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Nutrient and Phytoplankton Data from Storm Bay to Support Sustainable Resource Planning

Christine Crawford, Kerrie Swadling, Peter Thompson, Lesley Clementson, Thomas Schroeder, Karen Wild-Allen

Project No. 2009/067 Final Report

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Objectives

1. To provide information on the effects of a changing climate on water quality in Storm Bay and associated potential impacts on fisheries and aquaculture.

2. To collect nutrient and algal data from a targeted suite of sampling sites in Storm Bay to support sustainable development of the aquaculture industry.

Outcomes achieved to date

This project has provided preliminary data on environmental conditions in Storm Bay that is assisting managers and marine industries to better understand effects of climate change and climate variability on fisheries and aquaculture in the region, including changing currents and primary productivity. This information is being used to inform the development of climate change adaptive management strategies for commercial and recreational fisheries and for the potential expansion of salmon aquaculture into Storm Bay. The environmental characterisation of Storm Bay is also supporting planning in the region, by providing baseline data and data for projects modelling the bay's water circulation and ecosystem dynamics. This information will support the development of multiple use management plans for the region.

This project has established a baseline assessment program for water quality and productivity in Storm Bay, and collected environmental data monthly for 12 months. These data are important towards understanding climate variability and assessing the longer term impacts of climate change in the region. They will underpin more informed management of marine resources.

A comparison of the preliminary environmental data collected in 2010 with data collected by CSIRO at the same site in Storm Bay during 1985–89 indicates that salinities tend to be higher now in autumn and early winter compared with over two decades ago, and temperatures now are tending towards the higher values of 1985–89. Phosphate levels are clearly lower for most of the year in 2010, whereas nitrates are generally similar although indicate a pattern of higher winter values over an extended winter period. Chlorophyll *a* values in 2010 were mostly lower than in the 1980s, implying lower productivity; however the results must be assessed with caution because different extraction and analytical techniques were used in the two time periods. These preliminary data indicate changes are occurring and if the indications of lower productivity are correct then a reduction in fishery output can be expected. However, additional monthly data are required to determine whether change is long term or merely interannual variability, and to provide the replication necessary for statistical analysis. Monthly sampling is currently funded for another 12 months.

The baseline environmental data are also important to the salmon aquaculture industry which is looking at expanding into Storm Bay. Data important to understanding water movements in the region and data on nutrient concentrations collected before any finfish farming commences are essential for both farmers and government managers to assist selection of the best sites and for comparison of nutrient concentrations after farming commences – whether it is natural variability or as a result of farm wastes.

The environmental data collected in 2009–10 indicate that the proposed aquaculture site close to the eastern side of Bruny Island is primarily marine dominated, but did not experience any of the peak nutrient concentrations of the more offshore marine sites in deeper water. The site, approximately 1 km offshore from Nubeeba, was more influenced by freshwater from the Derwent River outflow and showed an unusual pattern of temperature and salinity stratification, possibly related to a deep hole nearby. The results from the Nubeena site suggest that a better knowledge of water movements in the area would be required before establishing large-scale aquaculture in the region.

The data collected over the 12-month period have also been used by CSIRO to support the implementation of a high resolution 3D coupled hydrodynamic, sediment and biogeochemical model of south-eastern Tasmania, which will be used in developing multiple use management systems for the region. In particular, nutrient concentrations at site 2 were used to calibrate a new in situ nitrate recorder moored at this site, and the modelled phytoplankton composition was based on data from site 3. The data collected have also been used to validate bio-optical models and to link satellite remote sensing observations to chlorophyll *a* concentrations in SE Tasmanian waters.

With the support of the Storm Bay sampling program, the open boundary of the SETAS biogeochemical model has been constrained sufficiently to allow a hindcast simulation of 14 months and an ongoing pilot near real time simulation. In the coming year these simulations will be validated against in situ data to confirm that the model captures the essential seasonal dynamics of southeast Tasmanian coastal waters.

Keywords

Climate variability, Storm Bay, water quality, productivity, offshore salmon aquaculture

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We acknowledge data support by the CSIRO Wealth from Oceans Flagship INFORMD project 'Fusion of bio-optical modelling and satellite observations to improve environmental model prediction in south-east Tasmania' (PI: Thomas Schroeder).

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2009/067	Nutrient and phytoplankton data from Storm Bay to support sustainable resource planning

Background

The East Australian Current (EAC) is predicted to penetrate further south causing significant warming and decreased productivity. Previous work (Harris et al. 1991) showed that the nutrient status of waters clearly indicated the influence of the EAC, and primary producers indicated the productivity of the region. Thus, nutrient and phytoplankton data from Storm Bay are likely to indicate effects of climate variability and change, and therefore Storm Bay is potentially an indicator of productivity for southern and eastern Tasmania. Such information is important to understanding changes in fisheries and aquaculture production and as a consequence, to assist with developing climate change adaptive management strategies.

Effects of climate change on marine productivity and associated fisheries have been identified as high priority for research by industry and government representatives at the Abalone, Crustacean and Marine Environment Research Advisory Group meetings in 2009.

CSIRO and TAFI have established a program (INFORMD- Inshore network for observation and regional management: Derwent-Huon) to guide multiple use coastal zone development and management. Storm Bay is an integral component of the INFORMD region and a priority is to understand both the short-term (climate variability) and long-term (climate change) drivers of productivity in the region and link these to production of fisheries and aquaculture. As part of INFORMD, CSIRO is investigating novel observing technologies (NOTe) to characterise the Derwent to shelf environment as well as improving environmental model prediction through a combination of bio-optical modelling and satellite observations. TAFI has funded a charter vessel to monthly sample water column environmental variables, and support the CSIRO observing system and satellite validation projects. Thus, an opportunity existed to obtain nutrient and productivity data in the Strom Bay region in a very cost-effective manner by collaborating with the existing research program.

Need

Knowledge of changing environmental conditions and productivity as a result of climate change is essential for adaptive management. In addition to direct applicability to fisheries and aquaculture in southern Tasmania, this information will have numerous important applications to other industries and stakeholders in the broader catchment.

This project has been developed with the support of the Department of Primary Industry, Parks, Water and the Environment and has been discussed by key industry stakeholders including the TSGA, TSIC, TAC and TRLFA. Broad stakeholder support has also been provided for the INFORMD parent project and through the TAFI Board. Support has also been obtained from the Derwent Estuary Program, which represents local government stakeholders in the Derwent catchment.

This project provided an opportunity for FRDC to invest in a project that will have significant influence on multiple use management in Australia.

Objectives

1. To provide information on the effects of a changing climate on water quality in Storm Bay and associated potential impacts on fisheries and aquaculture.
2. To collect nutrient and algal data from a targeted suite of sampling sites in Storm Bay to support sustainable development of the aquaculture industry.

Methods

1.1 Sample sites and collection

The Storm Bay sampling program started in November 2009 with samples collected initially from six sites, on a monthly time frame (Figure 1). After the first two months, site 4 was omitted as the travel time was too long. An analysis of the data indicated little difference in results from sites 3 and 4.

The central Storm Bay sampling site 2 is in the same location as the master study site of the CSIRO study in 1985–88 (Clementson et al. 1989, Harris et al. 1991).

1.2 Measuring key environmental variables

At each sampling site a Seabird SBE 19 plus CTD with fluorescence/turbidity (WETLabs), dissolved oxygen (Seabird SBE 43) and PAR Biospherical Instruments) sensors was lowered to 2–5 m above the seabed.

Table 1: Sample site locations

Site	Longitude	Latitude
1	147.3950	43.0666
2	147.5550	43.1700
3	147.6333	43.3167
4	147.7167	43.4833
5	147.6667	43.1166
6	147.4333	43.2000

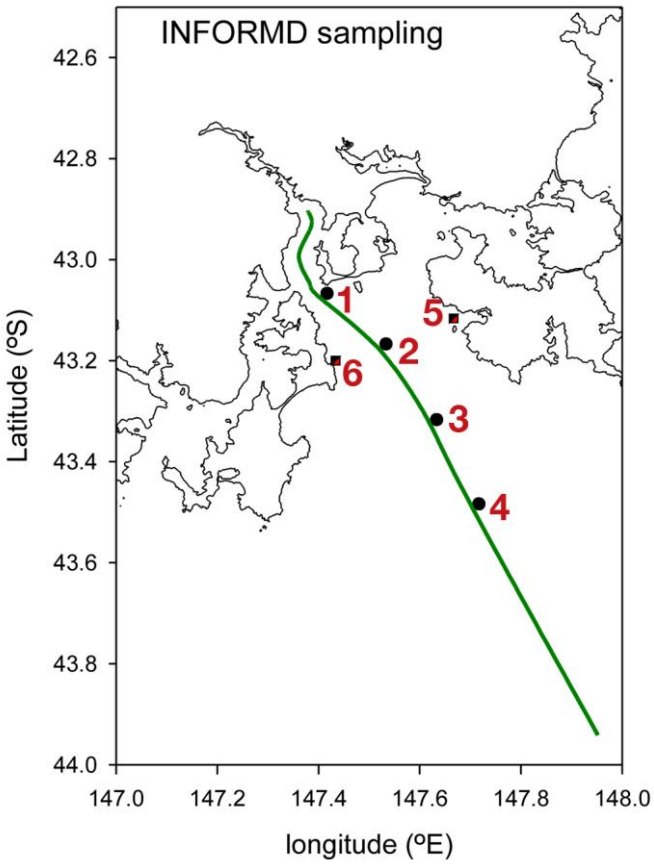


Figure 1: Map of the study area with site locations. The green line represents the track of a glider deployed by CSIRO.

At each site an 8 L Niskin bottle was used to collect water samples from 1 m and 10 m below the surface, and at ~2 m above the seabed. For the deeper site 3, samples were also taken at 50 m below the surface. All samples were analysed for total suspended matter (TSM), nutrient concentrations, pigment concentrations, phytoplankton identification and enumeration, microzooplankton and absorption analyses. Nutrient samples were collected

in 10 mL plastic tubes and stored at -20°C in the dark both on the boat and in the laboratory, until analysis. Eleven samples for phytoplankton were preserved in acid Lugols solution, and 500 mL microzooplankton and 2 L chlorophyll *a* samples were kept cold and dark until processing in the laboratory. Dissolved oxygen samples were periodically taken from the bottom Niskin sample at each site for Winkler analysis to calibrate the Seabird dissolved oxygen probe.

An integrated water column sample (12 m) using a weighted hose was collected for phytoplankton speciation and pigment analysis from February 2010. Prior to this, samples for phytoplankton speciation were collected from 1 m below the surface. Early results indicated that samples from the surface and 10 m were quite different. Therefore in January 2010 we examined phytoplankton distribution resulting from three different sampling methods: subsurface samples and 10 m samples collected with the Niskin bottle, and a depth integrated sample over 0–11 m. The depth integrated samples (0–11 m) had higher cell densities than either the surface or the 10 m samples (Figure 2) for most species. Small cells, such as crytophytes and small flagellates, were generally well represented by all sampling methods, whereas large cells, including the diatoms *Leptocyclindricus* spp., *Pseudonitzschia* spp. and *Skeletonema* spp. and the dinoflagellate *Prorocentrum* spp., were up to an order of magnitude more abundant when collected by the integrated method. One species of diatom, *Proboscia alata*, was only present in the integrated sample. Furthermore, the results showed strong vertical gradients of salinity (Figure 6) and therefore density observed between 4 and 5 metres depth. From the phytoplankton sampling it was apparent that this results in thin layers of phytoplankton that were not adequately resolved by sampling at a single depth. From this it was concluded that to sample the phytoplankton in Storm Bay adequately, it would be necessary to use a depth integrated approach.

Following the decision to include the integrated sampler, the sampling regime was revised in the following way. The contents of four sampling tube collections were mixed together and sub-sampled: duplicate 1l samples for phytoplankton were collected and preserved using acid Lugols solution, duplicate 1 L samples for pigments, 400–500 mL samples for microzooplankton, and 2 L for chlorophyll *a* were kept cold and dark until processing in the laboratory on return to shore.

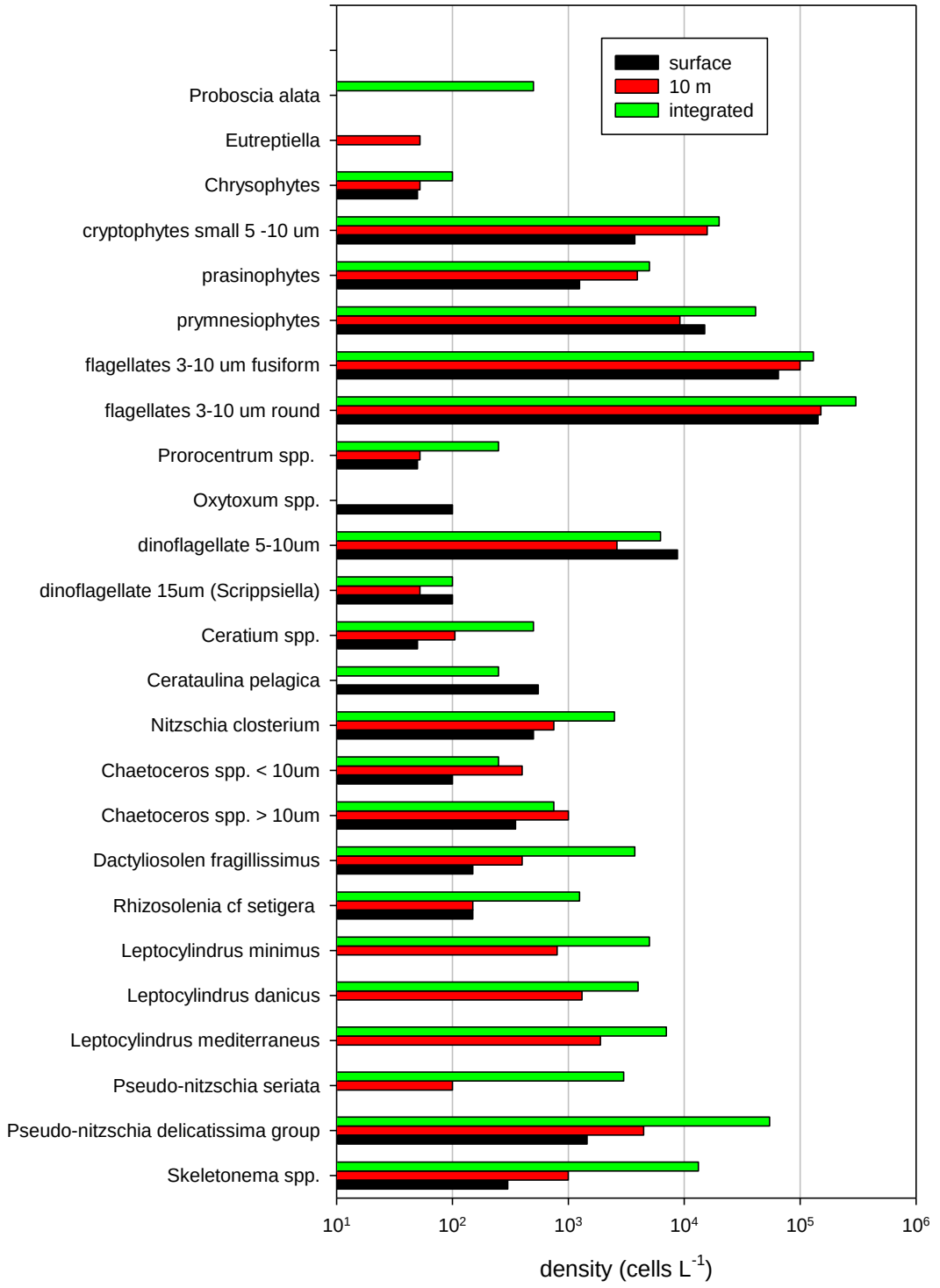


Figure 2: A comparison of cell counts from samples collected at the surface, at 10 m and using a tube for a depth integrated sample.

1.3 Sampling for bio-optical properties

Samples were collected for the analysis of pigment concentration and composition at all sites. Samples collected for particulate and dissolved absorption and total suspended matter (TSM) were collected from any of the five sites at 1 m depth if the site sampling time fell within the satellite (MODIS and MERIS) overpass time ± one hour. Generally only three of the sites could be sampled within these time requirements. If clear skies prevailed then 1–3 additional samples were collected within the satellite overpass time ± one hour at 'random' sites. At these random sites only samples for the bio-optical properties, including pigments, were collected (that is, there were no CTD, plankton or other data collected). The random sites were wherever the boat stopped and were generally never the same on any of the sampling trips. The purpose of the random sites was to increase the number of in situ samples that could be used to match satellite retrieved values of the bio-optical parameters and also to be used as input parameters for the development of regional algorithms. If the skies were overcast then samples were collected at the standard five sites only.

Samples for chromophoric dissolved organic matter (CDOM) analysis were collected directly from the Niskin bottle into glass Schott™ bottles after two rinses. The samples were stored in the cool and the dark until filtration on return to the laboratory.

Water samples for TSM, pigment and particulate absorption analyses were transferred from the Niskin bottles to clear HDPE 10 L carboys and stored in the cool and dark until filtration back at the laboratory (approximately 3–5 hours after collection).

1.4 Total suspended matter (TSM) analysis

Two litres of sample water was filtered through 47 mm pre-weighed glass fibre filters (Whatman GF/F). After filtration, the filters were rinsed with 50 mL of Milli-Q water to remove salt from the filter. The pre-weighed filters had been dried in a muffle furnace at 450°C for one hour, washed in Milli-Q water and then dried at 60°C to constant weight. Triplicate samples were collected from each site. After sample collection/filtration, the filters were dried to constant weight at 60°C and then muffled at 450°C for three hours to remove the organic matter. After the filters had cooled to 20°C, the filters were weighed to determine the weight of the inorganic content of the samples. The organic fraction was determined as the difference between the total suspended matter and the inorganic content.

1.5 Pigment analysis

One to two litres of sample water was filtered through a 25 mm glass fibre filter (Whatman GF/F) under subdued lighting, and the filter was then stored in liquid nitrogen until analysis. To extract the pigments, the filters were cut into small pieces and covered with

100% acetone (3 mL) in a 10 mL centrifuge tube. The samples were vortexed for about 30 seconds and then sonicated in an ice-water bath for 15 minutes in the dark. The samples were then kept in the dark at 4°C for approximately 15 hours. After this time 200 µL water was added to the acetone such that the extract mixture was 90:10 acetone:water (vol:vol) and sonicated once more in an ice-water bath for 15 minutes. The extracts were quantitatively transferred to a clean centrifuge tube and centrifuged to remove the filter paper. The final extract was filtered through a 0.2 µm membrane filter (Advantec MFS) prior to analysis by HPLC using a Waters–Alliance high performance liquid chromatography system, comprising a 2695XE separations module with column heater and refrigerated auto sampler and a 2996 photo-diode array detector. Immediately prior to injection the sample extract was mixed with a buffer solution (90:10, 28 mM tetrabutyl ammonium acetate, pH 6.5 methanol) within the sample loop. After injection, pigments were separated using a Zorbax Eclipse XDB-C8 stainless steel 150 mm x 4.6 mm ID column with 3.5 µm particle size (Agilent Technologies) and a binary gradient elution procedure. The flow rate was 1.1 mL min^{-1} and the column temperature was 55°C. The separated pigments were detected at 436 nm and identified against standard spectra using Waters Empower software. Concentrations of chlorophyll *a*, chlorophyll *b* and β,β-carotene in sample chromatograms were determined from standards (Sigma, USA) while all other pigment concentrations were determined from standards (DHI, Denmark).

1.6 Phytoplankton identification/cell counts

The Lugols preserved samples were transferred to 1 litre measuring cylinders (volume recorded) and allowed to settle for at least 24 hours. After this time approximately 900 mL was siphoned off and the remaining sample was transferred to a 100 mL measuring cylinder and again allowed to settle for at least 24 hours. After this time approximately 90 mL was siphoned off, the final volume recorded and thoroughly mixed before a 1 mL aliquot was taken and placed in a Sedgwick Rafter counting chamber and examined under a microscope.

The biovolumes of counted cells were estimated from standard geometries detailed in Hillebrand et al. (1999).

1.7 Particulate and detrital absorption

One litre of sample water was filtered through a 25 mm glass fibre filter (Whatman GF/F), under subdued lighting, and then stored flat in liquid nitrogen until analysis. Optical density (OD) spectra for total particulate and detrital matter were obtained using a Cintra 404 UV/VIS dual beam spectrophotometer equipped with integrating sphere. The OD spectrum of the phytoplankton pigment was obtained as the difference between the OD of the total particulate and detrital components. The OD scans were converted to absorption

spectra by first normalising the scans to zero at 750 nm and then correcting for the path length amplification using the coefficients of Mitchell (1990).

1.8 CDOM absorption

Samples for CDOM analysis were filtered through a 0.2 µm polycarbonate filter (Millipore) and stored at 4°C, in clean glass bottles, until analysis within 24 hours. Samples were allowed to equilibrate to room temperature in the dark before the CDOM absorbance was measured in a 10 cm path length quartz cell, from 200–900 nm, using the normal cell compartment of the Cintra 404 UV/VIS spectrophotometer, with Milli-Q water as a reference. Between sample scans, the reference cell was removed from the spectrophotometer and placed in a room temperature water bath to reduce temperature effects in the scans. The CDOM absorption co-efficient (m^{-1}) was calculated using the equation

$$a_{CDOM} = 2.3(A(\lambda)/l)$$

where $A(\lambda)$ is the absorbance(normalised to zero at 680 nm) and l is the cell path length in meters.

Curve fitting:

An exponential function (equation 1) was fitted to all CDOM and detritus spectra

$$a(\lambda) = a_{(350)}.\exp(-S(\lambda - 350)) + b \qquad (1)$$

over the wavelength range 350 to 750 nm. A non-linear least-squares technique was used to fit equation 1 to the untransformed data. The inclusion of an offset b allows for any baseline correction. In some samples, particularly samples containing cyanobacterial pigments, pigment extraction was incomplete, leaving small residual peaks in detritus spectra at the principal chlorophyll absorption bands. To avoid distorting the fitted detritus spectra, data at these wavelengths were omitted when all spectra were fitted.

Total particulate spectra were smoothed using a running box-car filter with width 10 nm, and the fitted detritus spectra subtracted. Subtracting fitted detritus spectra minimised any artefacts due to incomplete extraction of pigments. The resulting phytoplankton spectra were base-corrected by subtracting absorption at 750 nm to obtain $a_{ph}(\lambda)$.

1.9. Nutrient analysis

Prior to analysis, samples collected for nitrate/nitrite, silicate and phosphate analyses were allowed to thaw before equilibrating to room temperature. Each of the tubes was well mixed and placed in the auto-sampler of a 5-channel Lachat QuickChem 8000 series Automated Ion

Analyser. The concentration of each of the nutrients was determined using QuickChem methods as follows:

nitrate/nitrite (31-107-04-1-A), phosphate (31-115-01-1-I), silicate (31-114-27-1-D) and ammonium (31-107-06-4-A), which had been calibrated against standard solutions.

Results and discussion

2.1 Physical parameters – temperature and salinity

Surface salinity and temperature values (Figure 3a,b) indicate that site 3 is generally not influenced by the outflow of fresh water from the Derwent River and the northern end of the D'Entrecastreaux Channel as the salinities are around 35 all year and the temperature is generally cooler in summer and warmer in winter.

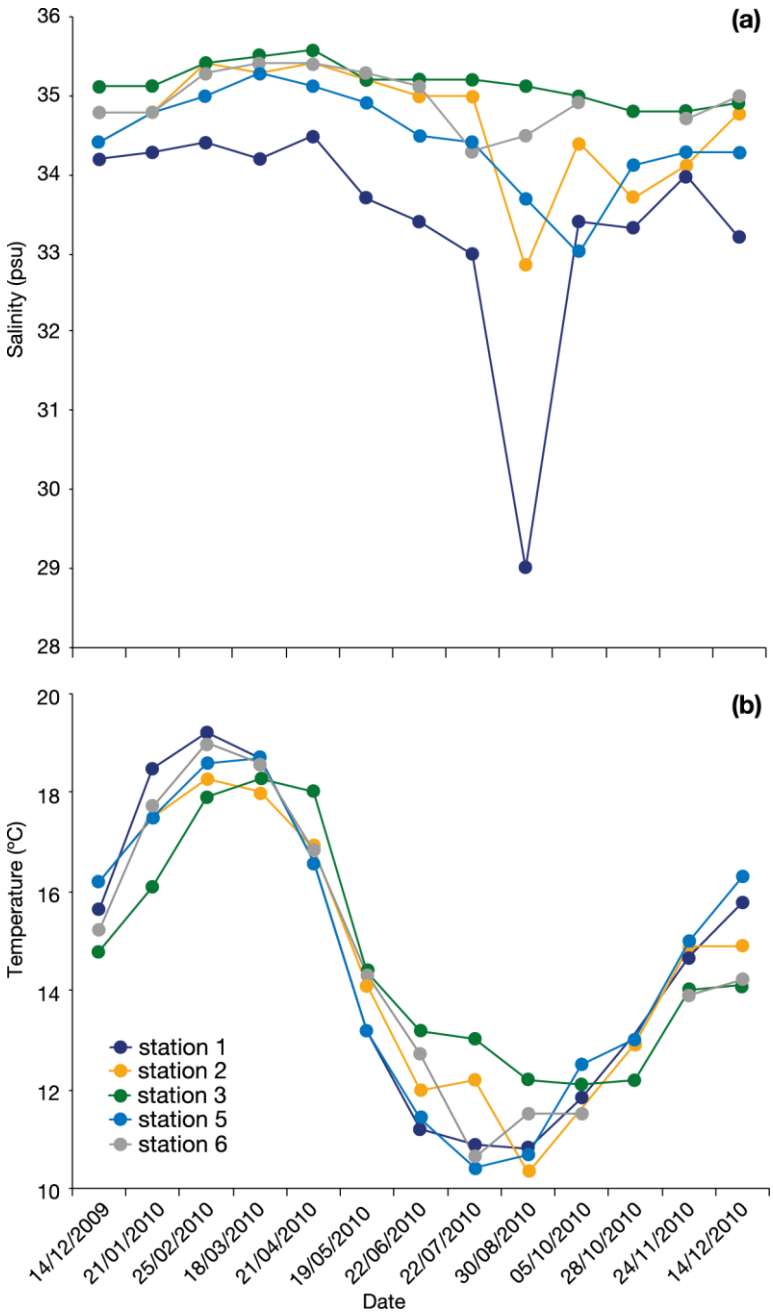


Figure 3: Salinity (a) and temperature (b) values at 0.5 – 1 m water depth at sampling sites in Storm Bay.

The low salinity values reflected at site 1 and to a lesser extent at sites 2 and 5 in August are due to high rainfall in the Derwent and Huon river catchments (Figure 4). During August 2010, a total of 114 and 132.6 mm of rain fell over the Hobart and Geeveston recording stations respectively. However, in Hobart most of the rain fell on one day with 62.8 mm falling on 12 August and 16.8 and 13.6 mm falling on 11 and 21 August respectively. Rain falling over Geeveston was slightly different with 32.8 mm falling on 12 August and 36.2 and 13.6 mm falling on 21 and 27 August respectively.

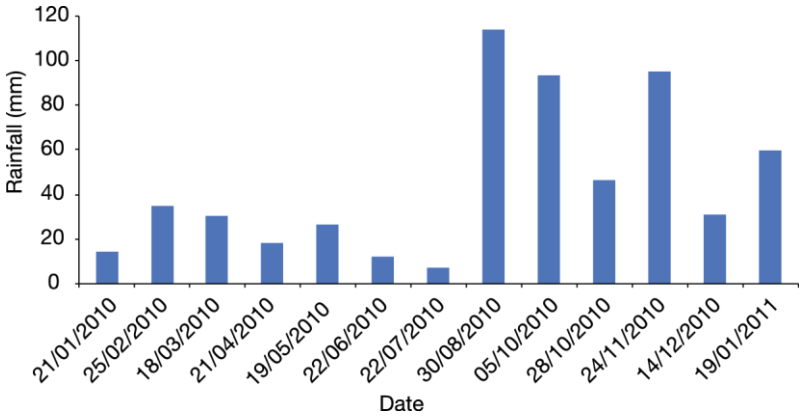


Figure 4: Rainfall recorded at the Hobart recording station between January 2010 and January 2011. Data from Bureau of Meteorology..

Water circulation in Storm Bay predominately has marine waters flowing north into the bay on the western side and the freshwater outflow from the Derwent River and the northern end of the D'Entrecasteaux Channel flowing south along the eastern side of the bay. This circulation pattern suggests that the freshwater flow would influence sites 1 and 5 the most while the marine flow would influence sites 3 and 6 the most. Site 2 could be influenced by either source depending on which source was the more dominant. In August the high rainfall caused a large pulse of freshwater to enter Storm Bay which flooded into the surface waters of site 2, but not as far south as site 3. This is reflected in the salinity and temperature values recorded for the surface waters at each site (Figure 3).

Monthly temperature and salinity profiles with depth also generally reflect this circulation pattern (Figures 5 and 6). At the commencement of sampling in December 2009 the temperature was warmest at site 5, with a thermocline at approximately 20 m depth, and lowest at site 3. In January 2010 there was a progressive decline in temperature with increasing distance into Storm Bay. Water temperatures were warmest and more similar at all sites in February and March, followed by a major change in April when site 3 was over 1°C warmer than the other sites. Temperatures decreased at all sites in May and again in June and July, especially at the inner sites and close to shore. Site 3 had the warmest water across the entire water column at this time. By early October the inner sites were similar to site 3 and by late October they were warmer. Temperatures at all sites in November had increased, with site 5 the warmest and a thermocline at 20 m. Water temperatures in December 2010 showed a similar pattern to that observed in December 2009.

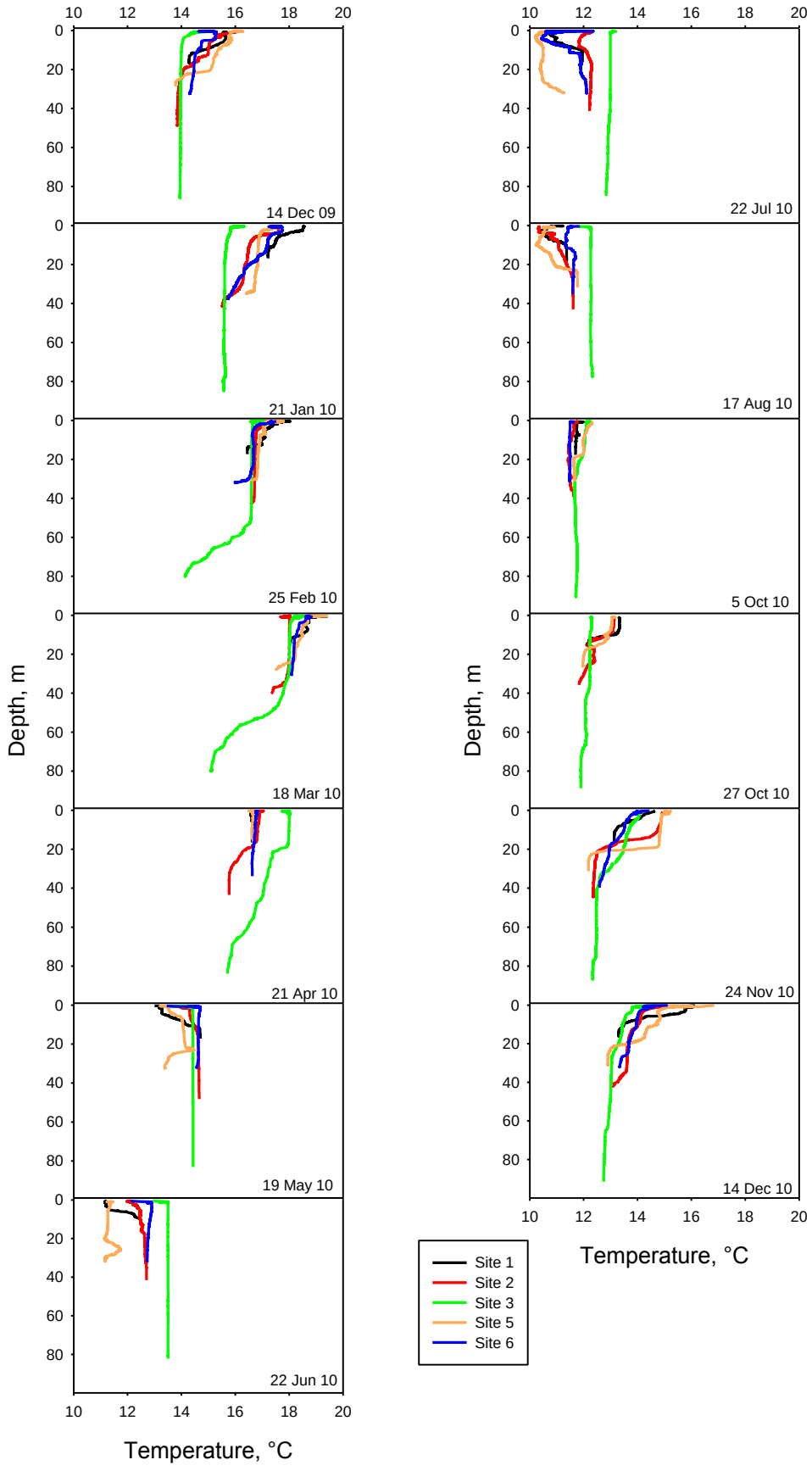


Figure 5: Monthly temperature profiles at the five sites for 13 months.

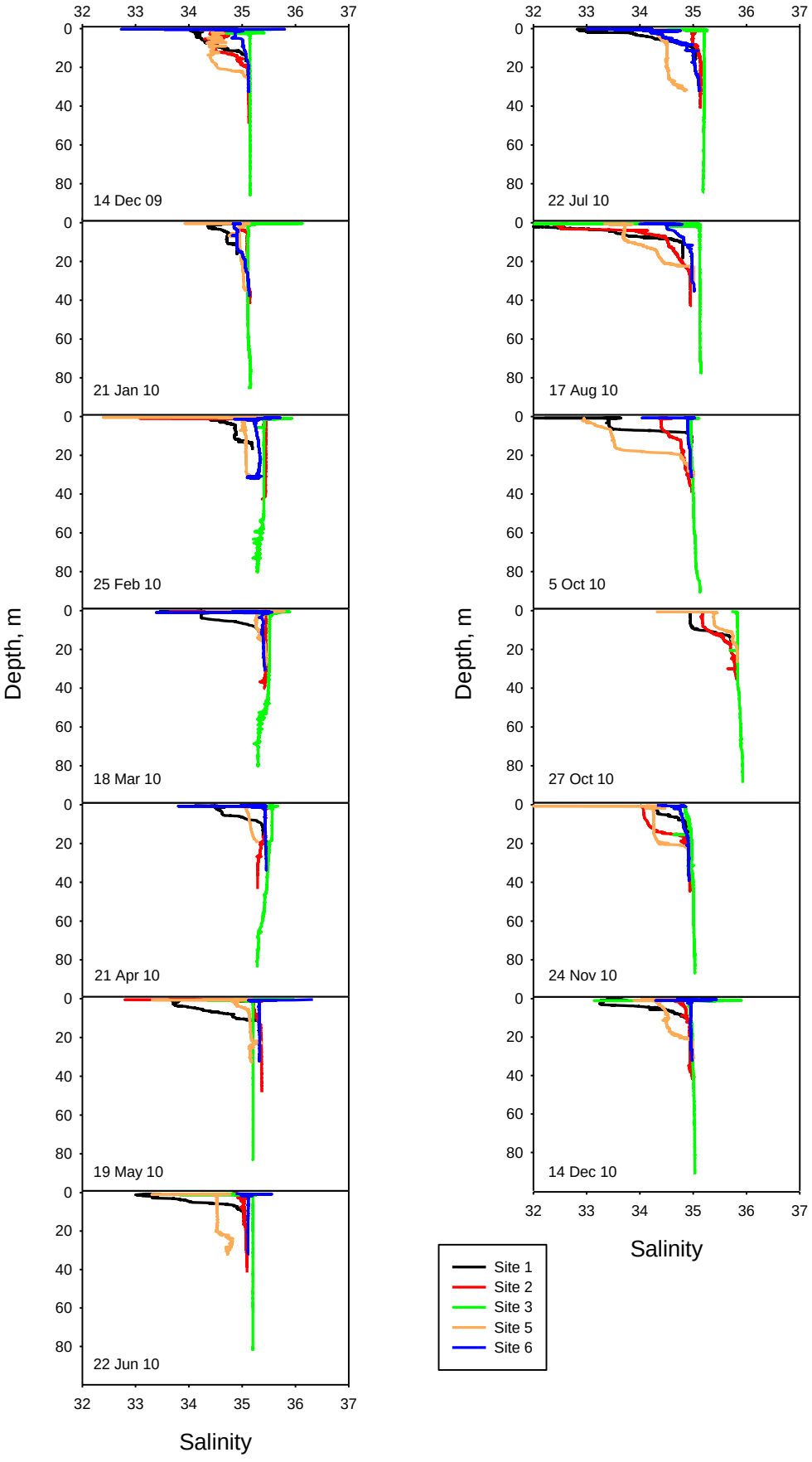


Figure 6: Monthly salinity profiles at the five sites for 13 months.

Salinity was highest at site 3 in all months except February and May and generally lowest at site 1, reflecting the freshwater flow from the Derwent (Figure 6). In most months the salinity at site 5 was lowest from about 5 m depth and a halocline was present at 20+ m. This unusual stratification of temperature and salinity could be influenced by a deep hole that was encountered after drifting while sampling in 32-33 m depth at site 5.

2.2 Physical parameters – nutrients

Nitrate concentrations at both the surface and 10 m showed a pattern of low values over spring, summer and autumn (generally <1 μM) and increased over winter–early spring to up to 4 μM, although there was some variation between sites (Figure 7). Site 5 generally had the lowest concentrations over winter. Bottom water nitrate concentrations were more variable, although a general increase over winter was apparent. The deepest site 3 at approximately 90 m depth had the highest nitrate concentrations in most months of the year, and these were particularly high in February and March, up to ~8 μM. Site 2 at 45 m depth also had relatively high values in most months of the year.

Ammonium concentrations were consistently low at the surface and <1 μM (Figure 7). They were similar across sites at 10 m depth, except for higher values at site 3 in February, March and November 2010. Bottom water ammonium concentrations were markedly higher in January at the two outermost sites and also relatively high at these sites in March and November, similar to concentrations at 10 m depth. Site 5 ammonium concentrations in bottom water, although generally within ANZECC guidelines (1.07 μm for marine waters, ANZECC 2000), were the highest of all sites in winter and December, and relatively high in February and March.

Phosphate concentrations were generally low and showed little variation between sites at the different depths over time (Figure 8). The exception was at site 3 in February and March when clear peaks in concentrations, much higher than ANZECC guidelines for marine waters, were evident.

Silicate concentrations were variable and tended to follow rainfall patterns, with highest values in surface waters over much of the year and especially at site 1, which peaked in winter and early summer (Figure 8). Bottom water values were generally the lowest in each month.

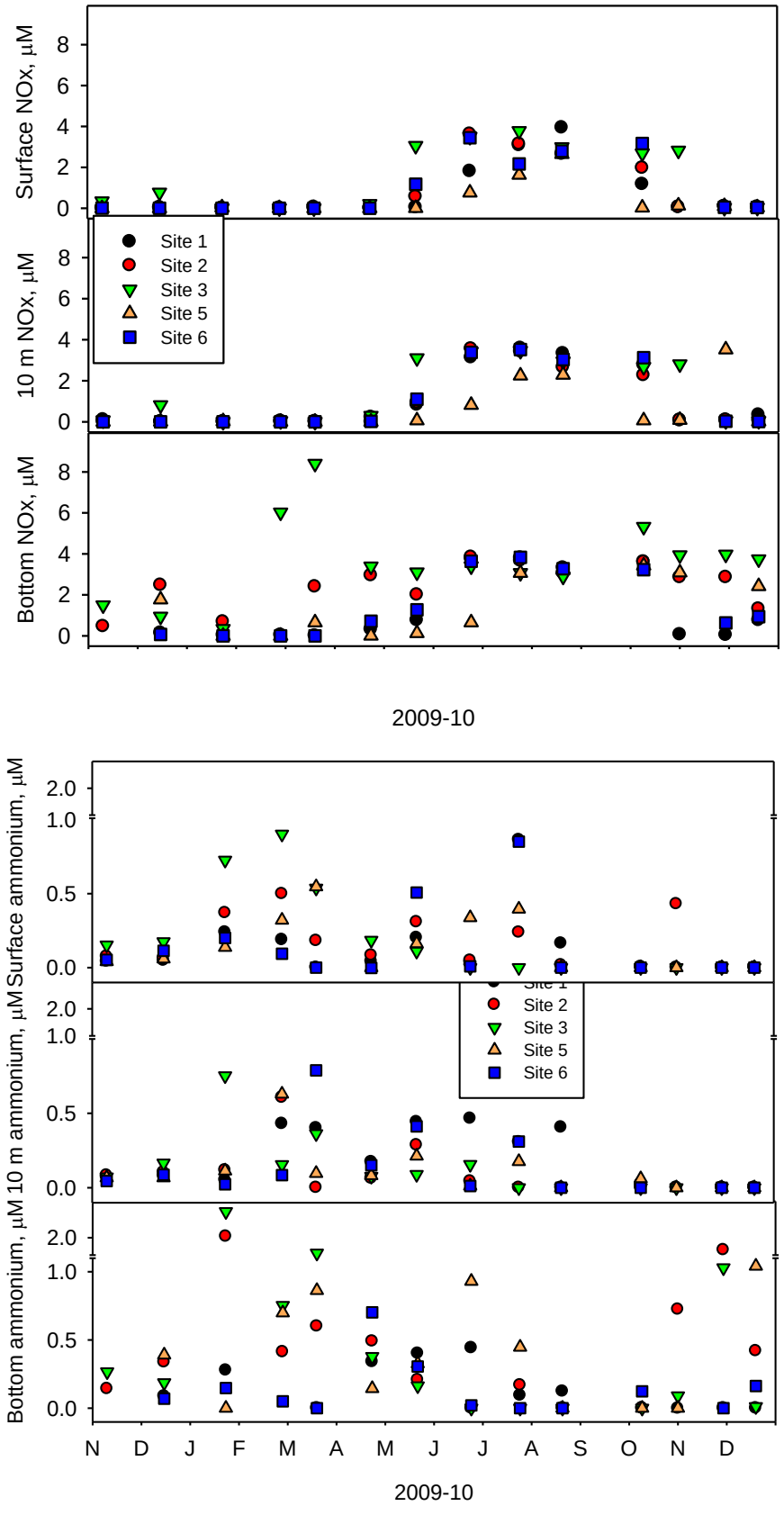


Figure 7: Nitrate and ammonium concentrations at 3 depths in 2009–10. Note truncated scale for ammonium.

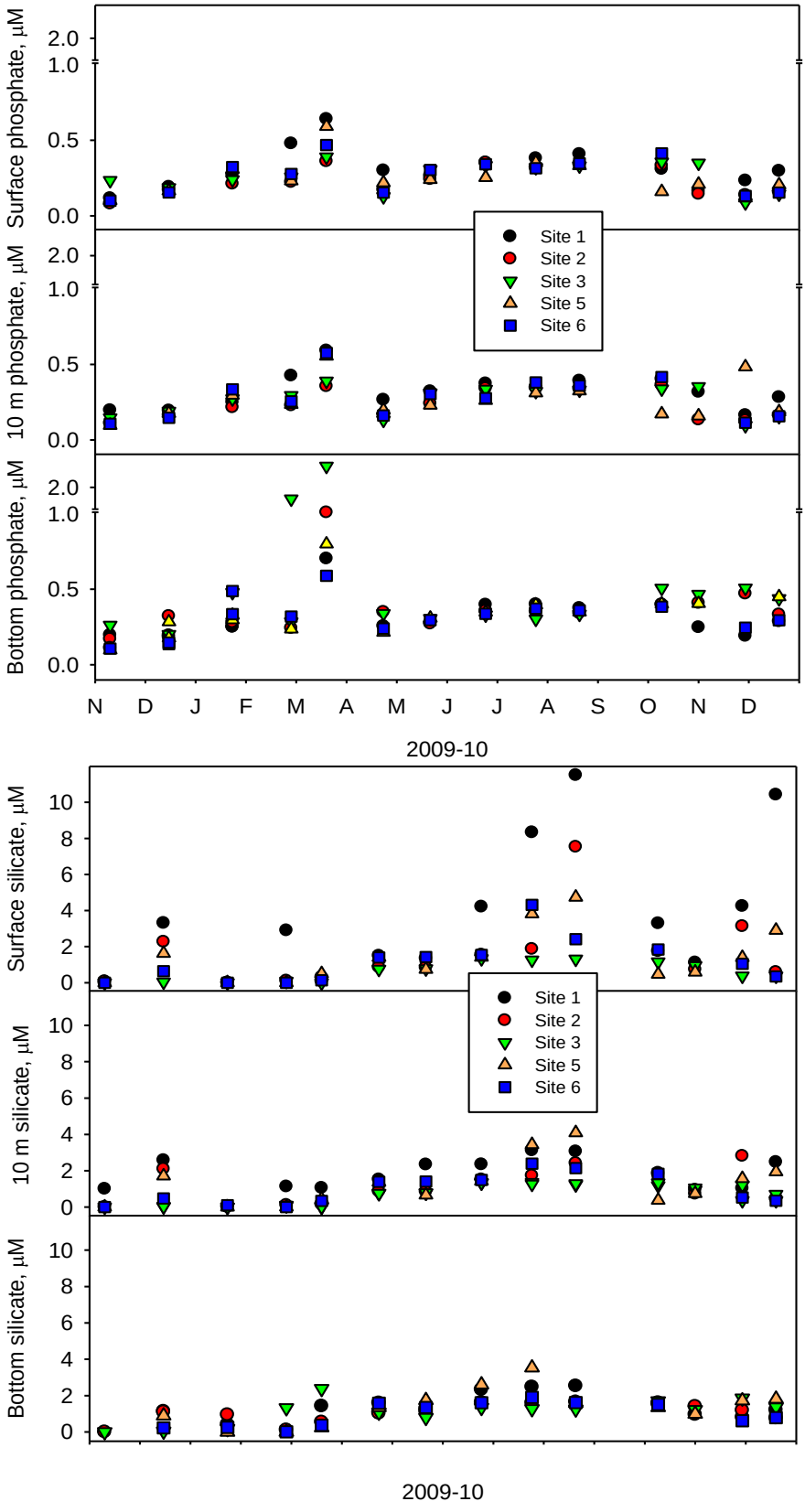


Figure 8: Phosphate and silicate concentrations at 3 depths in 2009–10. Note truncated scale for phosphate.

A comparison of nutrient concentrations at each site over the sampling period and presented as box and whisker plots (Figure 9) shows that median nitrate concentrations were highest at site 3 at all depths sampled, especially in bottom waters, whereas site 5 had the least variation with the 75 percentile much lower than at the other sites. Median phosphate concentrations were marginally lower at sites 2 and 5 at the surface and 10 m depth, although overall varied little between sites. Median silicate concentrations were highest at site 1. At 10 m depth median and 75 percentile ammonium values were highest at site 1, whereas in bottom waters the median was highest at sites 2 and 5 and the 75 percentile at site 3.

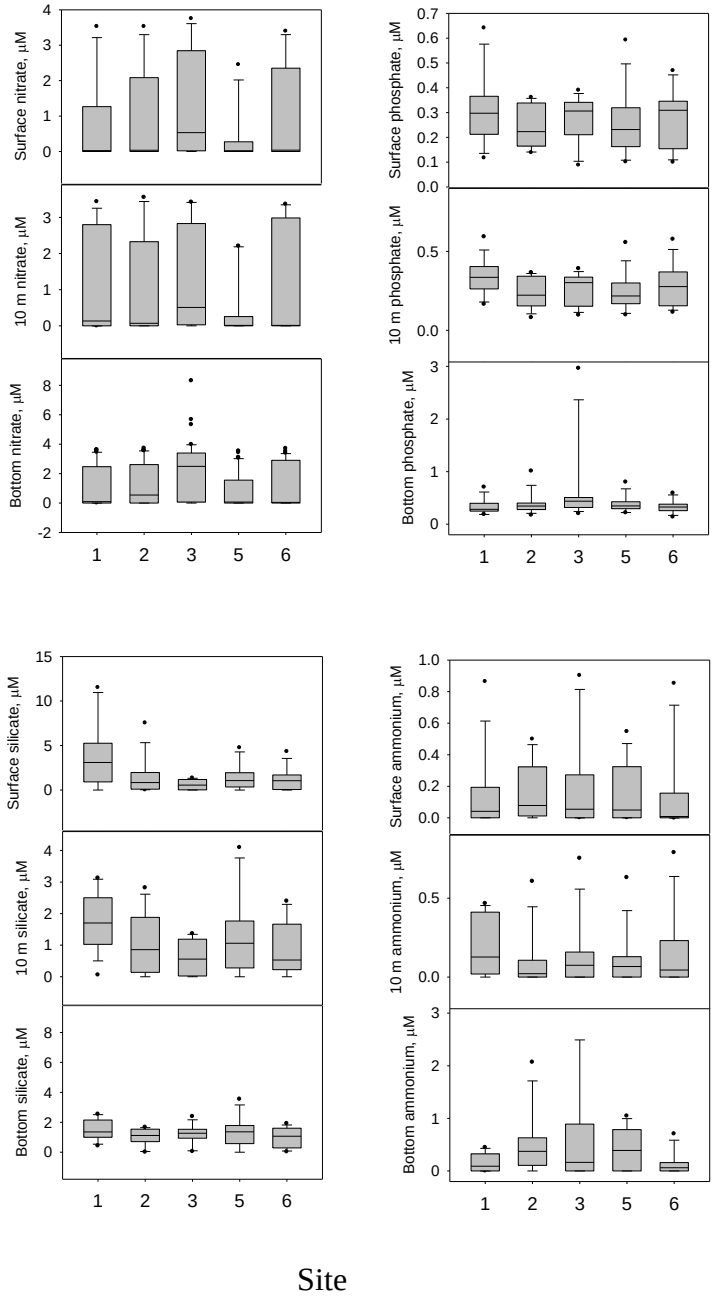


Figure 9: Box and whisker plots of nutrients concentrations at each site over the sampling period

2.3 Pigment and phytoplankton community composition

Phytoplankton biomass, as indicated by chl-*a* concentration, for the five sites sampled is shown in Figures 10 and 11. Statistically, a single factor ANOVA ($p < 0.05$) showed there was a significant difference between mean chl-*a* concentrations at the five sites. In general the biomass was lowest at site 6 and highest at site 1. On two occasions (21 April and 05 October 2010) the highest biomass was recorded at site 2. Biomass tended to increase at all sites except site 3 from around April/May until late in 2010 (Figure 11). Increased biomass was recorded at site 3 from 05 October 2010.

Pigment analysis is used to estimate algal community composition and concentration. Pigments which relate specifically to an algal class are termed marker or diagnostic pigments (Jeffrey and Vesk, 1997; Jeffrey and Wright, 2006). Some of these diagnostic pigments are found exclusively in one algal class (e.g. prasinoxanthin in prasinophytes), while others are the principal pigments of one class, but are also found in other classes (e.g. fucoxanthin in diatoms and some haptophytes; 19'-butanoyloxyfucoxanthin in chrysophytes and some haptophytes). The presence or absence of these diagnostic pigments can provide a simple guide to the composition of a phytoplankton community, including identifying classes of small flagellates that cannot be determined by light microscopy techniques. In this report we have based the description of the phytoplankton community composition on the pigments/algal groups listed in Table 2.

The pigment composition for the 1 m water samples from the five sites is shown in Figure 12. There is a general similarity in pigment composition between all sites with a presence of diatoms (as indicated by fucoxanthin), haptophytes (hex-fucoxanthin), prasinophytes (prasinoxanthan), cryptophytes (alloxanthan), cyanophytes (zeaxanthan) and green algae (chl-*b*) in nearly all monthly samples at all sites. The green algae could be in the form of euglenophytes or prasinophytes; the absence of the pigment lutein in all samples indicates that chlorophytes are not present in Storm Bay, at least at the sites sampled.

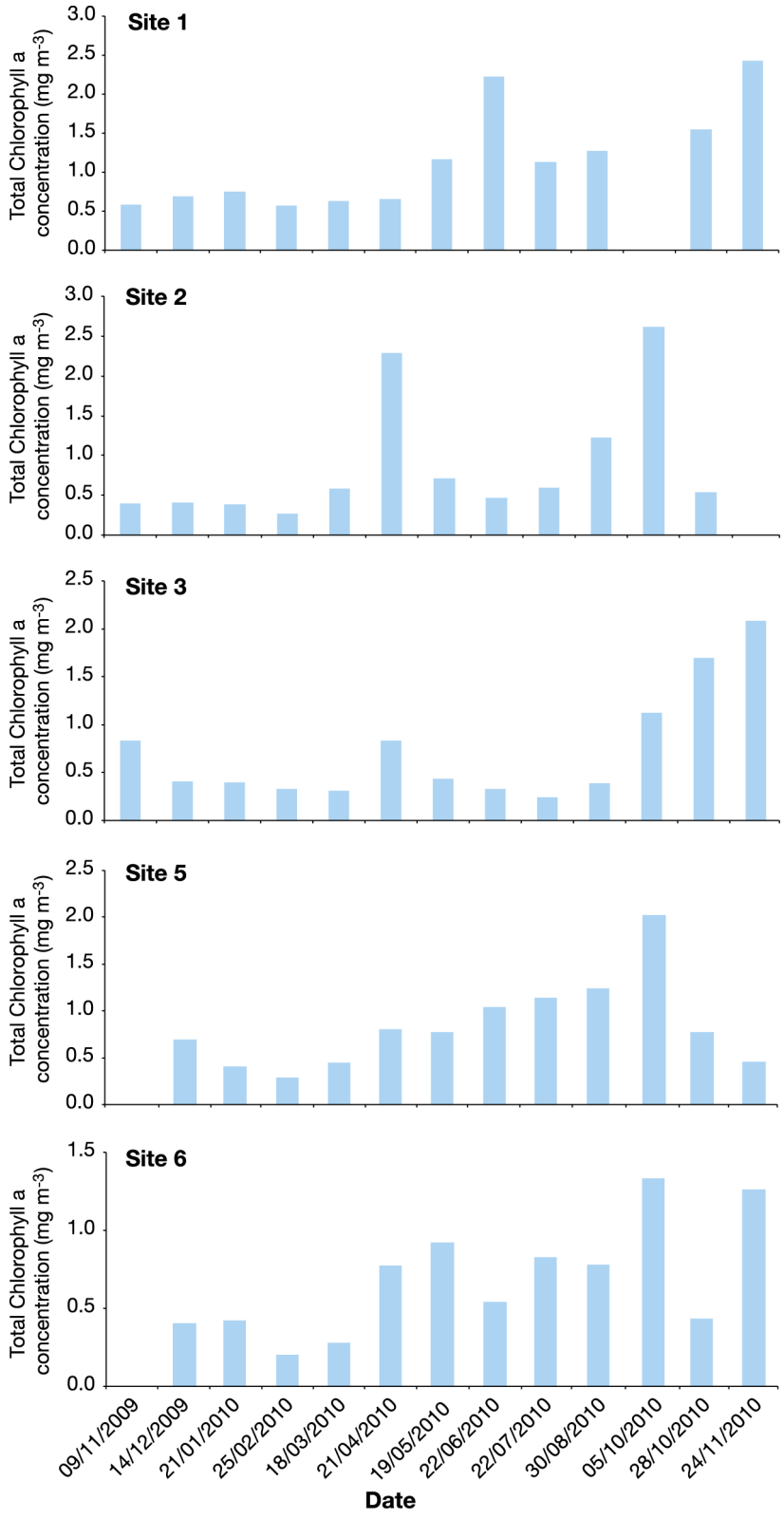


Figure 10: Surface chl-a concentration in samples collected from five sites in Storm Bay. Note the different scales for Chlorophyll a at each site.

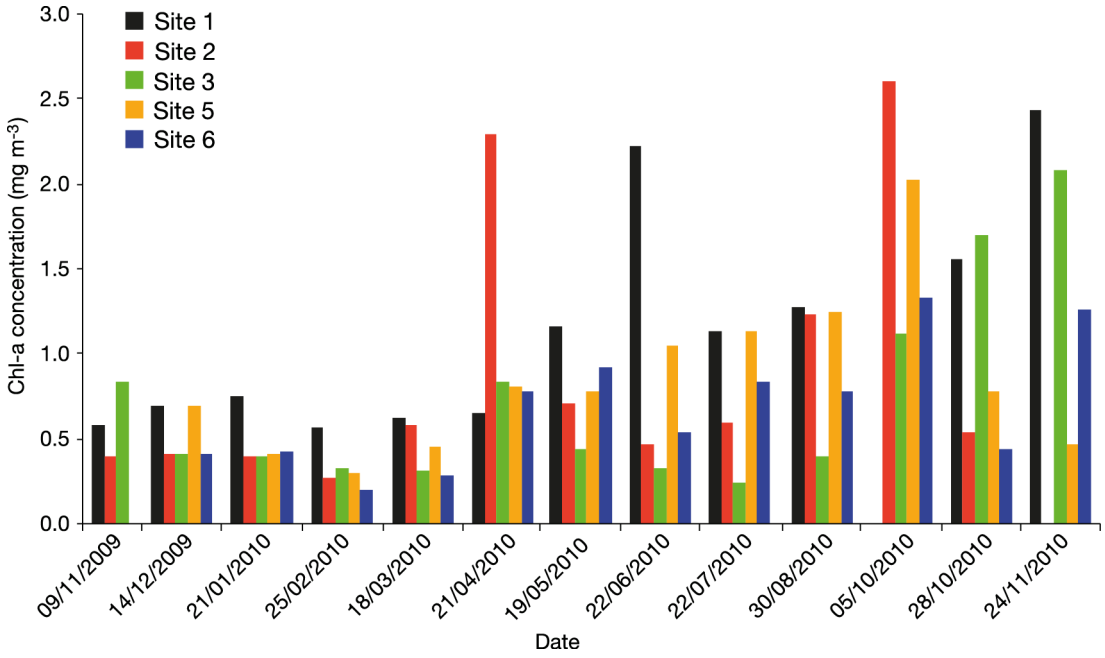


Figure 11: Surface chlorophyll *a* concentration in samples collected from five sites in Storm Bay.

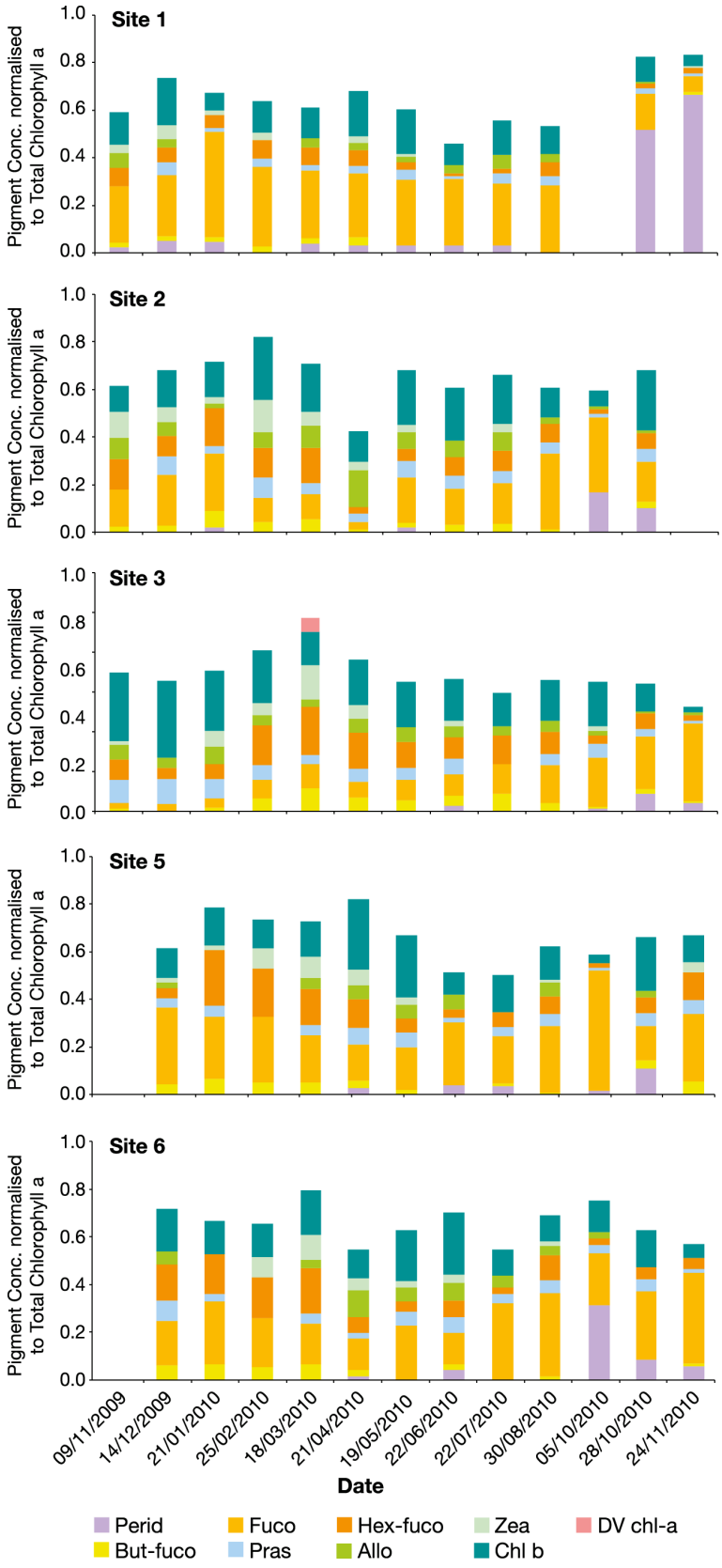


Figure 12: The composition of marker pigments for surface water samples collected from five sites in Storm Bay. See Table 2 for full pigment names.

Table 2. Biomarker pigments and the algal groups they represent.

Pigment name	Abbreviation	Algal group
Peridinin	Perid	Dinoflagellates
19'-butanoyloxyfucoxanthin	But-fuco	Chrysophytes
Fucoxanthin	Fuco	Diatoms
19'-hexanoyloxyfucoxanthin	Hex-fuco	Haptophytes
Prasinoxanthin	Pras	Prasinophytes
Alloxanthin	Allo	Cryptophytes
Zeaxanthin	Zea	Cyanophytes
Chlorophyll b	Chl b	Green algal groups
Divinyl chlorophyll *a*	DV chl a	Prochlorophytes

Sites 1 and 5, for most of the year sampled, are dominated by diatoms as indicated by the presence of fucoxanthin. Dinoflagellates (as indicated by peridinin) were nearly always present in small numbers at site 1, until October/November 2010 when they became the dominant algal group. At site 5 the presence of dinoflagellates was sporadic and only represented a small component of the community composition. Although site 5 showed a similar phytoplankton composition to site 1 for most of the year, it did not have the dinoflagellate bloom that site 1 had in October/November 2010.

Sites 2 and 6 also had a strong presence of diatoms throughout the year, but they were generally not as dominant as was observed at sites 1 and 5. In April 2010 site 2 had a biomass, as indicated by chl-a, nearly three times greater than the biomass at the other sites. The increased biomass appears to be due to an increased presence of cryptophytes (as indicated by alloxanthin). There was also an increase in alloxanthin concentration and hence cryptophytes at site 6 at the same time. Dinoflagellates were present at sites 2 and 6 during October and November 2010 in larger numbers than at site 5.

Generally, the phytoplankton community composition at site 3 was a mix of several algal groups in more equal numbers than at the other sites. Green algal groups appear to be dominant from November 2009 to January 2010, and then haptophytes had a stronger presence from February to April 2009 followed by diatoms during October/November 2010. The presence of DV chl-a at site 3 in March 2010 suggests the presence of prochlorophytes, a tropical species of phytoplankton commonly found in the tropical water masses. This would suggest that East Australian Current (EAC) water had flooded into Storm Bay sometime

prior to the sampling date. An SST image from 16 March (Figure 13) shows the extension of the EAC along the east coast of Tasmania and flooding into Storm Bay as predicted by the pigment composition. Site 3 was probably close to the northern edge of the intrusion of EAC water into Storm Bay as DV chl-a was not observed at any of the other four sites. It was observed at one of the random sites close to site 3.

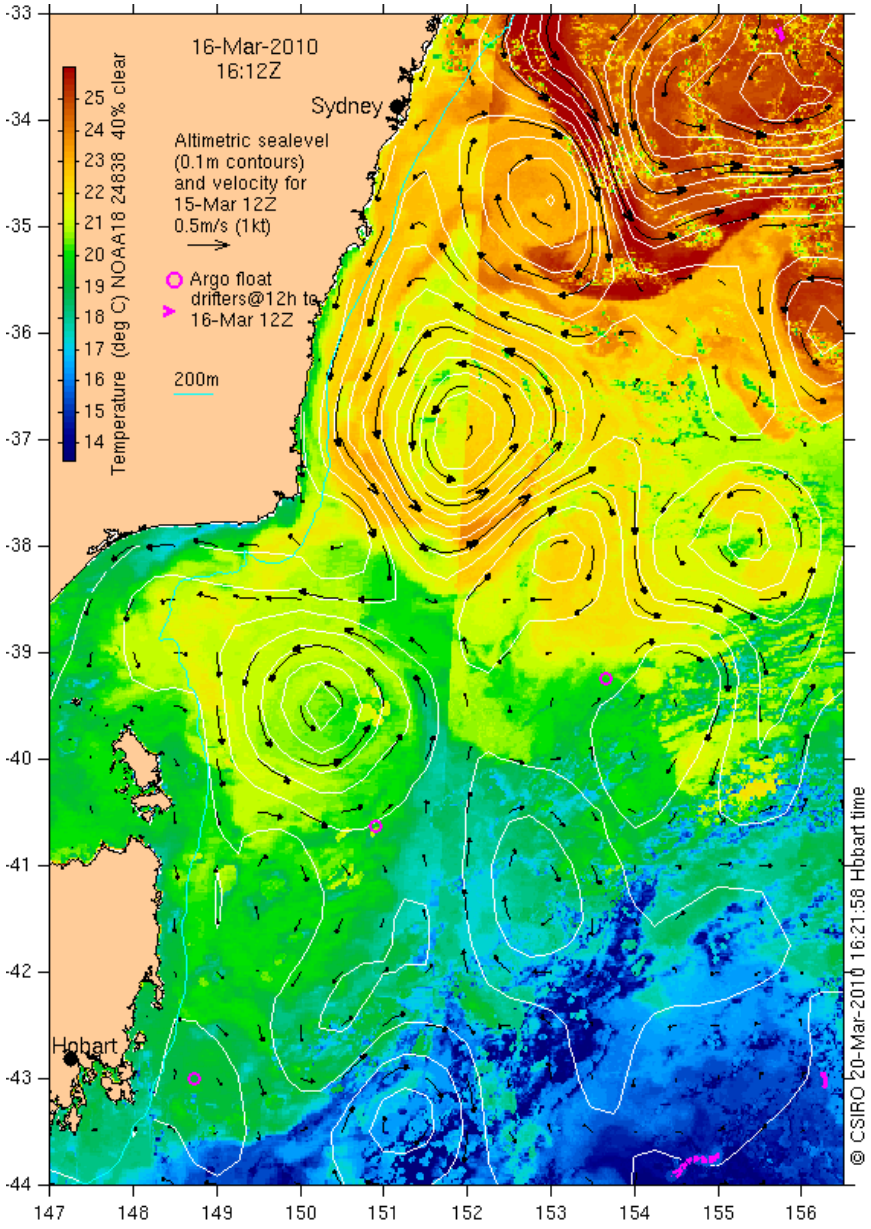


Figure 13: SST image from 16 March 2010 overlayed with velocity vectors. Image provided by David Griffin, CSIRO Marine and Atmospheric Research.

2.3 Optical properties

Light availability, one of the basic requirements for the development and sustainability of phytoplankton within the water column, is determined by the optical properties of the dissolved and particulate components within the water column. The extent to which the phytoplankton, detrital suspended matter (mineral material and heterotrophic microalgae) and the chromophoric dissolved organic matter (CDOM) absorb the light will determine what percentage of incident irradiance is available at any one depth.

Absorption (a) is an inherent optical property and therefore the total absorption is the sum of the absorption of the individual components, phytoplankton, detrital matter and CDOM within the water column. Total absorption of any water body can be expressed by

$$a(\lambda) = a_{ph}(\lambda) + a_{d}(\lambda) + a_{CDOM}(\lambda) + a_{w}(\lambda) \quad (2)$$

where a_{ph}, a_{d}, a_{CDOM} and a_{w} represent absorption due to phytoplankton, detrital matter, CDOM and water respectively. Values for a_{w} were taken from published results (Pope and Fry, 1997), whilst values for the other absorption coefficients were determined by laboratory analysis (see methods section).

Previous studies have reported the Huon River Estuary to have high concentrations of CDOM with $a_{CDOM}(440)$ values ranging from 0.58 to 12.8 m^{-1} (Burgess et al., 1993) and 0.13 to 14 m^{-1} (CSIRO, 2000; Clementson et al., 2004). From fieldwork in January 2008 (unpublished data; Clementson et al.), the Derwent River had $a_{CDOM}(440)$ values ranging from 0.15 (lower Derwent River) to 1.56 m^{-1} (Bridgewater). The outflow of the Huon River flows into the D'Entrecasteaux Channel and then north along the channel until it meets with the outflow of the Derwent River at the entrance to Storm Bay. Site 1, the site closest to the confluence of these CDOM sources has the highest $a_{CDOM}(440)$ values (0.11 – 0.35 m^{-1}) for the five sites studied (Figure 13) as would be expected. Site 3, generally not influenced by the outflow of fresh water from the Derwent River and the northern end of the D'Entrecasteaux Channel as indicated by the temperature and salinity data (Figure 3a,b) has the lowest $a_{CDOM}(440)$ values (0.04 – 0.12 m^{-1}). Regardless of which site had the highest or lowest absolute $a_{CDOM}(440)$ values, the absorption due to CDOM in the near-surface waters, at all sites, was around 69% of the total absorption (Figure 15). This compares well with the percent CDOM absorption of total absorption found in the mouth of the Huon River Estuary being never less than 60% (Clementson et al., 2008).

In general, CDOM was the dominant absorbing parameter at all sites, even site 3 which was the site least influenced by the freshwater flow. On only one occasion during the 12 months of the study was CDOM not the dominant absorbing parameter; at site 3 during November 2010 absorption due to phytoplankton accounted for 60% of the total absorption (Figure 15). CDOM absorbs strongly in the low wavelengths therefore light in the same wavelengths is

attenuated rapidly (1–2 m), often leaving the light available, in wavelengths that are inefficiently harvested by most pigments; the phycobilliproteins being an exception. This suggests that phytoplankton species in the Storm Bay system could be adapted to low light conditions and may partially explain why the phytoplankton biomass, as indicated by the chl-*a* concentration, was relatively low throughout the study period.

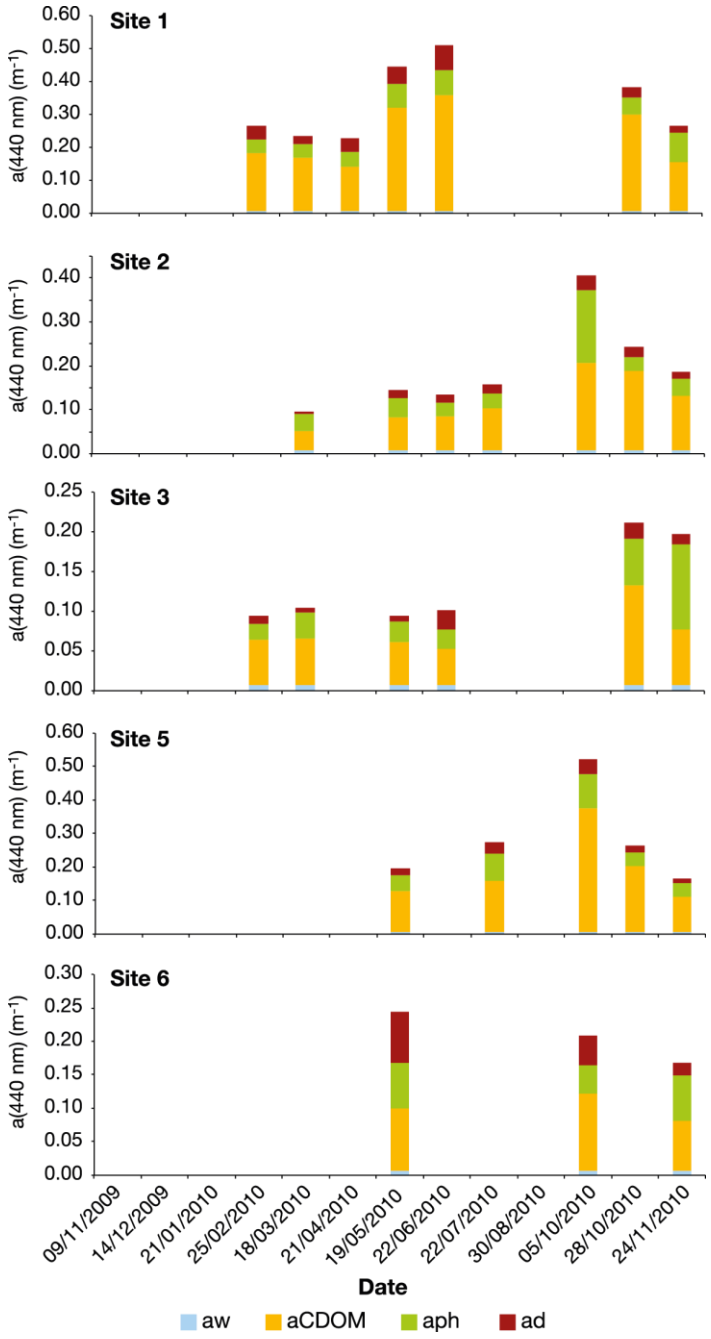


Figure 14: Absorption coefficients at 440 nm for phytoplankton, detrital matter and CDOM collected from five sites in Storm bay. Abbreviations for colours are described in the text.

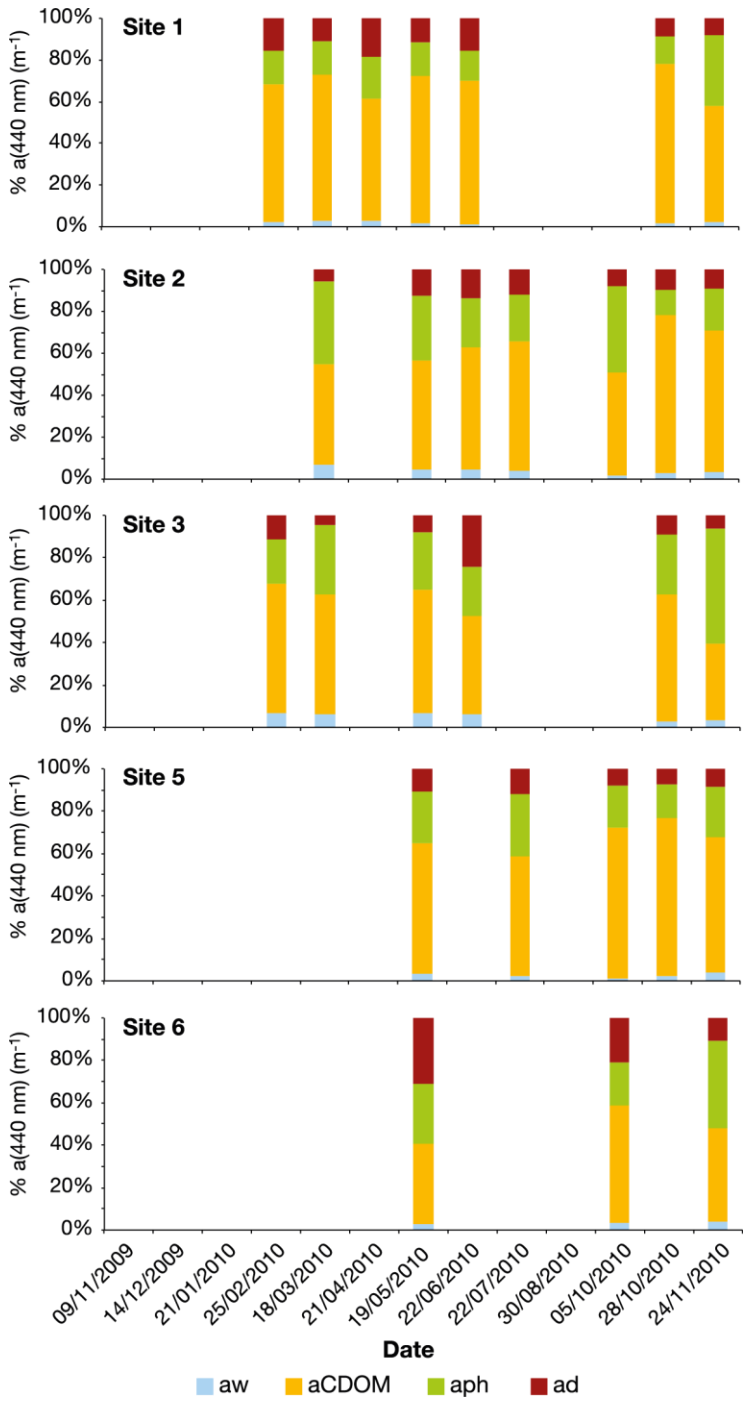


Figure 15: Percentage of the total absorption at 440 nm for each of the components – water, phytoplankton, detrital matter and CDOM for samples collected from five sites in Storm Bay. Abbreviations for colours are described in the text.

Data collected over the two-year Huon Estuary study (CSIRO, 2000) showed CDOM concentration to behave in a near-conservative manner, exhibiting a linear mixing plot with salinity. Although the salinity range in this study is quite narrow, compared to the range recorded in the Huon Estuary study, there is still a clear near conservative relationship between the $a_{CDOM}(440)$ values and the corresponding salinity recordings (Figure 16). This

relationship could be important in following the freshwater flow through Storm Bay by satellite remote sensing.

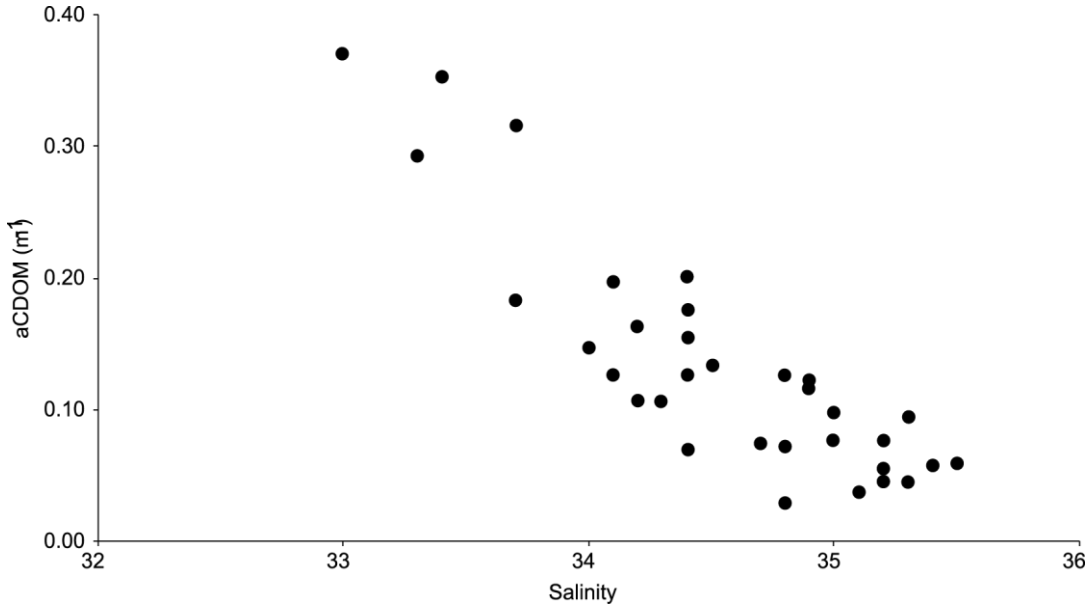


Figure 16: The absorption coefficients at 440 nm for CDOM plotted against salinity for the five sites sampled in Storm Bay.

In general, absorption due to detrital matter was the least dominant of the parameters that contribute to the total absorption (Figure 16). TSM values were generally quite low (<3 mg L^{-1}) except for the samples collected in November 2009 (Figure 17). However, the samples collected in November 2009 were collected from just below the surface of the water column whereas samples collected after November 2009 were collected from 1 m depth. Low values of TSM appear to be a feature of south-east Tasmanian waters. During the two-year Huon Estuary Study, TSM values rarely exceeded 6 mg L^{-1} throughout the entire estuary (CSIRO, 2000), and during a study of the Derwent River in 2008 TSM values ranged from 1.20 (mouth of the Derwent) to around 4.0 mg L^{-1} (around the Bowen Bridge). A further study in 2007 that collected samples from the D'Entrcasteaux Channel, Storm Bay and the east coast of Tasmania found TSM values to never exceed 3 mg L^{-1} and were generally <2 mg L^{-1}.

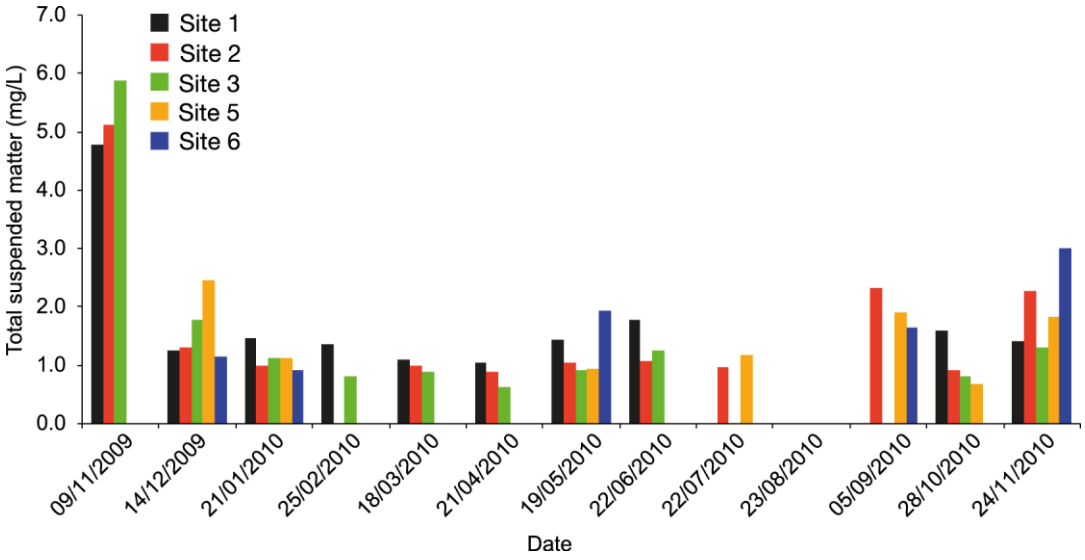


Figure 17: The TSM concentration for samples collected from five sites in Storm Bay.

When the TSM values from this study were further broken down to the organic and inorganic fractions, the organic fraction was the dominant fraction for 65% of the samples (Figure 18). This result compares favourably with the absorption coefficient data which suggests that absorption due to phytoplankton is generally more dominant than the absorption due to detrital matter.

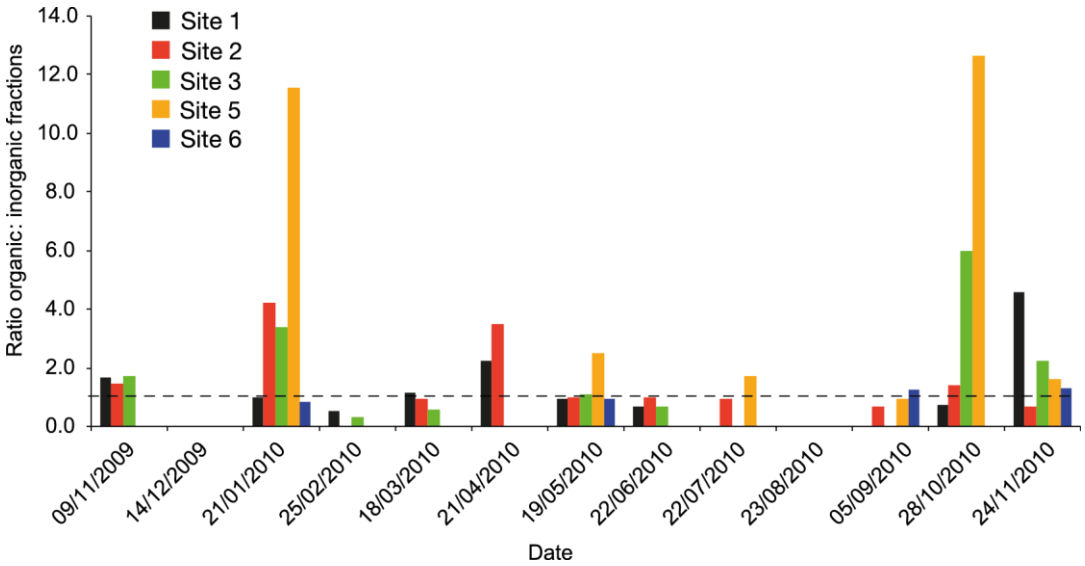


Figure 18: The ratio of the organic fraction to the inorganic fraction from the TSM samples collected from five sites in Storm Bay.

2.4 Phytoplankton biomass

Data from November to July for all sites (except site 4 which was dropped after sampling in November and December 2009) were pooled to examine 'annual' spatial patterns (Figure

19). The nearshore sites tended to have greater densities of phytoplankton. Diatoms were the dominant phytoplankton type at sites 1, 5 and 6; that is, the nearshore stations. *Noctiluca* was most abundant at site 1 followed by site 5 and rarely present at the other sites. Other dinoflagellates were less abundant overall than the other groups but showed similar patterns of abundance, declining with distance from shore.

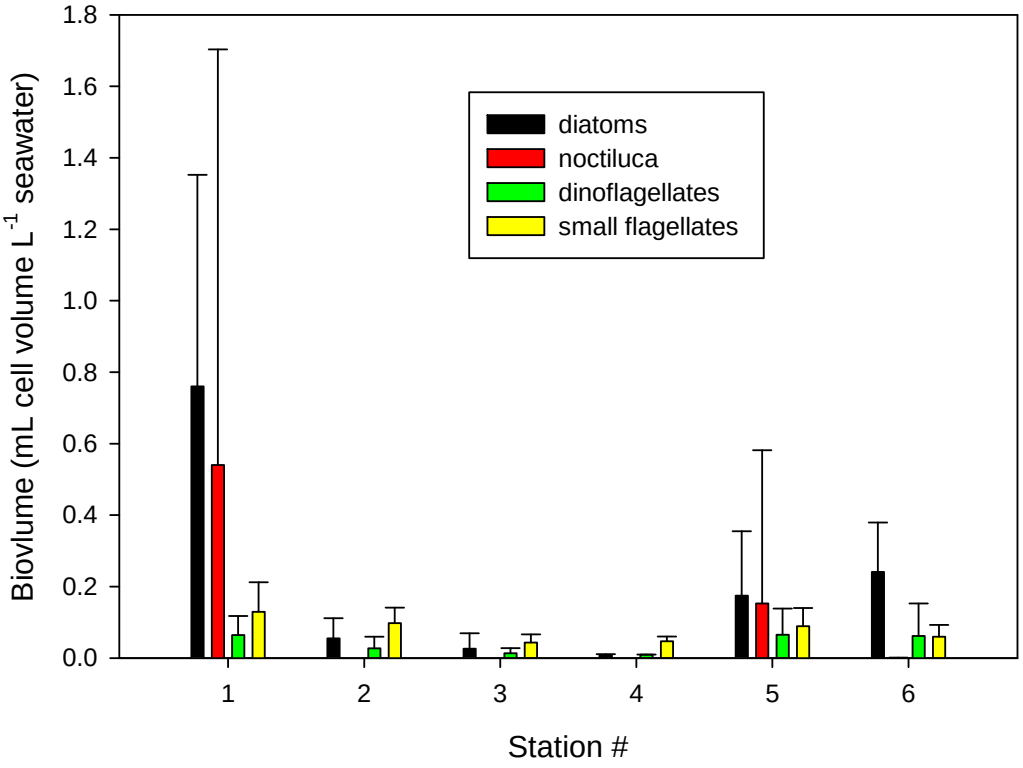


Figure 19: Averaged biomass of phytoplankton types at 6 sites in Storm Bay. See Table 1 and Figure 1 for locations. Note site 4 was only sampled twice.

Temporal trends in phytoplankton abundance were estimated for the entire study by averaging across all sites. If there was a spring bloom, we did not observe it when sampling in November 2009 (Figure 20). There was a substantial bloom of diatoms in January. At the same time the heterotrophic dinoflagellate *Noctiluca* also peaked, probably supported by the diatom bloom. There was another peak in diatoms in April and a subsequent peak in *Noctiluca* in May.

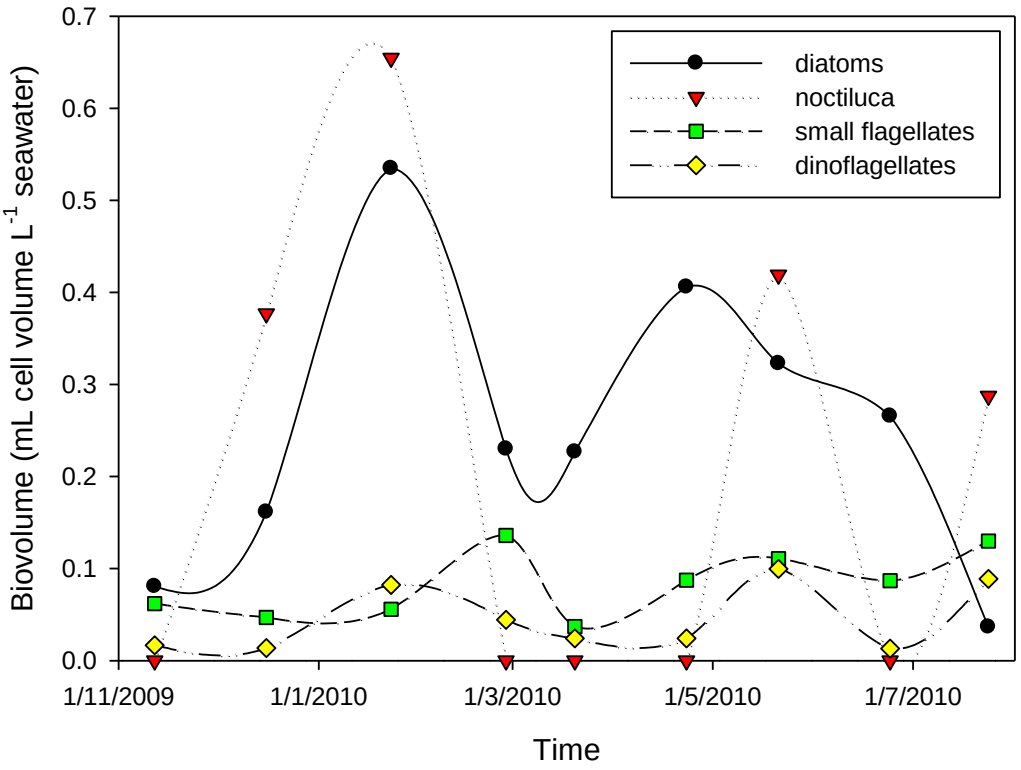


Figure 20: Temporal patterns of phytoplankton in Storm Bay.

2.5 Comparison of data over time

When the environmental data at site 2 from 2009–10 are compared with those collected by CSIRO in 1985–89 (Figure 21), the greatest difference is observed in phosphate concentrations. Phosphate was consistently lower in the monthly samplings of 2009–10 than in the late 80s. Chlorophyll *a* concentrations in 2010 were also generally amongst the lowest values that were recorded in 1985–89, except for September 2010. Salinity showed a trend of higher values in summer to early winter in 2010, suggesting an influx of EAC water during this time. Temperatures in autumn and early winter in 2010 were also amongst the highest values recorded during 1985–89. Nitrate concentrations showed similar seasonal patterns in the two sampling periods, with possibly the higher winter values lasting over a longer period of time in 2010 than in the 80s. However, further monthly sampling is required to provide the replication necessary for statistical comparisons.

When comparing results over time, there is a concern that the techniques and analytical equipment used will have changed so the results may not be directly comparable. However, one of the co-investigators in the current project, Lesley Clementson, conducted the nutrient analyses of the data from 1985–89. The flow injection technique she used was relatively new at the time and is still used today. The auto analyser type system that was used for the analyses in 2009–10 is probably capable of lower detection limits compared to those of the

1980s, but the levels recorded in Storm Bay are unlikely to show any difference. Chlorophyll *a* results, however, should be viewed with caution because both the extraction and analytical techniques differed between the two sampling periods.

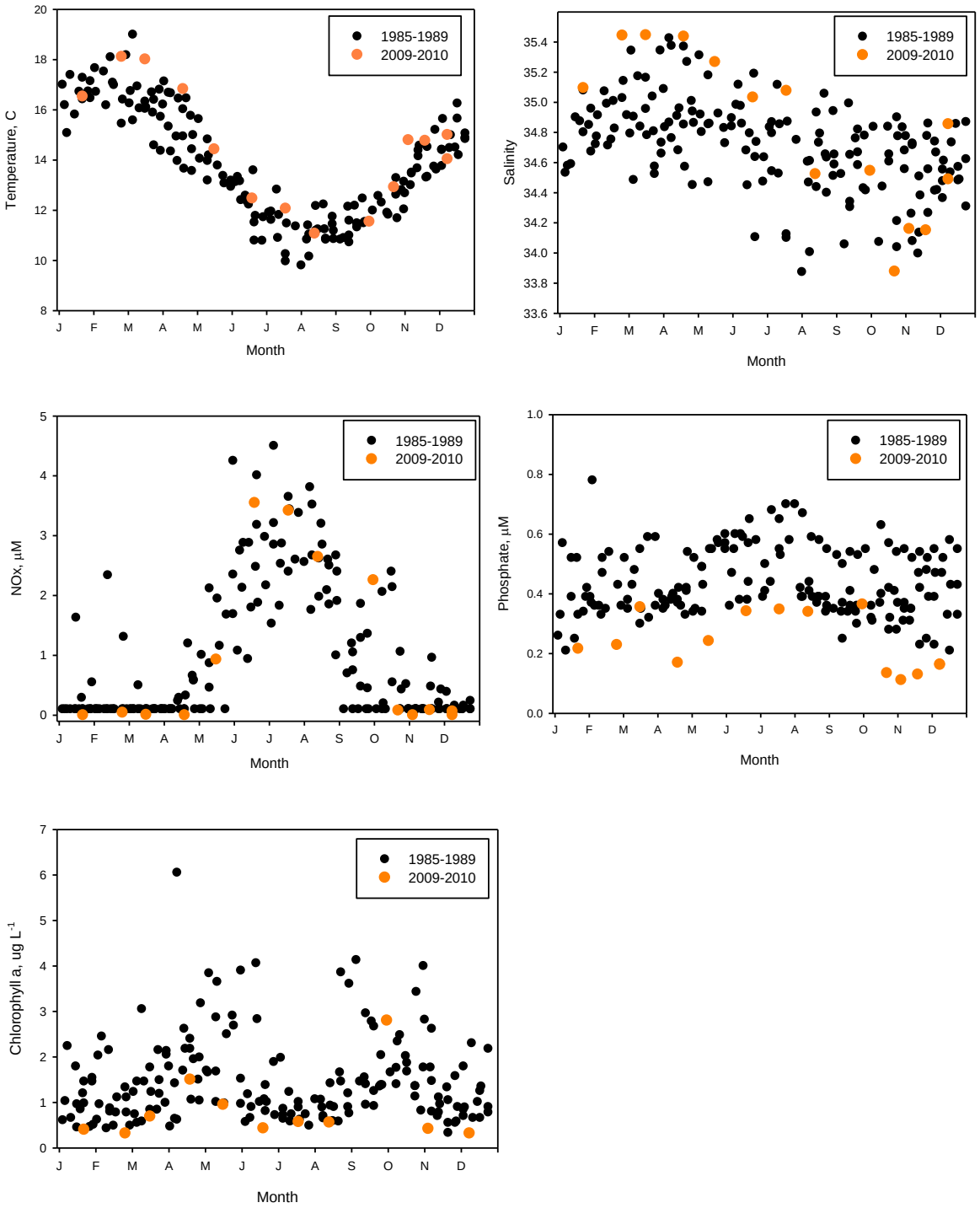


Figure 21: Comparison of nutrient and chlorophyll *a* data at site 2 collected by CSIRO in 1985–89 and in the current project 2009–10.

2.6 Additional use of the data

2.6.1 Biogeochemical modelling in the INFORMD region

Karen Wild-Allen and Jenny Skerratt, CSIRO

Data collected in the Storm Bay monitoring sites has been used to support the implementation of a high resolution 3D coupled hydrodynamic, sediment and biogeochemical model of South Eastern Tasmania (Figure 22).

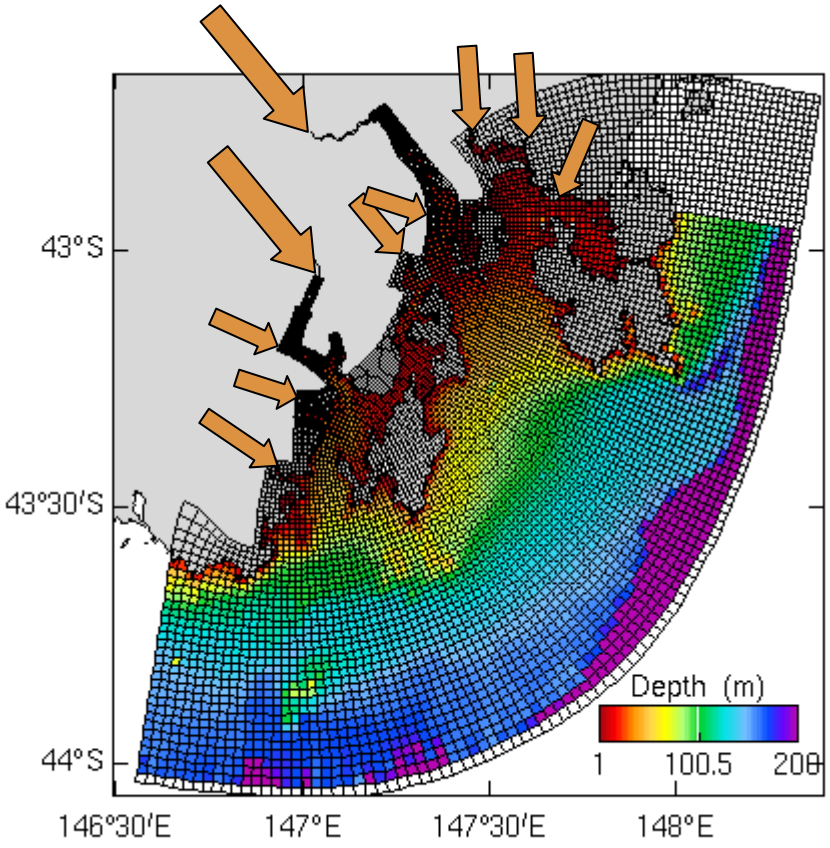
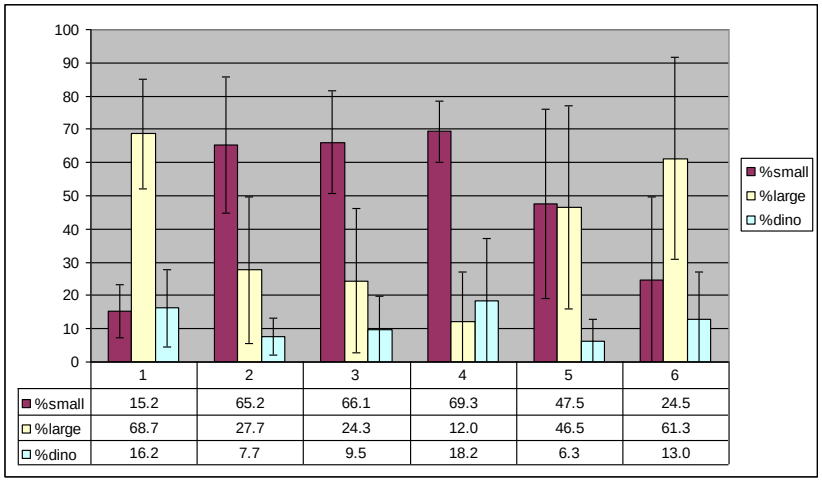


Figure 22: South-eastern Tasmania (SETAS) model grid and bathymetry with major river inputs indicated by arrows.

Forcing data required for model simulations includes meteorology, coastal inputs and ocean boundary information. The hydrodynamic model is nested in the large scale 'Bluelink' model and forced with meteorology fields from the ACCESS model and observed river flow. For the biogeochemical model coastal inputs are computed from observed nutrient and sediment loads in rivers and industry discharge data (Table 2).

BGC Input data	Site	Type	Done
Rivers	Derwent, Huon, Jordan, Esperance, Coal, NW Bay	DIP, NH4, NO3, PIP DOC,DOP,DON (Huon & Derwent only)	Huon & Derwent only
STP	17 STP's	DIP, NH4, NO3, Labile & Refractory Detritus	Y
Industry	29 Fish Farms	DIP, NH4, Labile Detritus	Y
Open boundary	Southwest, offshore, northeast	Phytoplankton biomass (small, large, dinos), NO3, DIP, Oxygen	Y

The offshore boundary is more difficult to constrain due to its long length and remote location. The Storm Bay sampling sites 3 and 4 collected monthly data in the outer reaches of the model domain. These data were especially useful for prescribing the composition of modelled phytoplankton along the open boundary (Figure 23).



	1	2	3	4	5	6
%small	15.2	65.2	66.1	69.3	47.5	24.5
%large	68.7	27.7	24.3	12.0	46.5	61.3
%dino	16.2	7.7	9.5	18.2	6.3	13.0

Figure 23: Observed phytoplankton biomass at Storm Bay sites 1–6. Note the dominance of small phytoplankton at sites 3 and 4 in the outer reaches of the model domain.

A time series of total phytoplankton biomass along the open boundary was estimated from remotely sensed chlorophyll concentrations (Figure 24) computed from MODIS imagery using a regional algorithm that distinguishes chlorophyll from CDOM (Schroeder et al., 2008). Total phytoplankton biomass was then proportioned into modelled small, large and dinoflagellate classes according to the mean observed ratio at sites 3 and 4 (Figure 23). The vertical profile assumed that phytoplankton were uniformly distributed throughout the surface to 30 m of water and had negligible concentration in deeper water.

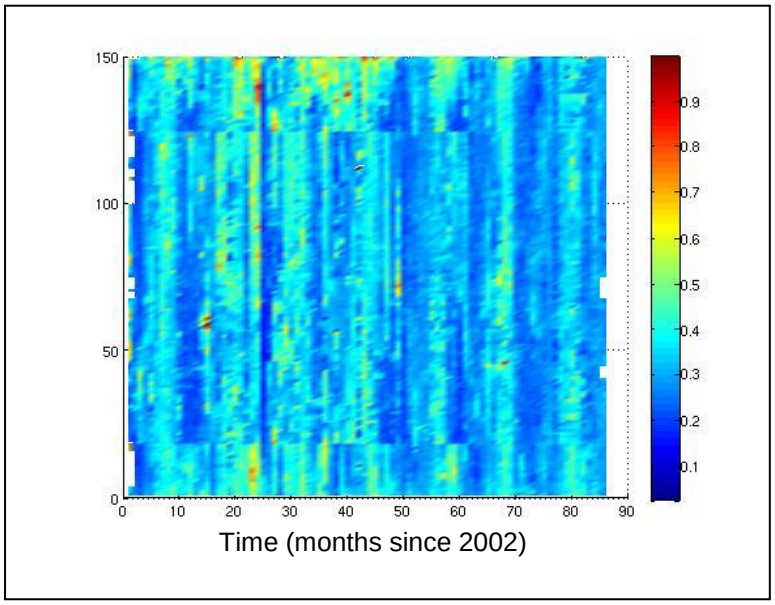


Figure 24: Time series of surface chlorophyll concentration derived from remotely sensed ocean colour imagery (MODIS + regional algorithm) for each grid cell (0-150) of the model boundary.

Nutrient concentrations at the modelled open boundary were estimated from a relationship computed from a time series deployment of an in-situ ultra violet spectrophotometer (ISUS) for the determination of nitrate. The ISUS was deployed on a benthic lander at 50 m at Storm Bay site 2 for a period of three months and the continuous nitrate record was calibrated against monthly samples (Figure 25).

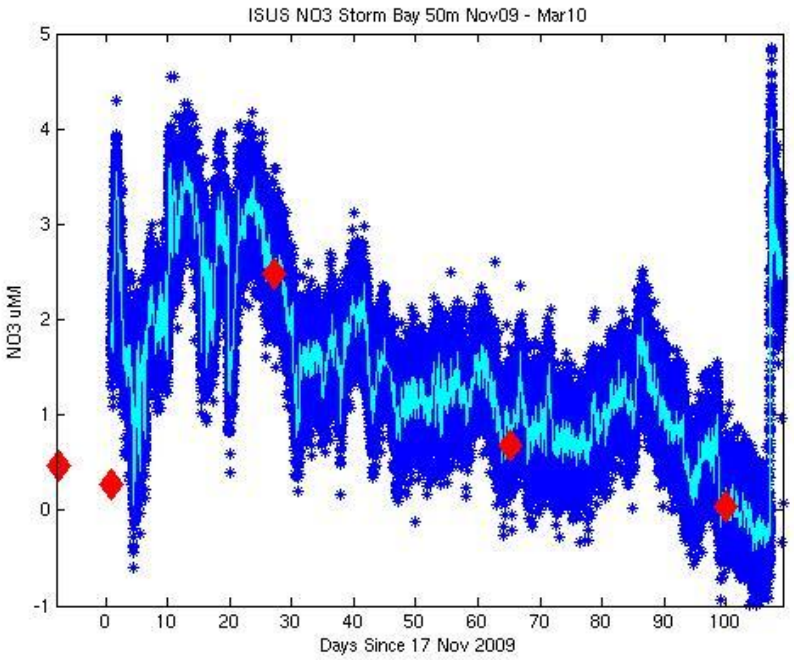
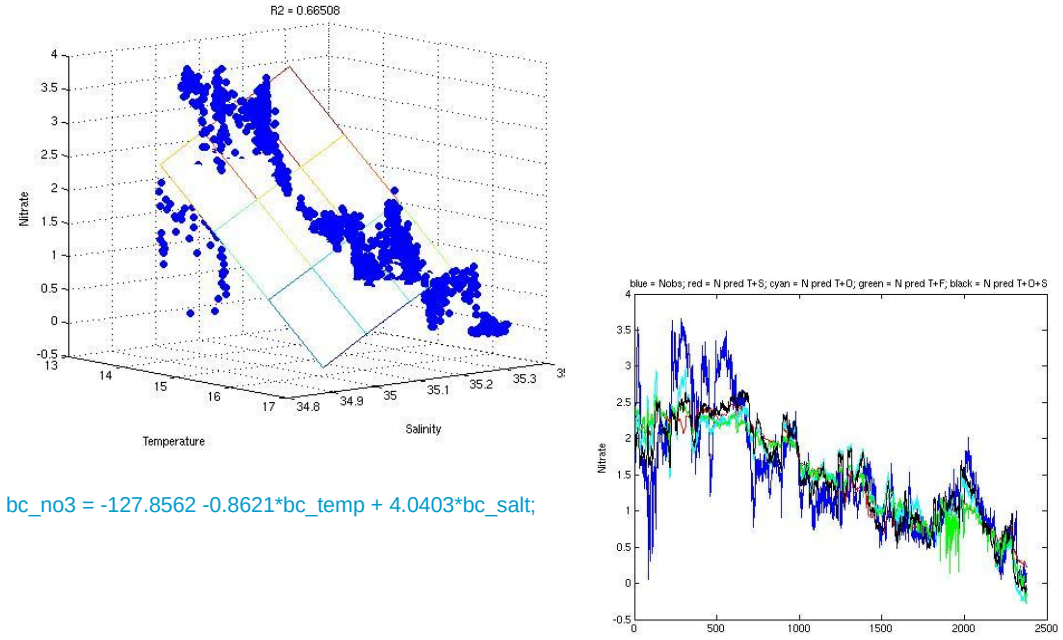


Figure 25: Continuous nitrate recorded with an ISUS sensor in 50 m of water at Storm Bay site 2. Monthly samples used to calibrate the record are shown in red.

Multiple linear regression showed that nitrate could be estimated from temperature and salinity with an R2 of 0.66 (Figure 26). This suggests that deep water nitrate concentrations in Storm Bay are related to the character of the water mass intruding onto the shelf. The computed relationship was generalised along the modelled open boundary estimate of the 3D temporally varying nitrate field coincident with temperature and salinity. Dissolved oxygen concentrations were estimated similarly and phosphate was inferred from Redfield ratio.



bc_no3 = -127.8562 -0.8621*bc_temp + 4.0403*bc_salt;

Figure 26: Multiple linear regression of nitrate on temperature and salinity (left). Time series of predicted nitrate (coloured) compared with observed nitrate (blue) (right).

The final biogeochemical model open boundary condition was prescribed as an upstream condition which only influenced water advected into the model domain; water leaving the model grid retained its derived concentration.

With the support of the Storm Bay sampling program, the open boundary of the SETAS biogeochemical model has been constrained sufficiently to allow a hindcast simulation of 14 months and an ongoing pilot near real time simulation. In the coming year these simulations will be validated against in situ data to confirm that the model captures the essential seasonal dynamics of south-east Tasmanian coastal waters. We look forward to using the Storm Bay sampling data to assist in this model validation exercise, thereby supporting the further application of these models to address science questions and management issues.

2.6.2 Changes in the size and biomass of the dominant krill *Nyctiphanes australis* in Storm Bay

Kate Picone and Kerrie Swadling, IMAS

The krill *Nyctiphanes australis* (Crustacea: Euphausiacea) is a key species in the pelagic food webs of the coastal waters of south-eastern Australia and southern New Zealand. Several predators take advantage of the high abundance and productivity of *Nyctiphanes australis* and feed on this species almost exclusively; e.g. muttonbirds (*Puffinus tenuirostris*), Australian salmon (*Arripis trutta*), barracouta (*Leionura atun*), jack mackerel (*Trachurus declivis*) and pigmy blue whale (*Balaenoptera musculus*). Observations have suggested that this krill species is in decline in eastern Tasmania, and this decrease in productivity has previously been linked to the collapse of a successful jack mackerel fishery in Tasmania (Young et al., 1996).

This component of the larger Storm Bay project provided a unique opportunity to compare data from 2009–10 to a comparable study conducted over 30 years ago. In late 1979 to early 1981 Graham Hosie sampled monthly throughout Storm Bay to examine the biology and the production of *Nyctiphanes australis*. Here we compare the abundance and biomass of krill communities sampled in Storm Bay in 2009–10 with those sampled in 1979–1981, and infer reasons for observed differences between the two sampling periods.

Sampling and laboratory methods

Zooplankton samples were obtained by the use of a 0.75 m diameter bongo net with 100 µm mesh size, vertically hauled through the water from a stationary vessel. Each haul sampled the entire water column to within 2 m of the bottom and returned two replicates. A General Oceanics flow meter was fitted in the mouth of one of the nets, which recorded the volume of seawater filtered. The zooplankton caught in each mesh net were concentrated in ~750 mL of seawater and anaesthetised with soda water. Upon return to the IMAS laboratory the samples were preserved with borax-buffered 4% formaldehyde.

Only samples from summer and spring when krill are most common in the water column have been analysed. Under a dissecting microscope, *Nyctiphanes australis* specimens were separated from the bulk of the zooplankton, and identified by life stage according to Hosie (1982), Baker et al. (1990) and Kirkwood (1984). Individuals were termed adults when no telson spines were present. Ten randomly selected individuals of each stage were selected and measurements were taken via ocular micrometre, according to Ritz and Hosie (1982), from the rostrum to the terminal spine.

Results and discussion

The abundance and biomass of *Nyctiphanes australis* found in Hosie (1982) and in the present study is shown in Figure 27 as a comparison. Hosie's data have high variation between the years, and abundance data from 2009–10 are comparable to Hosie's sampling in early 1981, but not to 1979 or early 1980. Biomass levels obtained in 1979–81 are, however, consistently higher than those obtained in 2009–10. All results, excluding December and February are approximately 5000 µg (5 mg) higher in the earlier study compared to 2009–10. A large portion of this difference may be due to the differences in size of each life stage (Table 3), where the earlier study found each life stage to be larger, or with a higher maximum limit to the range, particularly the adult specimens. The average length of juvenile krill had decreased by an average of 8% and adults by 18% since similar collections in the early 1980s (Ritz and Hosie, 1982). These observations, coupled with a predicted 2–3°C increase in seawater temperature in our region over the coming decades (IPCC, 2001), suggest that *Nyctiphanes australis* is in danger of declining dramatically, which will have ramifications further up the food web.

Table 3: The range of lengths (mm) observed in each life stage from Hosie (1982) and the current study (n=10).

	Length (mm)	
Stage	'79/'80/'81	'09/'10
Metanauplius	0.45 – 0.80	0.30 – 0.60
Calyptopis 1	0.80 – 1.28	0.85 – 1.20
Calyptopis 2	1.5 – 1.98	1.40 – 1.70
Calyptopis 3	1.5 – 2.55	1.65 – 1.95
Furcilia 1	1.82 – 3.43	2.05 – 2.75
Furcilia 2	2.25 – 4.55	2.25 – 3.25
Furcilia 3	3.18 – 6.60	3.20 – 4.20
Furcilia 4	4.75 – 11.63	3.95 – 4.20
Furcilia 5	4.75 – 11.63	4.00 – 4.30
Furcilia 6	4.75 – 11.63	4.35 – 4.70
Adult	11.00 – 20.75	7.10 – 13.90

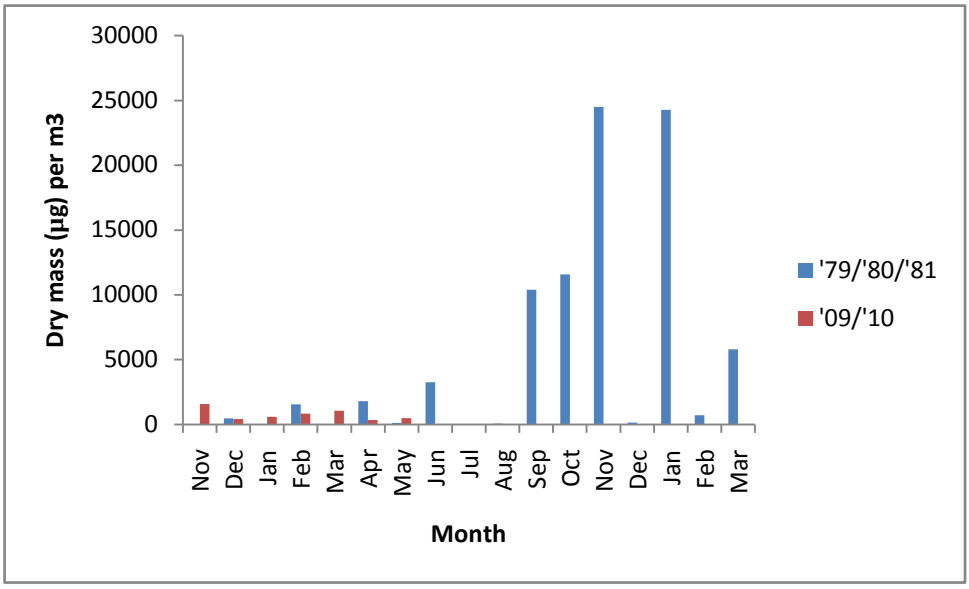


Figure 27: Abundance (top) and biomass (bottom) of krill collected during the two sampling periods December 1979 to March 1981, and November 2009 to May 2010.

The abundance of *Nyctiphanes australis* in 1979–81 had considerable inter-annual variation. The current study did not pick up this variation due to the timeframe of sampling. The interesting component of this comparison is the large decrease in biomass found in the current study. As abundances in total are comparatively similar in both studies, this suggests that the difference in biomass is due to smaller life stages dominating the communities, or that the individuals of the same life stage are, on average, smaller. Either scenario is plausible.

When considering why each life stage exists at a smaller size in the current study, it is interesting to note that the sea surface temperatures were higher in 2009–10 than in 1979–81.

In every ecosystem there will be inter-annual variation in environmental data, the abundance of individuals and the composition of the community. This has been seen in Storm Bay. Harris et al. (1991) found that in 1985–86 *Nyctiphanes australis* dominated the zooplankton community of Storm Bay; in 1986–87, salp species dominated the community; in 1987–88 both species were present at lower abundances; and in 1988–89 neither *Nyctiphanes australis* nor salps were the dominant species. This highlights the importance of long-term data sets. From this study it cannot be concluded beyond doubt that a decrease in *Nyctiphanes australis* abundance or biomass had occurred in Storm Bay since 1980, as we cannot state that 2009–10 was a 'normal' year.

This inter-annual variation is brought about by the influences of differing water masses around Storm Bay. For example, when the East Australian Current extends southwards, and Storm Bay receives nutrient-poor subtropical waters, the production of the whole ecosystem is decreased (Young et al., 1993). However, when subantarctic water penetrates northwards, cool nutrient-rich waters are brought to Storm Bay, resulting in a bloom of salps (Harris et

al., 1991), which with quicker reproduction times have the ability to outcompete *Nyctiphanes australis* for the nutrients. This highlights how sensitive the system is as the community composition can readily change from one year to the next.

To further determine the difference in the *Nyctiphanes australis* communities from 1980 to 2010, the timeframe of the current study needs to be increased to provide more information on inter-annual variation. This study is important in order to understand the potential changes to community structure that may occur as a result of natural variation and human induced changes in the environment. Krill are a key species in the local marine environment and any changes in the krill population are likely to affect higher trophic levels and possibly important fisheries.

Benefits and adoption

A major benefit of this project is providing actual data on climate variability in the local Storm Bay area. Although only 12 months of data are available, the study provides important information on current water quality and productivity, which has enabled a preliminary comparison with environmental data collected over two decades ago. It also provides a baseline of data for future comparisons. It is hoped that these data will assist to raise industry and community awareness of climate change issues.

This project has developed procedures and techniques for investigating and assessing water quality nutrient and productivity data from Storm Bay, which will be used for further monitoring and evaluation. The results from 12 months' sampling identify the need for continued sampling to increase the replication and to assess whether unusual results are due to one-off events or are part of the changing climatic conditions.

The results are also beneficial to the salmon aquaculture industry which is exploring options of expansion into Storm Bay. This baseline data on nutrient concentrations and patterns of water circulation before any farming activity occurs provides dual benefits to industry and government: i) increased environmental knowledge of sites in Storm Bay already identified by industry as potential new farm locations, and ii) baseline data before farming commences to enable more accurate analysis of environmental effects (or not) of any farms in the future.

An additional benefit of this project was the collaboration between scientists at TAFI (IMAS) and CSIRO, including sharing of expertise and collection of field samples, nutrient and productivity analyses, and data analyses. The data collected as part of this project have also been used in other CSIRO projects to validate environmental data collected by a range of new sophisticated equipment, including gliders and moored nitrate recorders.

The results of this 12-month study are currently being made available to industry and government through presentations and circulation of the results.

Further development

Another 12 months of monthly sampling is planned using funds received from the Winifred Violet Scott Charitable Trust. These data will enable a more rigorous assessment of changes in environmental conditions of Storm Bay from the 1980s to the present time. The data being collected will also be compared with water quality data collected at the mouth of the Derwent by the Derwent Estuary Program and in the Huon estuary and D'Entrecasteaux Channel as part of salmon farm monitoring since the mid 1990s. The Storm Bay data will also be evaluated against data from the CSIRO long-term monitoring site at Maria Island to

investigate whether similar trends in changing environmental conditions over decadal time scales are apparent.

Comprehensive sampling of the zooplankton community has been underway since the beginning of this project. Zooplankton (particularly krill, large copepods and salps) represent a major energy link between phytoplankton and higher order consumers such as fish. Climate-related and other changes to the Storm Bay ecosystem will influence both the abundance and community structure of zooplankton, which will have important ramifications for fisheries. To understand fully the fate of nutrients and primary production in Storm Bay, it is essential that zooplankton are assessed, and this aspect will form a fundamental component of the Storm Bay research program into the future. Some of the zooplankton samples have been sorted and analysed, but this work is not complete. A PhD student working on the zooplankton of Storm Bay commenced in April 2010.

This study has provided a 13-month set of baseline environmental data for Storm Bay that is relevant to fisheries, salmon aquaculture industry and coastal development. The project to date has indicated a considerable degree of spatial variability in environmental factors, which needs to be explored further before reaching conclusions about the trends observed in Storm Bay. Some important areas for further development are summarised below.

- There were indications that the seawater near Wedge Bay (site 5) experiences significant freshwater influence, and that nutrient loadings in bottom waters are occasionally higher than in other parts of the bay. Continued monitoring at the Wedge Bay site will improve our knowledge of water movements in the area, which is essential before establishing large-scale aquaculture in the region.

- A preliminary comparison between the 1985–89 and 2009–10 data has hinted at increasing salinity during autumn and early winter, increasing temperature in the summer months, lower phosphate and relatively stable nitrate. However, it is impossible to assess the meaning of these trends on the time span of one year. Only with continued sampling will the underlying mechanisms become clear.

- Chlorophyll *a* provides a measure of phytoplankton standing stock only. At present there is some indication of an overall decrease in chlorophyll *a*; however, to understand phytoplankton dynamics more fully it would be conducive to combine phytoplankton abundance data with measurements of primary productivity. The structure of the sampling program is such that traditional in situ measurements of primary productivity (e.g. ^{14}C uptake) cannot be routinely undertaken. An alternative is to use and expand the collection of dissolved oxygen concentrations.

- The development of coupled biogeochemical, sediment and hydrodynamical models for Storm Bay is a major step to understanding the circulation and productivity in the whole region. Future sampling at our sites is necessary for the continued refinement

and validation of the models. Water quality data over the coming year from the Storm Bay sampling program will be used in the SETAS biogeochemical model to validate simulations against in situ data to confirm that the model captures the essential seasonal dynamics of south-east Tasmanian coastal waters.

- It is indicated that the EAC is having a longer and more pronounced influence, meaning that warmer, saltier, low nutrient water is circulating into Storm Bay. Understanding the influences of major water masses (East Australia Current, subantarctic bottom water, Leeuwin/Zeehan Current) in the Storm Bay ecosystem is critical to improving our prediction of how climate change will impact on the system.

Planned outcomes

This project has achieved the planned outputs of establishing a monitoring program and providing one year of environmental data on water quality and primary productivity in Storm Bay. Continuity of this data will underpin sustainable development of marine industries in the region.

This environmental information supports the planned outcome of improved fisheries assessments in southern Tasmania for managers and industry by providing the initial data to commence an assessment of whether fisheries production is linked to climate variability (short-term – prediction of catches over 1–5 years), and to improved climate change adaptive management strategies through an improved understanding of long-term impacts (10–70 years) on commercially and recreationally harvested species in southern Tasmania.

The project has also assisted nutrient and algal characterisation of Storm Bay to support planning for finfish aquaculture in the region. It has provided baseline data before farming commences, information to support site selection and data for projects modelling the bay's carrying capacity for marine farming.

Conclusions

This project has established a baseline assessment program for water quality and productivity in Storm Bay, and collected environmental data monthly for 12 months. These data are important towards understanding climate variability and assessing the longer term impacts of climate change in the region. As a consequence, the data will underpin more knowledgeable management of marine resources by fishers and managers.

A comparison of the preliminary environmental data collected in 2010 with data collected by CSIRO at the same site in Storm Bay in 1985–89 indicates that salinities tend to be higher now in autumn and early winter compared with over two decades ago, and temperatures

now are tending towards the higher values of 1985–89. For most of 2010, phosphate are clearly lower than 1985–80, whereas nitrates are generally similar, although they indicate a pattern of higher winter values over an extended winter period. Chlorophyll *a* values in 2010 were mostly lower than in the 1980s, implying lower productivity; however, the results must be assessed with caution because different extraction and analytical techniques were used for chlorophyll *a* assessments in the two time periods. These preliminary data indicate that changes are occurring and if the indications of lower productivity are correct then a reduction in fishery output can be expected. However, additional monthly data are required to determine whether change is long term or is merely inter-annual variability, and to provide the replication necessary for statistical analysis. Monthly sampling is currently funded for another 12 months.

Results from the two sites close to shore – sites 5 and 6 – which have been identified by industry as potential sites for expansion of salmon aquaculture, indicate that site 6 is largely marine influenced whereas site 5 showed greater influence of freshwater flow from the Derwent River. Site 5 also had unusual stratification of temperature and salinity which is possibly due to a deep hole found near the sampling site. This suggests that site 5 in particular should be assessed in more detail before large scale development of salmon aquaculture in the region.

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Appendix 1 Intellectual Property

There are no intellectual issues associated with the project.

Appendix 2 Staff

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TAFI: Lisette Robertson, Andrew Pender, John Keane

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