CAWTHRON

The Quantity And Quality Of Suspended Particulate Material Of Near-Bottom Waters In The Motueka River Plume, Tasman Bay

Cawthron Report No. 1114

April 2006

CAWTHRON

The Quantity And Quality Of Suspended Particulate Material Of Near-Bottom Waters In The Motueka River Plume, Tasman Bay

Paul Gillespie
Lesley Rhodes

Prepared for
Stakeholders of the
Motueka Integrated Catchment Management Programme

Cawthron Institute
98 Halifax Street East, Private Bag 2,
Nelson, New Zealand.
Ph. +64 3 548 2319,
Fax. + 64 3 546 9464
www.cawthron.org.nz

Reviewed by: Grant Hopkins

Approved for release by: Rowan Strickland

Recommended citation:

Gillespie, P; Rhodes, L. 2006. The Quantity and Quality of Suspended Particulate Material of Near-Bottom Waters in the Motueka River Outwelling Plume, Tasman Bay. Prepared for Stakeholders of the Motueka Integrated Catchment Management Programme. Cawthron Report No. 1114. 28p.

PREFACE

An ongoing report series, covering coastal-sea components of the Motueka Integrated Catchment Management (ICM) Programme, has been initiated in order to present preliminary research findings directly to key stakeholders. The intention is that the data, with brief interpretation, can be used by coastal managers, environmental groups and users of coastal marine resources to address specific questions that may require urgent attention or may fall outside the scope of ICM research objectives. We anticipate that providing access to marine environmental data will foster a collaborative problem-solving approach through the sharing of both ICM and privately collected information. Where appropriate, the information will also be presented to stakeholders through follow-up meetings designed to encourage feedback, discussion and coordination of research objectives.

EXECUTIVE SUMMARY

Background

The information provided in this report was collected as part of a collaborative research effort called the Motueka Integrated Catchment Management (ICM) programme. The programme was designed to assess the effects of various land use practices on terrestrial, freshwater and marine ecosystems in a "ridge top to the sea" approach. One component of a Cawthron investigation into the effects of freshwater inflow quantity and quality on the productivity of the marine receiving environment is presented here.

Study objective

The present report describes the results of two detailed investigations of the quantity and quality of near-bottom (N-B) suspended particulate material (SPM) and related water column characteristics at a single location in western Tasman Bay that is influenced by the Motueka River outwelling plume. Results were interpreted with reference to the simultaneous investigation of scallop (*Pecten novaezelandiae*) feeding characteristics in order to assess the potential impact of high N-B suspended sediment loads on the nutritional quality of the feeding environment for benthic shellfish.

Overview of results and conclusions

In situ measurements taken over the experimental periods (23-25 February and 24-25 November 1999) indicated that major short-term fluctuations in turbidity can occur within the seawater layer approximately 0.5 m above the seabed in the region affected by the Motueka River outwelling plume. The observed near-bottom high turbidity (N-BHT) layer was a persistent, although fluctuating, feature at the site during the February sampling period. Although a single turbidity peak was observed during the November sampling period, it was short term, possibly due to an influx of low-turbidity oceanic waters. Suspended particulate materials 50 mm above the seabed were comprised largely of inorganic sediments and were therefore of poor nutritional quality for benthic suspension-feeding bivalves. Higher proportions of microalgae and/or other organic materials were present in water layers > 0.5 m above the seabed. The feeding activity of scallops on the seabed appeared to be temporarily disrupted in the presence of the N-BHT layer while those hung in water layers > 0.5 m above the seabed continued to feed normally.

During the February experimental period, the primary food component for scallops was the bloom-forming dinoflagellate, *Prorocentrum balticum*, while during the November sampling, benthic diatoms were proportionally more important than phytoplankton. During February, the phytoplankton bloom might have been expected to provide a significant boost to shellfish growth and condition however this was nullified in the benthic (N-B) feeding environment by the high proportion of inorganic sediment particles. The development and persistence of the N-B turbidity layer could theoretically result in serious stress to benthic bivalves or even large-scale mortality. Juvenile shellfish (including those that drop off commercial spat collection structures) would likely be particularly susceptible to such effects due to their lower energy reserves. This has implications regarding the need for imposing requirements for remedial

clean-up dredging beneath spat-catching structures. Further dredging for this reason may, in fact, exacerbate the N-B turbidity effects. Our results also emphasise the importance of considering the condition/stability of the sediment/water boundary layer before scheduling scallop seeding procedures in the vicinity of the Motueka river plume and/or (potentially) other coastal regions.

The origin of the fine particulate materials comprising the N-BHT layer is thought to be flood-related discharges from the Motueka River catchment. The long term persistence of the N-BHT layer, however, appeared to be the result of recurring tidal re-suspension of the fine particulates from the seabed. Although the N-BHT layer observed here is primarily a natural feature of the Motueka outwelling plume, it may be considerably exacerbated to create a chronic (longer term) phenomenon by repeated physical disturbances of the seabed (*e.g*. due to dredging and trawling activities) that compromise the integrity of the sediment-water interface.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

TECHNICAL TERMS

Phytoplankton (or planktonic microalgae)- single-celled plants that live and grow while suspended in the water column.

Benthic microalgae- single-celled microscopic plants (mainly diatoms) that live and grow on the seabed.

Dinoflagellates- a very diverse group of planktonic and benthic microalgae. Many of the toxin-producing species of phytoplankton are within this group.

Chlorophyll *a* (chl *a*)- the primary photosynthetic pigment for green plants. It can be used as a relative estimate of the biomass (dry weight or carbon content) of microalgae in a water or sediment sample.

Fluorescence- Chl *a* can be estimated by measuring the amount of light emitted by living phytoplankton cells that are exposed to a beam of artificial light. This emission is called fluorescence and can be measured by lowering a submersible detector over the side of a boat. The fluorescence readings then need to be calibrated using normal laboratory analytical techniques.

SPM (or suspended particulate material)- organic and/or inorganic particles that are suspended in the water column. It comprises the food supply for filter-feeding shellfish and can vary in composition and nutritional value.

SS (or suspended solids)- the analytical term often used in place of SPM. It is generally described as the total suspended solids (TSS), which includes both the organic and inorganic fractions, and the volatile suspended sediments (VSS), which includes only the organic fraction.

CTD- submersible sensor array/data logger that measures conductivity (from which salinity is calculated), temperature and depth simultaneously in seawater.
psu (or practical salinity units)- units based on conductivity characteristics and are equivalent to parts per thousand (‰). Freshwater would be expected to have a salinity of 0 psu while full seawater would be approximately 35 psu.

Transmissometer- Instrument for measuring the passage of light through water. The % transmission of light is one of a number of ways of assessing the turbidity of water. A beam of light of known intensity is directed through a section of water of known length and the percentage of light passing through the section to a detector (the % transmission) is determined. The lower the % transmission readings the higher the turbidity.

1. INTRODUCTION

1.1. Background

The information provided in this report has been collated and interpreted as part of a collaborative research effort called the Motueka Integrated Catchment Management (ICM) programme. Refer to Basher (2003) for a description of the programme structure and rationale. The programme was designed to assess the effects of various land use practices on terrestrial, freshwater and marine ecosystems in a "ridge top to the sea" approach.

As part of a Cawthron Institute (Cawthron) investigation into the effects of freshwater inflow quantity and quality on the productivity of the marine receiving environment, the data from a series of spatial surveys of the nutrient, chlorophyll *a* (chl *a*) and density structure of the water column in Tasman Bay were reviewed (Gillespie 2003, MacKenzie *et al*. 2003a and b). Although the surveys were carried out under various conditions of river flow, further, more spatially focused surveys within an area previously shown to be affected by the Motueka River outwelling plume (Tuckey *et al*. in press.) were required in order to evaluate the potential effects of particular climatic events (*e.g*. periods of unusually high rainfall/river flow). In particular, a better understanding was required of the effects of such events on the near-bottom waters that provide the living and feeding environment for benthic suspension-feeding shellfish.

The present report describes the results of two detailed investigations of the quantity and quality of near-bottom (N-B) suspended particulate material (SPM) and related water column characteristics at a single location in Tasman Bay. Results were interpreted with reference to a simultaneous investigation of scallop (*Pecten novaezelandiae*) feeding characteristics in order to assess the potential impact of high N-B suspended sediment loads on the nutritional quality of the feeding environment for benthic shellfish. Although the data set is historical, it is of particular relevance at the present time do to questions arising concerning recent declines in annual scallop harvests and proposed aquaculture developments in Tasman Bay.

1.2. Study Area

Tasman Bay is located at the northern end of the South Island of New Zealand (Figure 1). It is a large, relatively shallow embayment covering a primarily soft-sediment seabed habitat. Along with Golden Bay to the northwest and the Marlborough Sounds to the east, it comprises the area of New Zealand's major scallop (*Pecten novaezelandiae*) fishery. Natural populations of scallops are 'enhanced' by the collection of spat for reseeding of harvested areas. A rotational harvesting schedule is maintained with approximately three-year intervals for maturation of reseeded stock, however natural spatfall events can result in a more complex harvest schedule. In spite of careful management of the scallop resource, considerable inter-annual and regional variation occurs in scallop survival, growth and condition. Scallop harvests from Tasman Bay, which surpassed 500 tonnes per annum during the 1993/94 season, have seriously declined during more recent years (R. Mincher, CSECo, pers. com.). It has been suggested that variation in the quantity and quality of suspended particulate material

(SPM) available for benthic suspension feeders, such as scallops, may be a major contributing factor (Gillespie 1997).

Tasman District Council have designated aquaculture management areas (AMAs) in Tasman Bay for the longline culture of GreenshellTM mussel (*Perna canaliculus*) and the collection of both mussel and scallop spat. The AMAs, covering a total of approximately 4200 ha, consist of three separate zones on the western side of the Bay (Figure 1). The central zone is located about 5 km offshore from the mouth of the Motueka River, the largest freshwater tributary of the Bay (mean flow at Woodmans bend ~68 m3 s^{-1}). Parts of the AMA are presently being used for the seasonal collection of mussel and/or scallop spat and staged development of the remaining areas for mussel on-growing is planned pending resource consents and Ministry of Fisheries permits. Considerable uncertainty exists, however, regarding the productive potential of the site and the possible effects of catchment runoff within the Motueka River outwelling plume.

2. METHODS

2.1. Study Site

Two 24-hour investigations (24-25 February and 24-25 November 1999) were carried out at a single site (Site E1) in Tasman Bay. The site (depth ~23 m at mid tide) is located ~ 9 km offshore from the mouth of the Motueka River (Figure 1) within an area known to be influenced by the river outwelling plume (Tuckey *et al*. 2006). Daily mean flows of the Motueka River at Woodstock (July 1998 through December 1999) are shown in Figure 2.

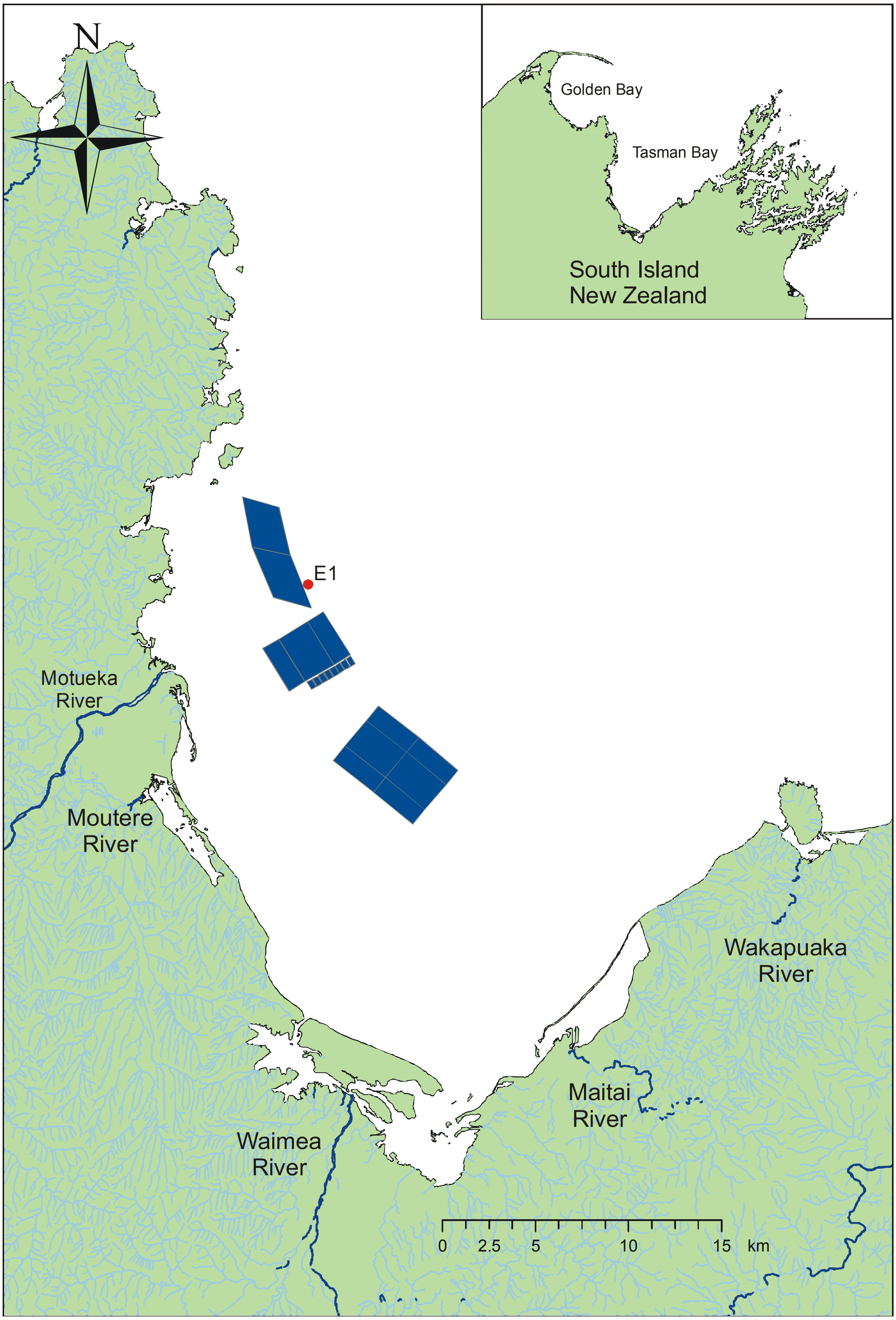


Figure 1. Study location diagram. Blue boxes are designated aquaculture management areas (AMA)s.

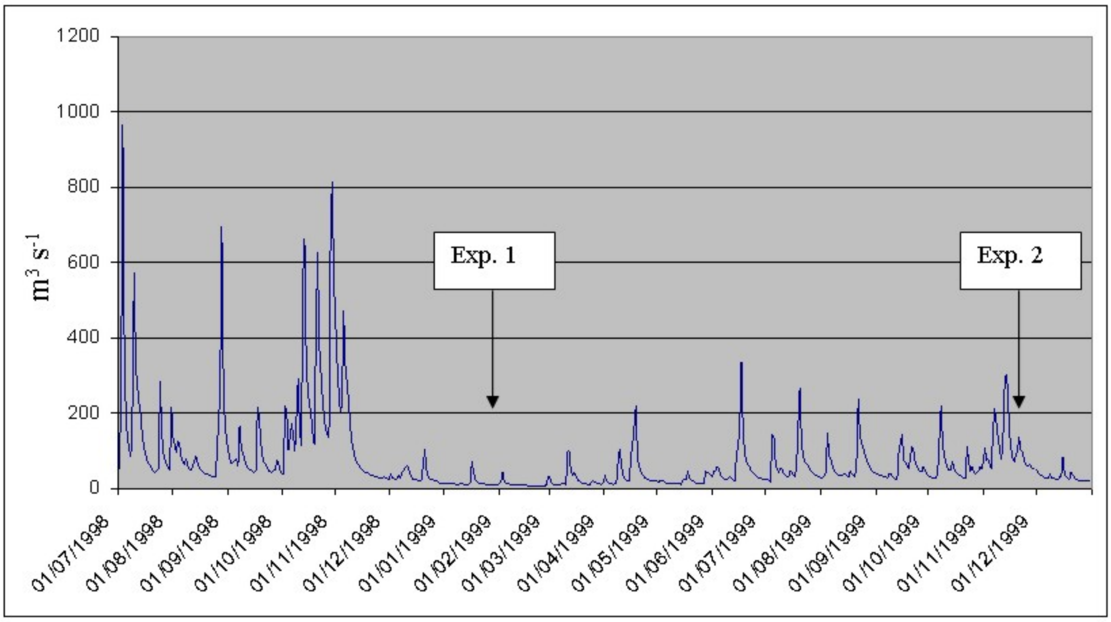


Figure 2. Daily mean flows of the Motueka River at Woodstock, 1998-1999.

2.2. Sampling design and field analyses

Field investigations were carried out aboard the Challenger Scallop Enhancement Company vessel, Tasman Challenger, anchored approximately 200 m off site. Although the methods used were similar on both occasions, difficulties with weather during the November study resulted in sampling limitations. A diagrammatic representation of the field deployment array is shown in Figure 3.

2.2.1. *In situ data and sample collection*

Current velocity and direction were recorded at the site using an Inter Ocean Systems Model S4 electromagnetic meter deployed 0.5 m above the seabed prior to each experiment. A Chelsea Aquapak CTD (conductivity, temperature, depth) profiler with additional fluorometric (chl *a*) and turbidity (transmissometer) sensors was set to log data at 15 min intervals and deployed at the seabed (sensors 0.2 to 0.5 m above the sediment/water interface). A pump and hose delivery system was installed to collect near-bottom (N-B) seawater samples from 50 mm above the seabed without disturbing the sediment/water interface. This was accomplished by deploying a weighted stand, fixed to the seabed, for attachment of the hose intake. The outlet end of the hose was attached to a float. Samples were collected at intervals by attaching the hose outlet to an electric pump, pumping 5 litres of water to clear the entire hose internal volume and then dispensing the sample into a container for subsequent subsampling and analyses. The apparatus was initially trialled with the hose intake monitored by SCUBA divers to ensure that underlying sediments were not disturbed.

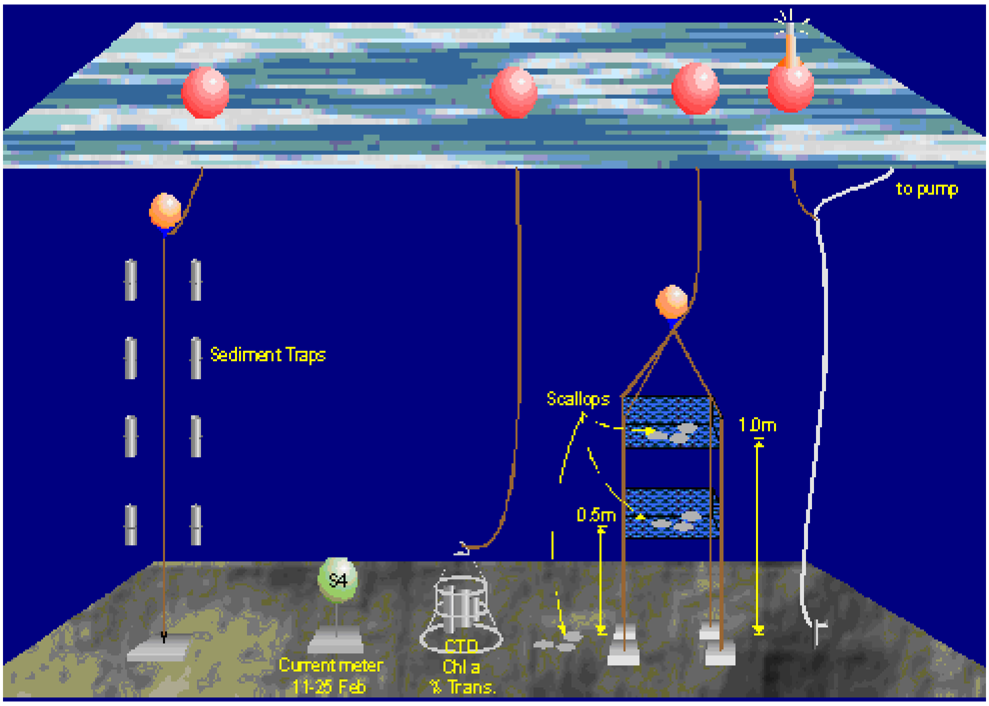


Figure 3. Diagram of field deployment array.

Additional seawater samples were collected periodically at 5 m depth intervals from the overlying water column using a 5-litre van Dorn sampler. Sediment cores and scallop samples were collected using SCUBA.

A coordinated study of sedimentation rates and water profile characteristics during the February experiment was reported by Gibbs (2001).

2.3. Scallop feeding

Scallops from the vicinity of the study site were held for at least 24 hours in tanks containing filtered seawater and then deployed at the study site in baskets (15 scallops each) at heights of 0.5 and either 1.0 m (February experiment) or 2.0 m (November experiment) above the seabed. Additional scallops were seeded directly onto the seabed. Scallops were sampled at various time intervals and intestinal tracts were excised and preserved in Lugol's iodine.

2.4. Laboratory analyses

Suspended solids analyses were carried out using a gravimetric technique (APHA 20th Edn. 1998, Method 2540D). Chlorophyll *a* was analysed spectro-photometrically (Lorenzen 1967, Strickland & Parsons 1968) and the same method was used to calibrate *in situ* flurometric chl *a* readings. The composition (species and abundance) of phytoplankton and benthic microalgae from seawater, sediment and scallop intestinal tract samples was determined using 10 ml Utermöhl chambers and inverted microscopy.

3. RESULTS

3.1. February 1999

3.1.1. *In situ measurements*

Current velocities, previously reported by Gibbs (2001), varied from 2 to 28 cm s^{-1} during the two-week period 11-25 February with the stronger flows occurring in conjunction with spring tides 15-20 February. During the neap tide (tidal range only ~2.3 m) experimental period (23-25 February), however, readings were lower; between 3 and 18 cm s^{-1}. Currents were predominantly in a south westerly direction.

The % light transmission (inversely related to turbidity) of seawaters (~ 200 mm above the seabed) varied from a high (least turbid) of 38% to a low (most turbid) of 7% (Figure 4). Values < 10% are extremely turbid, to the extent that light penetration is severely inhibited. In general, the highest turbidity readings were associated with periods of receding tidal flows, suggesting that the re-suspension of sediments from the seabed, due to tidal currents, may have been a major cause.

Temperature readings varied slightly between 18.3 and 19.0 ºC with the higher values associated with periods of low tide. Salinities were relatively constant (35.01-35.04 psu) however short term fluctuations in seawater density indicated inflow pulses of oceanic water (Figure 4).

Chl *a* concentrations (Figure 4) were high throughout the measurement period ranging from 4.6 to 5.3 mg m^{-3} (mean of 4.8 mg m^{-3}).

3.1.2. *Suspended particulate material (SPM) concentrations*

Water column profiles

Total suspended solids (TSS) concentrations of the water column (surface to 20 m) ranged from 3 to 7 g m^{-3} during the sampling period (Figure 5). Concentrations of volatile (organic) suspended solids (VSS) ranged from 13 to 20% of the TSS at the 20 m depth level (*i.e.* 2-4 m above the seabed) and up to 67% at shallower strata. The mean %VSS for all profile samples was 27%.

Near-bottom waters

Much higher concentrations of suspended particulate materials (up to 25 g m^{-3}) were observed in N-B waters collected from 50 mm above the seabed (Figure 6). Concentrations varied during the course of the 24-hour experiment by up to 14 g m^{-3}, with the highest values associated with periods of maximum tidal flows. SPMs of the N-B waters were mainly inorganic with the volatile fraction comprising only 4 to 20% (average of 8%) of the total during the course of the sampling period.

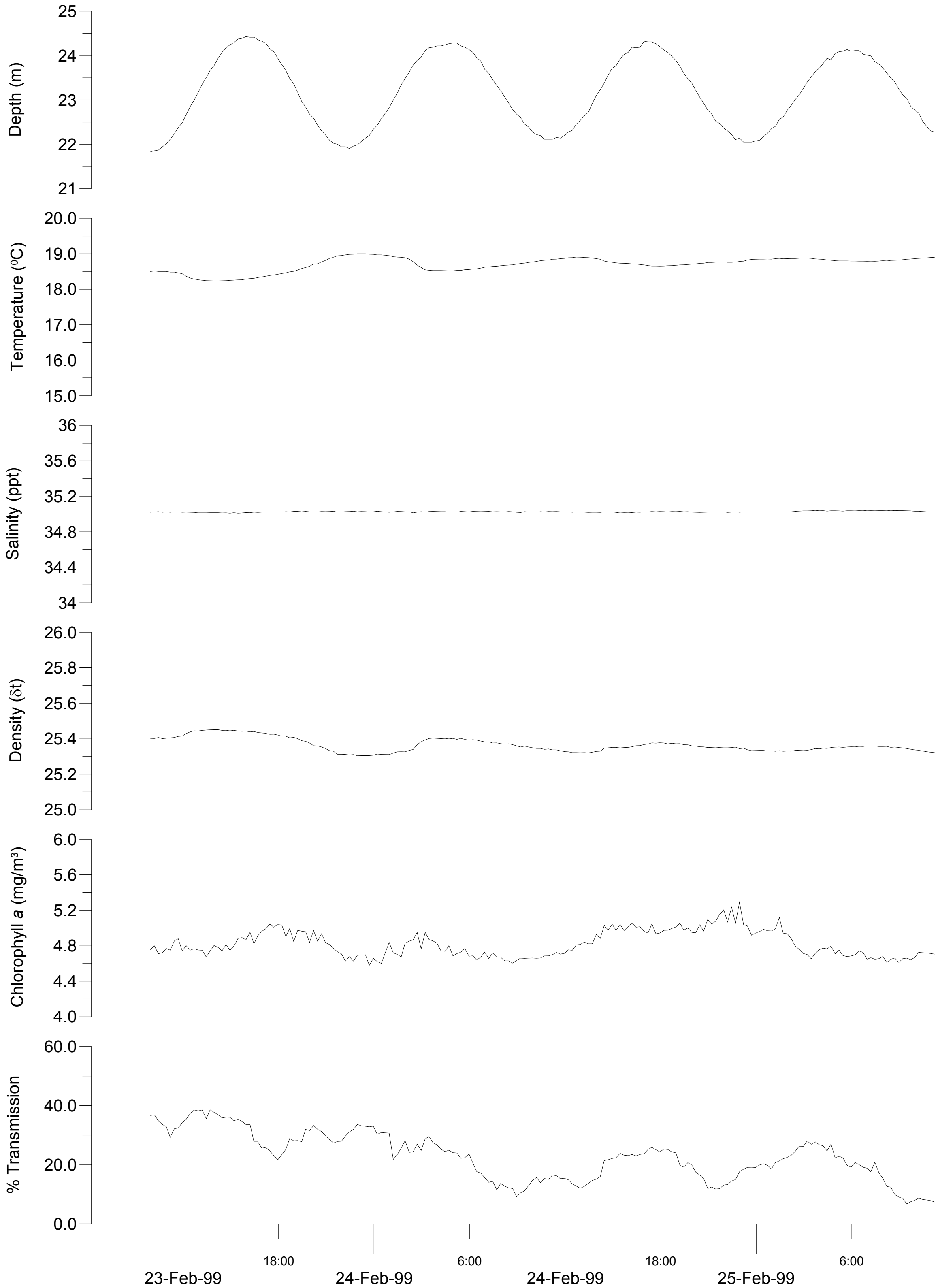


Figure 4. Seawater physical/chemical characteristics (*in situ* readings collected ~200 mm above seabed (Tasman Bay Site E1, 23-25 February).

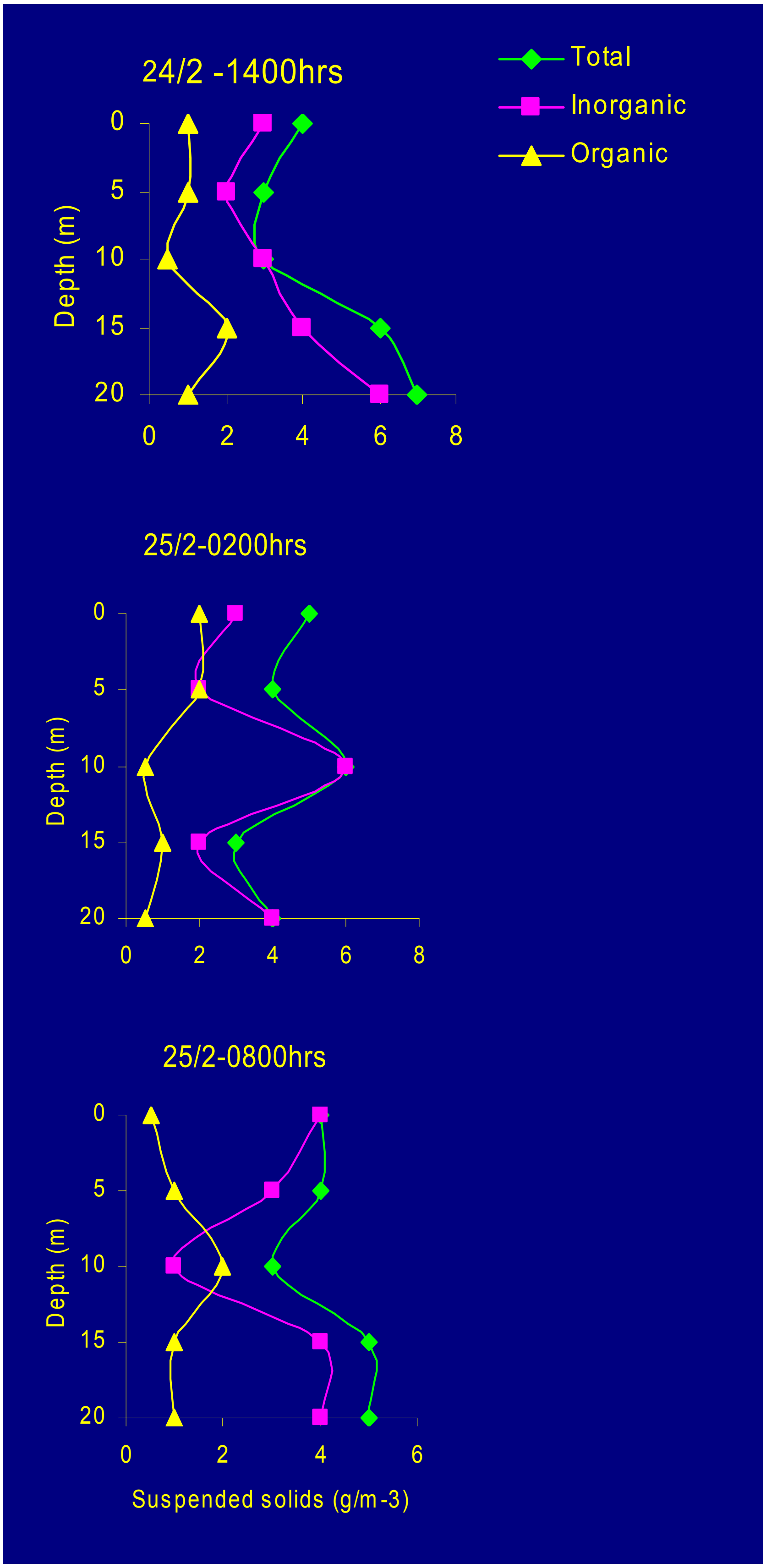


Figure 5. Water column profiles of suspended solids (Tasman Bay Site E1, 24-25 February). Note that near-bottom waters are not included.

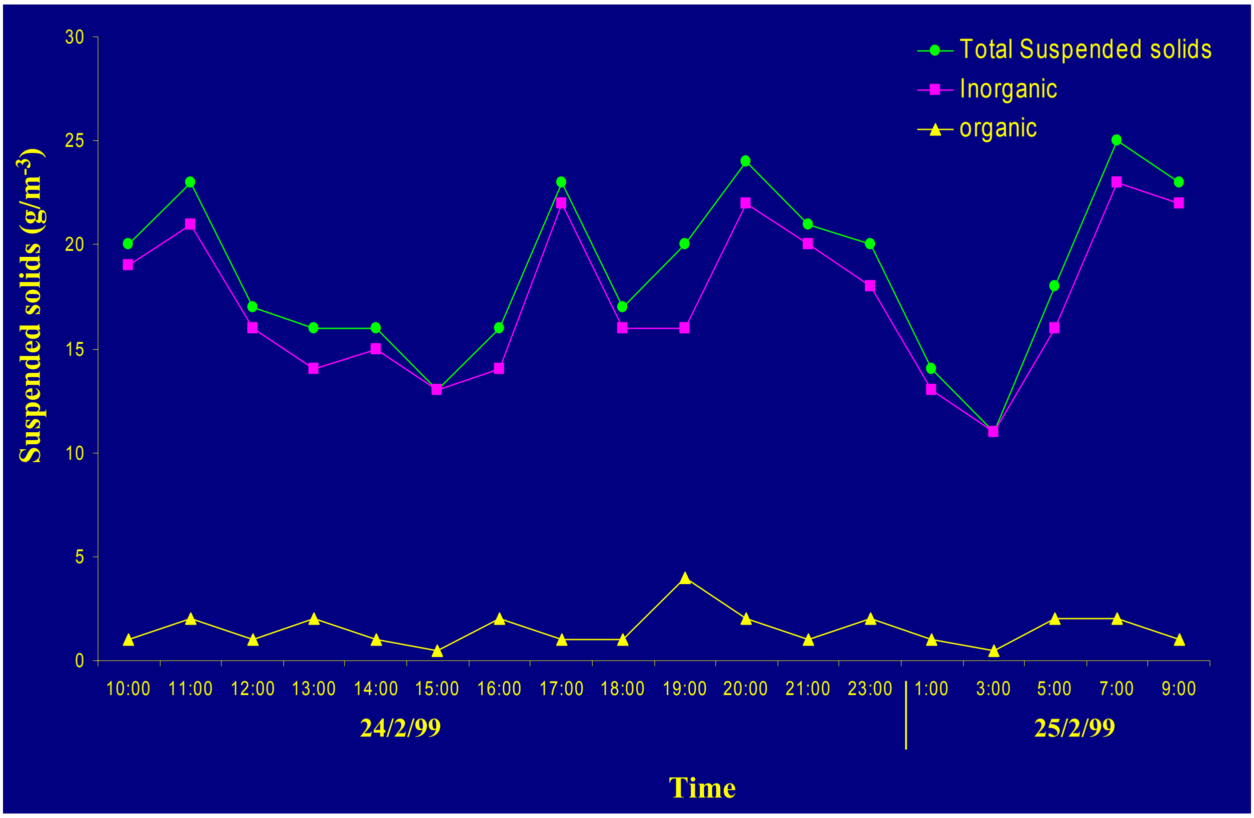


Figure 6. Suspended solids content of near-bottom waters (Tasman Bay Site E1, 24-25 February).

3.1.3. Microalgal composition

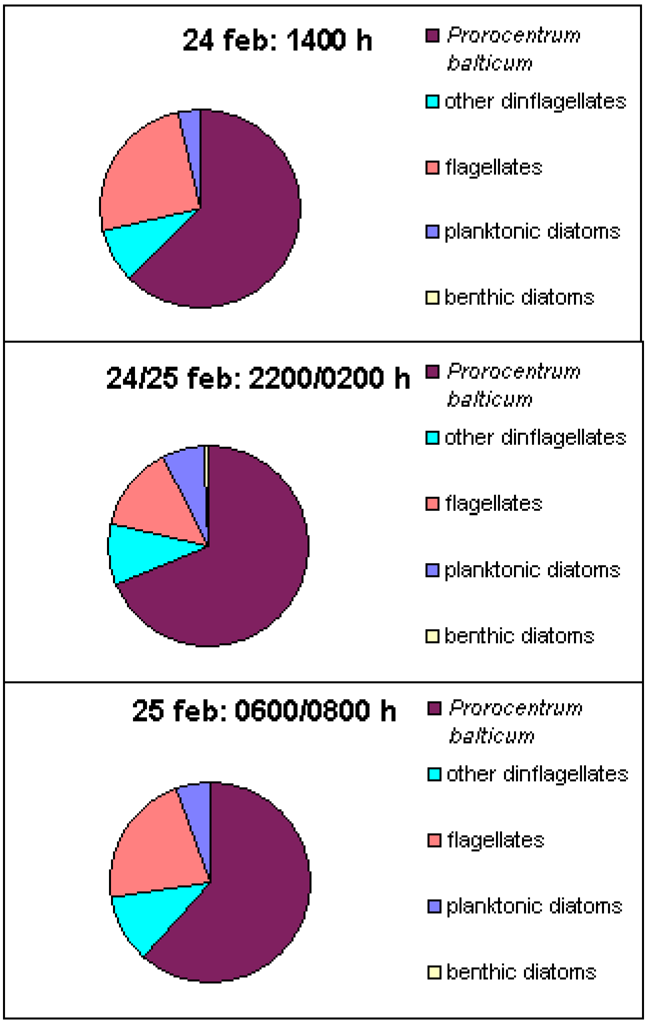
Water column profiles

During the sampling period, the phytoplankton community was dominated by moderate bloom proportions of the non-toxic dinoflagellate, *Prorocentrum balticum* (Table 1, Figure 7) with fewer numbers of other dinoflagellates and diatoms also present. Although a few samples were numerically dominated by small flagellates and ciliates, these were probably a small proportion of the total biomass. Highest concentrations of the bloom-former (up to 49,000 cells per litre) were observed at a depth of 20 m, with lesser densities in the shallower depth layers. A similar depth distribution was evident in the chl *a* profiles (Figure 8) with average concentrations of 2.1, 1.9, 1.4, 1.5 and 3.4 mg m^{-3} at 0, 5, 10, 15 and 20 m depths, respectively. Although some variations were observed over time, depth distributions, in terms of both cell counts and chl *a* concentrations, were relatively similar throughout the course of the sampling period. Depth integrated chl *a* concentrations (mean of 49.8 ± 8.4 mg m^{-2}) were consistent with the observed microalgal numbers.

Table 1. Phytoplankton counts (cells per litre) in Tasman Bay (Site E1) water column profile samples (24-25 February).

Date	Time	(m) Depth	*P. balticum*	Other Dinoflag.	Diatoms	Small flagellates & ciliates	Total
24.2.99	1000	Surface	10400	2600	200	1800	15000
		5	14800	2400	200	8400	25800
		10	14600	3000	0	7400	25000
		15	16600	3000	2600	7800	30000
		20	39000	3800	1200	7000	50600
	1400	Surface	11200	1600	6400	17800	37000
		5	9000	2000	0	6400	17600
		10	13400	1000	400	6100	20900
		15	41200	4400	0	8400	53600
		20	21000	3800	200	10800	35800
	2200	Surface	11200	2400	200	7600	21400
		5	10000	1600	400	5000	17000
		10	4200	800	0	1600	6600
		15	10600	1800	400	3400	16200
		20	45600	6000	600	2800	54200
25.2.99	0200	Surface	5200	2600	6800	1000	16000
		5	3200	1400	5200	9000	18800
		10	7800	1600	2400	2000	13800
		15	22200	3200	1400	1800	28600
		20	42000	3800	200	3000	49000
	0600	Surface	1400	2800	4400	10800	19200
		5	2600	2600	12200	9000	26400
		10	7400	2400	600	7400	17800
		15	23200	3800	3000	7000	37000
		20	200*	600	1200	5200	7200
	0800	Surface	7400	2100	5800	8800	22500
		5	4400	2000	200	3000	9600
		10	9400	1600	200	3600	14800
		15	9400	2600	0	9800	21800
		20	49000	5600	1400	1400	57200

A. Surface to 20 M (Integrated)



B. 20 M Depth

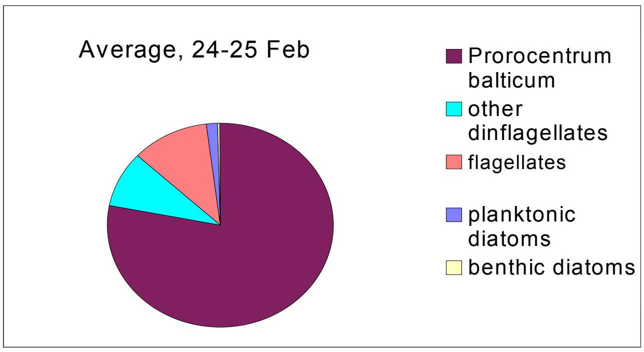


Figure 7. Phytoplankton community composition (Tasman Bay, 34-25 February).

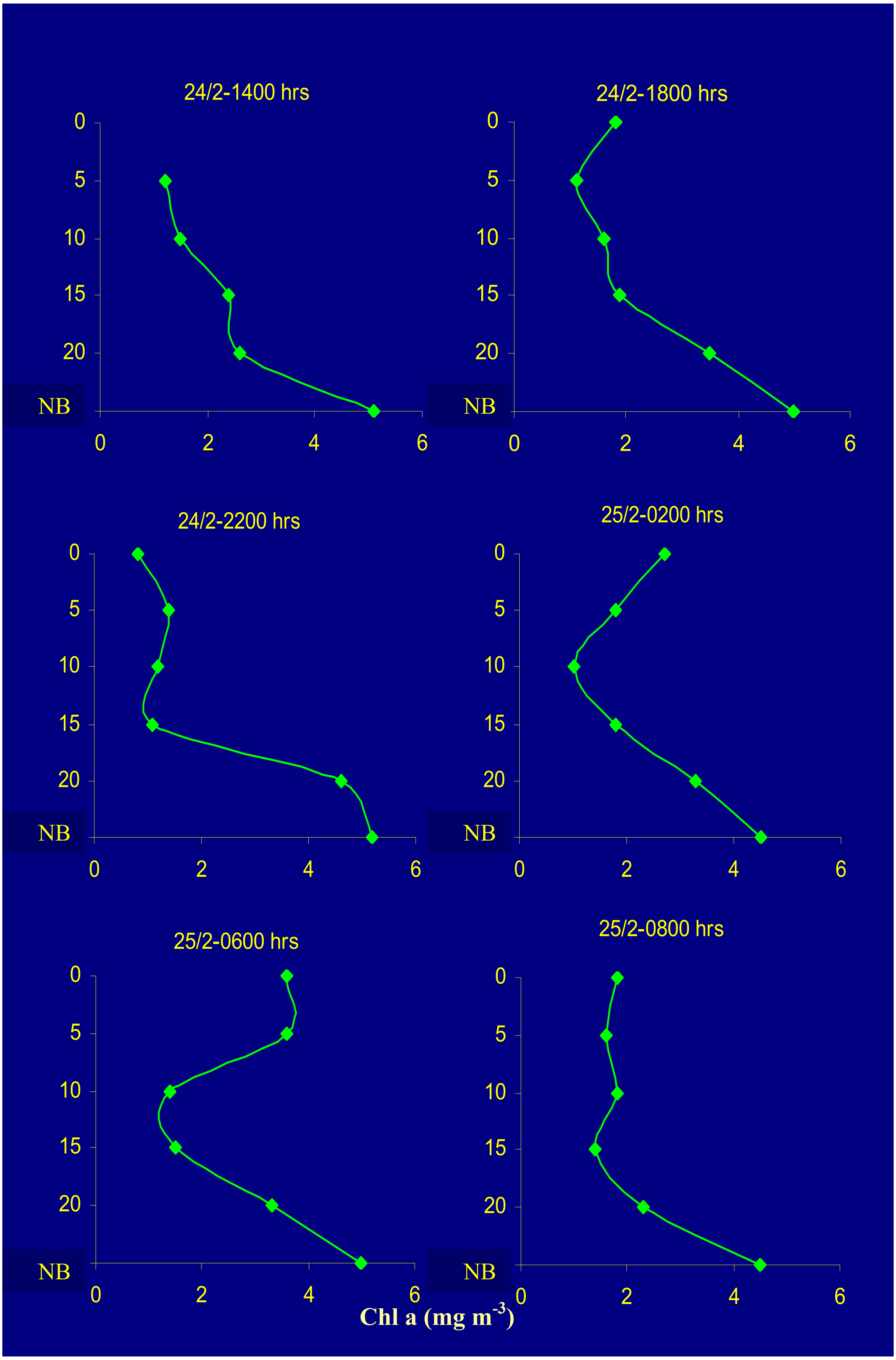


Figure 8. Water column profiles of chlorophyll *a* (Tasman Bay Site E1, 24-25 February). NB. = Near Bottom (50 mm above the seabed).

Near-bottom (N-B) water

Near bottom waters were also dominated by the bloom-forming dinoflagellate, *P. balticum*, with fewer numbers of other dinoflagellates, and benthic and planktonic diatoms (Table 2). As might be expected, higher numbers of typically benthic species of diatoms were present near the seabed in comparison to the water column above. Observed N-B taxa considered to be primarily of benthic life style were *Diploneis* sp., *Pleurosigma* sp., *Paralia marina* and *Navicula* sp. Some diurnal variation in microalgal composition was apparent with higher dinoflagellate numbers and lower diatom numbers observed at night (Figure 9). Chl *a* concentrations of N-B waters (Figure 8) were consistently higher than those in the water column above, ranging from 4.5 to 5.2 mg m^{-3} (mean 4.8 mg m^{-3}), however they were very similar to those measured *in situ* at 200 mm above the seabed.

Table 2. Microalgal counts (cells per litre) in near-bottom (pumped) seawater samples (24-25 February).

		Dinoflagellates		Diatoms		Total
Date	Time	*Prorocentrum balticum*	Total	Benthic	Total	All taxa*
24.2.99	1000	7400	7600	7400	20800	28400
	1100	4800	5000	4800	15600	20600
	1200	10400	10600	6600	13200	23800
	1300	11200	11400	9400	20000	31400
	1400	12400	12600	3800	11800	24400
	1500	4800	5200	5000	8800	14200
	1600	8600	9600	7600	13200	22800
	1700	9400	11000	3800	7000	18000
	1900	5000	5800	3200	5200	11000
	2100	9400	9800	7200	8800	18600
	2300	24000	25800	7400	10600	36400
25/2/99	100	32200	33800	9800	11800	45600
	300	14200	16000	2400	3400	19400
	500	17000	18200	10200	14800	33000
	700	12800	13800	4200	8000	21800
	900	9400	9800	13800	23800	33600

* Excluding small flagellates and ciliates.

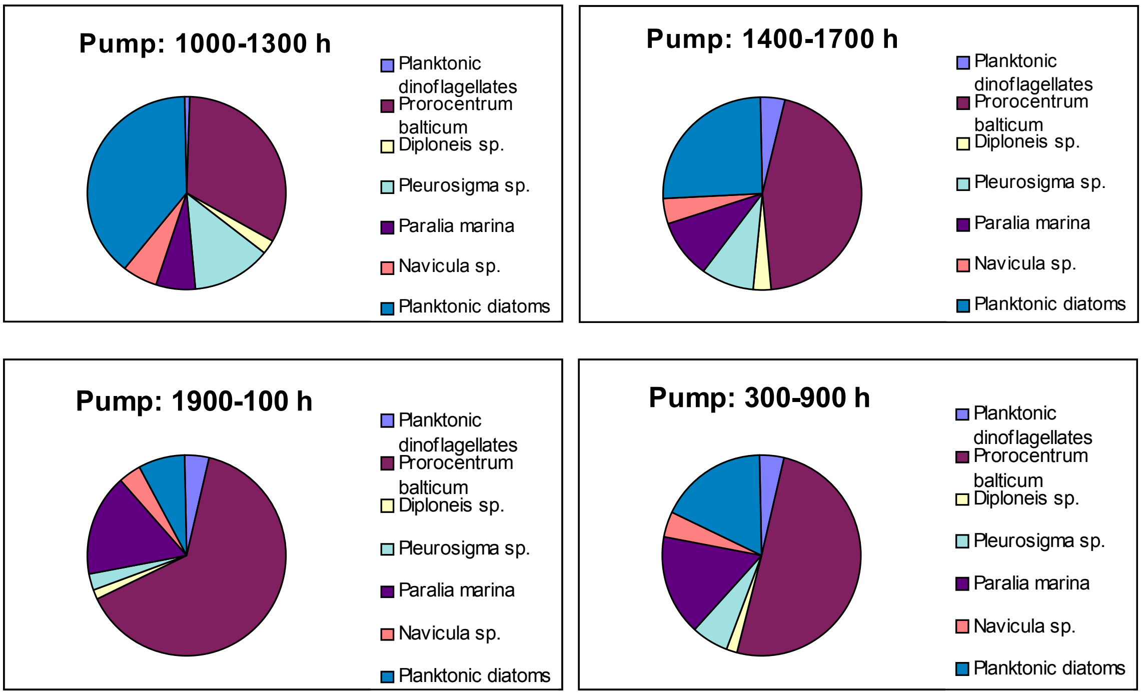


Figure 9. Temporal variation in microalgal composition of N-B waters (24-25 February).

Sediments

The microalgal composition of the sediments was largely comprised of typical benthic diatom species (Table 3, Figure 10), although the large planktonic *Coscinodiscus* sp. was also present in significant numbers. Interestingly, the bloom forming dinoflagellate, *P. balticum*, which dominated within the water column above, including the near-bottom waters, did not feature in the sediments.

Table 3. Microalgal composition of sediments in Tasman Bay Site E1 (25 February).

Taxon	Cells per ml of sediment
Coscinodiscus sp.	58
Pleurosigma sp.	218
Paralia marina	312
Navicula sp.	20
Thalassiosira sp.	32
Dinoflagellate cysts	38

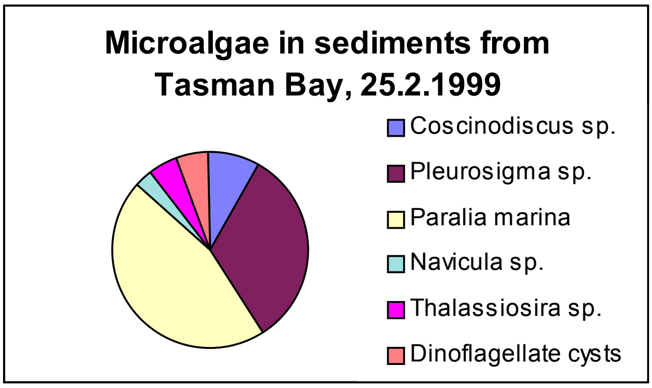


Figure 10. Proportional composition of microalgal taxa in sediments.

Scallop digestive tracts

Visual observation of the digestive tracts (made while carrying out dissection procedures) indicated that scallops seeded directly onto the sediments contained very little food material. By comparison, the digestive tracts of scallops incubated at 0.5 and 1.0 m above the seabed contained much larger volumes of food materials. Thus it was assumed that scallops on the seabed were not actively feeding during most of the experimental period.

A total of 18 taxa were observed in scallop digestive tract samples (Table 4). Although quantitative assessment of the samples was not possible, proportional comparison of the taxa, (Figure 11) showed that the bloom-forming dinoflagellate, *Prorocentrum balticum*, comprised 96 to 99% of all samples. Thus it was clear that this species provided the main food item for scallops during the sampling period. Although comparisons were largely masked by the dominance of the one species, more 'typically benthic' diatoms were present in scallops on the seabed while a greater variety of additional planktonic taxa were present in those hung at either 0.5 or 1.0 m above the seabed. No obvious diurnal variation in composition was detected.

Table 4. List of benthic and planktonic microalgal taxa found in scallop intestinal tracts (24-25 February).

Taxa	Life style
Ceratium furca	Planktonic
C. tripos	Planktonic
Dinophysis acuta	Planktonic
D. rotundata	Planktonic
Prorocentrum balticum	Planktonic
P. gracile	Planktonic
P. micans	Planktonic
P. triestinum	Planktonic
Protoperidinium bipes	Planktonic
Pyrocystis lunula	Planktonic
Coscinodiscus sp.	Planktonic
Diploneis sp.	Benthic
Pleurosigma sp.	Benthic
Paralia marina	Benthic
Navicula sp. (small)	Benthic
N. sp. (large)	Benthic
Thalassionema sp.	Benthic
Thalassiosira sp.	Benthic

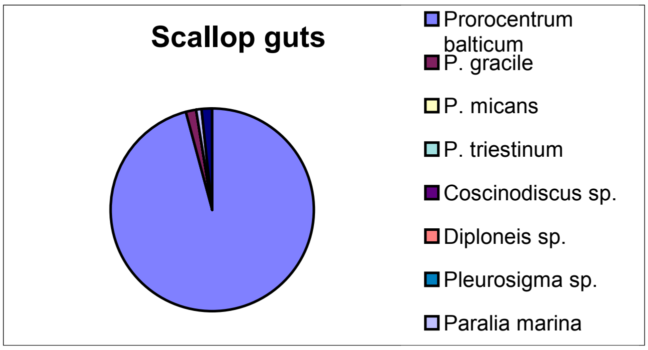


Figure 11. Proportional composition of microalgal taxa in scallop digestive tracts (25 February).

3.2. November 1999

3.2.1. In situ measurements

Current meter data are not available for the November experimental period due to a malfunction of the instrumentation. We note, however, that the period coincided with a tidal range of 4.2 m, which was similar to the spring tides during 15-20 February when tidal currents of up to 28 cm s^{-1} were observed (see Section 3.1.1). It is therefore expected that current velocities would have been greater than 18 cm s^{-1}, as observed during the February 23-25 experimental period.

The % light transmission, measured ~200 mm above the seabed, varied widely from a high of 54% to a low of 3% (Figure 12). Values < 10% are extremely turbid, to the extent that light penetration is severely inhibited. A major increase in turbidity occurred in conjunction with the ebbing tidal flow between 1500 and 1800 hours (24 November) followed by a general increase in water clarity thereafter.

Temperature readings varied slightly between 15.5 and 16.2 ºC. The lower temperature readings coincide with higher salinities indicating an intrusion of cooler, more saline oceanic waters (Figure 12). This intrusion may also have been responsible for the higher % transmission (lower turbidity) values observed later during the 25 November ebbing tide.

Chl *a* concentrations (Figure 12) were relatively low throughout the measurement period ranging from 0.9 to 1.9 mg m^{-3} (mean of 1.2 mg m^{-3}).

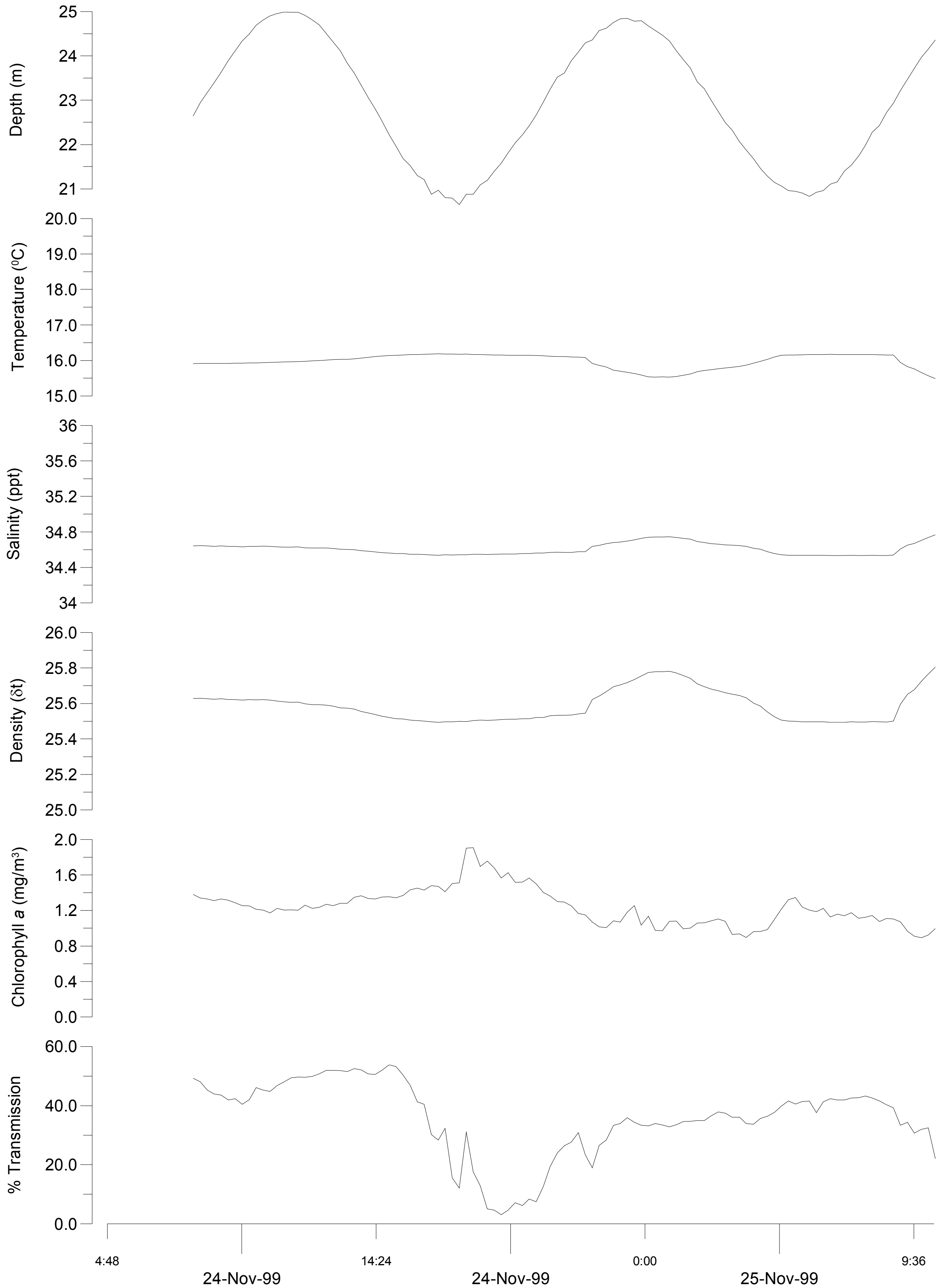


Figure 12. Variation of seawater *in situ* readings of physical/chemical characteristics collected ~200 mm above seabed (Tasman Bay Site E1, 24-25 November).

3.2.2. Suspended particulate material (SPM) concentrations

Water column profiles

Total suspended solids (TSS) concentrations of the water column (surface to 20 m) ranged from 3 to 10 g m^{-3} during the November sampling period (Figure 13) with the latter value corresponding to the lowest *in situ* transmissometer readings (Figure 12). Concentrations of volatile (organic) suspended solids (VSS) ranged from 10 to 25% of the TSS at the 20 m depth level (*i.e.* 1-5 m above the seabed) and up to 33 % at shallower depths. The mean % VSS for all profile samples was 19.4%.

Near-bottom (N-B) waters

N-B waters were only sampled on three occasions (24/11 at 0900 and 1200 and 25/11 at 0700) due to difficulties caused by rough sea conditions. These times corresponded to TSS concentrations of 10, 13 and 13 g m^{-3} and VSS concentrations of 1, 2 and 1 g m^{-3}, respectively. Corresponding *in situ* % transmission values (0.2 m above the seabed) were 42, 50 and 42%. Unfortunately no data are available for the period of lowest % transmission readings.

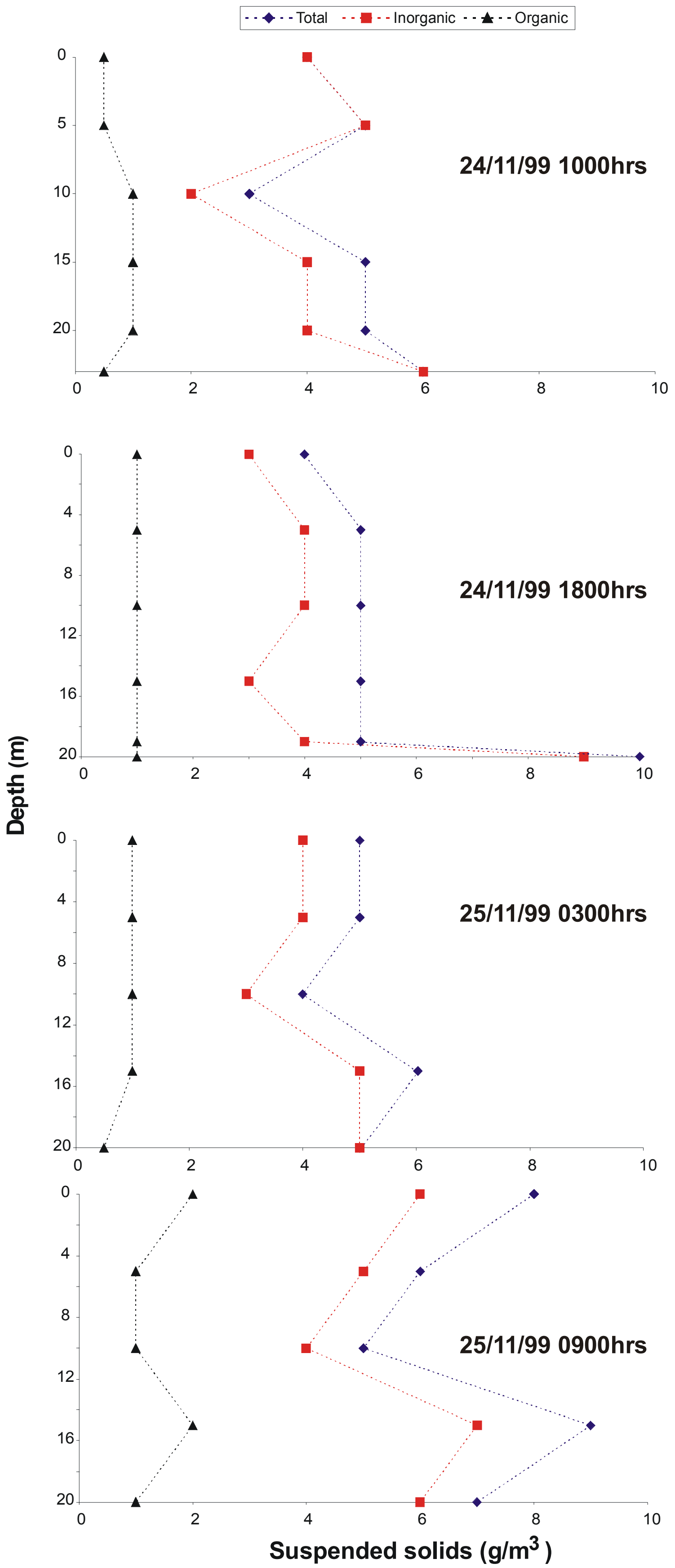


Figure 13. Water column suspended sediment profiles (Tasman Bay Site E1, 24-25 November). Note that near-bottom waters are not included.

3.2.3. *Microalgal composition*

Water column profiles and N-B waters

Most samples were dominated, numerically, by small flagellates and ciliates (Table 5), suggesting that this smaller size class may have contributed a significant proportion of the total microalgal biomass that was otherwise comprised mainly of the larger groups of dinoflagellates and diatoms. Due to the generally lower bivalve feeding efficiencies within the smaller size classes, we assume that dinoflagellates and diatoms were the primary food items.

Table 5. Phytoplankton counts (cells per litre) in Tasman Bay (Site E1) water column profile and N-B samples (24-25 November). N-B data are shaded.

Date	Time	Depth	Dinoflagellates	Diatoms	Small flagellates & ciliates	Total all taxa
24.2.99	1000	Surface	9400	4600	140800	154800
	"	5 m	8600	4600	141800	155000
	"	10 m	5400	2400	91600	99400
	"	15 m	11600	600	153700	165900
	"	20 m	5600	200	155600	161400
	"	N-B (pump)	1400	2600	20600	24600
	1200	N-B (pump	600	3400	26500	30500
	1400	Surface	5200	6000	65900	77100
	"	5 m	10600	3600	72000	86200
	"	10 m	7800	0	30200	38000
	"	15 m	15400	3000	56300	74700
	"	20 m	20600	400	52200	73200
	2200	Surface	12000	2800	75900	90700
	"	5 m	11000	1800	84000	96800
	"	10 m	5200	4600	12500	22300
	"	15 m	12800	1400	62300	76500
	"	20 m	14400	3400	101400	119200
25.2.99	0200	Surface	2800	3200	12900	18900
	"	5 m	4200	4800	6400	15400
	"	10 m	12200	3600	101600	117400
	"	15 m	21600	1800	96100	119500
	"	20 m	14200	200	113700	128100
	0600	Surface	8200	1600	181600	191400
	"	5 m	13400	2600	263900	279900
	"	10 m	19200	800	11400	31400
	"	15 m	17600	1200	9200	28000
	"	20 m	23000	3800	16800	43600
	0700	N-B (diver)	1800	5200	5900	12900
	0800	Surface	35800	800	16200	52800
	"	5 m	23600	2400	9600	35600
	"	10 m	1400	2600	20600	24600
	"	15 m	600	3400	26500	30500
	"	20 m	1800	5200	5900	12900

Sediments

Microalgal cell numbers in the sediments were low and comprised largely of the benthic diatoms, *Pleurosigma* sp. and *Paralia marina* (Table 6). High numbers of empty frustules of a variety of benthic diatoms were also observed.

Table 6. Microalgal composition of sediments from Tasman Bay Site E1 (25 November).

Taxon	Cells per ml of sediment
Pleurosigma sp.	166
Paralia marina	166
Ceratium furca	1
Coscinodiscus sp.	1

Scallop digestive tracts

Once again, based on observations made during dissection procedures, scallops seeded directly onto the seabed appeared to contain lower quantities of food materials than those held in baskets above the seabed. Scallops positioned on the seabed, or 0.5 m above, contained only three microalgal taxa. These were the typical benthic pennate diatoms, *Paralia* sp., *Navicula* sp. and *Pleurosigma* sp. Those hung at 1.0 or 2.0 m above the seabed contained the same taxa but also contained planktonic tintinnids. The latter also contained low numbers of the large planktonic centric diatom, *Coscinodiscus* sp. and copepod eggs.

4. DISCUSSION

4.1. Near-bottom high turbidity (N-BHT) layer

In situ measurements taken over the experimental periods (23-25 February and 24-25 November 1999) indicated that major short-term fluctuations in turbidity can occur within the seawater layer approximately 0.5 m above the seabed in the region affected by the Motueka River outwelling plume. Highest turbidity readings were associated with mid-tidal flows suggesting that tidal re-suspension events were directly responsible. These results were consistent with observed fluctuations in suspended solids (SS) concentrations in the N-B seawater layer (*i.e.* within 50 mm above the seabed). Recurrent peaks of > 20 g m^{-3} were observed over a 24-hour period during the February sampling. Contrasting seawater conditions were observed during the November sampling. *In situ* measurements during this period also showed major fluctuations in N-B turbidity, however, only one major peak occurred over the 24-hour experimental period. N-B SS observations, although limited to only three measurement times, indicated that the previously observed N-B HT layer was not a persistent feature during the November sampling period.

4.1.1. Possible causes

Relationships between development of the persistent N-B high turbidity layer and catchment sediment discharges are not particularly obvious because of the short duration of the data sets. Daily mean flows of the Motueka River (Figure 2) indicate a series of significant flood events during the latter half of 1998, including seven occasions when flows exceeded 400 $m^3 s^{-1}$. However no significant events occurred during the 15 week period prior to the February sampling. Therefore, if we assume that the February 1999 high N-B turbidity values were related to the earlier floods, the effects of such events can be relatively long-lived (*i.e.* persisting for a period of months). Although two moderate rainfall events occurred within the three-week period prior to the November experiment, resulting in flows of > 200 $m^3 s^{-1}$, these were apparently not severe enough to result in a persistent N-B high turbidity layer as observed in February.

The persistence of the N-BHT layer for long periods in the absence of significant storm discharges, suggests that the fine particulate materials at the sediment/water interface are readily re-suspended via tidal currents resulting in a horizontal turbidity flow. This is consistent with the hypothesis of Gibbs (2001) that episodic strong current flows and seiching of the summer near-bottom density discontinuity feature in Tasman Bay produces highly variable turbulence that enhances benthic re-suspension. Indeed tidal currents at the study site were within a range reported to be capable of re-suspending fine particulate materials from seabed environments (Giles & Pilditch 2004, Jago *et al*. 2002).

It is possible that dredging/trawling activities within the region reduce the integrity of the sediment boundary layer such that re-suspension occurs more readily. This could occur due to the levelling of three-dimensional structure (*e.g.* beds of horse mussels, tube worms, hydroids or bryozoans) on the seabed, or the disruption of epibenthic diatom communities (Gillespie *et al*. 2000) that produce exo-polymeric substances that bind sediment particles together making them more resistant to re-suspension (Austen *et al*. 1999). Since sediment erodability can be influenced by infauna communities (Widdows *et al*. 2000, Roast *et al*. 2004), changes in community structure caused by dredging/trawling disturbances could theoretically also contribute to development of the N-BHT layer.

4.2. Inhibition of scallop feeding

Examination of the volume and composition of scallop intestinal tract contents suggested that SS concentrations throughout the February sampling period were within a range that was inhibitory to their feeding activity. Unfortunately the effects of SS on the New Zealand scallop (*Pecten novaezelandiae*) have not been thoroughly investigated to date. For example, Nicholson (1978) found that a silt concentration of 80 g m^{-3} reduced the pumping rate of the New Zealand scallop by 92%. Although his observations of the effects of lower concentrations were less clear, he reported a 20% reduction in filtration rate for a concentration of 16 g m^{-3}. Thus some inhibition might be expected to occur within the concentration range observed during the February experiment and over a 2-3-hour period during the November experiment. Stevens (1987) demonstrated inhibition of scallop gill tissue activity and scallop mortality associated with very high suspended sediment concentrations (*i.e.* 0.05-0.6%), however these were in a concentration range 10-fold higher than observed in the present study. Nonetheless, we could assume that SS concentrations at the sediment/water interface would be significantly higher than those observed 50 mm above the seabed and it is therefore possible that conditions lethal to scallops, particularly juvenile scallops, might have been in place during the February experiment.

4.3. Nutritional value of the suspended particulate material (SPM)

N-B SPMs appeared to be of poor nutritional value due to their low proportion of organic to inorganic constituents. Contrasting conditions were observed in the water column > 0.5 m above the seabed. Here, SPM concentrations were lower and contained higher proportions of organic materials. Thus farmed shellfish grown on culture ropes higher up in the water column would not have been compromised by the poor nutritional characteristics of the N-B waters. Indeed water column chl *a* profiles (surface-20 m) indicate good food availability during February and lower but still adequate food availability during November.

Comparisons of microalgal communities within the water column, N-B waters, sediments and scallop intestinal tracts indicate a strong but variable compartmentalisation of food components between benthic suspension feeders (*e.g.* scallops) and farmed mussels suspended above the seabed. This separation breaks down during phytoplankton bloom periods when the bloom species comprise the dominant food item for both. Planktonic and benthic taxa observed during the present study were in general agreement with the results of Gillespie (2003). *Paralia marina* and *Pleurosigma* sp. were seen to be particularly dominant components of the benthic microalgal community and the high proportion of benthic vs. planktonic taxa in sediments and N-B waters during non-bloom periods is consistent with the findings of Gillespie (2003) that indicated the relative importance of the benthic microalgae to the overall production of Tasman Bay.

It is interesting that the February results coincide with a significant dinoflagellate bloom that, in the absence of the unusually high N-B inorganic sediment concentrations, would have constituted ideal growth conditions for benthic suspension feeding shellfish. Mid to late summer dinoflagellate maxima have been observed previously in Tasman Bay and are thought to be a typical feature of the phytoplankton seasonal succession for the region (Mackenzie and Gillespie 1986). Scallop gut contents (February sampling) were in all cases dominated by the bloom forming dinoflagellate (*Prorocentrum balticum*), however scallops on the seabed contained lesser food quantities than those held in cages above the seabed. Thus, although blooms of planktonic microalgae can provide significant energy boosts for scallops (Gillespie 1997) this may not always be the case. During the February experimental period, high chl *a* concentrations were observed in N-B waters but the nutritional value of the SPM was greatly reduced by the high inorganic sediment concentrations that appeared to prevent scallop feeding.

4.4. Implications for management of shellfish resources

4.4.1. Scallops

High silt concentrations have been shown to adversely affect scallops (Nicholson 1978, Stevens 1987). Although it is difficult to relate experimental SS concentrations from the literature to the environmental concentrations observed here, our results suggest that the quantity and quality of the feeding environment for scallops, and potentially for other benthic fauna, can be significantly compromised by the development of the N-BHT layer. Although this feature was observed within the region of Tasman Bay influenced by the Motueka River outwelling plume, its spatial extent has not yet been determined and it could at times cover larger areas of the Bay. Poor growing conditions for benthic shellfish can apparently persist for a period of months after a major catchment sediment discharge and mortalities are likely to occur in such cases. Potential implications for the scallop industry and related enhancement activities are therefore considerable. Major fluctuations in scallop population densities and growth characteristics are likely to occur within the region affected by the Motueka River outwelling plume. Natural spat settlement and survival are also likely to be interfered with periodically by storm-related catchment sediment discharges. Knowledge of conditions within the N-B environment could help commercial scallop managers to avoid some of the risks. For example, seeding of juvenile scallops into an area affected by high concentrations of inorganic suspended sediments in N-B waters would likely result in poor survival and possibly large-scale mortality. Once more information is available on the spatial extent and duration of the N-BHT layer (and its relationship to river flows), it may be possible to carry out a risk assessment based on predictions of future events. This information requirement is currently being addressed through long term deployment of a N-B data-logging turbidity/chl *a* sensor at a plume-affected site in Tasman Bay.

4.4.2. Mussels

Implications for mussel long-line culture are likely to be less significant because mussels are less sensitive to high inorganic sediment loads and the crop would be positioned high enough in the water column to be above the N-B turbidity zone. Water column chl *a* concentrations and phytoplankton counts (February) indicated sufficient food availability within the entire profile to support mussel growth, with a consistent trend of higher availability within the bottom 3-5 m.

4.4.3. Spat collection

There have been some concerns that spat-collecting activities in regions near to the study location (Site E1) may result in problems associated with an over abundance of animals beneath spat collection structures. The perceived problems relate to bivalve spat and other settlement species being dislodged and dropping to the seabed, where they may survive resulting in changes to the benthic community structure. The concern is that unnaturally high population densities could result in localised food depletion and/or disease or predation problems that could spread to surrounding regions. Our results, however, suggest that the long term survival of drop-off organisms is likely to be limited by periodic storm events and development of the N-BHT feature. This hypothesis is consistent with the findings of Hopkins and Webb (2004) who demonstrate periodic high mortalities of juvenile shellfish beneath spat lines. Sediment depositional events may also reduce the risk of the spread of shellfish diseases or the over abundance of predators such as the 11-arm sea star.

5. SUMMARY AND CONCLUSIONS

5.1. Background

The information provided in this report was collected as part of a collaborative research effort called the Motueka Integrated Catchment Management (ICM) programme. The programme was designed to assess the effects of various land use practices on terrestrial, freshwater and marine ecosystems in a "ridge top to the sea" approach. One component of a Cawthron investigation into the effects of freshwater inflow quantity and quality on the productivity of the marine receiving environment is presented here.

5.2. Study objective

The present report describes the results of two detailed investigations of the quantity and quality of near-bottom (N-B) suspended particulate material (SPM) and related water column characteristics at a single location in western Tasman Bay that is influenced by the Motueka River outwelling plume. Results were interpreted with reference to the simultaneous investigation of scallop (*Pecten novaezelandiae*) feeding characteristics in order to assess the potential impact of high N-B suspended sediment loads on the nutritional quality of the feeding environment for benthic shellfish.

5.3. Overview of results and conclusions

In situ measurements taken over the experimental periods (23-25 February and 24-25 November 1999) indicated that major short-term fluctuations in turbidity can occur within the seawater layer approximately 0.5 m above the seabed in the region affected by the Motueka River outwelling plume. The observed near-bottom high turbidity (N-BHT) layer was a persistent, although fluctuating, feature at the site during the February sampling period. Although a single turbidity peak was observed during the November sampling period, it was short term, possibly due to an influx of low-turbidity oceanic waters. Suspended particulate materials 50 mm above the seabed were comprised largely of inorganic sediments and were therefore of poor nutritional quality for benthic suspension-feeding bivalves. Higher proportions of microalgae and/or other organic materials were present in water layers > 0.5 m above the seabed. The feeding activity of scallops on the seabed appeared to be temporarily disrupted in the presence of the N-BHT layer while those hung in water layers > 0.5 m above the seabed continued to feed normally.

During the February experimental period, the primary food component for scallops was the bloom-forming dinoflagellate, *Prorocentrum balticum*, while during the November sampling, benthic diatoms were proportionally more important than phytoplankton. During February, the phytoplankton bloom might have been expected to provide a significant boost to shellfish growth and condition however this was nullified in the benthic (N-B) feeding environment by the high proportion of inorganic sediment particles. The development and persistence of the N-B turbidity layer could theoretically result in serious stress to benthic bivalves or even large-scale mortality. Juvenile shellfish (including those that drop off commercial spat collection structures) would likely be particularly susceptible to such effects due to their lower energy reserves. This has implications regarding the need for imposing requirements for remedial clean-up dredging beneath spat-catching structures. Further dredging for this reason may, in fact, exacerbate the N-B turbidity effects. Our results also emphasise the importance of considering the condition/stability of the sediment/water boundary layer before scheduling scallop seeding procedures in the vicinity of the Motueka river plume and/or (potentially) other coastal regions.

The origin of the fine particulate materials comprising the N-BHT layer is thought to be flood-related discharges from the Motueka River catchment. The long term persistence of the N-BHT layer, however, appeared to be the result of recurring tidal re-suspension of the fine particulates from the seabed. Although the N-BHT layer observed here is primarily a natural feature of the Motueka outwelling plume, it may be considerably exacerbated to create a chronic (longer term) phenomenon by repeated physical disturbances of the seabed (*e.g.* due to dredging and trawling activities) that compromise the integrity of the sediment-water interface.

6. ACKNOWLEDGEMENTS

The authors thank Challenger Scallop Enhancement Company for use of the Tasman Challenger for collection of data during the two investigations. Cawthron staff, Stephen Brown, Rowan Strickland, Lincoln MacKenzie and Rod Asher assisted in carrying out field investigations. Max Gibbs (NIWA, Hamilton) carried out a coordinated study of sedimentation characteristics of the study location and data were shared accordingly. Seawater suspended sediment analyses were carried out by the Cawthron Environmental Laboratory. We also thank Aaron Quarterman and Grant and Steph Hopkins for help with preparation of the figures and report formatting. This research was carried out under contracts CAW805 and CO9X0014 to the NZ Foundation for Research Science and Technology.

7. REFERENCES

Austen I, Anderson. TJ, Edelvang K. 1999. The influence of benthic diatoms and invertebrates on the erodibility of an intertidal mudflat, the Danish Wadden Sea. Estuarine, Coastal and Shelf Science 49: 99-111.

Basher LR ed. 2003. The Motueka and Riwaka Catchments: a technical report summarising the present state of knowledge of the catchments, management issues and research needs for integrated catchment management. Landcare Research New Zealand Publication. 120 p.

Gibbs MM. 2001. Sedimentation, suspension, and resuspension in Tasman Bay and Beatrix Bay, New Zealand, two contrasting coastal environments which thermally stratify in summer. New Zealand Journal of Marine & Freshwater Research 35: 951-970.

Giles H, Pilditch CA. 2004. Effects of diet on sinking rates and erosion thresholds of mussel Perna caniculus biodeposits. Marine Ecology Progress Series 282: 205-219.

Gillespie P. 1997. Tasman Bay scallops: feast or famine? Seafood New Zealand 5: 38-39.

Gillespie P. 2003. Benthic and planktonic microalgae in Tasman Bay: Biomass distribution and implications for shellfish growth. Report prepared for Stakeholders of the Motueka Integrated Catchment Management Programme. Cawthron Report No. 835.

Gillespie PA, Maxwell PD, Rhodes LL. 2000. Microphytobenthic communities of subtidal locations in New Zealand: taxonomy, biomass and food web implications. New Zealand Journal of Marine & Freshwater Research 34: 41-53.

Hopkins G, Webb S. 2004. Adaptive Management Plan 2003/2004 Season Report: Tasman and Golden Bay Spat Catching sites. Prepared for the Ringroad Consortium. Cawthron Report No. 905.

Jago CF, Jones SE, Latter RJ, McCandliss RR, Hearn MR, Howarth MJ. 2002. Journal of Sea Research 48: 259-269.

Lorenzen CJ. 1967. Determinations of chlorophyll a and phaeopigments: spectrophotometric equations. Limnology and Oceanography 12: 343-346.

MacKenzie AL, Gillespie PA. 1986. Plankton ecology and productivity, nutrient chemistry and hydrography of Tasman Bay, New Zealand, 1982-1984. New Zealand Journal of Marine & Freshwater Research 20: 365-395.

MacKenzie L, Adamson J, Gillespie P. 2003. a. Water column stratification and the spatial and temporal distribution of phytoplankton biomass in Tasman Bay, New Zealand. Report prepared for Stakeholders of the Motueka Integrated Catchment Management Programme. Cawthron Report No. 837.

MacKenzie L, Gillespie P, Thompson S. 2003. b. River inputs, remineralisation and the spatial and temporal distribution of inorganic nutrients in Tasman Bay, New Zealand. Report prepared for Stakeholders of the Motueka Integrated Catchment Management Programme. Cawthron Report No. 837.

Nicholson J. 1978. Feeding and reproduction of the New Zealand scallop *Pecten novaezelandiae*. Unpublished MSc thesis, Auckland University.

Roast SD, Widdows J, Pope N, Jones MB. 2004. Sediment-biota interactions: mysid feeding activity enhances water turbidity and sediment erodability. Marine Ecology Progress Series 281: 145-154.

Stevens PM. 1987. Response of excised gill tissue from the New Zealand scallop *Pecten novaezelandiae* to suspended silt. New Zealand Journal of Marine & Freshwater Research 21: 605-614.

Strickland JD, Parsons TR. 1968. A practical handbook of seawater analyses, 2nd edition. Bulletin of Fisheries Research Board of Canada 167. 311 p.

Tuckey BJ, Gibbs MT, Knight BR, Gillespie PA. Tidal circulation in Tasman and Golden Bays: Implications for river plume behaviour. Accepted for publication. New Zealand Journal of Marine & Freshwater Research.

Widdows J, Brinsley MD, Salkeld PN, Lucas CH. 2000. Influence of biota on spatial and temporal variation in sediment erodability and material flux on a tidal flat (Westerschelde, The Netherlands). Marine Ecology Progress Series 194: 23-37.