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Benthic and planktonic microalgae in Tasman Bay: biomass distribution and implications for shellfish growth

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Benthic and planktonic microalgae in Tasman Bay: biomass distribution, and implications for shellfish growth

Motueka Integrated Catchment Management
(Motueka ICM) Programme Report Series

by

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Cover Photo: A view of Tasman Bay (Cawthron 2002)

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.

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1 INTRODUCTION

The information provided in this report was collected 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 planktonic and benthic microalgal biomass (and associated environmental characteristics) were compared along a series of transects in Tasman Bay. Seawater inorganic nutrient data and a description of microalgal community structure, collected simultaneously during a companion study, are reported by MacKenzie *et al.* (2003) and Gillespie and Rhodes (*in prep*.). Studies of the utilisation of benthic diatoms by scallops in Tasman Bay are reported in Rhodes *et al*. (2001). A specific goal of the work was to identify trends over space and time that could benefit the sustainable management of coastal shellfish resources in Tasman Bay.

In a variety of shallow subtidal marine environments, a significant proportion of the total microalgal biomass has been reported to be associated with the seabed (Charpy-Roubaud and Sournia 1990). Planktonic (or 'phytoplankton') and benthic (seabed) microalgae are recognised as being principle components of the diet for suspension-feeding bivalves in coastal waters (Gillespie *et al*. 2000). Benthic microalgal communities at sites in Tasman Bay have been shown to be less dense and comprised of different species than sites of similar depths in less exposed sites in the Marlborough Sounds (Gillespie *et al*. 2000, Christensen *et al*. 2003). Determination of the temporal and spatial variation of the biomass of benthic versus planktonic microalgal communities is critical to the understanding of energy flow and factors controlling the growth and condition of bivalve resources. This is particularly true in the relatively shallow (<70 m depth) Tasman Bay where, in most regions, sufficient sunlight penetrates to the seabed to support some degree of photosynthetic activity (plant growth).

Environmental data, collected during a two-year study (1995-1997), have been summarised and appended to this report to provide background information to aid management decisions regarding the sustainability of fish and shellfish resources in Tasman Bay. We recognise, however, that evaluation of ecosystem processes in Tasman Bay will also provide useful insight for the management of other single-catchment dominated systems in New Zealand, *e.g.* Golden Bay, Pegasus Bay.

2 METHODS

2.1 Study area

Tasman Bay is located at the northern end of the South Island of New Zealand (Figure 1), and 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. In spite of careful management of the scallop resource, considerable inter-annual and regional variation occurs in scallop growth and condition. Scallop harvests from the region (including Golden Bay and the Marlborough Sounds) over the period 1990-2002 ranged from 231 to 850 tonnes per annum (data from R. Mincher, Challenger Scallop Enhancement Company, Nelson). 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 the major contributing factor (Gillespie 1997).

Tasman District Council has designated an aquaculture management area (AMA) in Tasman Bay for the longline culture of Greenshell™ mussel (*Perna canaliculus*) and the collection of both mussel and scallop spat. The AMA, covering a total of approximately 4200 ha, consists 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 annual flow 67 m^3 s^{-1}). Parts of the AMA are presently being used for the seasonal collection of mussel or scallop spat and staged development of the remaining areas for mussel on-growing is planned pending resource consents, however, considerable uncertainty exists regarding the productive potential of the site.

2.2 Site characteristics

The present study monitored 15 sampling sites situated along three transects (A-C) that extended offshore in Tasman Bay from <10 to 25 - 30 m in depth (Figure 1). Transect C, off Cable Bay (eastern Tasman Bay), was relocated further to the east (off Delaware Bay) as of March 1996, and designated Transect D. Two transects (A and B) intersected zones of the AMA and all four transects intersected scallop enhancement areas. The transects were positioned in different geographical regions of the Bay to determine whether contrasting characteristics of microalgal biomass and community structure were observable; *e.g.* in areas of differing sediment textures or riverine influences. Site coordinates were established for relocation with an accuracy of ± 100 m (Table 1) using a Trimble Pathfinder Global Positioning System (GPS).

Table 1. Tasman Bay sampling locations in WGS84 format and approximate depths.

Site	Depth (m)	Latitude (S)	Longitude (E)
A1	5	41° 03’ 21.726”	173° 01’ 27.556”
A2	12	41° 02’ 57.518”	173° 02’ 59.480”
A3	15	41° 02’ 47.859”	173° 04’ 08.851”
A4	18	41° 02’ 38.831”	173° 05’ 26.622”
A5	23	41° 02’ 32.047”	173° 06’ 38.337”
B1	5	41° 13’ 35.000”	173° 06’ 48.000”
B2	12	41° 10’ 29.577”	173° 06’ 02.524”
B3	15	41° 09’ 43.080”	173° 07’ 34.905”
B4	18	41° 08’ 35.568”	173° 09’ 18.346”
B5	20	41° 07’ 34.044”	173° 10’ 51.189”
C1	3	41° 09’ 32.862”	173° 24’ 50.496
C2	12	41° .09’ 16.386”	173° 24’ 36.700”
C3	20	41° 10’ 49.880”	173° 21’ 32.505”
C4	22	41° 10’ 14.111”	173° 20’ 50.361”
C5	30	41° 07’ 35.810”	173° 19’ 02.327”
D1	5	41° 07’ 46.000”	173° 30’ 24.000”
D2	10	41° 07’ 39.000”	173° 30’ 22.000”
D3	15	41° 07’ 43.000”	173° 30’ 07.000”
D4	20	41° 07’ 26.000”	173° 29’ 50.000”
D5	25	41° 07’ 06.000”	173° 29’ 27.000”
D6	30	41° 06’ 08.809”	173° 25’ 30.532”

Analyses of environmental characteristics at sites along Transect A, B, C and D were carried out on 14, 14, 4, and 11 occasions (1995-1997), respectively. Depth profiles of water column conductivity, temperature, chlorophyll *a* (chl *a*) and light intensity were measured using a Chelsea Instruments “Aquapack” multi-parameter profiler and a LICOR submersible photosynthetically active radiation (PAR) sensor. Seawater salinity and density values were automatically calculated according to standard procedures using Chelsea Aquapack software. The relative degree of water column stratification was compared according to the surface to bottom range (discontinuity) of sigma t values. Secchi depth readings were made routinely as an indication of surface water clarity.

Seawater samples were collected with a messenger activated 5 l Van Dorn sampler for evaluation of phytoplankton species composition, nutrient concentrations (results reported separately) and calibration of *in situ* chl *a* measurements.

Sediment samples were collected on one occasion by SCUBA divers and an Ekman grab sampler when depths were greater than 30 m, to describe the grain size distribution of the seabed at each site. Particle size distributions of the upper 20 mm sediment layer were analysed using standard techniques for soil analysis (Nicholson 1984) modified for marine sediments. After removing and weighing the >2 mm size fraction and removing shell debris by acidification, the remaining material was separated into three fractions prior to weighing; clay (<0.002 mm), silt (0.002 - 0.02 mm) and sand (0.02 - 2 mm).

Definition Box 1: Technical definitions

psu (or practical salinity units) are based on conductivity and temperature 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.

CTD- submersible sensor array/data logger that measures conductivity, temperature and depth simultaneously in seawater.

Water column density structure- The density structure of the water column is controlled by the variation in temperature and concentration of dissolved salts (*i.e.* salinity) with depth. The oceanographic convention is to express density as

$$\sigma_{S.T.P.} \text{ (or } \sigma_t) = (\text{density} - 1) \times 10^3).$$

Thus water with a density of 1.02400 would have a sigma t value of 24.0. Freshwater inflows, because they are less dense than seawater, generally spread out in a floating plume of lower salinity (brackish) water over the surface of the sea. When water of lower density is situated above water of greater density, the water column is said to be stable. In other words it is relatively resistant to vertical mixing. The difference between the maximum and minimum sigma t values in the water column (the density profile discontinuity) is a simple means of comparing the relative strength of the stratification gradient.

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.

PAR (or photosynthetically active radiation)- particular wave lengths of the sun's radiation that are used by plants for photosynthesis. PAR can be measured in the water column using a submersible sensor.

Secchi depth- A simple measure of water clarity carried out by lowering a black and white disk (Secchi disk) into the water and recording the depth at the point where it disappears from sight.

2.3 Microalgal biomass

Sediment and water column chl *a* concentrations were used as relative indicators of benthic and planktonic microalgal biomass, respectively. These analyses were coordinated with the collection of environmental data (Section 2.2).

2.3.1 Benthic microalgae

Twelve randomly placed, intact sediment cores were collected at each site by SCUBA divers using 62 mm diameter Perspex tubes. Once on board the vessel, each of the cores was subsampled with open-ended 10 ml syringe barrels (15.6 mm diameter). At sites deeper than 30 m, samples were collected with an Ekman grab sampler and subsampled similarly at the surface. Due to a hinged lid on the grab sampler, reasonably undisturbed sediments were able to be obtained, including the flocculent boundary layer. The top 5 mm of the syringe cores were sliced off and distributed into separate plastic centrifuge tubes for storage.

Six of the replicate samples were frozen (-20ºC) for later analyses of chl *a* as a relative measure of photosynthetic biomass. For this analysis, sediments were thawed, extracted overnight in 90% acetone (4ºC in the dark) and analysed spectro-photometrically, with corrections for pheopigments, according to procedures described in Lorenzen (1967) and Strickland & Parsons (1968).

The remaining six replicates were processed for determination of microalgal species composition. These results will be reported in a separate companion report describing benthic and planktonic community structure (Gillespie and Rhodes, *in prep.*).

2.3.2 Planktonic microalgae

Fluorometrically-derived chl *a* profiles of the water column were collected with a fluorometer concurrently with the environmental data collected by the "Aquapack" profiler. They were calibrated by GFC-filtration of 1000 ml water samples collected with a Van Dorn water sampler from specific depths, followed by grinding of filters, extraction and spectro-photometric analysis as described for benthic microalgae. Mean chl *a* (extracted)/chl *a* (fluorescence) did not vary consistently according to depth or region. Therefore, the overall mean value (2.59 ± 0.95, $n = 233$) was used as a correction factor. Corrected values were averaged over 1 m depth intervals and total depth integrated values were calculated.

Definition Box 2: Microalgae

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

Benthic microalgae- single-celled microscopic plants that live and grow on the seabed.

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. The conversion (chl *a* to carbon) can vary according to the species of microalgae present and a number of environmental characteristics. As an example, a diatom/dinoflagellate-dominated phytoplankton community under light-limited conditions would be expected to contain 28-32 mg chl *a* per g Carbon (Hunter and Laws 1981).

Phaeopigments (or phaeophytin)- refer to a variety of pigments formed as breakdown products of chlorophyll as cells die and decompose.

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.

3 RESULTS AND DISCUSSION

3.1 Site characteristics

3.1.1 Sediment texture

Sediment textures ranged from sandy to sandy/mud, with varying amounts of shell debris (Figure 2). With the exception of the nearshore site A1, sites along the western transects (A and B) were muddier, containing roughly 40-70% silt/clay. Sites along the eastern transect (C and D) were predominantly composed of sand. These results are consistent with existing NZOI sediment chart information (Mitchell 1987) and numerous unpublished aquaculture site assessments (1999-2003) which indicate that silts dominate, particularly in western and central regions of the Bay, with varying amounts of sand. According to the sediment grain size characteristics, the study sites were typical of the soft sediment substrata that lie beneath a large proportion of Tasman Bay. This suggests that benthic observations made at individual sites are likely to be representative of large areas and can probably be safely extrapolated to provide general conclusions covering the greater Bay area.

3.1.2 Water column density structure

Water column profile characteristics (all sites and sampling occasions) are summarised in Appendix 1. Salinity and temperature profiles along transect A and B indicated the influence of the Motueka River and a number of smaller streams that discharge to the western side of the Bay. Density profiles at selected sites (all sampling occasions) are shown graphically in Appendix 2. Examples for offshore Sites A5, B5 and C5/D5 are shown in Figure 3. Surface water salinities ranged from 16.5 to 35.1 psu at nearshore sites, with values <30 psu commonly observed on transects A and B.

Density stratification along the three transects (as indicated by the surface to bottom sigma t discontinuity) varied considerably over the study period, but generally indicated some degree of stratification on most sampling occasions (Figure 4). Transect A, which is affected by the Motueka River plume, was generally the most strongly stratified while Transect C/D on the eastern side of the Bay was least stratified. Comparison of the density profiles with mean daily flows of the Motueka River (Figure 5) suggests that strongly stratified conditions can remain for a period of weeks after a major flood event. For example, the stratified conditions observed at Transect A and B sites (17-18 January 1996) appear to have been a remnant of a flood event of 300 to 600 m^3 s^{-1} that occurred three weeks earlier on 24-25 December 1995. Freshwater influences were also observed at the seaward ends of the western transects with values of 30-33 psu commonly occurring after significant rainfall. Near-bottom salinities were generally >34 psu at all sites/sampling occasions.

Thus, the freshwater influences, particularly in the vicinity of the Motueka River plume, resulted in a complex circulation pattern consisting of varying periods of water column stability probably terminated by wind-induced mixing events. Depending on the timing of the mixing events, these conditions can have profound effects on phytoplankton production. Phytoplankton blooms, for example, generally occur during stratified conditions, however this can only happen when sufficient plant nutrients (dissolved nitrogen, phosphorus and silicon) are present. Once the nutrients are exhausted, production declines again until nutrients are replenished either by a mixing event or further input via freshwater discharge. See MacKenzie *et al.* (2003) for a discussion of nutrient concentrations during the study period.

3.1.3 PAR and water clarity

Photosynthetically active radiation (PAR) penetrated to the seabed at all sites (Table 2); however the measured light intensities at approximately 0.5 m above the seabed were highly variable over time. Irradiances were generally <10% of the surface readings at depths >15 m, with readings down to 1% or lower commonly observed. Although a weak relationship was observed between Secchi depth readings (overall range, 0.9-12.0 m) and near-bottom PAR, it is likely that subsurface turbidity layers were a major factor in controlling PAR availability at the seabed, particularly at the deeper sites.

Secchi readings indicated reduced water clarity at sites nearer to shore (Figure 6), particularly on the western side of the Bay (Transects A and B). These results are likely to be related to sediment input from freshwater tributaries and sediment resuspension at the shallower nearshore sites. Reduced water clarity (as indicated by Secchi depth readings <4 m) was also periodically observed at outer transect sites. In each case, these could be linked to significant rainfall events and resulting high flows in tributary streams within a period of <3 days prior to sampling. These results indicated potential catchment land use-related effects to water clarity over a large proportion of Tasman Bay. Since water clarity can have a major effect on microalgal productivity due to light limitation, follow-on implications for shellfish nutrition could also be expected, suggesting that light availability was probably the main controlling factor of microalgal productivity.

Table 2. Photosynthetically active radiation (PAR) measured at 0.5 m above the seabed (all sites and sampling occasions).

	PAR (μ Mol m^{-2} s^{-1})	
Depth (m)	**Range**	**Mean ± S.D.**
3 - 7	0.6 - 425	129 ± 153
9 - 14	2.2 - 121	9.0 ± 7.2
15 - 18	0.4 - 58	13.0 ± 19.0
20 - 30	0.2 - 20	5.8 ± 6.0

3.2 Microalgal biomass

3.2.1 Benthic microalgae

Sediment chl *a* concentrations (all sites and occasions) ranged from 1.8 to 192 mg m^{-2} (Appendix 3). Examples are shown for a winter/spring (Figure 7) and a summer period (Figure 8). Although highest values were generally associated with the shallower sites, these were also the most variable over time; probably because of episodic, storm-related physical disturbance of the seabed. Concentrations were generally highest during mid summer; however, high levels were also occasionally observed during midwinter, in association with calm sunny periods (Figure 9). At some sites, seasonal maxima and minima were less distinct.

The mean ratio of chl *a* to phaeophytin was 0.5 ± 0.9. Highest ratios were generally associated with shallower sites (mean 1.1) as compared to the offshore sites (mean 0.3), suggesting that a higher proportion of the seabed microalgal biomass was in a state of senescence at deeper locations due to lower light availability.

3.2.2 Planktonic microalgae

Water column chl *a* concentrations ranged from 0.2 to 6.4 mg m^{-3} (all sites and occasions) (Appendix 1). Depth profiles of chl *a* concentration (Appendix 2) demonstrated distinct subsurface maxima during most sampling occasions; however, the depth and the magnitude of the maxima

varied considerably over time. Examples are shown for Sites A5, B5 and C5/D5 (Figure 3). Lowest concentrations were observed at the sea surface (possibly as a result of UV inhibition of phytoplankton growth), while values >3 mg m^{-3} were generally associated with near bottom waters. In general, chl *a* maxima of offshore sites (A5, B5, C4 and D5) ranged from 1-3 mg m^{-3}. These concentrations indicate that, on most occasions throughout the study period, sufficient particulate food was available (somewhere within the water column) to adequately support bivalve shellfish growth. On some winter occasions (A5-23/7/96, B5-24/7/96 and 20/6/97), lower concentrations, (between 0.5 and 1.0 mg m^{-3}), were observed throughout the water column. Although these conditions would likely result in lower bivalve growth rates, they appeared to be relatively short term events. On four occasions, nearshore sites on the eastern side of the Bay contained mean chl *a* concentrations of <0.5 mg m^{-3}, *i.e.* concentrations that would not be expected to support mussel shellfish growth unless food components other than phytoplankton were present. Therefore, terrestrial input of particulate organic material (*e.g.* from the Motueka catchment) may be of relatively greater importance in nearshore waters. This will be assessed in future ICM-related projects.

Sampling dates with depth ranges that contained >1 mg m^{-3} chl *a* (*i.e.* those that would be expected to provide optimum growing conditions for shellfish, including spat), are expressed graphically in Figure 10. This provides a rough guide as to the potential benefits of selecting specific depth ranges for optimising shellfish aquaculture production rates.

Depth-averaged water column chl *a* concentrations (Figures 11-13) ranged from 0.2 to 3.2 mg m^{-3} with the highest and lowest average values both associated with shallow, nearshore sites. Although no major phytoplankton blooms were observed during the study period, some consistent seasonal peaks in biomass were evident. These corresponded generally to the autumnal and winter/spring diatom peaks reported previously for a single site in northern Tasman Bay (MacKenzie and Gillespie 1986); however, summer peaks in phytoplankton biomass were also observed during the present study.

Summary averages of areal chl *a* levels for various depth ranges in Tasman Bay are shown in Table 3. Since these values represent a seasonal average for the dominant sediment habitats within the different depth ranges and geographical regions, they can be used to generate a rough estimate of the average phytoplankton and benthic microalgal biomass for the Bay. Such information can then be used to provide input to ecological models designed to assess the productive potential of the Bay in terms of aquaculture and/or fishery harvest.

Table 3. Average planktonic, benthic and total chlorophyll *a* composition of Tasman Bay sites grouped according to depth. Data are presented as means ± SD (*n*).

	Chlorophyll *a* (mg m^{-2} ± SD)		
Depth (m)	**Planktonic**	**Benthic**	**Total**
<10	7.2 ± 4.5 (*34*)	32.3 ± 39.1 (*33*)	37.3 ± 37.2 (*33*)
10-19	18.2 ± 8.7 (*85*)	13.3 ± 10.3 (*81*)	31.5 ± 14.1 (*81*)
>20	26.4 ± 9.5 (*60*)	8.7 ± 9.4 (*56*)	35.0 ± 13.1 (*56*)

3.2.3 Benthic vs planktonic microalgae

The extent that benthic bivalves and other suspension-feeding animals are reliant on phytoplankton as a source of food is a question open to debate. Our hypothesis is that in Tasman Bay, benthic microalgae (primarily diatoms living on the seabed) make an important contribution to the growth potential of the near-bottom feeding environment for cockles, surf clams, scallops, oysters, mussels, *etc*. (Gillespie 1997, Gillespie *et al*. 2000). This can occur through current (or disturbance-driven) resuspension of the sediment dwelling microalgae into the near-bottom water layer.

In order to determine how important benthic microalgae are to the productivity of the Bay (extending to fish and shellfish resources), it was necessary to determine the relative proportion of planktonic versus benthic microalgal biomass, and to determine whether or not any significant seasonal trends occur. Comparisons of benthic chl *a*, as a percentage of total (benthic + planktonic) chl *a* contained in a one square metre area (surface to bottom), are described graphically for all sites and occasions (Appendix 2). These comparisons show that benthic microalgae do indeed contribute significantly to the total photosynthetic biomass of soft sediment habitats in Tasman Bay, out to depths of at least 20 - 25 m. The average of all sites and occasions was 39% benthic, with 66%, 40% and 27% relating to transect sites 1, 3 and 5, respectively. At the shallower sites in particular, benthic microalgae often comprised 70 to 99% of the total chl *a*, suggesting that these sediment-living communities may (in addition to terrestrial detritus) be a primary food supply for seabed animal communities of shallow subtidal environments.

Seasonal comparisons of the percentage of benthic chl *a* at selected transect sites are summarised in Figure 14. Highest benthic contributions generally occurred during midsummer (January/February) periods. However, similarly high contributions also occurred occasionally during winter/spring periods; probably under calm, clear conditions of maximum water clarity.

4 SUMMARY

4.1 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 Institute (Cawthron) investigation into the effects of freshwater inflow quantity and quality on the productivity of the marine receiving environment, is presented here. Other components are presented in a series of related (companion) reports.

In the present report, the planktonic and benthic microalgal biomass (and associated environmental characteristics) of Tasman Bay are described in order to determine their relative importance as food sources for bivalve shellfish and identify key controlling factors. Analyses were carried out at 15 sites along a series of transects in the Bay at one to two-month intervals, over a two-year period. A specific goal of the work was to identify trends over space and time that could benefit the sustainable management of coastal shellfish resources in Tasman Bay.

4.2 Water column stratification

Salinity and temperature profiles of the study sites clearly showed the influence of freshwater inflows over the majority of Tasman Bay. The density structure of the water column was strongly affected by freshwater inflows to a distance of at least 10 km offshore, particularly along the western side of the Bay and encompassing the proposed Aquaculture Management Areas). Stratified conditions were most prominent following moderate to high rainfall events. Such conditions can persist for a period of weeks after a significant flood event. These findings show the potential for catchment-related terrestrial runoff to impact upon aquaculture activities in a variety of ways (*e.g.* enhancement or inhibition of primary production, contamination of seawater and/or sediment environments).

4.3 Water clarity

Reduced water clarity was commonly observed at nearshore sites of all transects (particularly those of the western side of the Bay) and was often observed at offshore sites when sampling followed significant rainfall events (*i.e.* elevated flows of the Motueka River) within approximately three days. Thus, water clarity throughout much of the Bay appears to be strongly affected by land runoff of sediments. Water clarity can, in turn, affect the amount of light available for photosynthesis, both within the water column and at the seabed. Sufficient light penetrates to the seabed throughout a majority of the Bay to support some degree of photosynthetic activity. However, light levels at the seabed were highly variable, depending on the clarity of the water, and often low enough to limit microalgal growth, particularly at depths >15 m. Phytoplankton and benthic microalgal production can therefore be inhibited by sediment inflows. This appears to be relatively more significant in nearshore and near bottom waters, where sediment resuspension can potentially maintain high turbidity levels for considerable periods of time after a flood event.

4.4 Microalgal biomass (food for shellfish)

Benthic and phytoplanktic microalgae are both important contributors to the photosynthetic productivity of Tasman Bay. This study provides further evidence that both are major components of the food supply for suspension-feeding shellfish. Seasonal cycles of benthic and planktonic microalgal biomass support the hypothesis that their relative importance for shellfish growth can vary over time. Peak phytoplankton biomass was observed during the winter/spring period with

occasional additional peaks during summer. This is consistent with the winter/spring diatom bloom period and summer dinoflagellate peaks reported by MacKenzie and Gillespie (1986). The benthic microalgal cycle was dominated by a consistent mid-summer peak, suggesting that light availability is the main controlling factor. However, at some sites a secondary peak was observed during August/September after a period of particularly low phytoplankton biomass and high water clarity. Comparisons of the benthic and planktonic cycles indicate that benthic microalgae can play a major role in shellfish nutrition by ensuring continuity of the particulate food supply during periods of particularly low phytoplankton abundance.

Subsurface chl *a* maxima were a regular feature of the water column profiles and were often found at mid water or near bottom levels. With the exception of a few early to mid winter sampling occasions, chl *a* concentrations of > 1 mg m^{-3} were observed somewhere within the water column at all offshore sites (including those within the proposed Tasman Bay AMA). These results support the existing knowledge, as evidenced by the successful scallop fishery and mussel spat production, that Tasman Bay has potential for shellfish aquaculture development. If mussel farm developments are to prosper, however, it may be necessary to adopt a management approach that utilises depths >4 m in order to optimise production.

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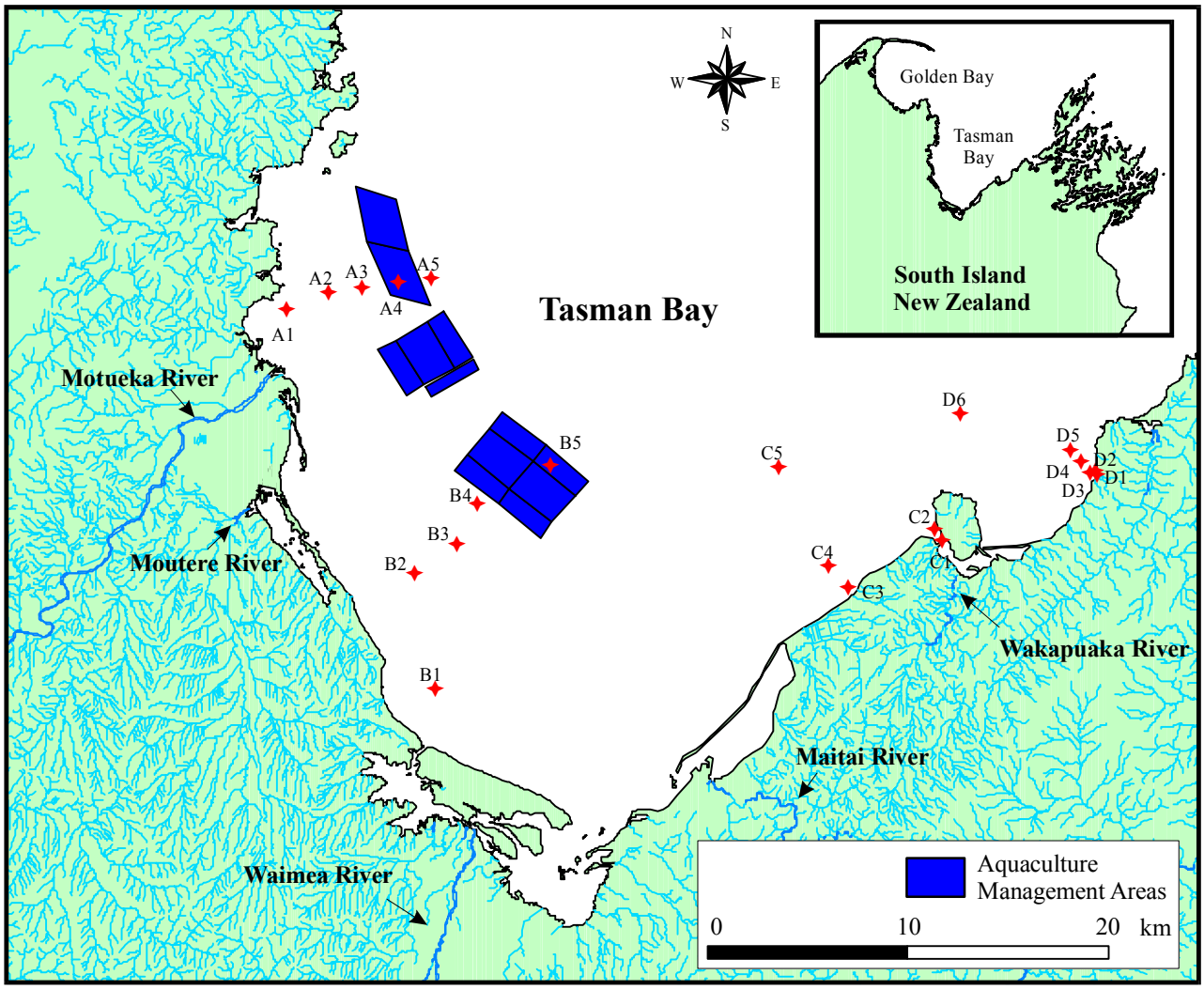


Figure 1. Study location diagram showing transects and sampling sites in Tasman Bay.

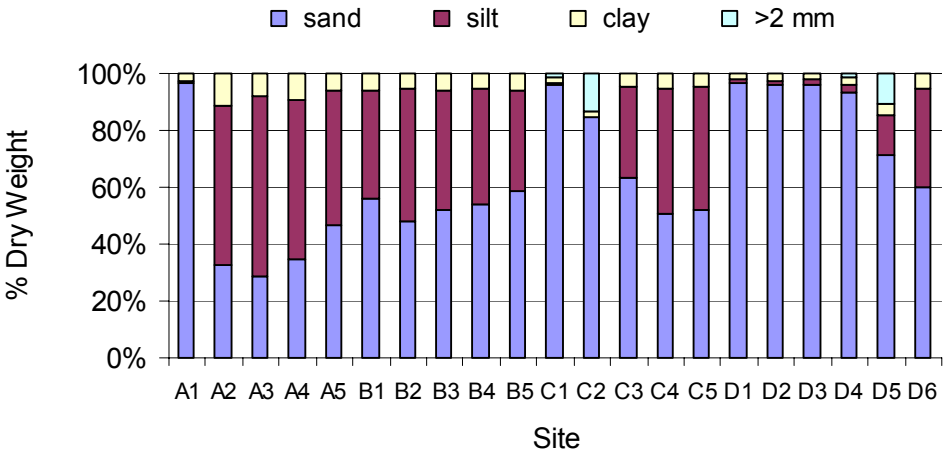


Figure 2. Sediment particle size distribution at Tasman Bay study sites.

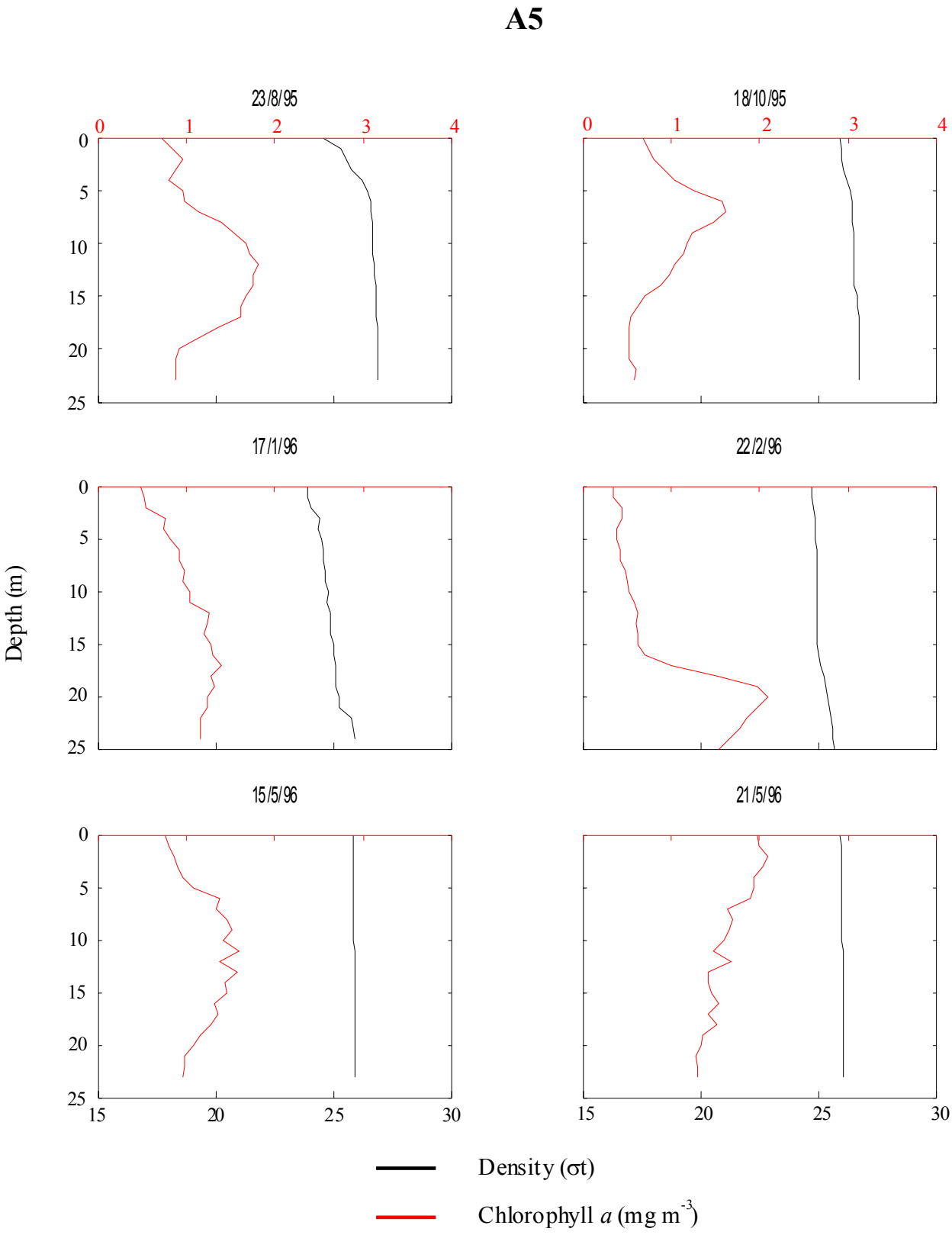


Figure 3. Water column chlorophyll *a* and density profiles at offshore Site A5 (all sampling occasions).

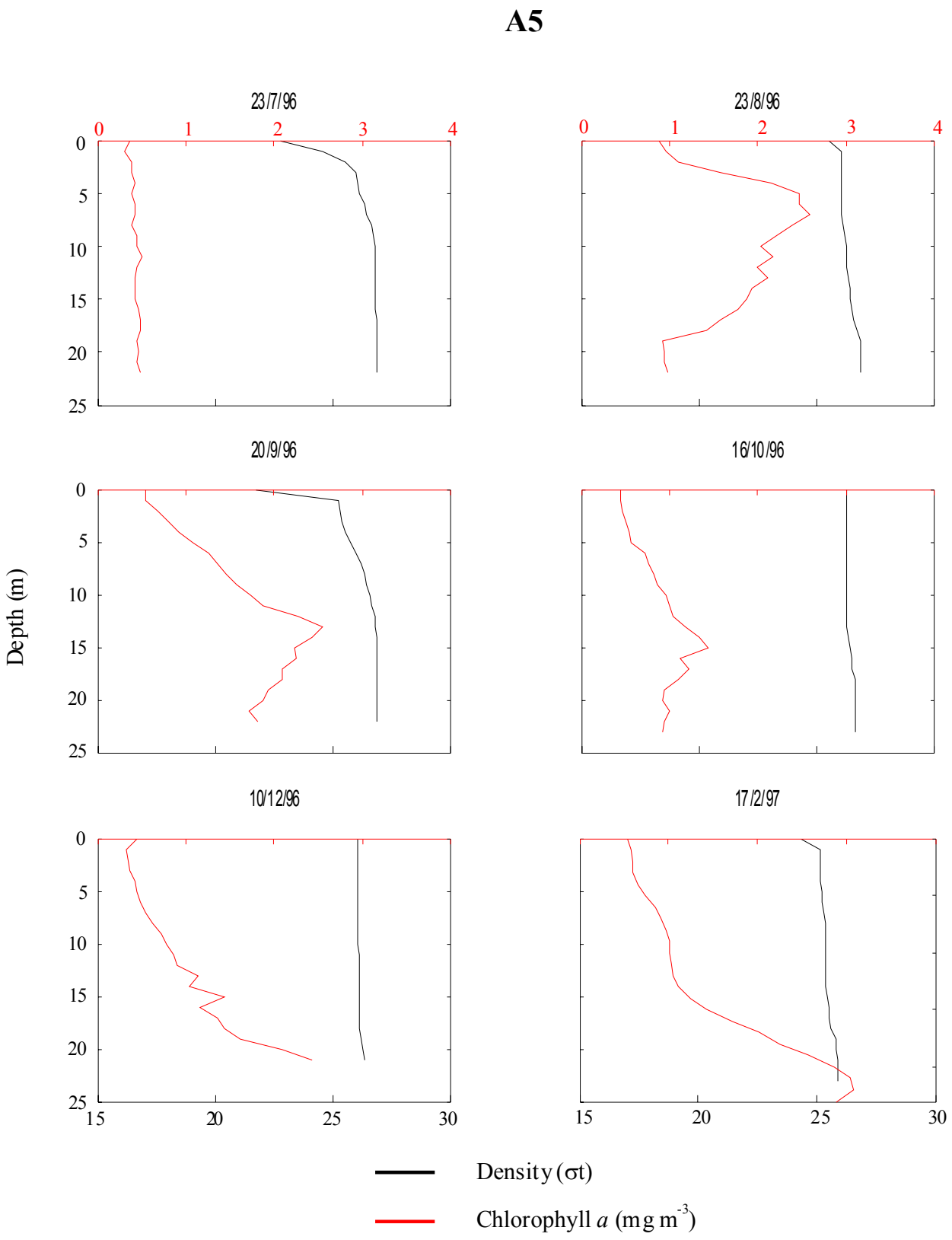


Figure 3. continued.

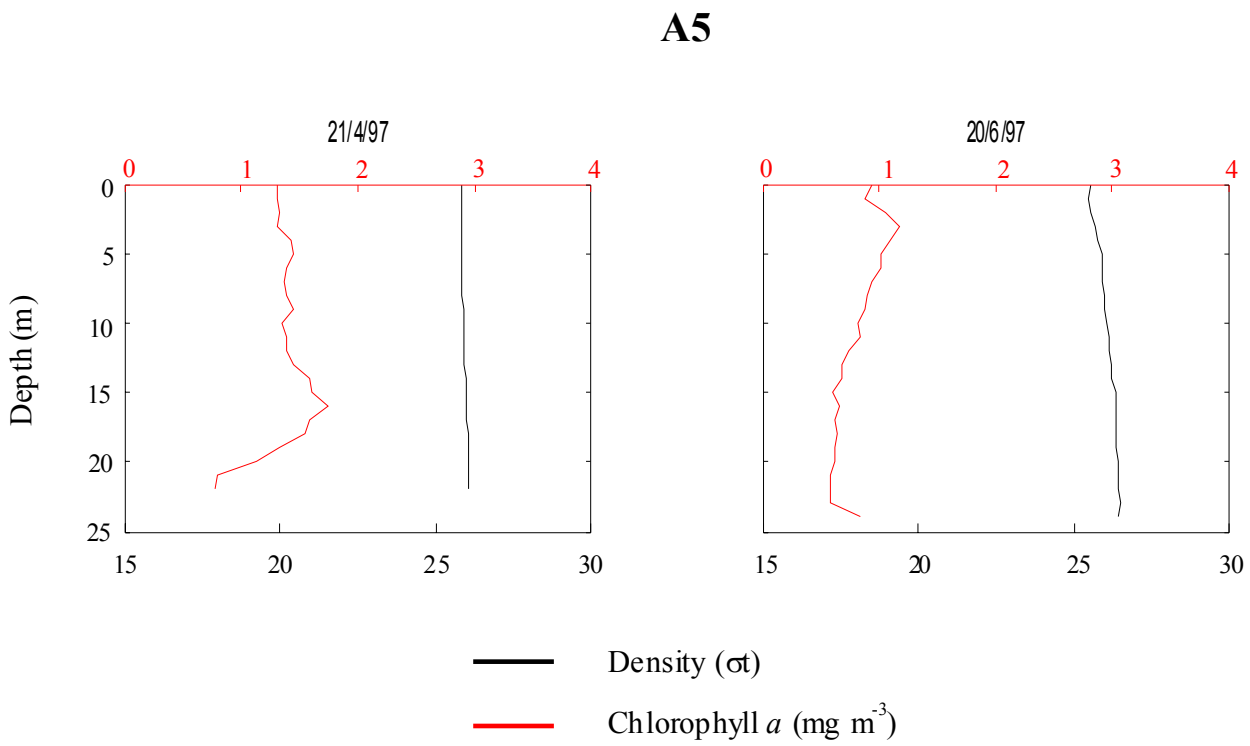


Figure 3. continued.

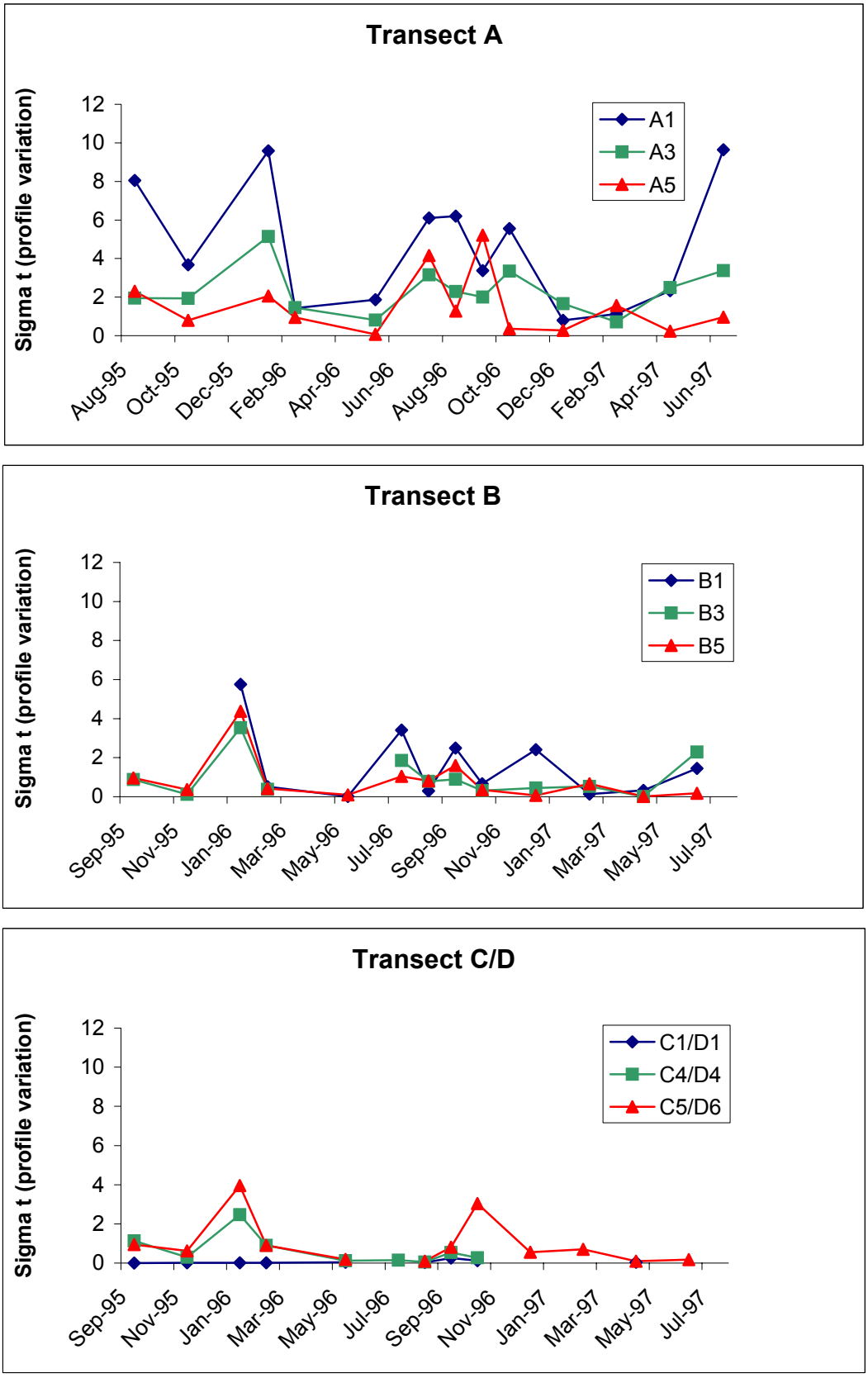


Figure 4. Seasonal variation of the seawater density stratification (surface to bottom sigma t discontinuity) along Tasman Bay transects.

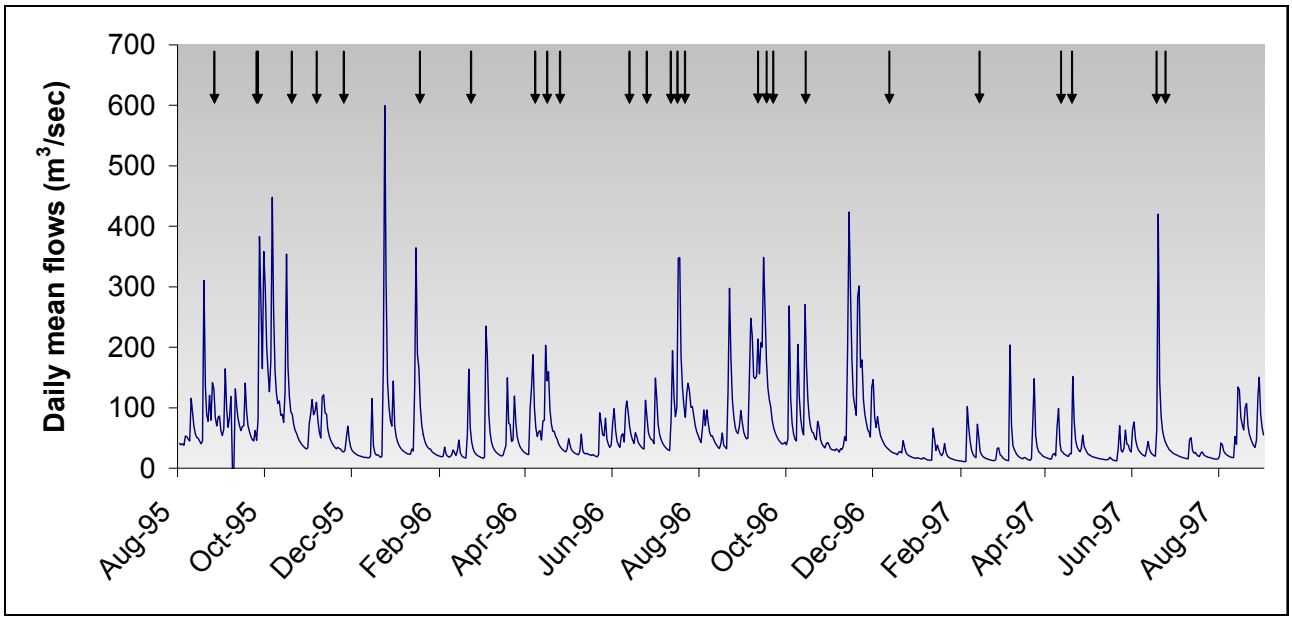


Figure 5. Daily mean flow of the Motueka River at Woodstock. Data provided by Martin Doyle, Tasman District Council. Arrows refer to approximate dates of water column profile analyses.

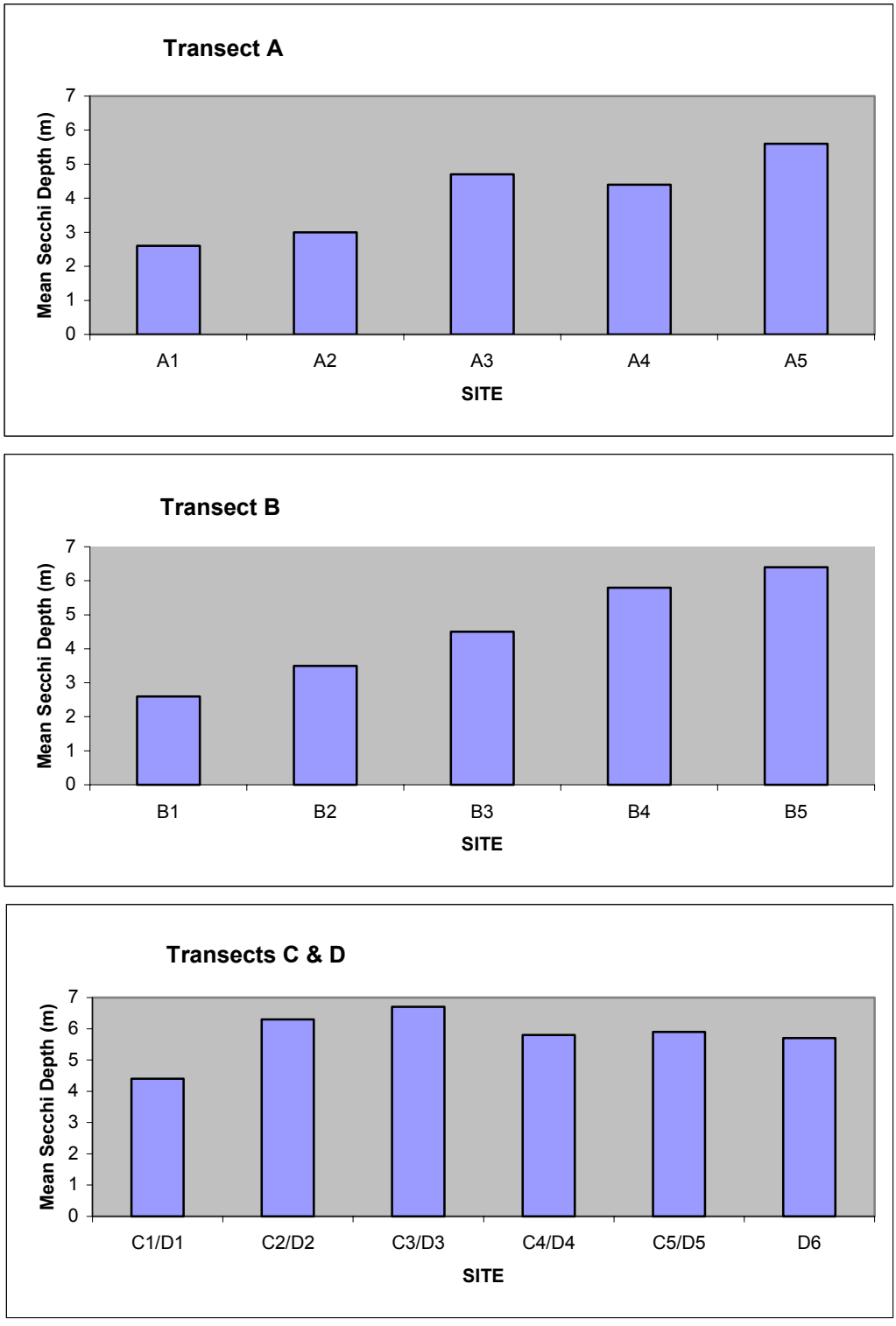


Figure 6. Average Secchi depth at Tasman Bay study sites (all sampling occasions).

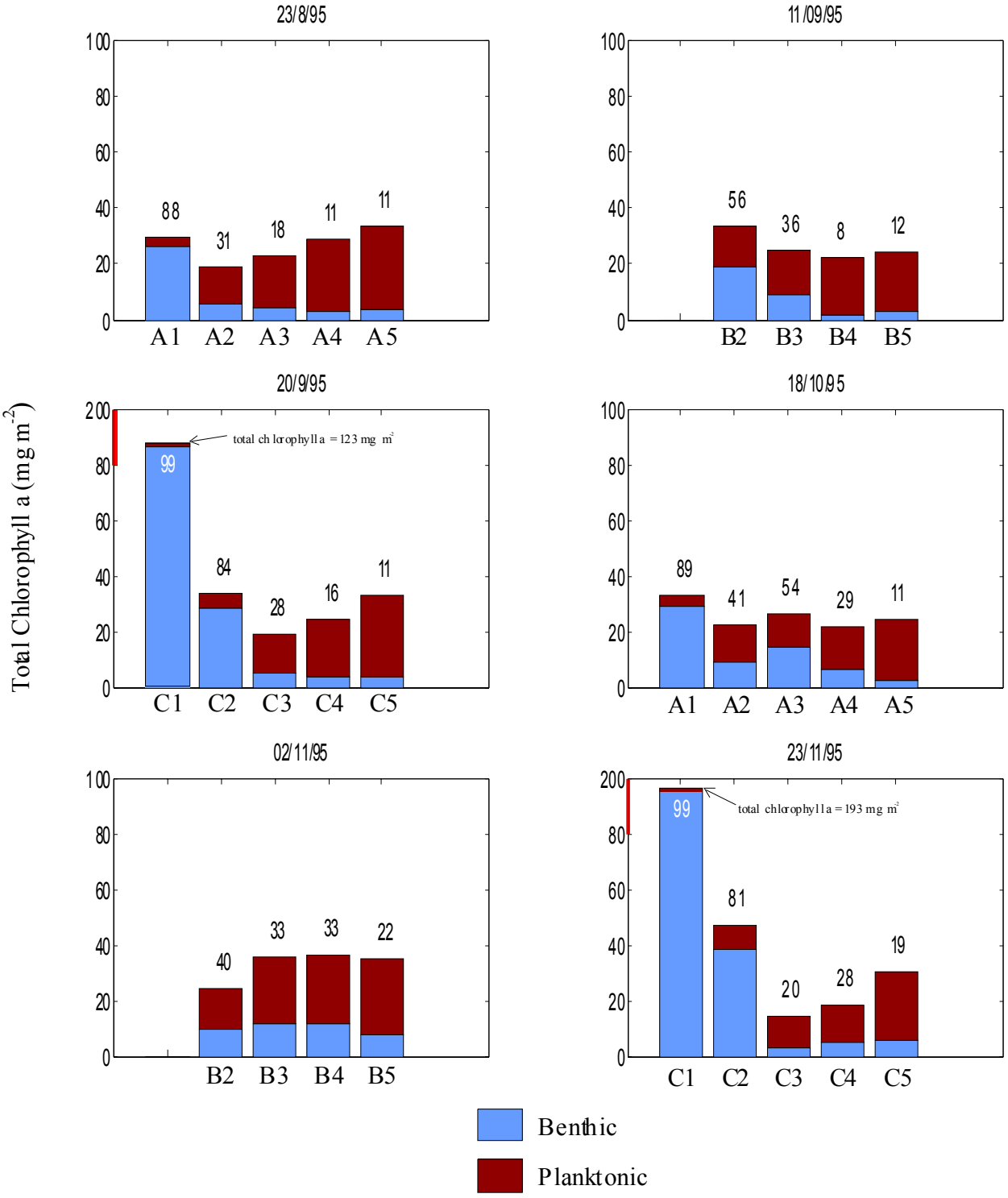


Figure 7. Areal benthic, planktonic, and total chlorophyll *a* contents at Tasman Bay sites (winter-early summer period).

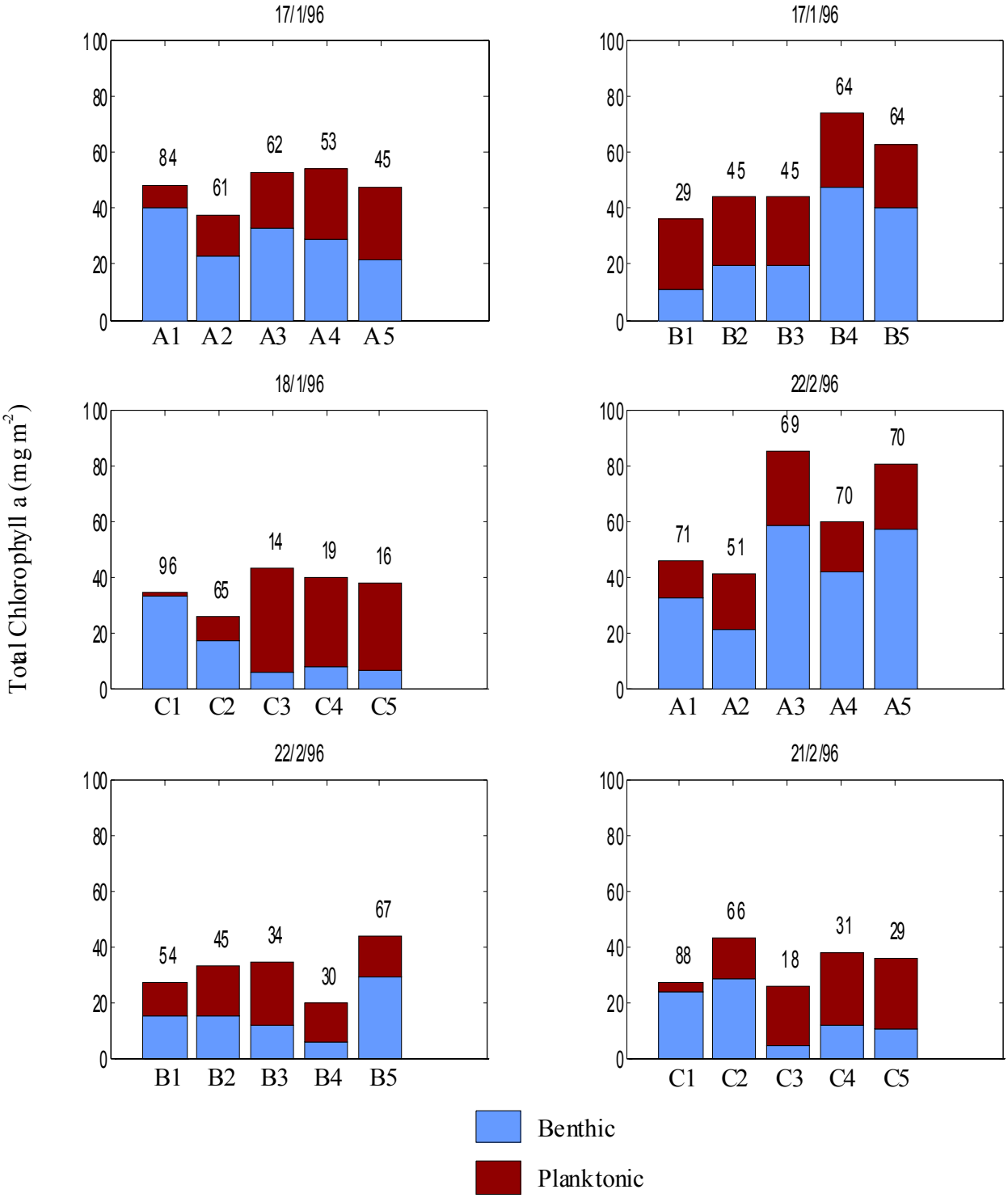


Figure 8. Areal benthic, planktonic, and total chlorophyll *a* contents of Tasman Bay sites (mid summer period).

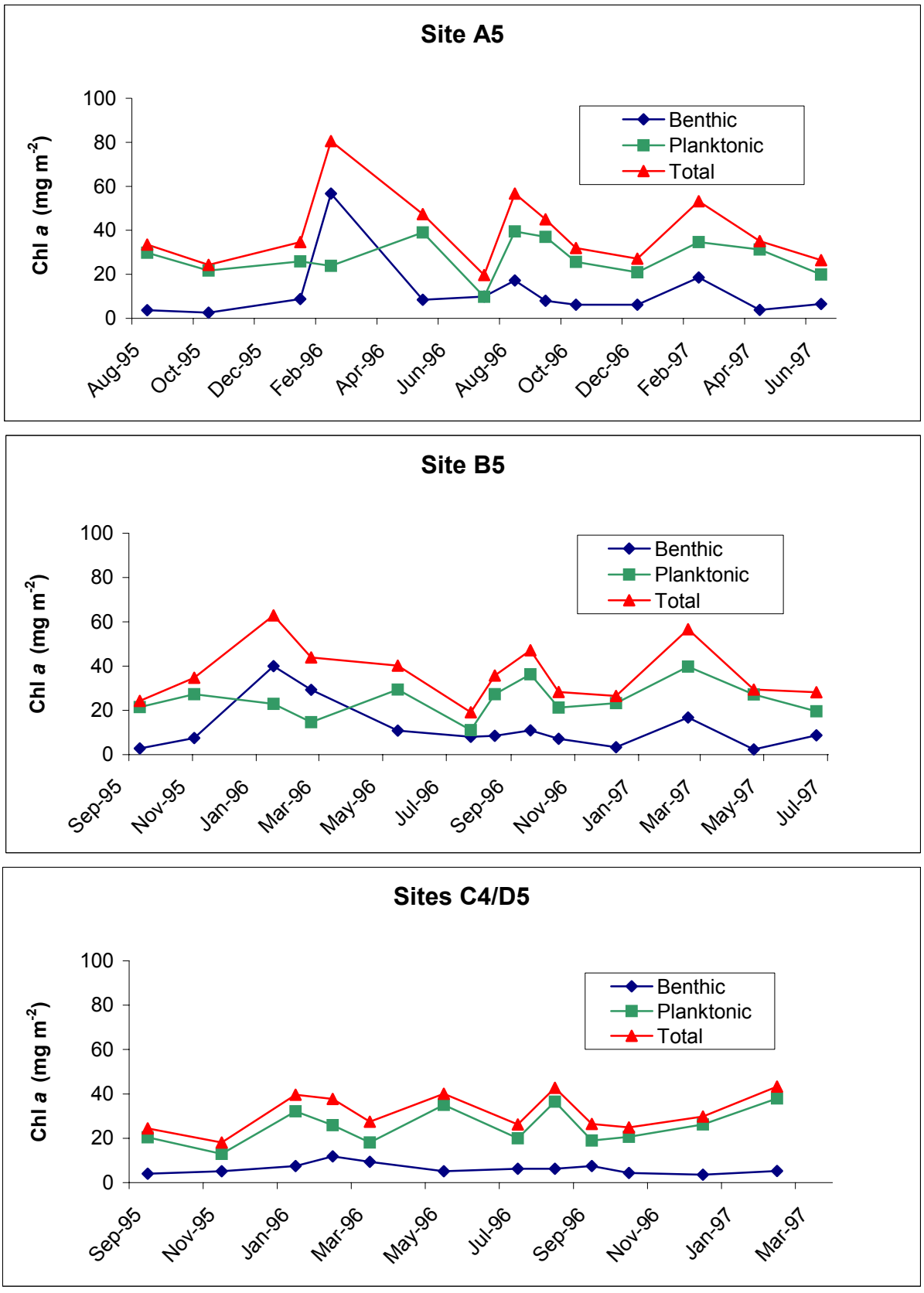
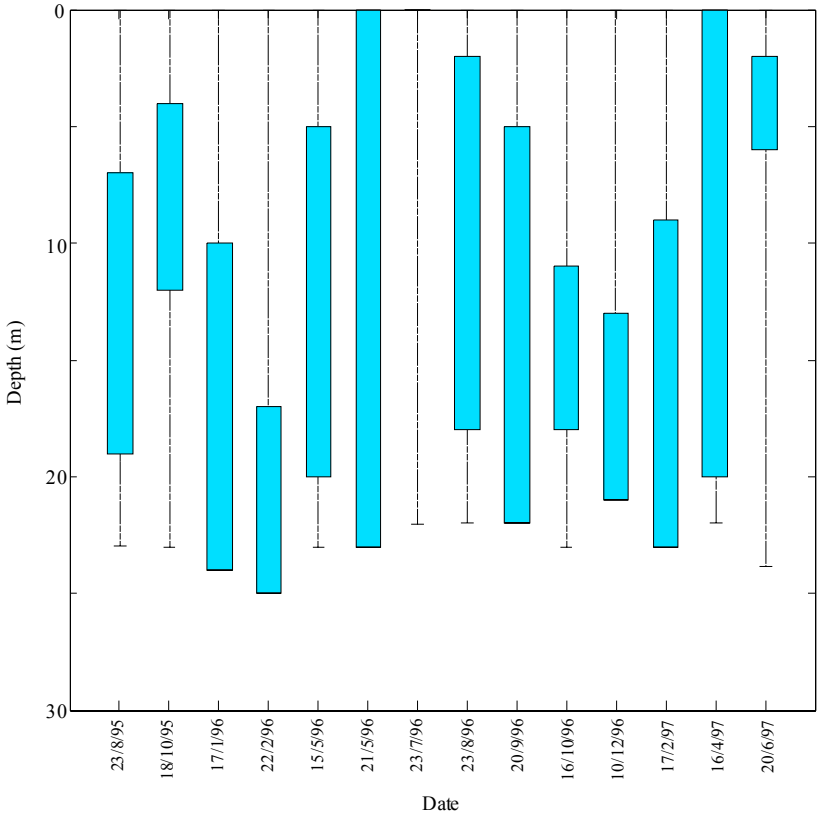


Figure 9. Seasonal variation of benthic, planktonic and total chlorophyll *a* concentrations at sites A5, B5, and C4/D5.

A5



B5

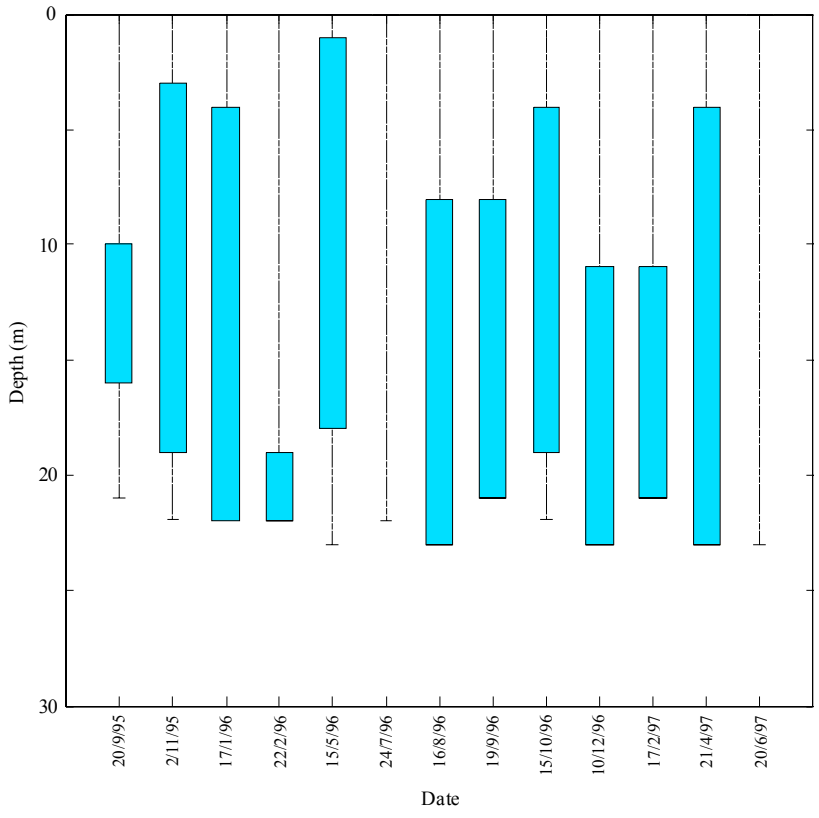


Figure 10. Depth range of water column chlorophyll *a* concentrations > 1 mg m^{-3} at Tasman Bay sites A5, B5, and C4/D5 (all sampling occasions).

C5/D5

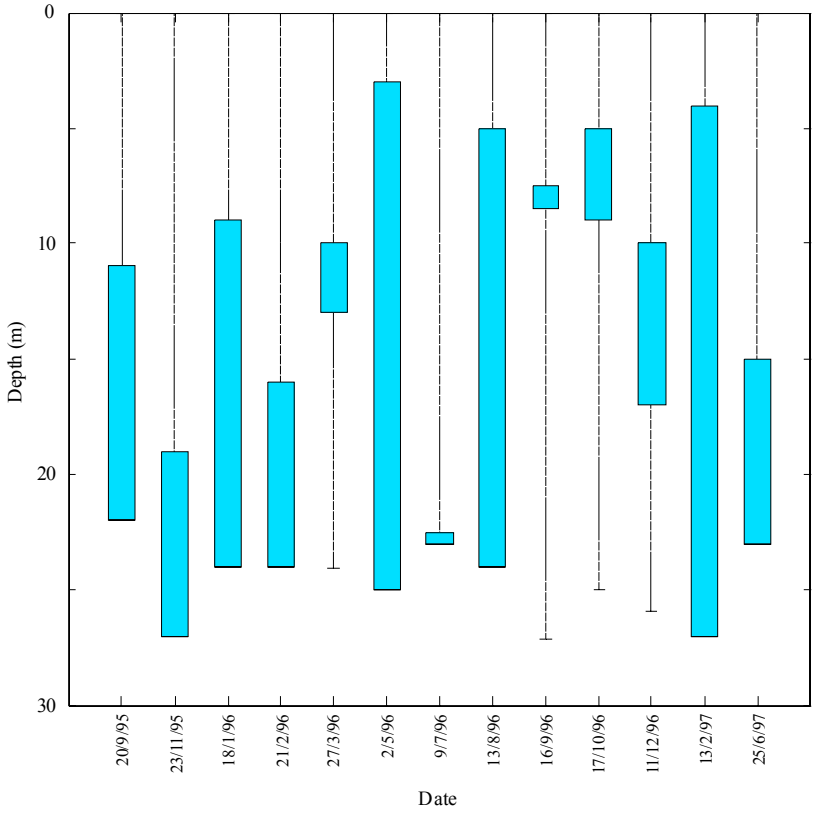


Figure 10. Continued.

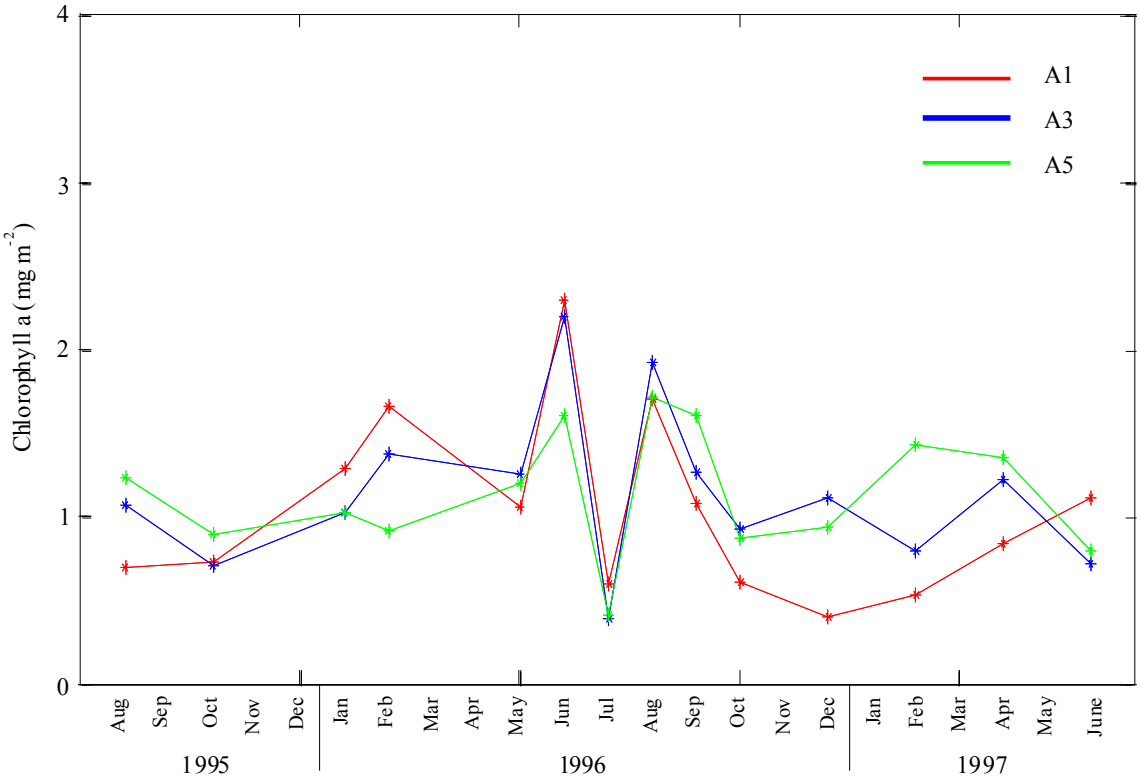


Figure 11. Seasonal variation of depth-averaged planktonic chlorophyll *a* concentrations at selected sites in Tasman Bay (Sites A1, A3 and A5).

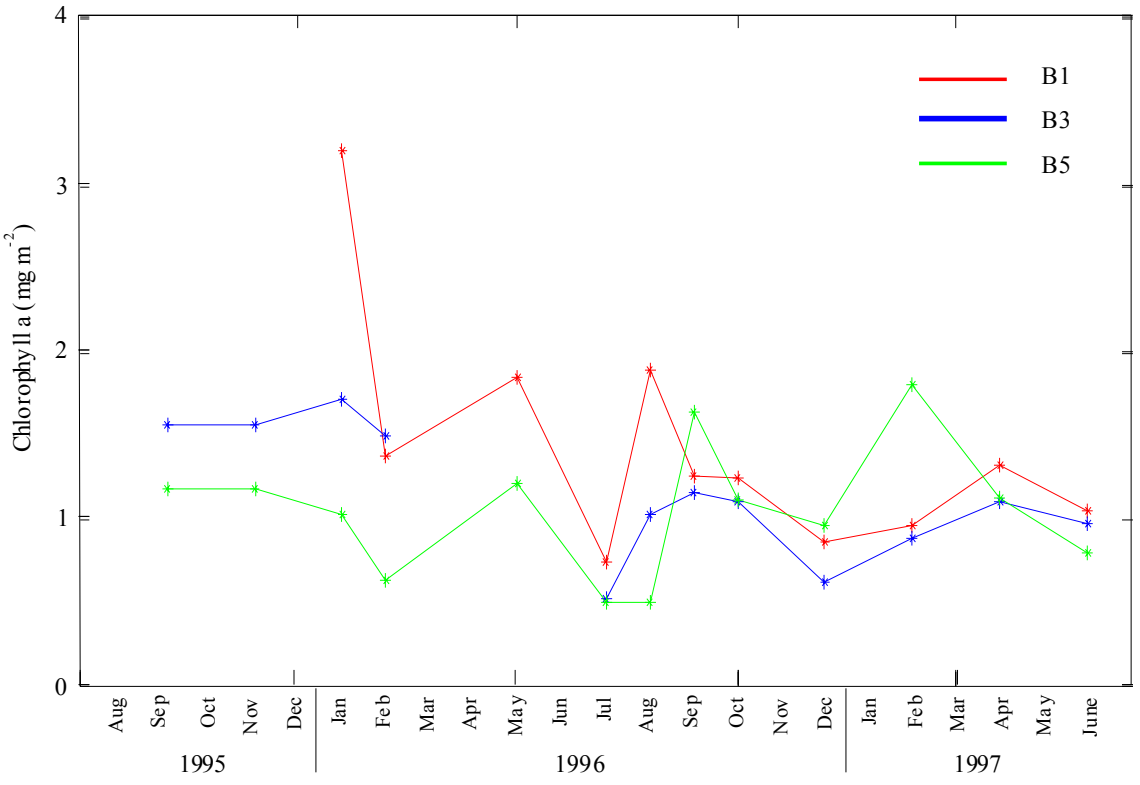


Figure 12. Seasonal variation of depth-averaged planktonic chlorophyll *a* concentrations at selected sites in Tasman Bay (Sites A1, A3 and A5).

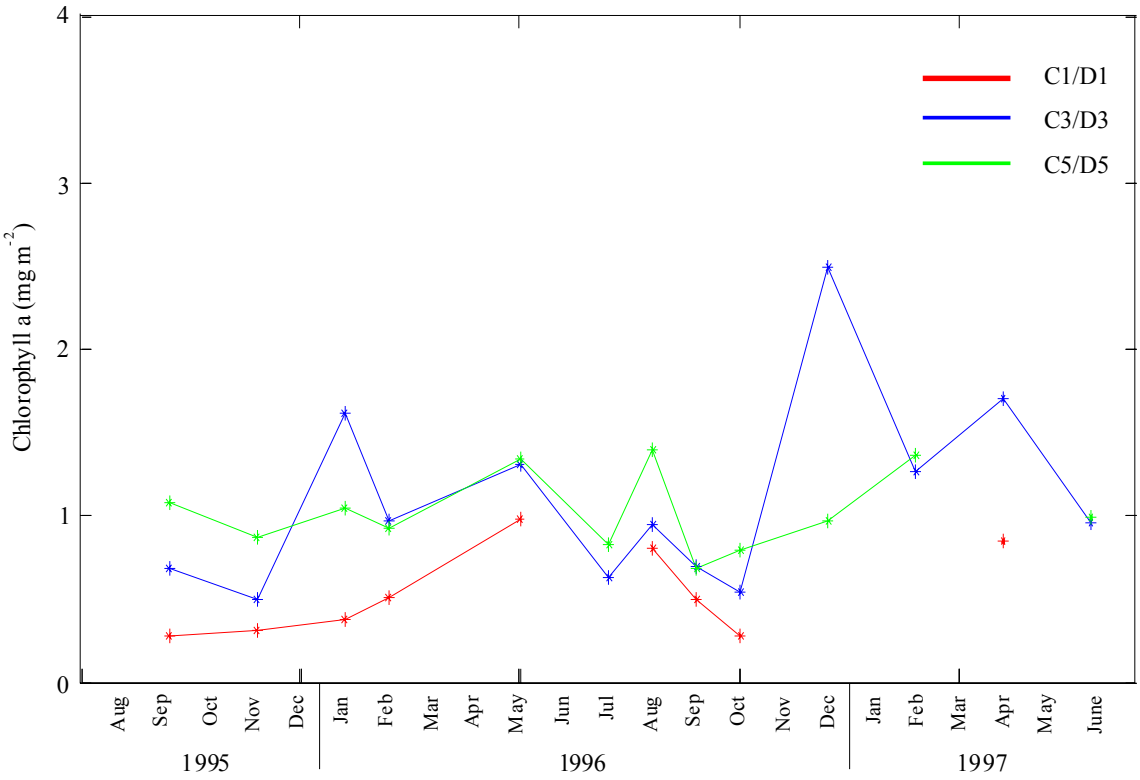


Figure 13. Seasonal variation of depth-averaged planktonic chlorophyll *a* concentrations at selected sites in Tasman Bay (Sites C1/D1, C3/D3 and C5/D5).

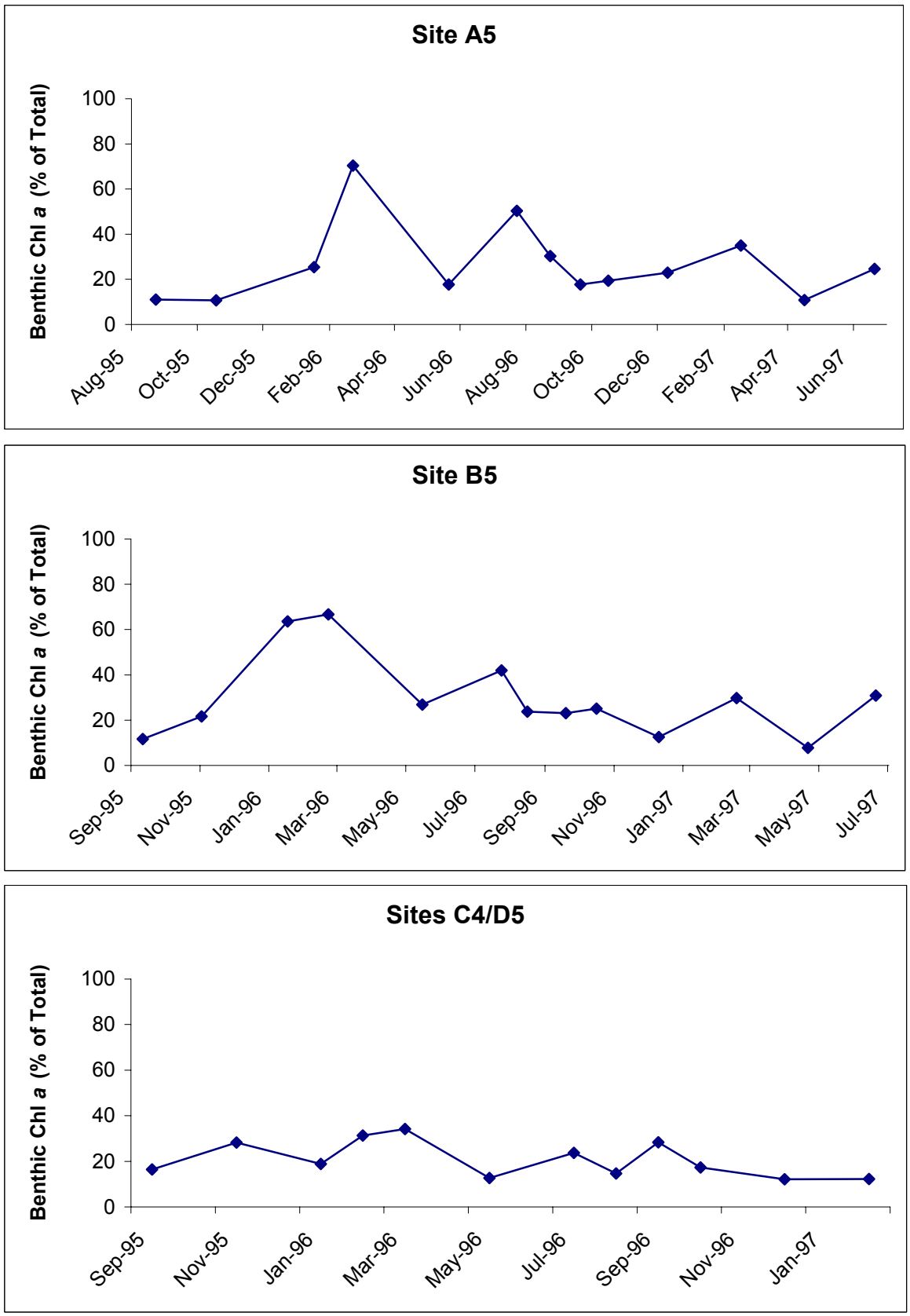


Figure 14. Seasonal variation of benthic chlorophyll *a* as a percentage of total (benthic + planktonic) chlorophyll *a* at sites of 20-25 m depth in Tasman Bay.

Appendices

(All appendices are provided on the accompanying CD to this report)

Appendix 1

Water column profile characteristics at Tasman Bay sites (August 1997-June 1997)

Appendix 2

Water column chlorophyll a and density profiles at selected Tasman Bay sites (all sampling occasions)

Appendix 3

Areal benthic, planktonic, and total chlorophyll a composition of Tasman Bay sites (all sampling occasions)