Monthly (or every 2 months if limited resources)
Chlorophyll-a	Monthly (or every 2 months if limited resources)
Habitat extent (esp. seagrass)	Every 5 years
Important indicators	
Animal and plant species Abundance (macroinvertberates)	Every 5 years
Shoreline position	Incorporate TasMarc program
Nutrients in the water (NOx, PO4, NH4). Include TN, TP is funds available	Monthly (or every 2 months if limited resources)
Toxicants	If specific need and if funds available
Pathogens	Collaborate with TASQAP program and councils
pH	Monthly (or every 2 months if limited resources)
Specific Community monitoring	
Algal blooms	When occur
Mass mortalities	When occur
Litter	To be determined by community groups
Invasive species	When occur

Table 4. Recommended sampling sites in each estuary. Details of locations in each estuary are given in the estuary descriptions in the Results section. Samples should be taken during a falling or low tide.

Estuary	**Recommended monitoring sites**	**Comments**
Port Sorell	PL1, PL2, PU1, PU2	Boat required for PU1, PU2
Leven	LL1, LM1, LU1, LU2	
Inglis	IL1, IM1, IU2	
Black	BL3, BU1, BU3	Important as reference estuary
Montagu	ML3, MU2, MU3	Site access is difficult
Arthur	AL1, AM2	AM2 requires boat access

The Port Sorell estuary has strong stakeholder and community interest, providing an excellent opportunity to involve these groups in a monitoring program. The local oyster grower has expressed interest in participating in a monitoring program and has previously assisted in the collection of water quality data. The location of the oyster leases provides an opportunity to collect water quality data at or near sites PU1 and PU2. Community groups have also expressed interest in providing assistance for a water quality monitoring program.

Access to monitoring sites in the Montagu estuary is difficult. There is potential to develop partnerships with oyster growers in the region, which could provide an avenue for collecting water quality data at or near site ML3. Land owners on the western side of the upper Montagu River estuary have previously given access to their property and use of their small boat ramp. We do not recommend that monitoring be conducted by boat in the upper estuary unless the boat operator knows the area well. With permission from land owners, the upper monitoring sites could potentially be accessed.

Only site AL1 in the Arthur estuary has land access. There is potential to develop partnerships with boat cruise operators, which could provide an avenue for collecting water quality data in the upper estuary. Monitoring could potentially be conducted at site AL1 by community groups and AM2 by boat cruise operators. Site AM2 is adjacent to a small wharf used by one of the cruise operators.

Costing

There are no costs associated with collecting temperature, salinity, dissolved oxygen, turbidity and pH once equipment has been purchased, except for periodic servicing of the equipment. Costs for analysis of dissolved nutrient and chlorophyll *a* analysis is provided in Table 5. The costs were provided by Analytical Services of Tasmania on July 2008. Fees and charges increase annually and are generally indexed against inflation.

Other associated costs include:

- Hiring of a regional coordinator on a part time basis
- Macroinvertebrates survey every five years
- Benthic habitat mapping with a seagrass survey every five years.

Table 5: Total cost of estuarine health indicators required to monitor the six estuaries in NW Tasmania for one year**.** Note chlorophyll *a* costs can be reduced if samples are filtered by monitoring staff.

Estuary	Indicator	Sites	Sampling Freq	Cost/yr
Port Sorell	Nutrients @ $40/sample	4	monthly	$1,920
	Chlorophyll *a* @ $50/sample	4	monthly	$2,400
Leven River	Nutrients @ $40/sample	4	monthly	$1920
	Chlorophyll *a* @ $50/sample	4	monthly	$2,400
Inglis River	Nutrients @ $40/sample	3	monthly	$1,440
	Chlorophyll *a* @ $50/sample	3	monthly	$1,800
Black River	Nutrients @ $40/sample	3	monthly	$1,440
	Chlorophyll *a* @ $50/sample	3	monthly	$1,800
Montagu River	Nutrients @ $40/sample	3	monthly	$1,440
	Chlorophyll *a* @ $50/sample	3	monthly	$1,800
Arthur River	Nutrients @ $40/sample	2	monthly	$960
	Chlorophyll *a* @ $50/sample	2	monthly	$1200
	AST admin. @$27/batch of samples	-		$324
Total				**$20,844**

Challenges to the monitoring program

A major challenge for the NW Tasmanian region will be to secure the resources required, both financial and human to continue monitoring. The community, stakeholders and local and state governments will all need to contribute and work in close cooperation, so that sufficient resources are available to routinely assess the condition of NW Tasmanian estuaries. This is essential to maintaining and improving on the current status of water quality in the region.

Reporting

If monitoring continues in the future we recommend that an annual reporting mechanism is developed, which reports findings to the public. A Report Card reporting system for stakeholders has been developed for several estuaries/regions around Australia. Some excellent examples include Moreton Bay available at http://www.healthywaterways.org and Gippsland Lakes available at http://www.ginrf.org.au/reportcard/list.asp. This reporting system should be adopted for the NW region because of its ability to communicate in a simple, easily understood format to the community on the status of the health of these estuaries.

Data Storage

With permission from NRM Cradle Coast the data collected during this baseline study has been made publicly available. A Memorandum of Understanding between TAFI and DPIW has been signed and all data collected will be stored on the DPIW water quality database. The data can be viewed on the Water Information Services of Tasmania (WIST) website. DPIW currently use WIST to display water quality data for a number of rivers around Tasmania. Storing estuarine data in association with riverine data provides a useful mechanism for assessing the source and fate of nutrients in the catchments. We recommend that data collected from future monitoring programs in NW Tasmania are also made publicly available via WIST.

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Appendix 1

Table 1. Recommended default trigger values for water quality parameters in South East Australian estuaries (ANZECC guidelines)

Turbidity (NTU)	Chlorophyll a µ g/L	PO_4 µ g/L	Nitrate µ g/L	NH_4^+ µ g/L	DO (% sat)	pH
0.5 - 10	4	5	15	15	80 - 110	7.0 – 8.5

Table 2. Draft indicator values for Tasmanian estuarine water quality parameters (Murphy *et al*. 2003).

Draft indicator levels		Low	Medium	High	Very High
Turbidity	NTU	0 to 4	4.1 to 10	10.1 to 20	>20
Chlorophyll *a*	µ g/L	0 to 2	2.1 to 5	5.1 to 10	>10
Nitrate	µ g/L	0 to 20	21 to 50	51 to 100	>100
PO_4	µ g/L	0 to 5	6 to 15	16 to 30	>30

Appendix 2

Taxonomic list of species and abundance for the six Key estuaries surveyed.

Taxonomic name	Arthur	Black	Inglis	Leven	Montagu	Port Sorell
Annelida	0	0	0	0	0	0
Arenicola bomboyensis	0	0	2	1	0	0
Arenicola sp.	0	1	11	1	0	0
Aricidea pacifica	0	0	21	0	8	8
Boccardiella limnicola	59	3	377	306	151	0
Capitella spp.	0	1	10	4	3	2
Dipolydora sp.	0	0	17	28	0	0
Dipolydora pencillata	0	1	31	0	0	5
Glycerid sp.	0	0	2	0	0	0
Goniada sp.	0	0	0	1	0	0
Leodomas johnstonei	0	0	0	0	0	6
Lumbrinereidae unid.	0	0	1	1	0	1
Magelona sp.	0	11	6	27	0	107
Mediomastus australiensis	2	0	0	2	0	0
Microspio granulata	0	0	1	0	1	3
Nephtys australiensis	4	45	7	30	13	58
Nephtys longipes	0	0	0	0	0	2
Nereididae A	0	0	0	4	0	0
Olganereis edmondsi	0	0	0	0	0	1
Oligochaeta unid.	874	0	13	5	0	0
Paraprionospio sp.	0	0	1	0	0	0
Phyllodoce sp.	0	3	3	2	0	1
Scolelepis carunculata	0	0	0	0	0	5
Scoloplos normalis	0	38	63	99	1	1
Scoloplos simplex	0	28	3	1	11	1
Sigalianidae unid.	0	0	0	0	0	1
Simplisetia aequisetis	0	2	23	235	164	0
Spionid unid	0	0	1	0	0	0
Cnidaria						
Anemone	0	0	0	1	0	0
Edwardsia sp.	0	0	1	7	0	7
Crustacea						
Alpheus sp.	0	0	1	0	0	1
Amarinus lacustris	0	0	0	8	0	0
Amarinus laevis	31	0	1	0	3	0
Amarinus laevis juv.	12	0	0	0	0	0
Amarinus spp.	5	0	1	27	4	0
Biffarius arenosus	0	1	0	0	0	6
Biffarius juv.	0	11	0	0	0	0

Biffarius poorei	0	0	0	0	0	2
Biffarius spp.	0	23	4	13	1	29
Cirolanidae unid	0	0	0	1	0	0
Cyclaspis sp.	0	0	0	0	3	7
Dimorphostylus colefaxi	0	1	9	3	0	0
Gammaropsis sp.	0	1	8	215	10	3
Gammaropsis sp.B	0	0	0	0	1	0
Grapsidae juv. unid.	0	1	0	0	0	0
Heloecius cordiformis	0	0	1	1	0	1
Limnoporeia kingi	0	1	0	0	0	0
Limnoporeia sp.	6	88	3	6	11	4
Macrophthalmus latifrons	0	2	0	2	0	6
Melitidae sp.	1	0	0	0	0	0
Mictyris platycheles	0	0	0	1	0	4
Mysidae unid.	0	1	0	0	3	4
Oediceratidae unid.	2	0	0	0	0	0
Paracalliope	0	0	1	0	0	0
Paracalliope australis	0	0	0	0	9	17
Paracallope lowryi	20	0	0	0	0	8
Paracorophium sp.	1100	1494	579	1003	1685	1
Paragraspus gaimardii	0	0	3	0	0	0
Phoxocephalidae unid.	0	0	0	10	8	17
Sphaeromatidae unid.	0	0	13	9	0	0
Tanaidae unid.	0	0	0	0	0	1
Tethygeneia sp.	5	13	1	0	35	0
Urohaustorius spp.	0	0	0	0	1	44
Insecta						
Atriplectides dubius	9	0	0	0	0	0
Ceratopogonidae unid.	11	0	20	18	0	0
Chironominae	149	15	75	21	16	0
Curculionidae (larvae)	3	0	0	0	0	0
Diptera unid. Pupae	1	0	0	0	0	0
Dolichopodidae unid.	3	0	31	4	0	0
Elmidae (larvae)	1	1	0	1	0	0
Orthocladinae	1	0	0	1	0	0
Psychodidae	0	1	0	0	0	0
Stratiomyidae	0	0	0	1	0	0
Tanypodinae	0	0	0	0	1	0
Tipulidae	3	1	1	1	0	0
Velidae spp	0	0	1	0	0	0
Mollucsa						
Arthritica helmsi	33	97	49	479	149	3
Ascorbis victoriae	38	0	6	34	4	2
Austroginella sp.	0	0	0	0	0	2

Austroginella tasmanica	0	0	0	0	0	1
Eumarcia fumigata	0	0	0	0	0	1
Hydrococcus brazieri	0	0	0	0	126	0
Katelysia sp.	0	17	19	44	0	5
Lanternula sp.	0	0	0	0	0	1
Lanternula tasmanica	0	0	0	0	0	2
Lepton trigonale	0	0	0	0	0	11
Musculista senhousia	0	0	0	0	0	1
Mysella donaciformis	0	9	2	32	45	104
Nassarius spp.	0	51	7	6	1	6
Paphies sp.	0	2	135	403	1	0
Patelloida insignis	0	0	0	1	0	0
Polinices conicus	0	0	0	2	0	0
Retusa pelyx	0	0	0	1	0	0
Tatea rufiabris	1	0	0	0	2	0
Tellina deltoidalis	0	0	12	0	0	1
Thracia sp.	0	0	0	3	0	0
Venerupis sp.	0	0	2	23	0	1
Xenostrobus inconstans	0	0	0	1	0	0
Nemerteans						
Nemerteans unid.	0	0	1	28	0	1
Sipuncula						
Phascolosoma annulatum	0	0	0	0	0	2
Total no. species	25	31	47	51	30	49

Appendix 3

GPS co-ordinates (decimal lat/longs) for the 27 sites sampled in this study

Estuary	Site	Latitude	Longitude
Arthur River	AL1	41.0514	144.66646
Arthur River	AL2	41.04819	144.69516
Arthur River	AM1	41.05496	144.72733
Arthur River	AM2	41.05732	144.74843
Arthur River	AU1	41.06895	144.76518
Arthur River	AU2	41.07431	144.76762
Black River	BL3	40.84283	145.30888
Black River	BU1	40.84645	145.30927
Black River	BU3	40.84716	145.30151
Inglis River	IL1	40.98738	145.7352
Inglis River	IM1	40.97902	145.71941
Inglis River	IU1	40.97849	145.70584
Inglis River	IU2	40.97343	145.70134
Leven River	LL1	41.15398	146.16858
Leven River	LM1	41.16256	146.15373
Leven River	LM2	41.15974	146.12502
Leven River	LU1	41.15182	146.11217
Leven River	LU2	41.15493	146.10519
Leven River	LU3	41.15844	146.10036
Montagu River	ML3	40.75284	144.93187
Montagu River	MU2	40.76755	144.92943
Montagu River	MU3	40.77173	144.93086
Port Sorell	PL1	41.16255	146.56021
Port Sorell	PL2	41.18876	146.57529
Port Sorell	PM1	41.20387	146.58426
Port Sorell	PU1	41.23466	146.59752
Port Sorell	PU2	41.23409	146.56779