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BAY OF PLENTY COASTAL WATER QUALITY

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The assistance of John Gibbons-Davies in conducting the often-unpleasant task of taking samples way offshore in less than ideal conditions was greatly appreciated. In addition, the helpfulness of the laboratory staff, Dave Basset, and Amanda Austrin in processing all samples and calibrating instruments is acknowledged.

Cover photograph: Bowentown entrance to Tauranga Harbour, October 1997.

Executive Summary

This report presents results from the first series of comprehensive coastal water quality surveys conducted within the Bay of Plenty from August 1996 through May 1997. Surveys were conducted at sites along two transects extending out to the edge of the continental shelf off Tauranga and Whakatane on each of four occasions. It is intended to repeat the surveys once every third year until an adequate baseline data set is established.

Objectives of the programme included the assessment of nutrient status of the shelf waters and the relative contribution from terrestrial/anthropogenic inputs versus those from the open ocean. Surveys were structured to maximise data acquisition that would improve the understanding of the ecosystem/physical dynamics. Information gained from the study will assist in future reviews and monitoring of Environment B·O·P's coastal plan.

Findings based on the results of these surveys should be treated as preliminary due to each sample being collected from a reasonably unique set of conditions with no repetition. In terms of variations in water quality, near-shore waters were of lower quality and generally continued to improve out to the limit of sampling. Inshore waters could be classed as "mesotrophic" but are close to the high quality "oligotrophic" oceanic waters sampled out on the edge of the continental shelf, especially for the Whakatane transect.

Productivity as indicated by chlorophyll-a was slightly higher on average for the inshore waters off Tauranga. This feature appears to be related to the interaction of Tauranga Harbour with the coastal waters. The freshwater influence from land runoff on the inshore waters off Tauranga during winter appeared to account for around 2.8% of the water mass. In summer with reduced land runoff this appeared to decline to 1.4%.

Terrestrial nutrient inputs to the near-shore waters off Tauranga have the potential to increase nutrient concentrations by around 25% in winter and 12% in summer. Although this shows the potential for adverse impacts from terrestrial nutrient enrichment of the inshore coastal waters, far greater changes could be caused by coastal upwelling. Based on nutrient levels measured in the deep oceanic water on the edge of the continental shelf, upwelling near the shore could potentially result in nutrient increases up to 600%.

A combination of nutrient and physical parameters indicated that nutrient-rich deep oceanic water was moving in on to the continental shelf in several of the sampling runs. It appeared that such intrusion of water was more likely to occur in winter and spring as shown in several other studies.

Several other interesting features were highlighted by the results including possible nutrient recycling from the sediments of the mid-shelf region. Low dissolved oxygen levels were also of concern (65% sat.), but appear to be related to the in-shore movement of deep oceanic water and not excessive depletion as the result of eutrophication.

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Chapter 1: Introduction

1.1 Scope

As a component of Environment B·O·P's Regional Monitoring Programme, surveys of Bay of Plenty coastal water quality are conducted once every third year. The objectives of this programme are the provision of data to;

- provide reliable baseline data
- assess nutrient status
- improve understanding of ecosystem/physical dynamics
- highlight terrestrial/oceanic nutrient contributions
- monitor effectiveness of coastal and land plans and assist in reviews
- address Environment B·O·P's responsibilities under RMA

This report presents the results from the first comprehensive survey of Bay of Plenty coastal waters undertaken as part of the Regional Monitoring Programme.

1.2 Background

World wide shallow inshore waters such as those of the Bay of Plenty are recognised for their high productivity. They are generally important for both natural ecosystems and the economies of countries with these resources. However shallow coastal waters are also highly susceptable to a range of water quality issues. There is a growing recognition of the ways in which pollutants are transported to and possibly accumulated in marine environments. For example it has been estimated that more than 95% of nitrogen delivered by river to the coast accumulates there. The particle reactivity of most pollutants results in the coastal margin, not the deep ocean, being the ultimate sink for all contaminants.

One of the greatest problems facing many countries is one of eutrophication or nutrient enrichment of coastal waters. Even relatively minor nutrient enrichment can lead to subtle changes in food webs from those based on large diatoms to others based on small flagellates and bacteria. As flagellate species become more common as a result of nutrient enrichment, increased blooms of toxin producing species may occur as has been well documented in Japan's Seto Inland Sea (Nakanishi *et al*., 1992). Eutrophication can also lead to anoxia in bays and shelf waters as the result of high productivity and organic enrichment.

A series of extensive toxic algal blooms in 1992/93 onwards prompted some research of the plankton communities and nutrient status within the Bay of Plenty shelf waters (Chang 1994). In addition, a survey of nutrient levels at the 15 m depth contour was conducted throughout the Bay of Plenty off sandy shore coastal profile sites (McIntosh 1994). However, these studies are limited and Environment B·O·P's regional monitoring programme has previously only included enclosed marine waters. This lack of data has made it difficult to assess variations between inshore and offshore plankton and productivity and the influence of oceanic waters.

Similarly when NIWA prepared a model study to identify various scenarios for improving the nutrient status of Tauranga Harbour (Liley *et. al.* 1993) one of the main conclusions was: "Offshore variations in TIN could be a significant factor in fine tuning the results of this study. Further monitoring of offshore nutrient concentrations is recommended to refine the modelling predictions and thus more accurately the likely benefits of any catchment management scenario, particularly Scenario 3."

The studies of the Bay of Plenty coastal waters presented in this report will help improve the holistic approach to resource management taken by Environment BOP. It addresses Environment BOP's responsibilities under the Resource Management Act (1991) in relation to the sustainable management principals set out in Part II (section5) and directives to monitor the state of the environment as set out Part IV (section 35; 1&2a, section 30; 1a). It will also provide data that can be used to monitor the effectiveness of the coastal plan and land plans, particularly in the long-term, and provide a better understanding of terrestrial influences when reviewing these plans.

1.3 NIWA Research Assistance

The Bay of Plenty coastal waters monitoring programme involved co-operative research input from NIWA. All fieldwork was conducted by Environment BOP and water quality data made available to NIWA. In return NIWA are undertaking the taxonomic identification and enumeration of plankton communities. Plankton counts were not complete at the required time for reporting the physical/nutrient results so these will be reported later.

This co-operative approach then provides the opportunity to study the relationships between the physical environment, primary productivity, and the structure of plankton assemblages within the Bay of Plenty for the same amount of fieldwork required to monitor either aspect alone.

Chapter 2: Methods

2.1 Location and Physical Environment

Two transects were sampled within the Bay of Plenty, which is situated on the north-east coast of the North Island, New Zealand. These are shown in Figure 2.1 below. One transect extends from the 10 m depth contour just north of Tauranga Harbour's southern entrance out 30 km to the 200 m depth contour. The second transect extends a similar distance offshore directly out from the entrance of the Whakatane Estuary. Grid references for the sampling points along each of these transect are provided in Appendix 1.

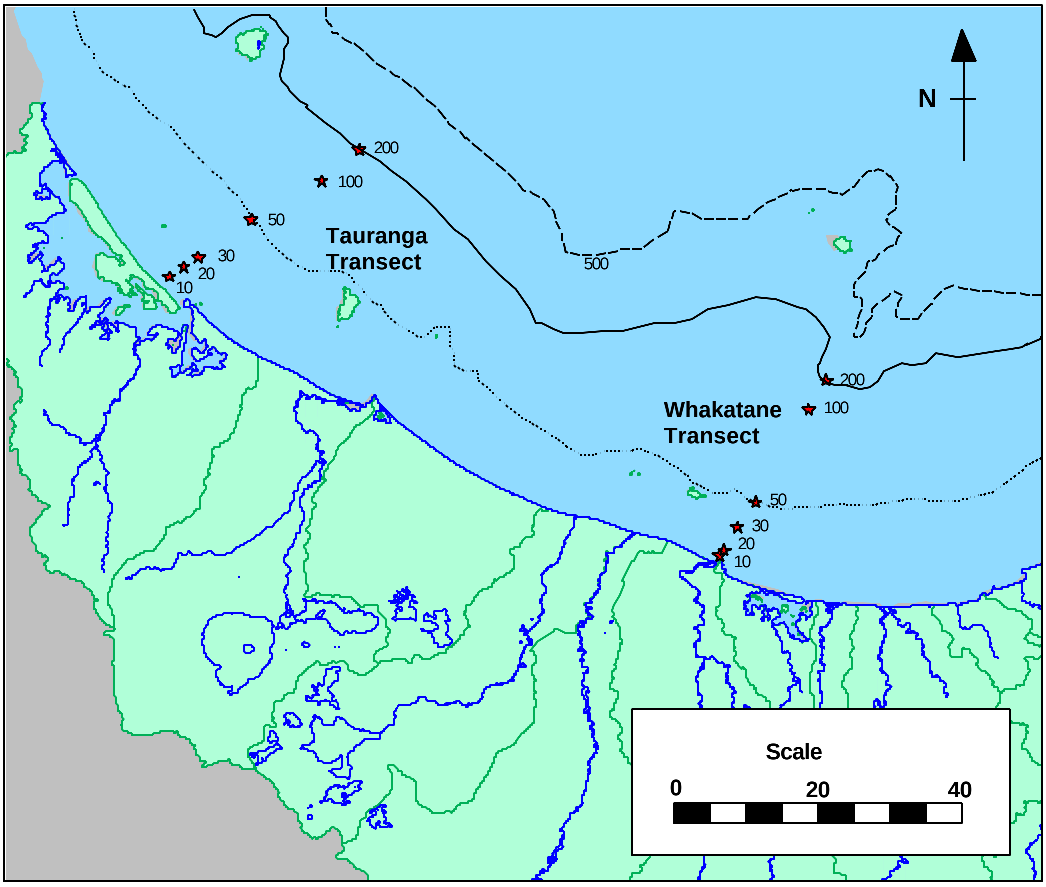


Figure 2.1 Location of transect sampling sites in Bay of Plenty coastal shelf waters.

The Bay of Plenty coastline is exposed to wind and waves from the northwest to easterly directions and is a lee shore in respect of New Zealand's prevailing south-westerly wind flows. Offshore waters are predominantly influenced by the East Auckland Current, which flows south-eastward along the north-east coast of the North Island to East Cape where the main core of the current turns north-eastward (Ridgway and Greig 1986). Influence of the current is thought to be variable with limited penetration inshore.

Inshore currents are highly variable responding to both tidal effects and wind forcing (Healy et al 1988, Harms 1989). During periods of high wind strengths, currents were observed to flow in the direction of the wind with velocities of up to 40 cm sec^{-1}. In addition, periods of onshore bottom current occurred with offshore wind and the reverse with onshore winds. Residual current flows during periods of weak and variable winds appear to be to the south, possibly as an inshore influence of the East Auckland Current. Similar residual currents have been observed from a long-term current observation on the east Coromandel shelf (Bradshaw et al 1991).

The inshore end of the Tauranga transect is influenced by tidal currents and flushing associated with the southern entrance of Tauranga Harbour. A similar situation exists with the Whakatane transect and estuary.

The southern entrance to Tauranga Harbour has a recorded flow of 153 $x10^6$ m^3 with maximum current speeds of 2.65 $m.s^{-1}$ (Beca Carter Hollings and Ferner Ltd 1978). Freshwater inflows to the southern harbour have been estimated to be around 30.5 m^3s^{-1} (<1% of tidal compartment) with the Wairoa River contributing 58% of the total (McIntosh 1994). The catchment of the northern Tauranga Harbour basin is much smaller with total freshwater inflow of around 4.6 m^3s^{-1}.

Catchment geology's of the southern Tauranga Harbour basin are dominated by ignimbrite eruptions from the Taupo Volcanic Zone and have deep ash cover. The predominant soil groups are yellow brown loams and pumice soils.

In contrast to the Tauranga situation Whakatane Estuary is much smaller with a high riverine influence. The Whakatane River, which flows into the estuary, has a mean flow of 57 m^3s^{-1}. Peak ebb-tide flows from the estuary have been gauged at 140 m^3s-1 during river flows of 18 m^3s-1 (Healy 1983). Catchment soils are still influenced by volcanic ash but most soils are derived from weathering of the underlying greywacke rocks.

2.2 Sampling Programme

Sampling along each transect was conducted four times within a year to obtain data on seasonal variations in water quality and plankton assemblages. Past spatial variations in plankton blooms etc between the western and eastern areas of the Bay of Plenty suggest regional differences in water quality. The two transects were located (within practical constraints) to help identify possible variations. Extending each transect out to the edge of the continental shelf (200 m depth) ensured that neritic coastal waters were fully covered and allowed comparison to oceanic water masses.

At each of the sampling sites instrument readings, water samples, bacterial samples, and plankton samples are taken at specified depths. Appendix 1 sets out the sampling programme in detail listing depths and all chemical, physical, and biological analyses conducted.

In general instrument readings were taken every 5 m from the surface down to the bottom or 60 m which was the full length of the cable. At the 100 and 200 m depth contour sites, instrument readings for specified depths below 60 m were taken within a six litre Van Dorn sample bottle immediately upon its retrieval to the surface

Sampling plans for plankton, chlorophyll-a, dissolved and particulate nutrients, and other water quality indicators was set to maximise information on various aspects of a very dynamic system within a limited budget.

2.3 Methods

All instrument readings of physical water parameters were taken with a fully calibrated YSI 3800 data logger. Water clarity was measured using a standard Secchi disc and the vertical light extinction co-efficient derived from data obtained using a Li-COR meter with LI-190SA light sensor.

Analyses were conducted by Environment BOP’s laboratory (international Accreditation New Zealand certified) or as indicated with methods for all parameters set out on the next page in Table 2.1.

Table 2.1 Analysis methods and detection limits

Parameter	Method	Detection limit[+]
Chlorophyll-a*	Acetone extraction of pigments and spectroflourometric measurement.	0.01 mg/m^3
Particulate-N*	Acid digestion, then indophenol blue colorometry.	1 mg/m^3
Particulate-P*	Acid extraction and molybdenum blue colorometry.	1 mg/m^3
SiDR*	Molybdosilicate colorometry.	0.001 g/m^3
TP	Acid persulphate digestion, NWASCO Misc. Pub. No. 38, 1982, molybdenum blue colorometry.	0.008 g/m^3
DRP	APHA 4500-P-F (modified) automated.	0.004 g/m^3
TN#	Persulphate digestion, automated Cadmium reduction APHA 4500-NO3-F (modified).	0.02 g/m^3
TOXN	automated Cadmium reduction APHA 4500-NO3-F (modified).	0.001 g/m^3
NH4-N	NAWASCO Mis. Pub. No. 38 1982, phenolhypochloate (saline method).	0.005 g/m^3
Turbidity	APHA 19th ed. 2130B-HACH 2100N ratio and signal averaging	0.1 NTU
SS	APHA 19th ed. Method 2540D	1 g/m^3

+ Detection limit with 95% confidence, some results are below this level

* Analysis conducted by NIWA laboratory, Hamilton.

Analysis conducted by Watercare services laboratory, Auckland.

Chapter 3: Results

3.1 Physical Attributes

3.1.1 Water Clarity

Results for measurements of Secchi depth and vertical light extinction co-efficient (vlec) are displayed in Figure 3.1. Both the Whakatane and Tauranga transects continued to show significant improvements in water clarity out to the edge of the continental shelf. Inshore (10 m depth) secchi depth measurements ranged from 2 – 5 m while offshore values showed a larger degree of variation. At the 200 m contour visibility measured with the Secchi disc reached up to 25 m in autumn but only averaged around 10 m in spring and early summer.

Similar seasonal variations in water clarity were apparent for the Whakatane and Tauranga transects based on both Secchi depth and vlec. Not only are the clearest waters recorded in late summer/autumn, but they also tend to intrude further inshore with the greatest inshore/offshore gradient beginning around the 30 m depth contour or 7 km offshore.

3.1.2 Salinity

Salinity profiles for both the Whakatane and Tauranga transects are presented in Figure 3.2. Seasonal changes of similar magnitude are recorded for both transects with the salinity values being highest in late summer and autumn. At this time of year variations between the salinity of inshore and offshore waters appears to be minimal.

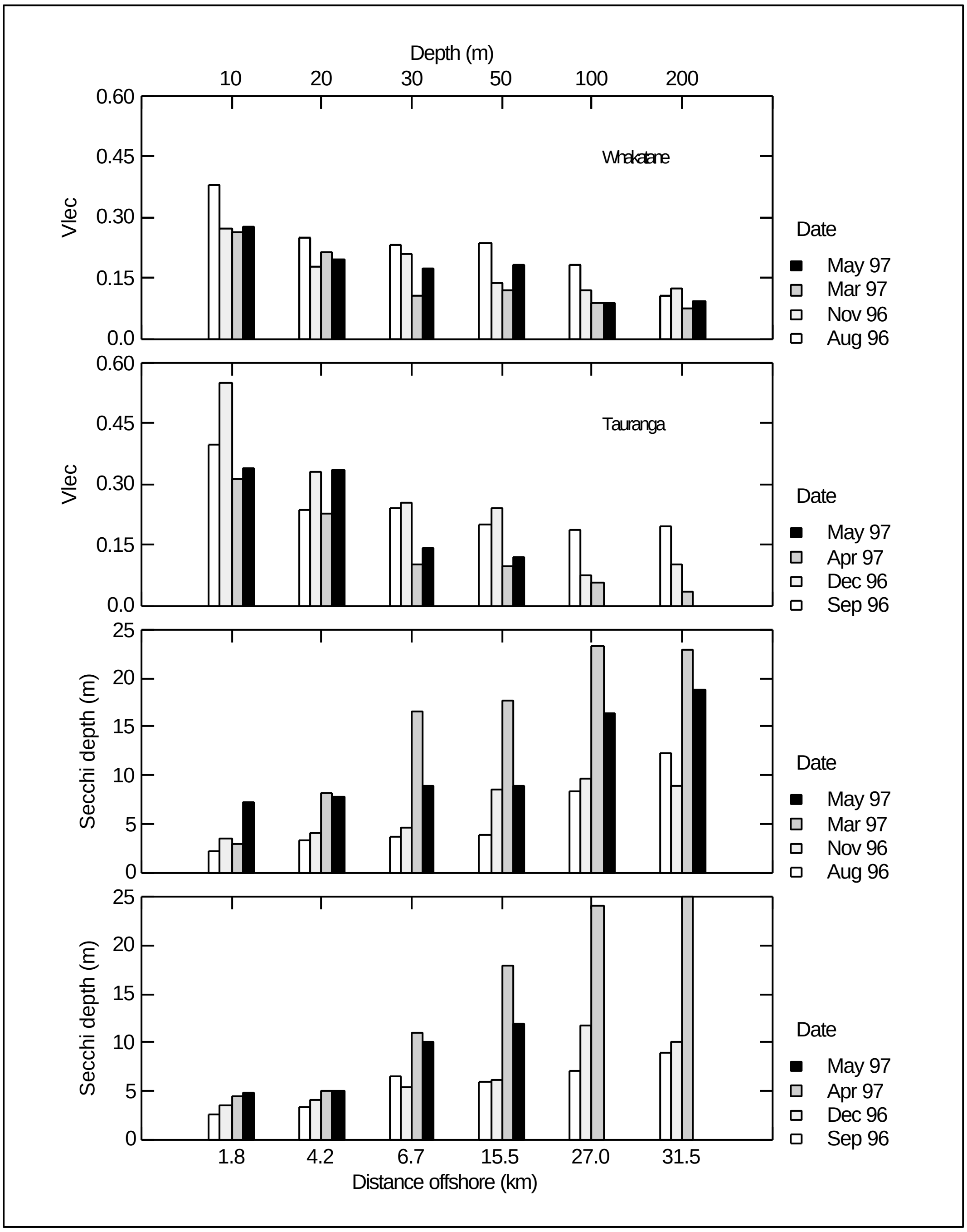
All results show some freshwater influence inshore with the strongest influence occurring during the winter and spring months. For the winter and spring sampling occasions of the Tauranga transect, an inshore surface plume is obvious for some distance offshore, possibly because of water discharged from the southern entrance of Tauranga Harbour.

3.1.3 Temperature

The strongest features of the temperature results shown in Figure 3.3 are the expected seasonal changes and stratification of the shelf waters. The warm stratified surface waters are clearly shown in the early autumn sampling of the Whakatane transect when seasonal water temperatures were still very close to their peak levels for the year.

Another feature of the temperature profiles for both sites is the clear delineation of the deep oceanic water. This water mass occurs at the edge of the continental shelf in depths of around 100 m or more. It is stable in respect of temperature with very little change between seasons of the year even though it is only being sampled at its periphery. There is some indication that oceanic water may have moved in across the shelf to a small degree such as in the May sampling occasion on the Whakatane transect.

Figure 3.1 Secchi depth and vertical light extinction coefficient values recorded on the Whakatane and Tauranga transects at the 10,20, 30, 50, 100 and 200 m



depth contours on the continental shelf.

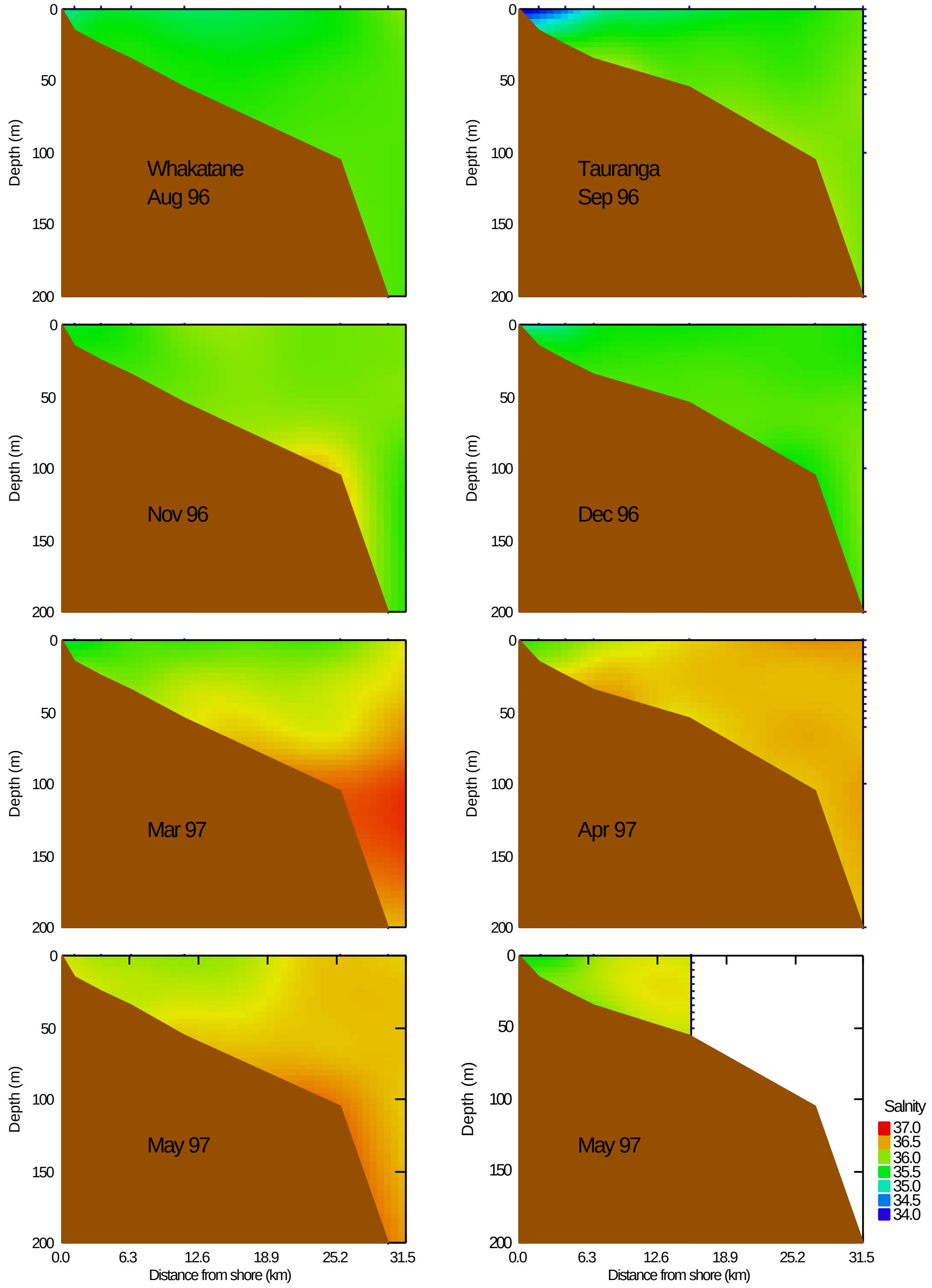


Figure 3.2 Salinity profile plots for Whakatane (left) and Tauranga transects with measurements from the 10,20,30, 50, 100 and 200 m depth contours on the continental shelf.

3.1.4 Suspended Solids and Turbidity

Results for the sites and depths at which suspended solids and turbidity were sampled are shown in Figures 3.4 – 3.7. Turbidity has a close relationship to suspended solids and hence exhibits the same patterns and trends displayed in the suspended solids results. There are also very similar results for both the Whakatane and Tauranga transects.

Trends in values of surface water samples decreasing with distance offshore were apparent but showed a high degree of variability. Maximum values of surface waters around 12 g/m^3 for suspended solids occurred inshore on the Tauranga transect in December while minimum values where around 1 g/m^3 in April.

One of the clearest features of the results was the higher suspended solids and turbidity values recorded just above the bottom at the inshore sites. The bottom water samples at the 10 m site for both the Whakatane and Tauranga transects recorded the highest suspended solids values of 19 & 26 g/m^3 respectively. Turbidity showed very similar trends with values of 9.5 & 4.9 NTU recorded respectively at the 10 m sites.

3.1.5 Dissolved Oxygen

Dissolved oxygen profiles for the Whakatane and Tauranga transects are shown in Figure 3.8 for each of the four sampling occasions and expressed in terms of % saturation to standardise results for different temperatures and depths. On the March sampling of the Whakatane transect a fault with the dissolved oxygen probe prevented the collection of any valid data. Results show patterns consistent with the oxygen respiration requirements of marine life and photosynthesis of plankton.

Highest oxygen levels tend to be recorded near the surface in less than 30 m of water where plankton was actively producing oxygen. Values were also highest in the late spring/early summer sampling occasions when plankton densities and light levels are generally at the highest levels. Peak values of 8.8 mg/L or 110 %sat. were recorded on the Whakatane transect and 8.9 mg/L or 112 %sat. for Tauranga.

Both transects show that while oxygen is being produced near the surface and saturating the water, depletion is occurring near or at the bottom. This is especially apparent in the deeper waters of the shelf where water depth restricts light penetration (hence photosynthesis) and mixing or diffusion of oxygen from surface waters. The lowest dissolved oxygen values were not recorded in the deepest waters but on the mid-outer shelf region. Lowest values also coincided with the time of year that plankton productivity may have been at peak levels. Dissolved oxygen values dropped to 5.6 mg/L (68 %sat.) and 5.2 mg/L (64 %sat.) on the Whakatane and Tauranga transects respectively.

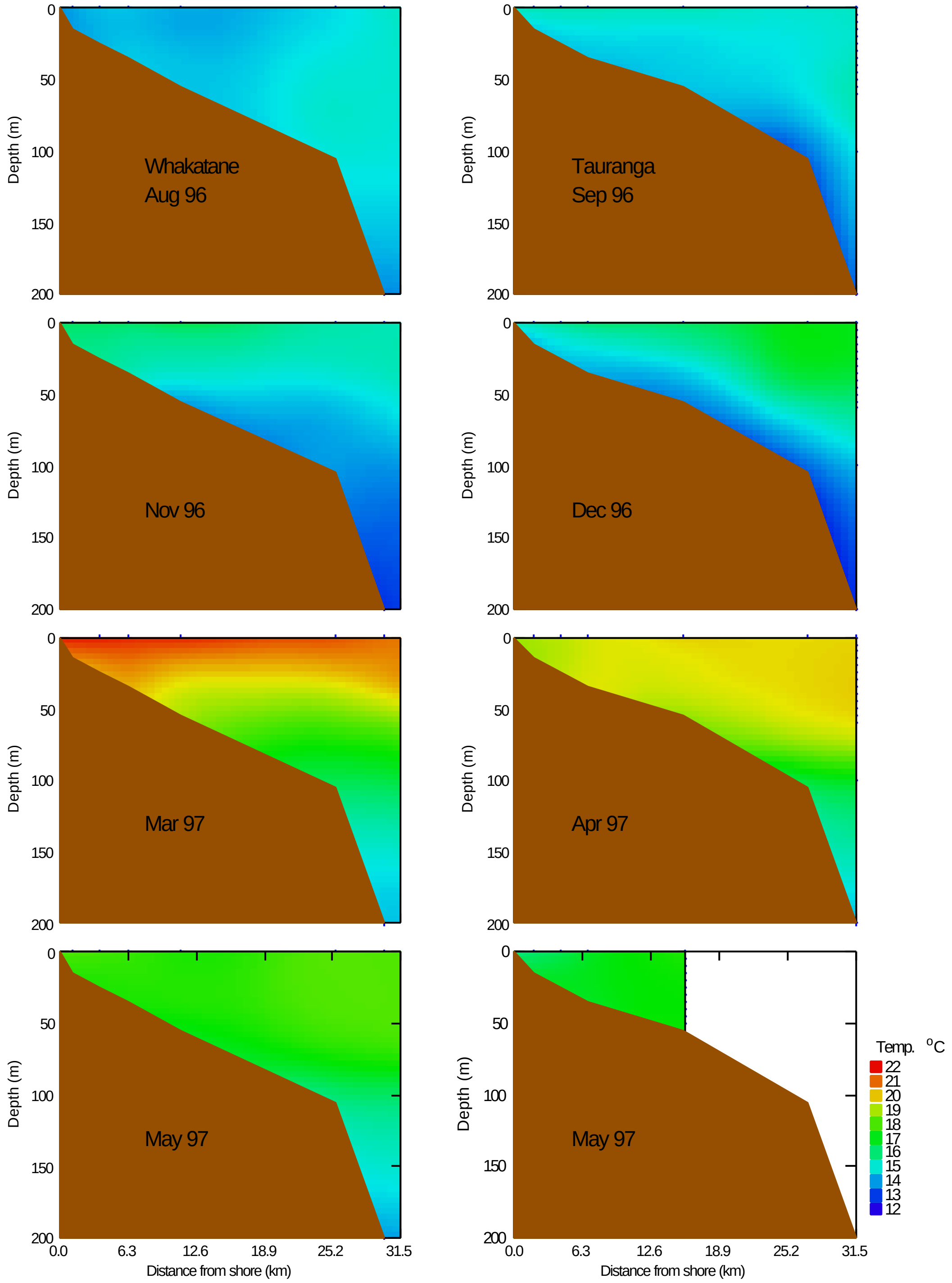


Figure 3.3 Temperature (^{o}C) profile plots for Whakatane (left) and Tauranga transects with measurements from the 10,20,30, 50, 100 and 200 m depth contours on the continental shelf.

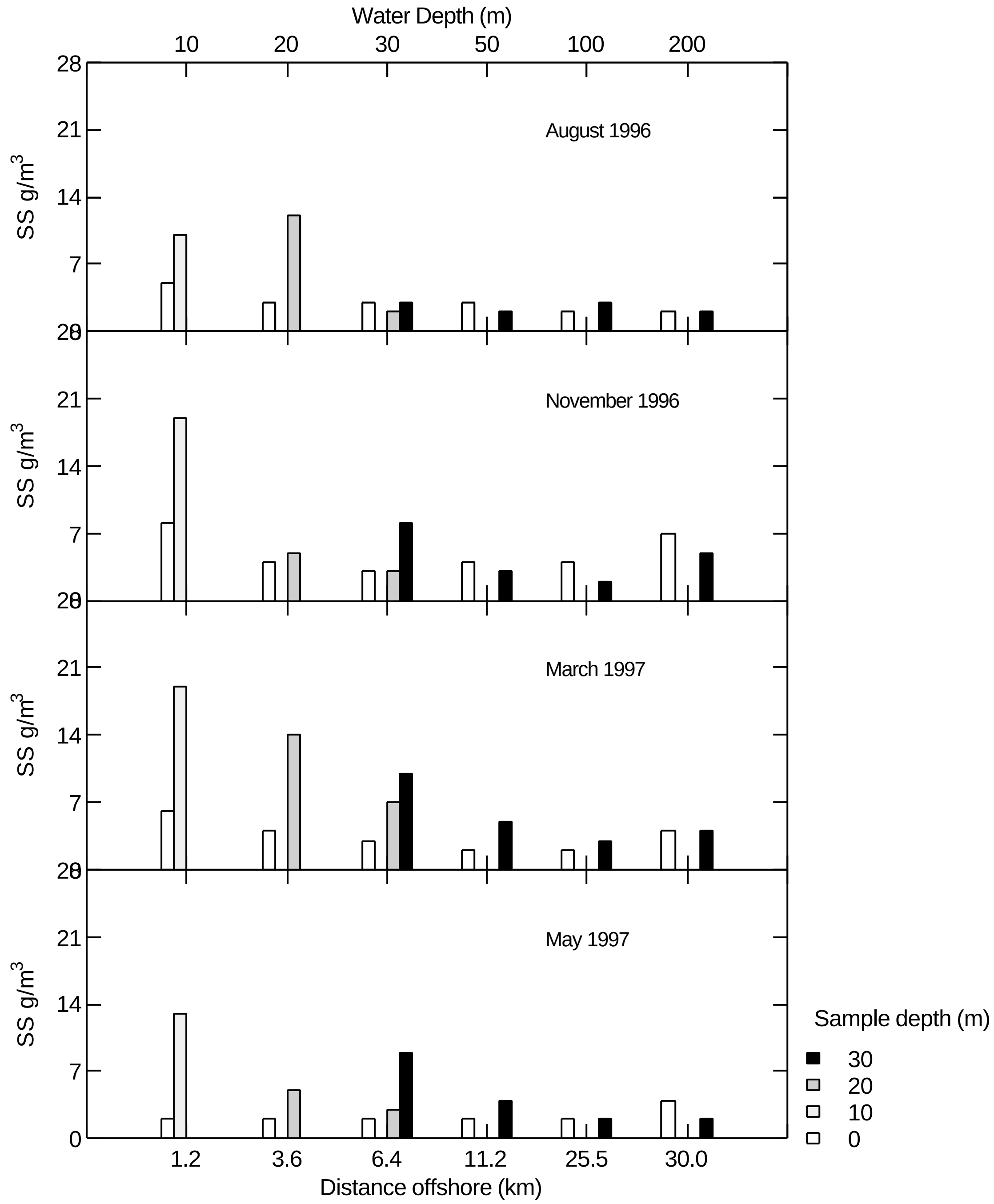


Figure 3.4 Suspended Solids values recorded on the Whakatane transect at the 10, 20, 30, 50, 100 and 200 m depth contours on the continental shelf.

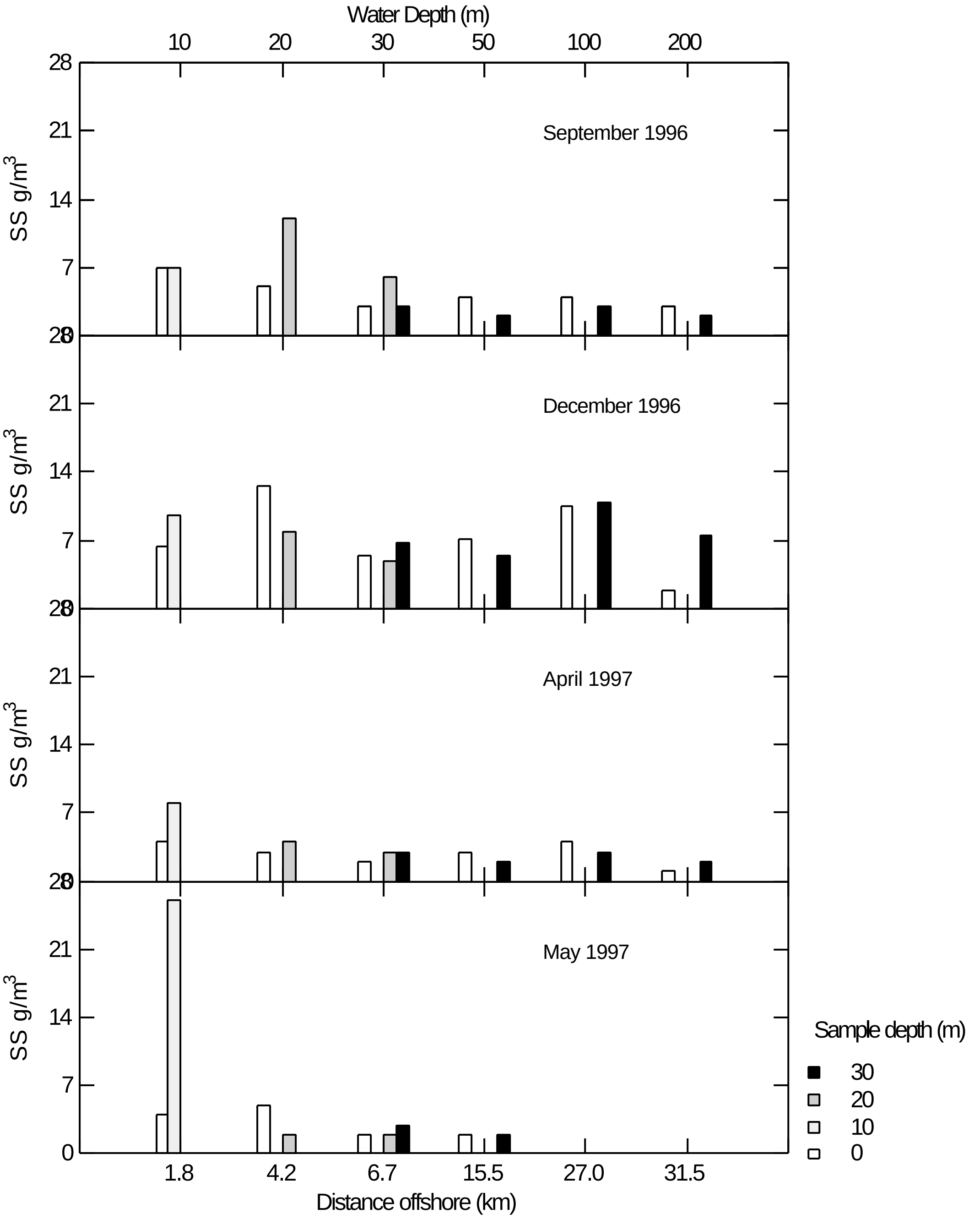


Figure 3.5 Suspended Solids values recorded on the Tauranga transect at the 10, 20, 30, 50, 100 and 200 m depth contours on the continental shelf.

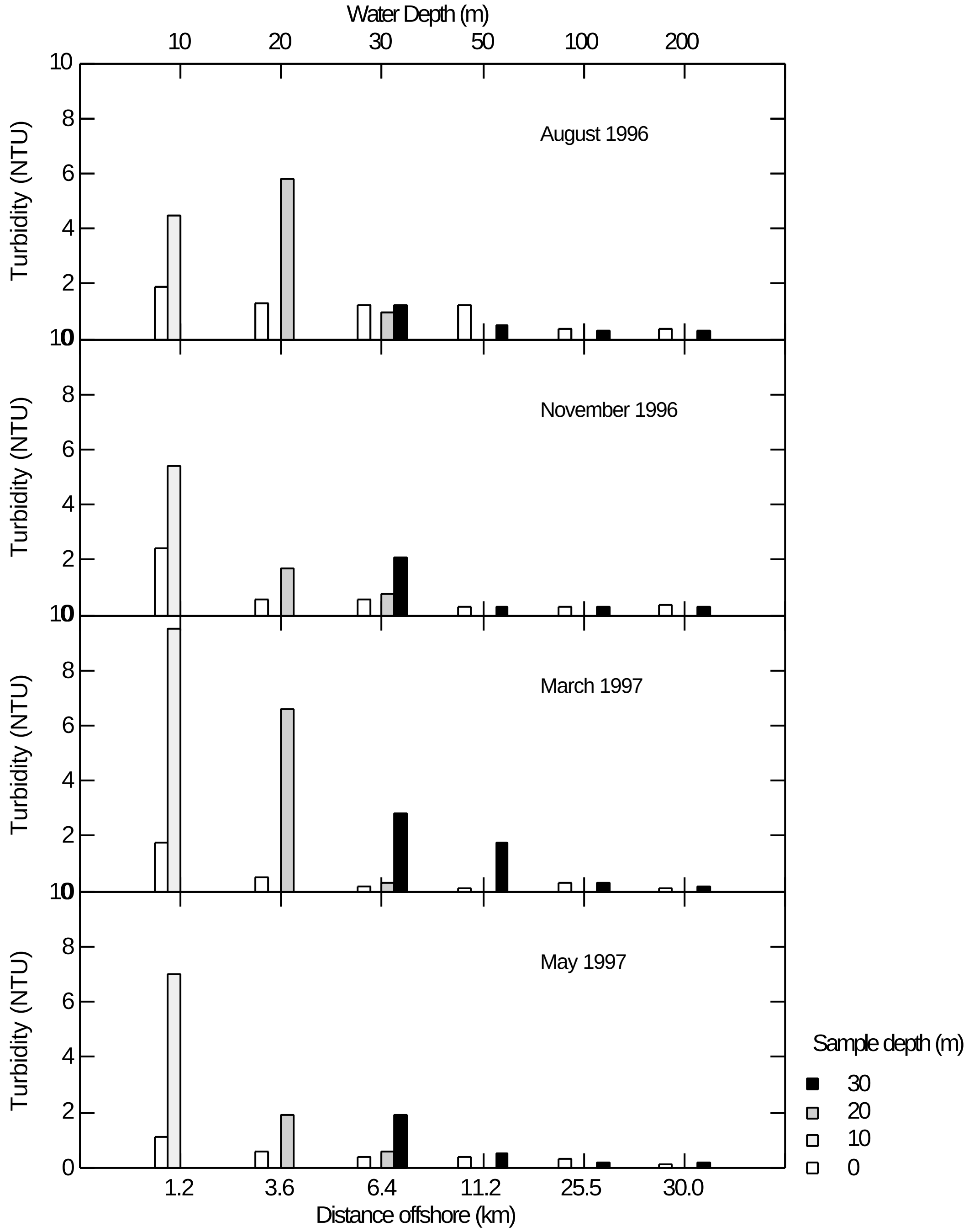


Figure 3.6 Turbidity values recorded on the Whakatane transect at the 10, 20, 30, 50, 100 and 200 m depth contours on the continental shelf.

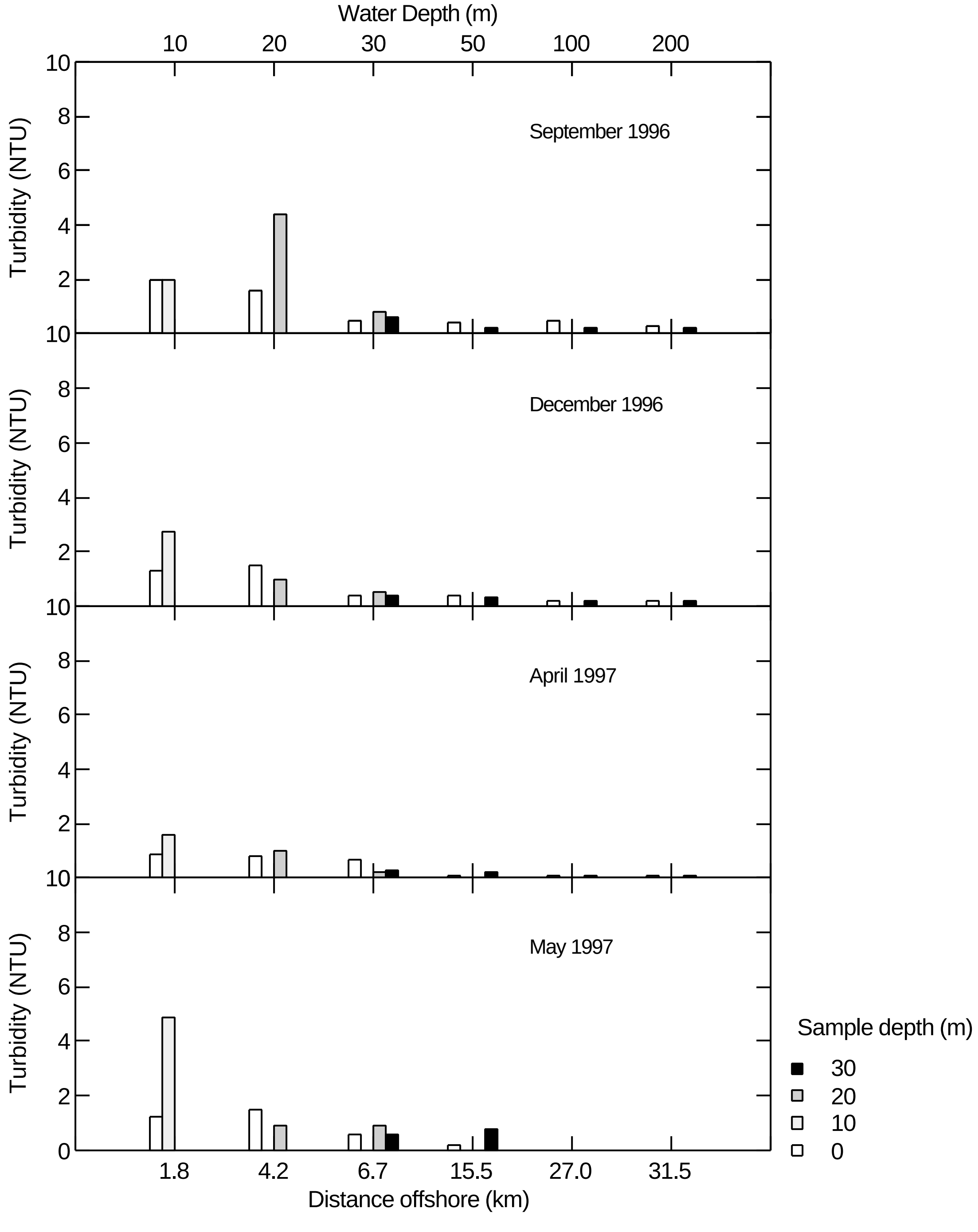


Figure 3.7 Turbidity values recorded on the Tauranga transect at the 10, 20, 30, 50, 100 and 200 m depth contours on the continental shelf.

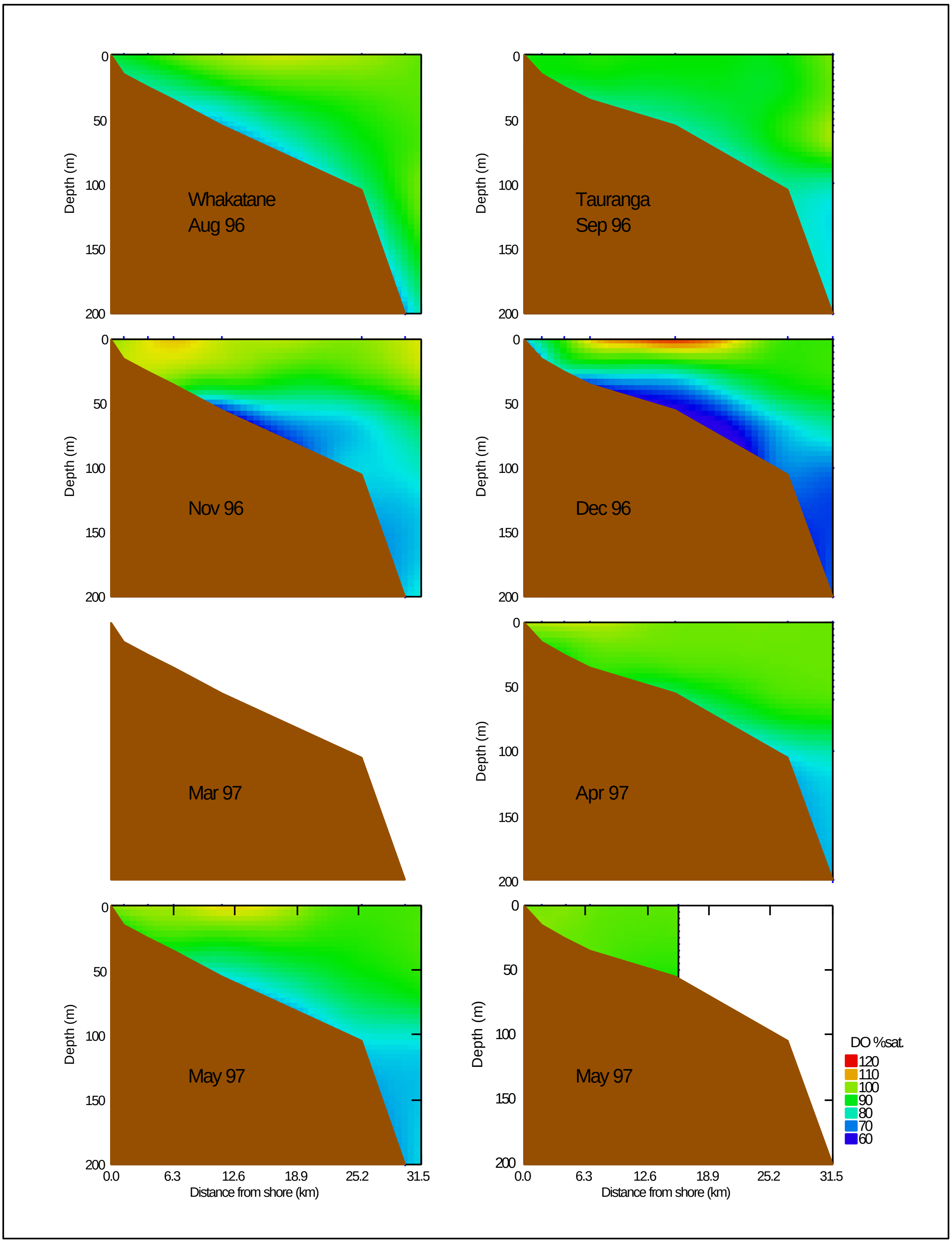


Figure 3.8 Dissolved oxygen (% sat.) profile plots for Whakatane (left) and Tauranga transects with measurements from the 10,20,30, 50, 100 and 200 m depth contours on the continental shelf.

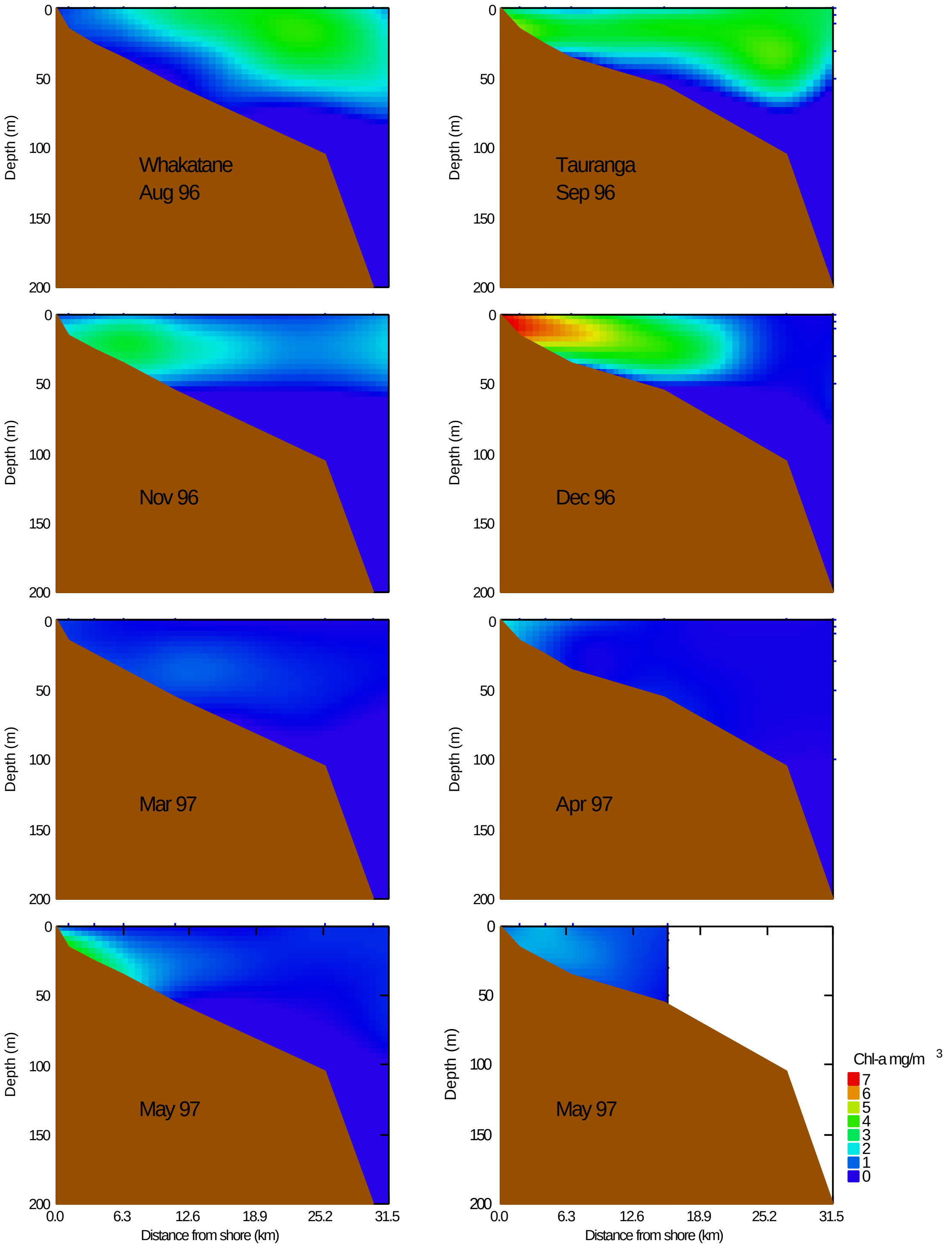


Figure 3.9 Chlorophyll-a profile plots for Whakatane (left) and Tauranga transects with measurements from the 10,20,30, 50, 100 and 200 m depth contours on the continental shelf.

3.1.6 Chlorophyll-a

Figure 3.9 displays the results of chlorophyll-a profiles sampled on the Whakatane and Tauranga transects. Samples were only taken to a depth of 50 m so extrapolation below this level as shown in the graphics is unreliable. For display purposes, the maximum range in chlorophyll values was set at 7 mg/m^3. This produced profile plots with the same trends and patterns as found by using the full range but allowed better resolution of the data. The only data omitted by this treatment were recordings of 11 and 16 mg/m^3 at the 10 & 30 m contours on the Tauranga transect in December and a sample with a result of 8 mg/m^3 on Whakatane transect.

Chlorophyll-a levels were highest in near surface waters in early spring – early summer for both the Whakatane and Tauranga transects. Highest chlorophyll-a levels occurred in the December samplings run of the Tauranga transect at the shallow inshore sites near the entrance of Tauranga Harbour. Both the 11 and 16 mg/m^3 values were recorded at a depth of 10 m at the 10 m and 30 m contour sites respectively. In late summer chlorophyll-a levels tended to be around 1 mg/m^3 or less throughout the water column and across the shelf.

3.2 Nutrients

3.2.1 Dissolved Reactive Silica

Dissolved reactive silica samples were only taken from surface water at each of the monitoring sites and results are displayed in Figure 3.10. Results show consistently higher values nearest the coast. Maximum concentrations were similar for both the Whakatane and Tauranga transects at around 3-3.5 mg/L. Dissolved reactive silica reached very low levels in a zone across the shelf at distances of approximately 6-25 km offshore during the spring/summer period. This seasonal pattern of depletion coincides with the seasonal peak in chlorophyll/plankton levels.

3.2.2 Dissolved Reactive Phosphorus

Profiles of dissolved reactive phosphorus concentrations throughout the water column are shown in Figure 3.11 for both the Whakatane and Tauranga transects for each of the four sampling occasions. There are no clear seasonal trends but the Tauranga transect recorded very low concentrations in surface waters down to a depth of 50 m out across the whole shelf. The most obvious features of the results were the high concentrations present at times in the bottom water of the mid-shelf zone. In the deep offshore waters, consistently high concentrations of dissolved reactive phosphorus were recorded on all sampling occasions for both transects.

Minimum concentrations of dissolved reactive phosphorus were below the detection limit of 0.001 g/m^3 while similar maximum values around 0.027 g/m^3 were recorded for both transects.

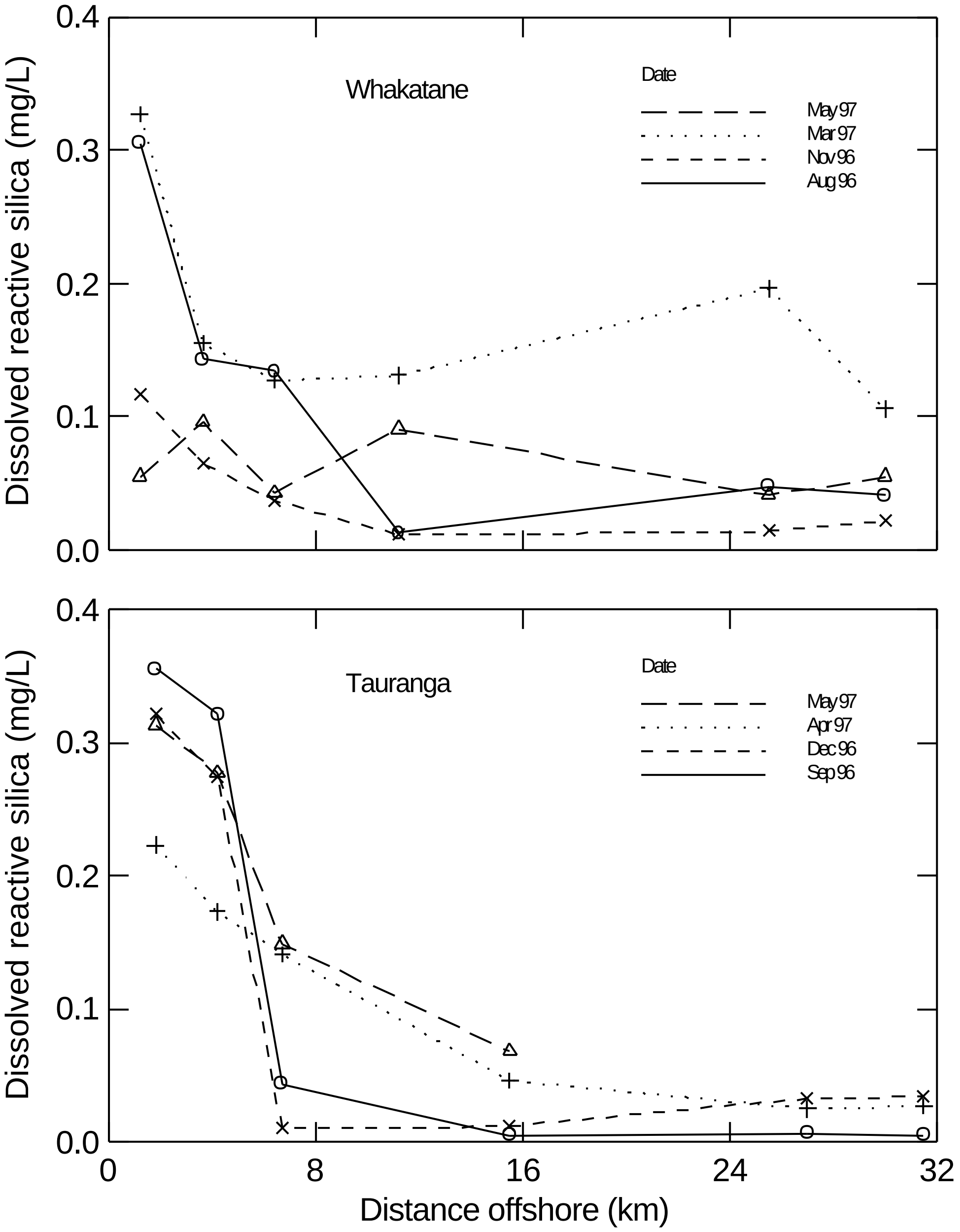


Figure 3.10 Concentration of dissolved reactive silica recorded in surface waters on the Whakatane and Tauranga offshore transects in the Bay of Plenty.

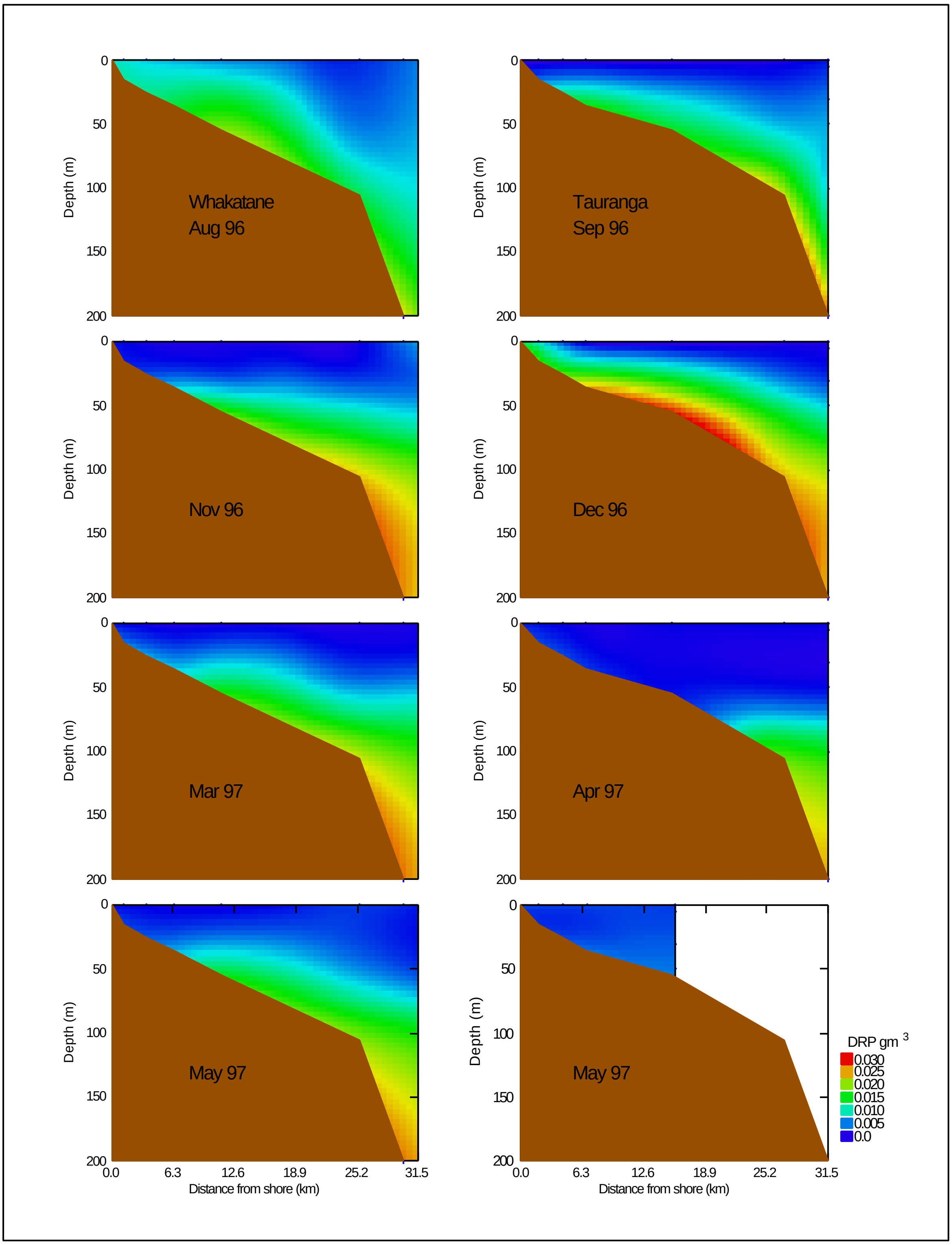


Figure 3.11 Dissolved reactive phosphorus profile plots for Whakatane (left) and Tauranga transects with measurements from the 10,20,30, 50, 100 and 200 m depth contours on the continental shelf.

3.2.3 Total Phosphorus

Total phosphorus showed a similar pattern to many of the other parameters measured. Concentrations were generally higher within 10 – 15 km of the coast and lowest out at the 100 and 200 m depth contours 25 – 30 km offshore (Figures 3.12 & 3.13). Both transects showed higher concentrations in winter/spring with this seasonal pattern being strongest for the Tauranga transect. In addition, the strongest offshore gradient in concentration of total phosphorus in the surface water occurred during winter for both transects.

Differences between total phosphorus concentration at the surface and bottom at the three inshore sites where comparison is possible, shows higher concentrations tend to occur near the bottom, particularly on the Whakatane transect.

Minimum concentrations of total phosphorus recorded for the Whakatane and Tauranga transects were 0.004 and 0.002 g/m^3 respectively with maximum recorded concentrations being 0.028 and 0.045 g/m^3.

3.2.4 Particulate Phosphorus

Particulate phosphorus concentrations were highest overall in samples taken at the bottom (Figures 3.14 & 3.15). Surface water samples tended to have higher concentrations of particulate phosphorus inshore as opposed to the low levels out at the edge of the continental shelf. Seasonal patterns were not marked with the Tauranga transect showing higher concentrations in early spring to summer. Whakatane transect showed little seasonal variation inshore but did tend towards lower concentrations at the edge of the continental shelf in late summer/autumn.

Values for the concentrations of particulate phosphorus recorded from the Whakatane transect ranged from 0.57-18.00 mg/m^3, and 0.61-20.80 mg/m^3 for the Tauranga Transect. Maximum particulate phosphorus values were around half of the maximum total phosphorus values recorded.

3.2.5 Particulate Nitrogen

Particulate nitrogen concentrations had a high degree of similarity to the geographical and seasonal variations shown by particulate phosphorus. Results are shown in Figures 3.16 and 3.17. The greatest difference from the patterns already stated above for particulate phosphorus were the relatively high concentrations of particulate nitrgen recorded from the offshore waters of the Whakatane transect in March.

Values for the concentrations of particulate nitrogen recorded from the Whakatane transect ranged from 7.00-85.90 mg/m^3 and 4.63-134.00 mg/m^3 for the Tauranga Transect. Concentration of particulate nitrogen tended to average around 30 – 35% of the total nitrogen values recorded.

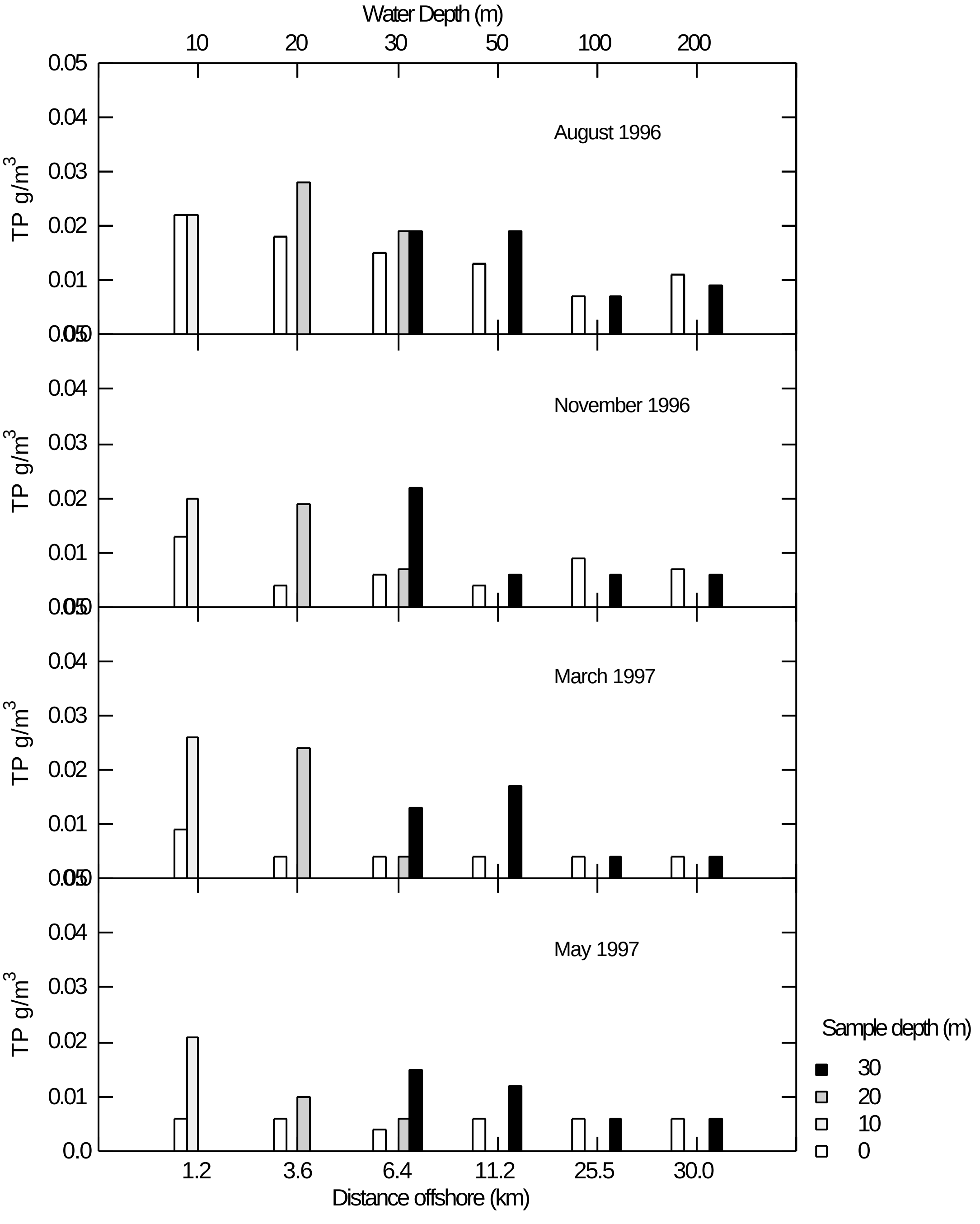


Figure 3.12 Total phosphorus values recorded on the Whakatane transect at the 10, 20, 30, 50, 100 and 200 m depth contours on the continental shelf.

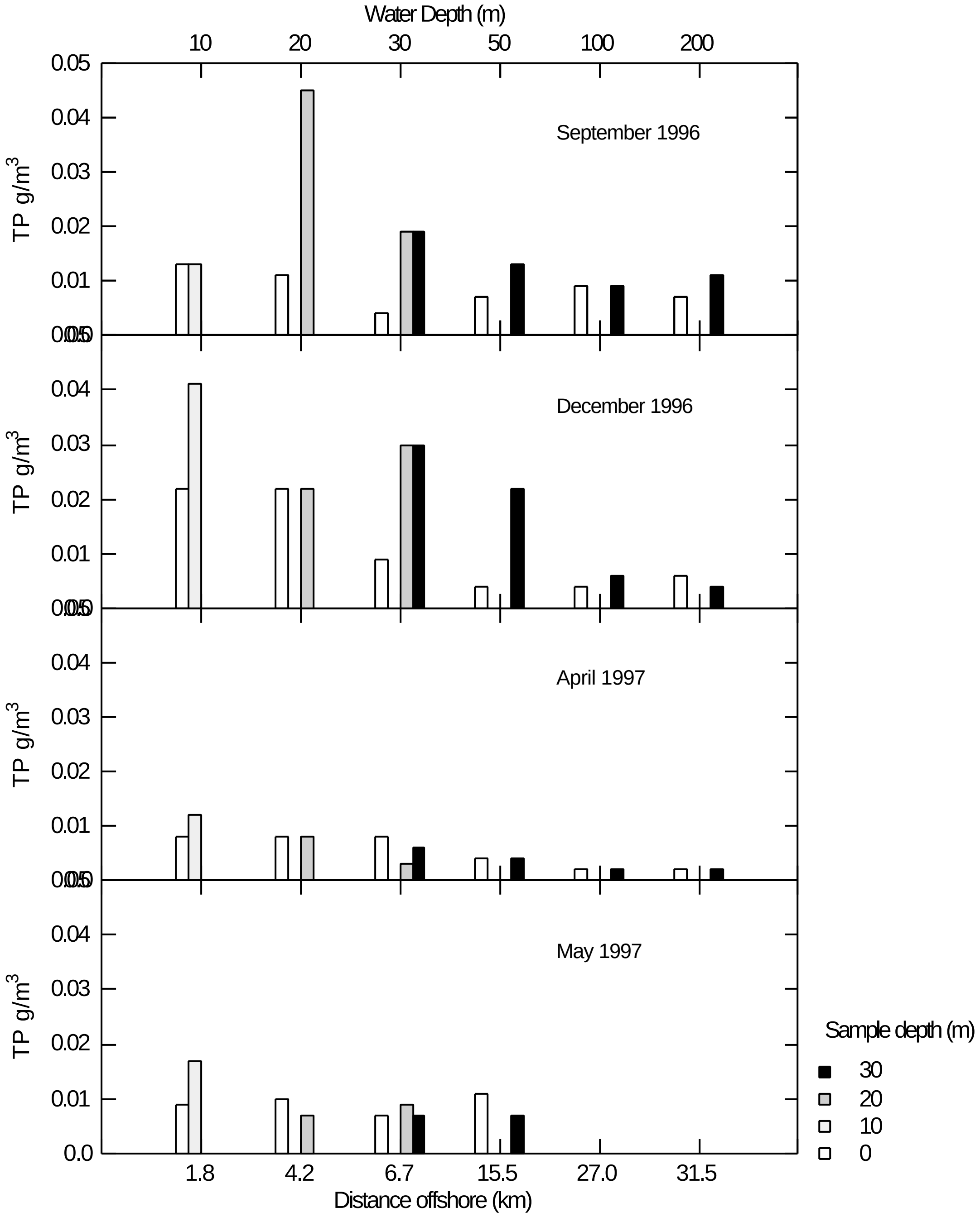


Figure 3.13 Total phosphorus values recorded on the Tauranga transect at the 10, 20, 30, 50, 100 and 200 m depth contours on the continental shelf.

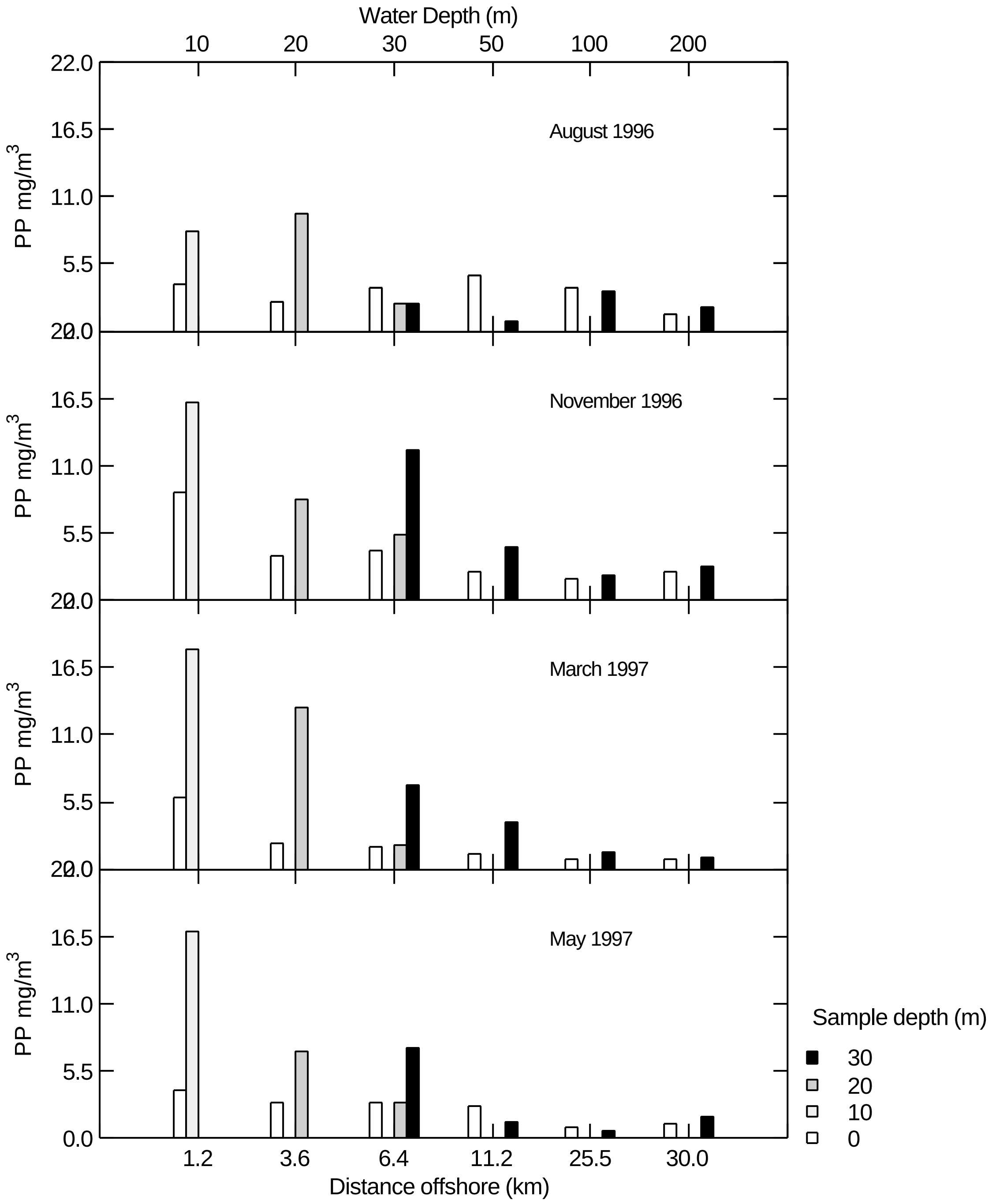


Figure 3.14 Particulate phosphorus values recorded on the Whakatane transect at the 10, 20, 30, 50, 100 and 200 m depth contours on the continental shelf.

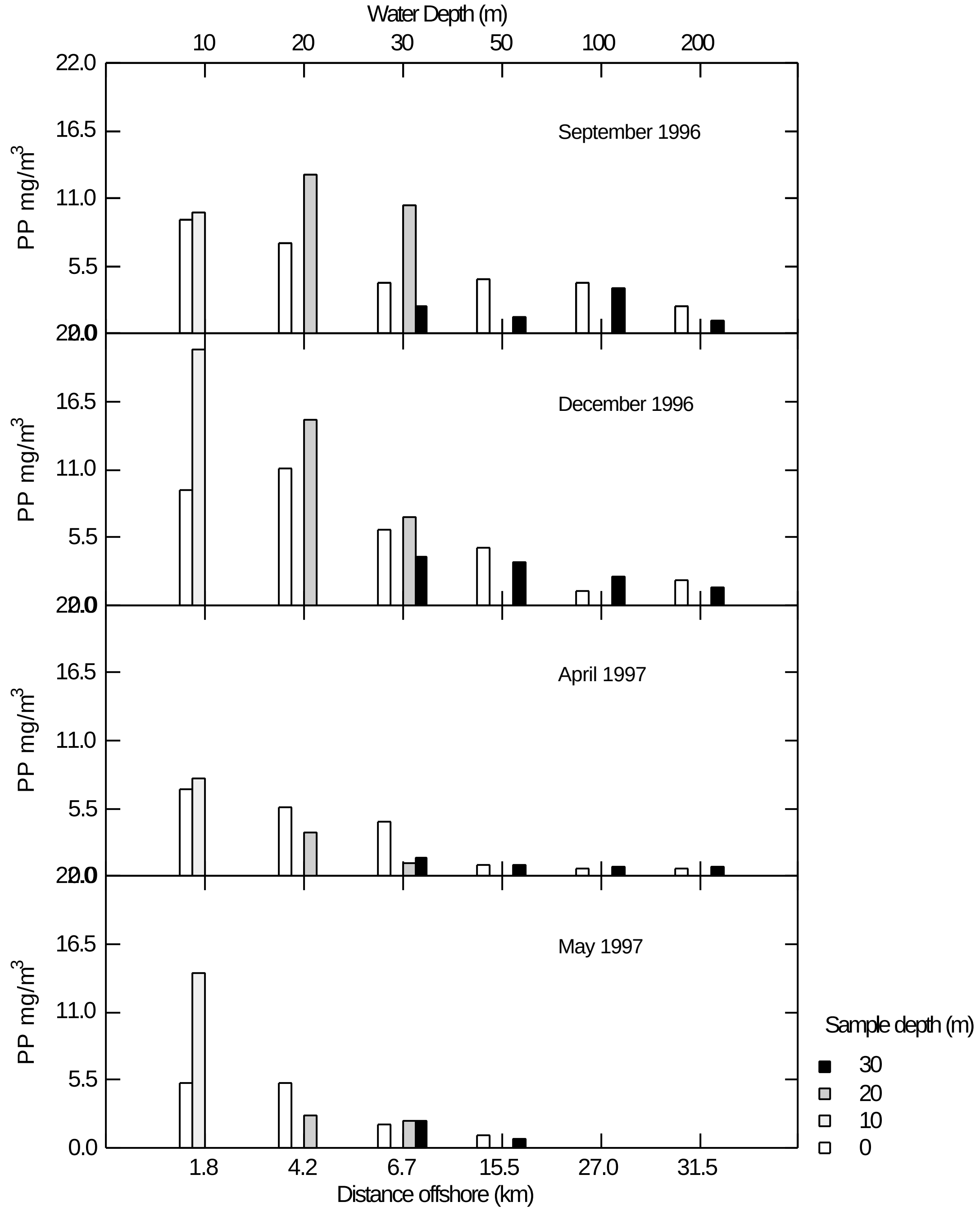


Figure 3.15 Particulate phosphorus values recorded on the Tauranga transect at the 10, 20, 30, 50, 100 and 200 m depth contours on the continental shelf.

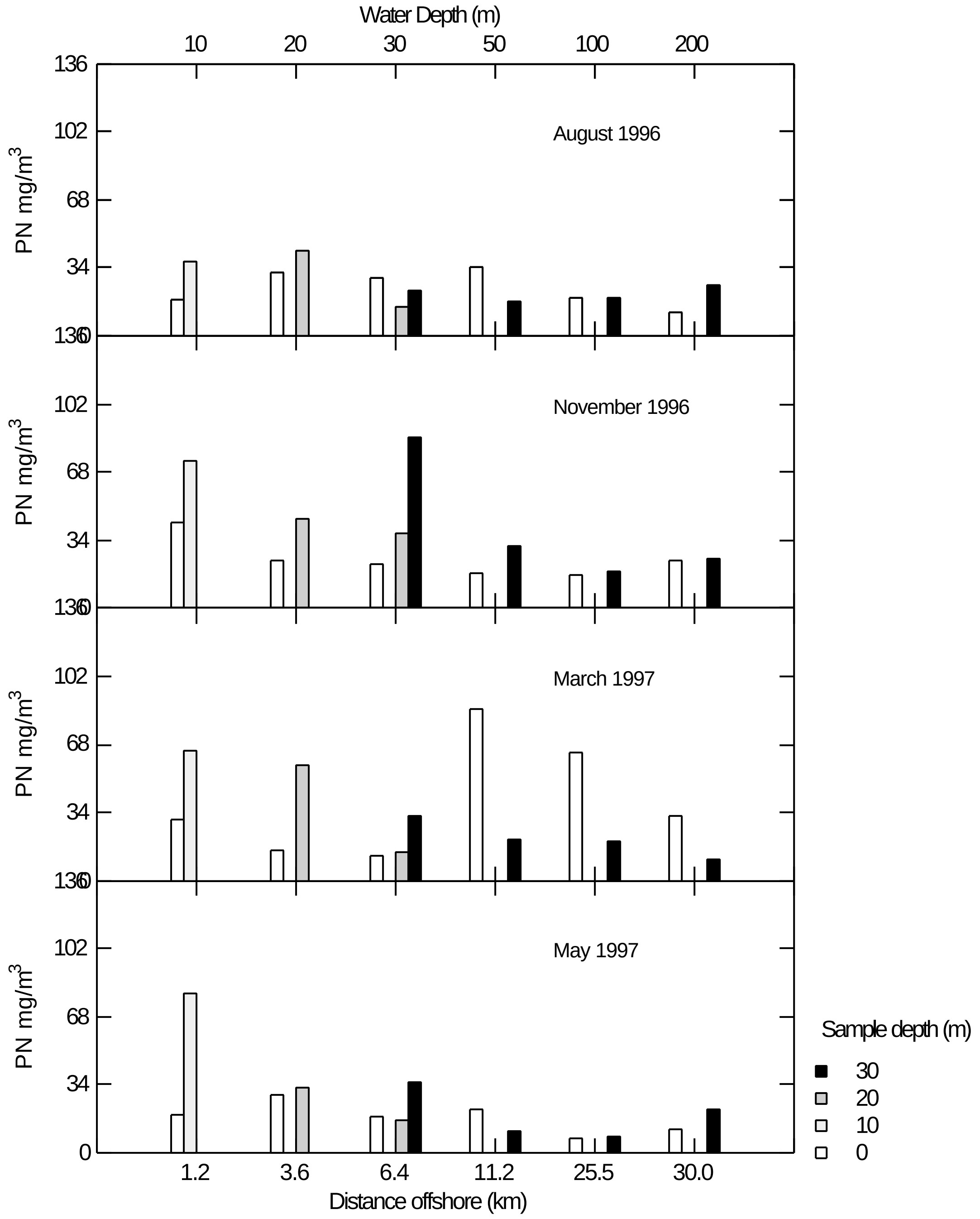


Figure 3.16 Particulate nitrogen values recorded on the Whakatane transect at the 10, 20, 30, 50, 100 and 200 m depth contours on the continental shelf.

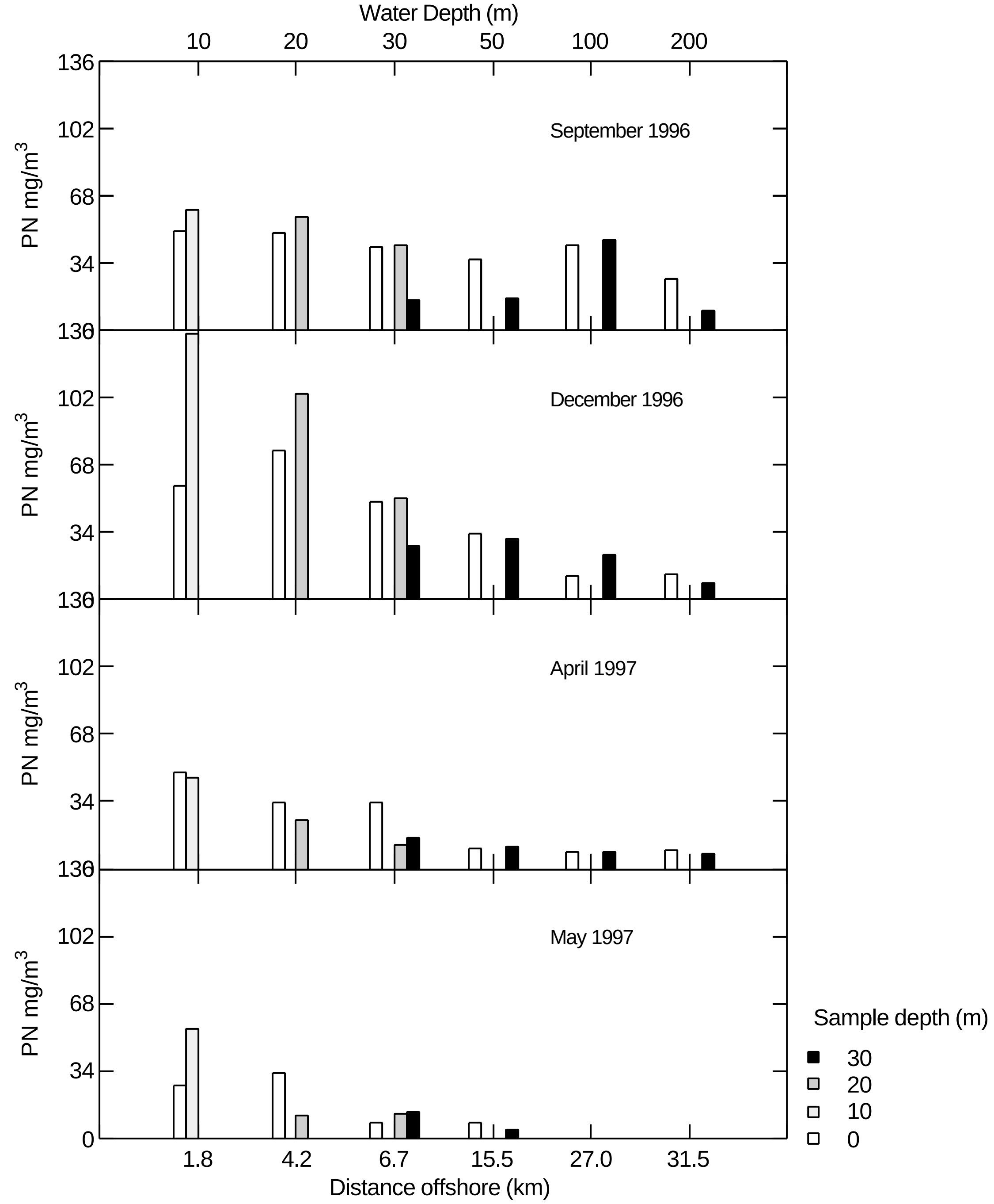


Figure 3.17 Particulate nitrogen values recorded on the Tauranga transect at the 10, 20, 30, 50, 100 and 200 m depth contours on the continental shelf.

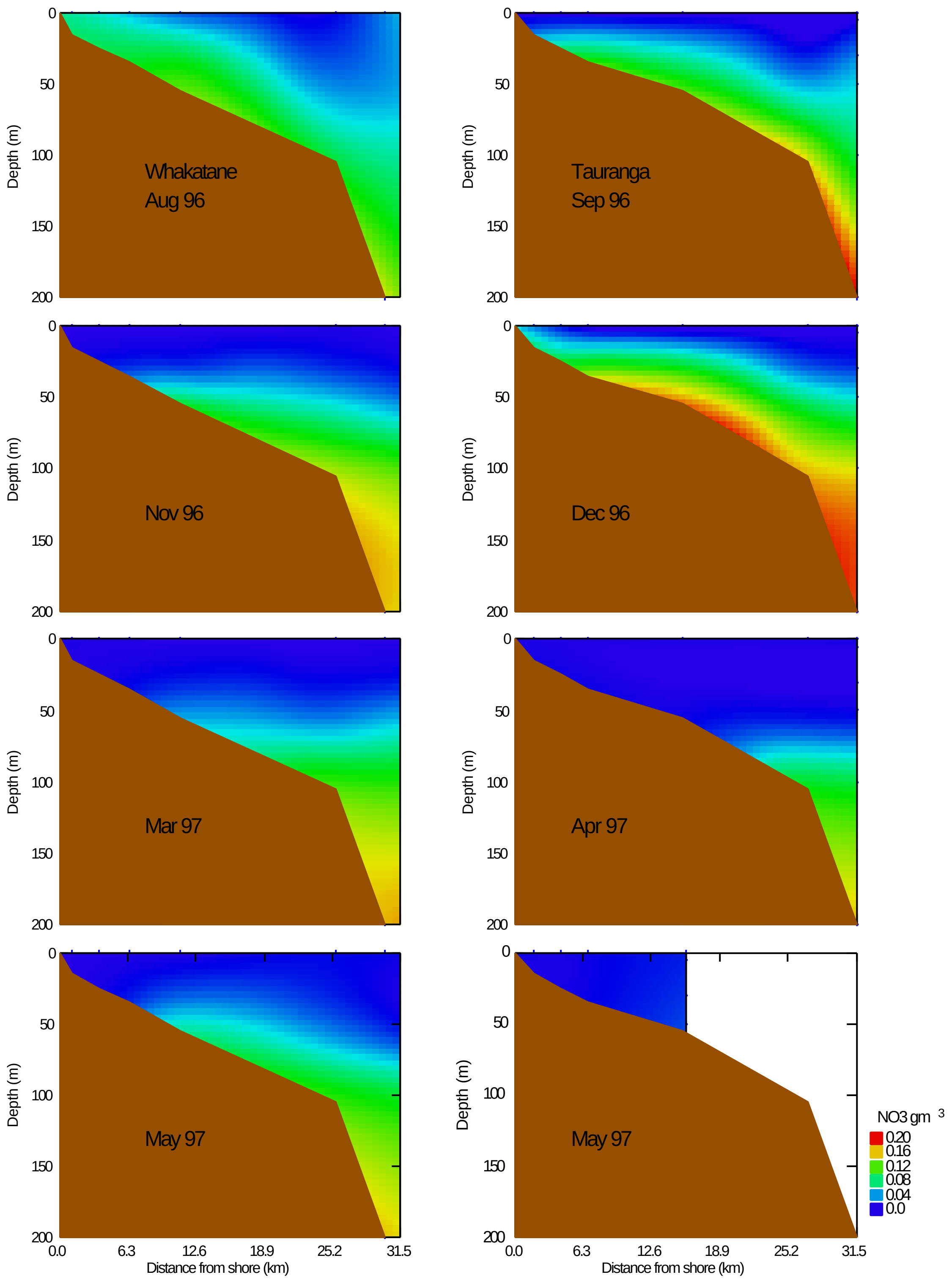


Figure 3.18 Total oxidised-nitrogen profile plots for Whakatane (left) and Tauranga transects with measurements from the 10,20,30, 50, 100 and 200 m depth contours on the continental shelf.

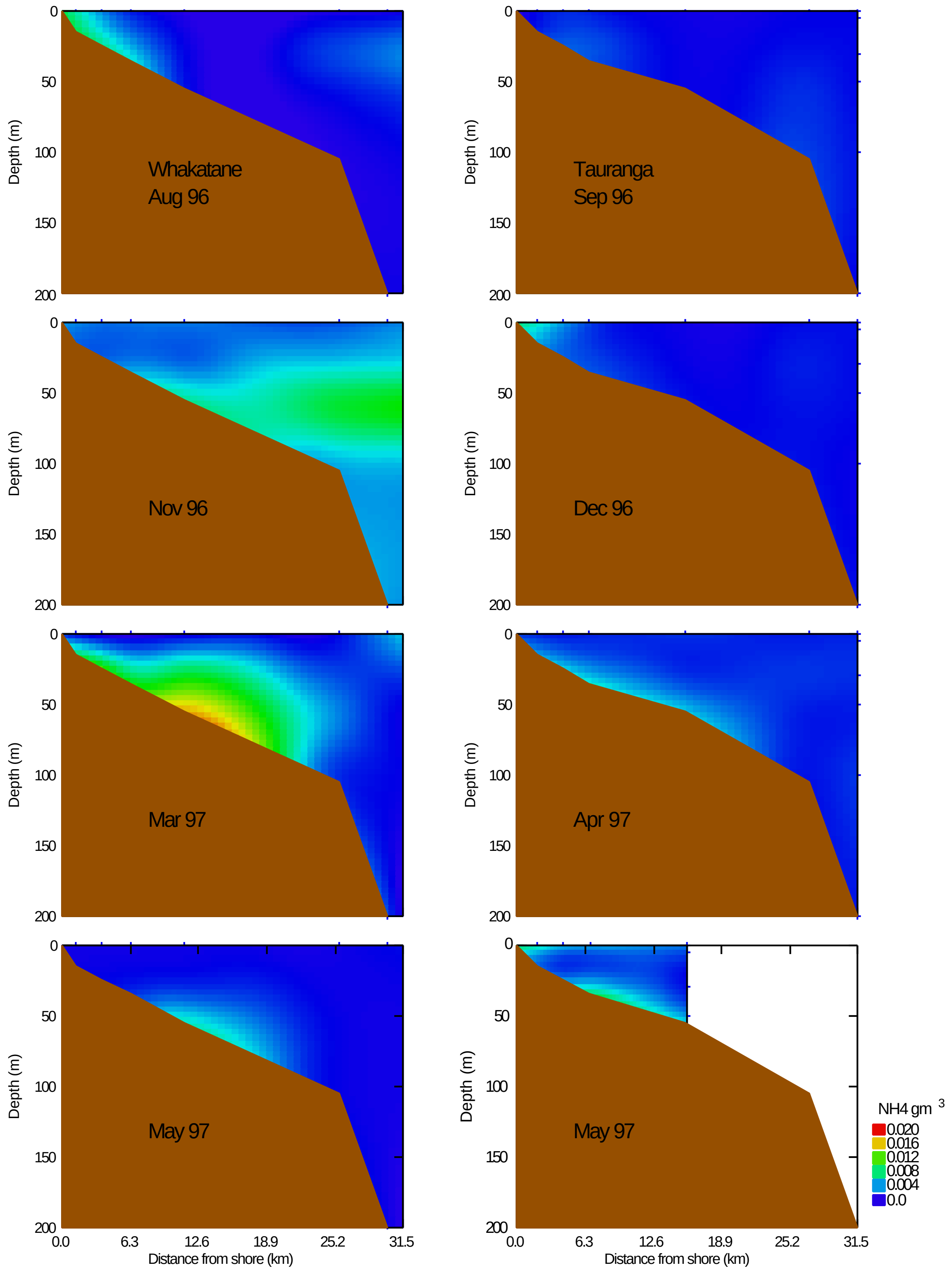


Figure 3.19 Ammonium-nitrogen profile plots for Whakatane (left) and Tauranga transects with measurements from the 10,20,30, 50, 100 and 200 m depth contours on the continental shelf.

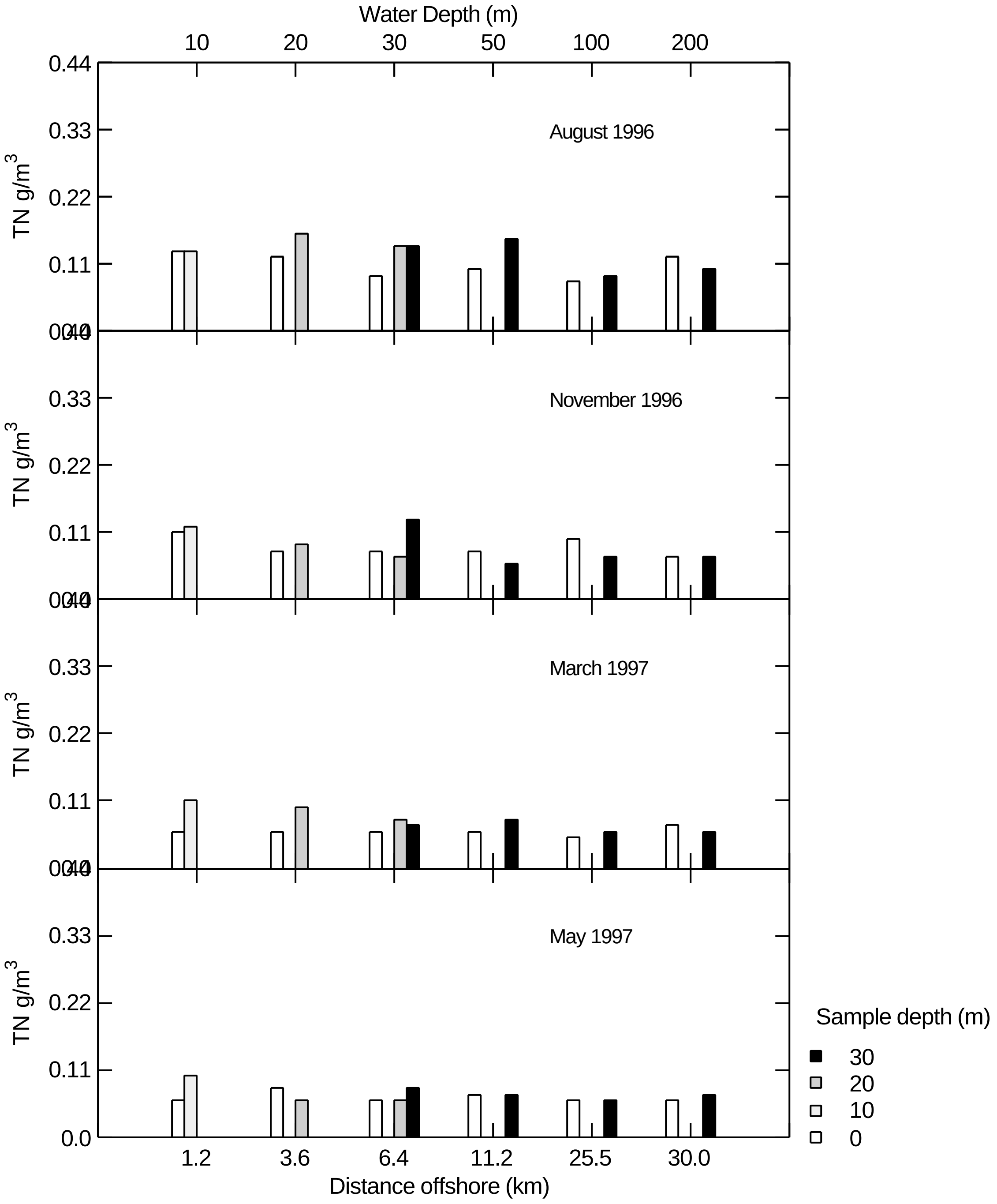


Figure 3.20 Total nitrogen values recorded on the Whakatane transect at the 10, 20, 30, 50, 100 and 200 m depth contours on the continental shelf in 1996/97.

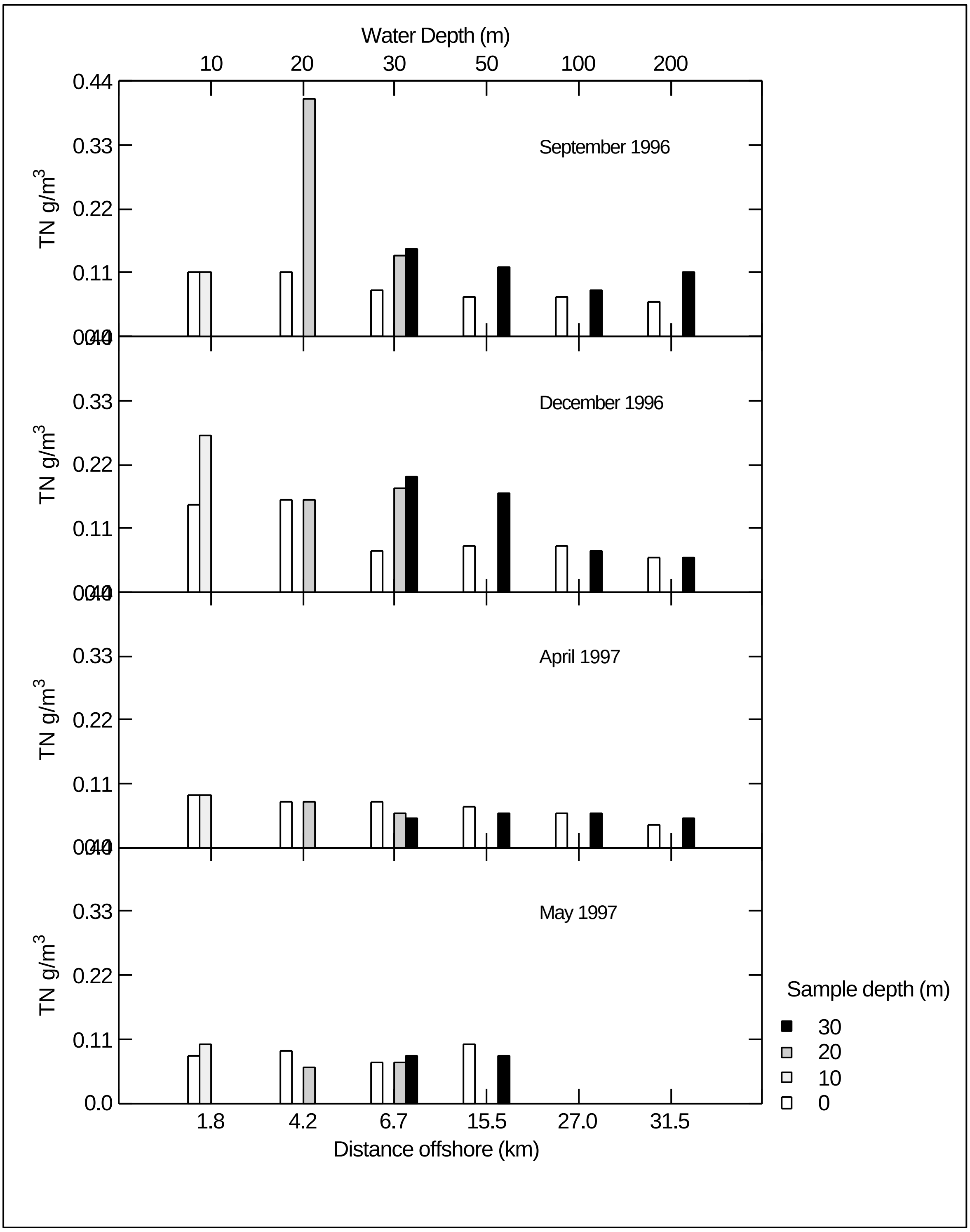


Figure 3.21 Total nitrogen values recorded on the Tauranga transect at the 10, 20, 30, 50, 100 and 200 m depth contours on the continental shelf in 1996/97.

3.2.6 Total Oxidised-Nitrogen

Total oxidised-nitrogen concentrations showed similar trends along both the Whakatane and Tauranga transects (Figure 3.18). Both transects show higher concentrations of total oxidised-nitrogen in the deep oceanic water at the edge of the continental shelf in depths of around 100 m or more. Surface waters always had lower levels than the bottom waters. Higher levels near the bottom were particularly evident in water greater than 30 m depth and there may have been some seasonal variation as levels were highest in winter to late spring.

The December results from the Tauranga transect show high levels of oxidised-nitrogen throughout the bottom water of the mid-shelf region. Concentrations were similar to those recorded in the deep oceanic water.

Overall, late summer to autumn samples appeared to have lower concentrations of total oxidised-nitrogen. The Whakatane transect recorded concentrations of total oxidised-nitrogen from 0.001 – 0.163 g/m^3 while Tauranga values ranged from 0.001 – 0.195 g/m^3. Maximum values for each transect were recorded near the bottom out on the edge of the continental shelf at the 200 m depth contour.

3.2.7 Ammonium Nitrogen

Ammonium nitrogen concentrations tended to be very low along both the Whakatane and Tauranga transects. The maximum value of 0.031 g/m^3 recorded on the Tauranga transect (at the bottom in 10 m depth) was twice that of the next highest value for either transect. Highest concentrations of ammonium nitrogen averaged over a reasonable area were recorded on the Whakatane transect (see Figure 3.19). Moderate levels occurred mid-water near the edge of the continental shelf in November 1996 with the highest values in bottom water of the mid-shelf region in March 1997.

There was little consistency in patterns of ammonium nitrogen concentration between the two transects, especially in comparison to other nutrient parameters. Seasonal patterns or inshore/offshore gradients of changing ammonium concentration were also not apparent.

3.2.8 Total Nitrogen

Figures 3.20 and 3.21 show the results for total nitrogen levels sampled along both the Tauranga and Whakatane transects. Overall mean value of total nitrogen along the Tauranga transect was 0.103 g/m^3 which was higher than that recorded for the Whakatane transect, 0.086 g/m^3. Predominant features of the results were a trend of higher concentrations to occur inshore with a clear seasonal pattern. Highest concentrations of total nitrogen occurred in winter/spring for both transects.

Chapter 4: Discussion

4.1 Trophic Status

Trophic status of a water body is a term that refers to productivity and nutrient status and is a principal factor affecting marine and freshwater ecosystems. Most definitions defining eutrophic conditions (nutrient enrichment of the waters) tend to be qualitative and refer simply to nutrient or organic matter enrichment from external sources that result in high biological productivity.

High nutrient levels generally increase primary productivity of aquatic ecosystems because of blooms or rapid increases in phytoplankton biomass. Measurements of the photosynthetic plant pigment Chlorophyll-a are used as an indicator of phytoplankton biomass. In turn, this parameter is used to provide a quantitative guide with which to assess the trophic status of a water body. Levels of chlorophyll-a below 1 mg/m^3 are generally considered to be typical of “oligotrophic” or nutrient-poor ocean waters. “Eutrophic” or nutrient rich waters have concentrations in excess of 10 mg/m^3 and the phytoplankton biomass widely regarded as blooms. Waters with concentrations between these two levels are referred to as “mesotrophic”.

The limited number of sampling occasions in this study lowers the confidence of assessing trophic status based on chlorophyll-a concentrations. However averaging all the available data for each site sampled (*ie* all seasons and depths) produces the results provided in Table 4.1 below.

Table 4.1 Average chlorophyll-a concentrations (mg/m3) recorded at each site on the Whakatane and Tauranga transects.

Transect	**10 m**	**20 m**	**30 m**	**50 m**	**100 m**	**200 m**
Whakatane	1.338	0.775	1.753	1.084	1.200	1.053
Tauranga	3.288	2.849	2.149	1.362	1.325	0.777

Results from the Whakatane transect have an unusually low concentration of chlorophyll-a recorded at the 20 m depth site in respect of the overall gradients established in the study. Inshore sampling of the Whakatane transect always coincided with high tide which reduced the influence of nutrients *etc* fed in from the Whakatane River. This chance timing may also have precluded measuring potentially higher chlorophyll-a concentrations. However, putting this aside the inshore waters of the

Whakatane transect out a depth of 30 m lie at the very low end of having a mesotrophic status. Waters from around 50 m depth and greater are borderline between oligotrophic and mesotrophic.

A similar trend exists for the Tauranga transect except that average concentration of chlorophyll-a is higher. Inshore waters are easily grouped in to mesotrophic and could be applied to the waters out to 100 m depth. Only the 200 m depth site was consistently low enough to clearly be termed oligotrophic.

Comparison with Environment BOP's long-term monitoring of Tauranga and Ohiwa Harbour (July 1992 – September 1997) provides similar results. Sites near the entrances to Tauranga Harbour have average chlorophyll-a concentrations of 1.7 –1.8 mg/m^3 with higher levels recorded further into the upper harbour (2.8 mg/m^3). Two sites within Ohiwa Harbour result in average values of 1.6 and 0.9 mg/m^3. Both these harbours have high tidal exchange with the open ocean and reflect to a certain degree the chlorophyll-a concentrations found in the near-shore coastal waters. This reinforces the data pointing to higher phytoplankton biomass being a feature of the coastal waters around Tauranga Harbour.

On a wider regional scale the series of Sea Wif satellite images of chlorophyll-a (Appendix 2) indicate higher concentrations occur on the northeast coast in comparison to the northwest or southeast coasts of North Island for the period covered. The most intense, widespread and frequent blooms appear to be centralised around the outer Hauraki Gulf. The Sea Wif images also show the seasonal trends and cross shelf gradients highlighted by this study.

A number of possible factors could account for the higher phytoplankton biomass in this region of the Bay of Plenty. These include nutrient inputs from treated sewage, coastal upwelling and plankton blooms drifting down from the outer Hauraki Gulf. Generally, terrestrial inputs via rivers and streams are greater in the central Bay of Plenty near the Whakatane transect.

Use of nutrient concentration has also been used as a means of assigning trophic status but is poorly developed, particularly for marine waters. This is partly due to geographical variations in water chemistry and complex interactions that influence the effects of nutrient enrichment. Vant (1997) showed how sediment resuspension in the Manukau Harbour reduced light intensities within the water column and lowered the potential growth of phytoplankton in the nutrient rich waters. Also assessment should be based on large data sets to ascertain statistically significant interpretation with little overlap among the ranges of the different water types (Ignatiades et al 1992).

Because of the clearly established vertical, offshore and seasonal gradients of the nutrient data gathered from transects, summary statistics and comparison is difficult and less meaningful. In Table 4.2 below average values of total oxidised nitrogen and dissolved reactive phosphorus are given by combining all data for each site for water depths of 10 m or less.

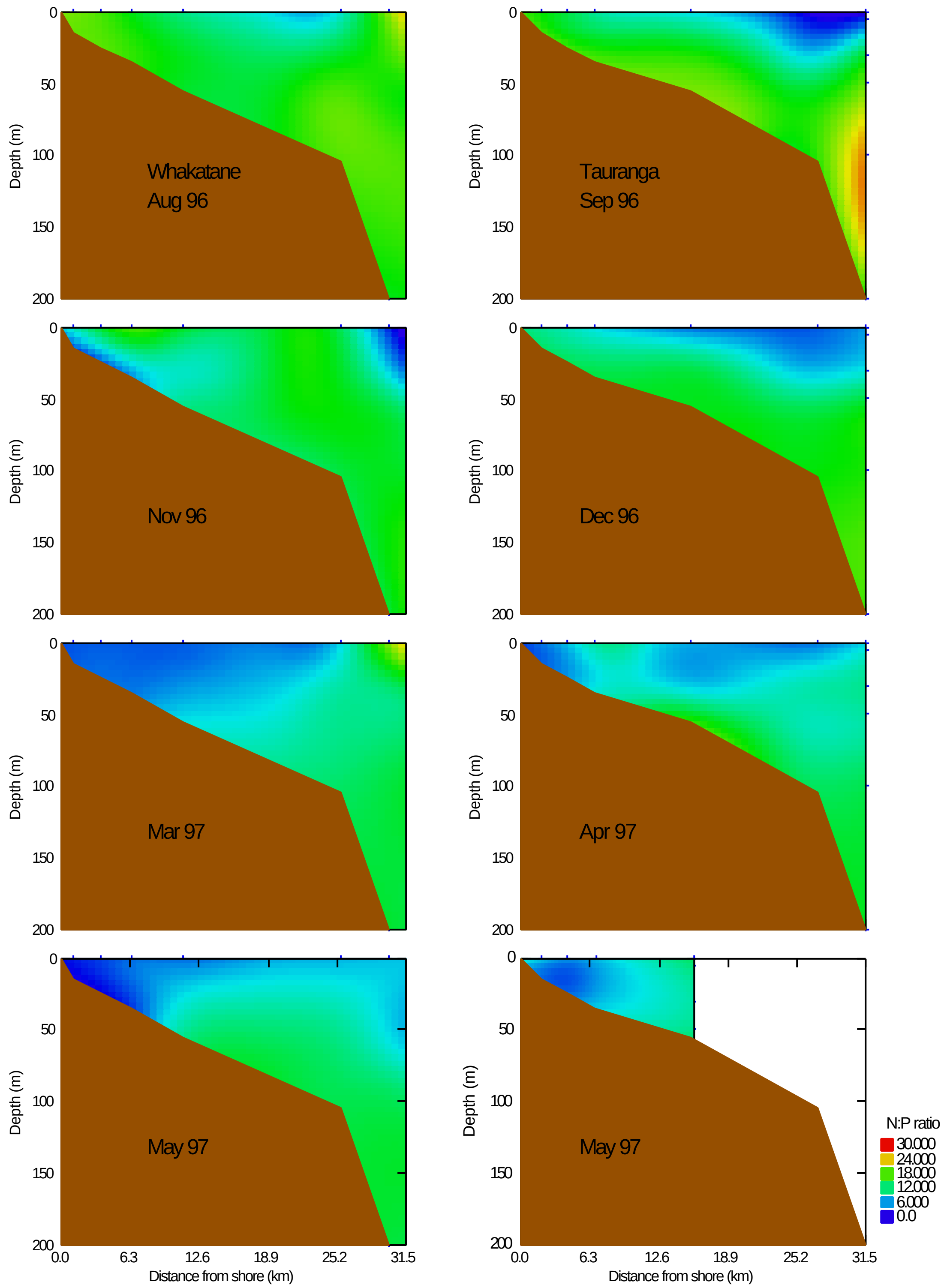


Figure 4.1 Inorganic N:P ratios from sampling the Whakatane and Tauranga transects at the 10, 20, 30, 50, 100 and 200 m depth contours on the continental shelf.

Table 4.2 Mean nutrient concentrations sampled in water of 10 m depth or less.

Transect	**10 m**	**20 m**	**30 m**	**50 m**	**100 m**	**200 m**
	TOX-N g/m^3					
Whakatane	0.019	0.018	0.013	0.009	0.006	0.011
Tauranga	0.019	0.008	0.002	0.004	0.001	0.001
	DRP g/m^3					
Whakatane	0.004	0.002	0.003	0.002	0.002	0.003
Tauranga	0.005	0.002	0.001	0.001	0.001	0.001

Even at the inshore sites, where values reflect the influence of terrestrial nutrient inputs the concentration of TOX-N and DRP are relatively low. In comparison, the eutrophic waters of the north-eastern Manukau Harbour normally have an inorganic nitrogen concentration around 0.5 g/m^3 throughout the summer period (Vant 1997). Overall, nutrient enrichment of the surface inshore waters appears to be low in line with the indications gained from the chlorophyll-a data.

Often of more importance than the absolute concentrations of nutrient are the ratios of bio-available nitrogen and phosphorus, which are the two main nutrients required for plant growth. Studies of these ratios in marine plankton show an average ratio (Red Field ratio) of 16:1 is ideal for growth. As the ratio shifts lower nitrogen will begin to restrict growth or higher and phosphorus will become limiting. Established geographic trends show a tendency towards phosphorus limitation in tropical waters and nitrogen limitation in temperate waters. In many instances, some other nutrient such as iron or physical conditions may be limiting growth.

Figure 4.1 presents the ratios of inorganic nitrogen to phosphorus measured along each transect. Nitrogen often appears to be low relative to phosphorus in the inshore surface waters, especially in summer and autumn when this trend was very pronounced. Overall there was little indication that phosphorus might be seriously limiting. The only instances being in the deep-water (100 m) on the Tauranga transect in winter. Generally the bottom waters of the shelf and deep water of the shelf edge had favourable N:P ratios. The pattern of low N:P ratios in surface water may be associated with depletion of nitrogen by phytoplankton.

Eutrophication of coastal waters often results in hypoxia of bottom waters. This occurs when blooms of phytoplankton lead to an accumulation of organic material on the sea floor. The decompostion of this organic material by bacteria depletes all the available oxygen in the lower water column. Bottom-dwelling benthos is then unable to survive in the reduced oxygen conditions and the whole ecosystem collapses. Overseas this occurs on a large scale in the Gulf of Mexico with a persistent dead zone of some 17,000 km. Moderate depletion of oxygen down to around 75% saturation levels has been observed in association with algal blooms in Manukau Harbour (Vant 1997) with no apparent ecological damage.

In this study DO levels declined to 65% saturation in bottom water of the mid-shelf region. Although this occurred at the time of peak chlorophyll-a measurements, other data indicated that the deep oceanic water was moving on to the shelf at the same time. The DO of the deep oceanic water (below the thermocline) was generally between 70-80% saturation, which indicates that very little oxygen depletion has taken place. Taking into account the possible influence of deep oceanic water the highest level of oxygen depletion appears to be around 20% in bottom water of the outer shelf. Diurnal variations in DO levels are often greater than this as shown by Vant (1997) in the Manukau Harbour. Overall there were no indications that ecologically damaging levels of DO were occurring but the lowest values recorded are marginal and of some concern.

4.2 Oceanic and Terrestrial Nutrient Sources

Identification of the sources of nutrient to coastal waters is crucial for effective management of the resources. Inshore waters derive nutrient from anthropogenic sources (coastal outfalls), terrestrial inputs via rivers, oceanic inputs and atmospheric deposition. Detailed overseas studies have demonstrated that atmospheric contributions can be high. Beddig et al (1997) found that atmospheric contribution of nitrogen to the German Bight was around 30% while rivers accounted for most of the remainder (around 70%).

Detailed and extensive studies are required to quantify such nutrient budgets but indications of nutrient sources can be gained from the data gathered in this study.

Nutrient contributions to the inshore coastal waters via streams and rivers can be assessed from gradients of salinity and elements such as silica. A study of the Tairua Estuary (Bell 1994) showed that dispersion of dissolved reactive silica from the estuary was of a conservative nature and could be used as an indicator in much the same way as tracer dyes etc.

Salinity ranges measured in this study were very small indicating minimal freshwater influence on nutrient results. The small salinity range also reduced the correlation with dissolved reactive silica ($r^2 = -0.585$) compared to the results of Bell (1994). The inshore site at 10 m on the Tauranga transect showed a drop in salinity of around 1.0 in winter/spring sampling when land runoff is high and 0.5 during summer/autumn. This equates to maximum levels of land runoff of around 2.8% of the water mass in winter and 1.4% in summer. Average freshwater inflow to the southern Tauranga Harbour is slightly less than 1% of the tidal compartment per tidal cycle. Taking into account higher freshwater inflows in winter and recycling of water back into the harbour the results seem to be in reasonable agreement.

Land runoff appeared to account for around 1% of the surface water mass further out to the edge of the continental shelf in winter based on salinity. The results showed that in autumn there was virtually no freshwater influence offshore from Tauranga.

Using silica to derive influence of freshwater runoff from land yields similar results to those of salinity. However, in the absence of silica data from Bay of Plenty rivers the average concentration of around 9.0 g/m3 as reported for the Tairua River (Bell 1994) has been used for calculations. For the inshore waters of the Tauranga transect the estimates are that freshwater runoff is around 3% of the water mass in winter and 1.7% in autumn.

During the March samplings run of the Whakatane transect a weak freshwater influence was shown in the salinity profiles for surface waters out to the edge of the continental shelf. This was in contrast to the extent of freshwater influence detectable along the Tauranga transect in April which was very limited. The dissolved reactive silica results presented in Figure 3.10 were in very good agreement with the Whakatane salinity results. It appears that fresh water influence across the continental shelf of the Bay of Plenty may be variable but greater off Whakatane.

Average nutrient concentration of river flows into the Bay of Plenty are an order of magnitude greater than those of the coastal waters. Land runoff could potentially result in a 25% increase in nutrient concentration during winter close inshore on the Tauranga transect. In summer potential increases would be much smaller at around 10-12%. Results of an earlier inshore survey at a large number of sites in 15 m of water off the sandy coastline showed the highest freshwater influence occurred offshore of the larger rivers (McIntosh 1994) such as the Kaituna and Rangitaiki. In addition, elevations in nitrate nitrogen were found to be directly associated with the points of freshwater inflow and all nutrients declined with distance from the shore. Both these studies show that the nutrient status of inshore waters of the Bay of Plenty are dependent on the magnitude of freshwater inflows to the coast.

Nutrient concentrations measured in the bottom water at the edge of the continental shelf off Whakatane and Tauranga were similar to the high levels recorded in up-welling ocean water off Westland, New Zealand (Bradford 1983, Chang *et al* 1995). Also for comparable depth samples, very similar nitrate concentrations were recorded off the northeast coast of Northland, New Zealand (Zeldis *et al* 1998). These nutrient rich waters have concentrations of inorganic nitrogen and phosphorus not far below that of many Bay of Plenty rivers. If these nutrient rich waters up-well and intrude into the surface waters of Bay of Plenty they could potentially increase nutrient concentrations by 600%.

Results of total oxidised nitrogen and dissolved reactive phosphorus in Figures 3.11 and 3.18 showed very high nutrient levels in bottom water of the mid-shelf region, particularly off Tauranga in December. It is also interesting that in autumn (March) when sampling of the Whakatane transect indicated that freshwater was moving offshore there may have been some weak onshore movement of bottom water. A long-term study of shelf waters off Sydney in Australia (Pritchard *et al* 1997) has shown that upwelling is most likely to occur from August – December and very unlikely around April-May. The results from this study appears to follow a similar pattern. Zeldis *et al* (1988) found current and wind induced upwelling along the northeast coast of Northland to be a major factor influencing nitrate concentrations of shelf waters.

To determine the relative importance of terrestrial versus the oceanic upwelling of nutrient rich waters in contributing to the nutrient status of the inshore coastal water, a more detailed assessment is needed. Particularly, in the frequency and strength of up-welling events. It is currently intended to repeat this survey programme every three years. In addition, there are studies currently being undertaken on the northeastern continental shelf of New Zealand by NIWA. This research programme is focusing on effects of variable cross-shelf water exchange, nutrient recycling, and the influence of physical dynamics such as internal waves and tides. Some of the research findings from this study may help understand the processes occurring within the Bay of Plenty.

In addition to nutrient inputs from outside of the coastal waters, recycling can occur within the shelf system. An important form of nutrient recycling is the accumulation and breakdown of organic matter within the bottom sediments. Generally the sediments are very fine in the mid-outer shelf region and tend to be anoxic. The breakdown and nitrogen compounds under anoxic conditions will generally result in ammonium-nitrogen being released from the sediments. At the end of summer (March) relatively high ammonium-nitrogen levels were detected in bottom water in the mid-shelf region of the Whakatane transect. Unfortunately, the DO probe was out of commission otherwise some interesting data might have been associated with this feature.

One area of weakness that still exists in understanding the oceanographic dynamics on the continental shelf of the Bay of Plenty is the influence in terms of frequency and intensity of currents. A more detailed understanding of the interaction of the East Auckland Current and wind driven currents throughout the bay would then allow modelling and prediction of various influences such as El Nino weather patterns on productivity and general water quality. It would also be useful for predicting areas of inshore waters that would be most affected by particular rivers or discharges. This includes highlighting areas of sediment accumulation or inshore migration and interactive effects on ecosystems and productivity.

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Appendices

Appendix 1

Bay of Plenty Neritic Marine Water Quality

Marine water quality monitoring of Bay of Plenty neritic coastal waters will be undertaken every third year to provide baseline and descriptive information. The programme will alternate with Environment BOP's Bathing Water Quality and Shellfish Quality assessments. Programme objectives are to show the extent of terrestrial freshwater and nutrient influence on near-shore water and seasonal changes with the intrusion of oceanic water on to the continental shelf. Also to provide data on the productivity and trophic status of these waters.

Currently information on the quality and extent of the inshore waters is very limited with only one coastal site being monitored in 20 meters of water off the Bowen Town entrance of Tauranga Harbour. Variations in near-shore water quality also appear to exist between the western Bay of Plenty and the central/eastern regions.

Monitoring of two transects which extend from 10 m depth out to the edge of the continental shelf at 200 m will take place four times a year (summer, autumn, winter, spring). One transect will run approximately 30 km from the Mount Maunganui entrance of Tauranga Harbour and the other 30 km out from Whakatane. Intended location of each sampling site is provided below.

At each sampling station the following will be recorded: vertical light attenuation, secchi depth, dissolved oxygen profile, temperature, pH, salinity, chlorophyll a, dissolved and particulate nutrients and plankton (NIWA). A schedule of the intended profile for each station and parameter is shown in the sampling plans below. Mid-water sampling for chlorophyll a and nutrients will vary according to the depth of the thermocline in which they will be taken.

Sampling plan for instrument recordings (Saln, Cond, DO, Temp, pH) 336 records (42 per transect). More measurements may be recorded than indicated for depths up to 65m (the length of the cable).

Sample				**Sampling Station** (depth contour m)				
Depth (m)			10	20	30	50	100	200
0	.	.	x	x	x	x	x	x
5	.	.	x	x	x	x	x	x
10	.	.	x	x	x	x	x	x
20	.	.	.	x	x	x	x	x
30	.	.	.	.	x	x	x	x
50	.	.	.	.	.	x	x	x
60	.	.	.	.	.	.	x	x
100	.	.	.	.	.	.	x	x
200	.	.	.	.	.	.	.	x

Sampling plan for Chl a, and plankton samples 200 samples (25 per transect)

Sample				**Sampling Station** (depth contour m)				
Depth (m)			10	20	30	50	100	200
0	.	.	x	x	x	x	x	x
5	.	.	x	x	x	x	x	x
10	.	.	x	.	x	x	x	x
20	.	.	.	.	x*	.	.	.
30	.	.	.	.	x	x*	x*	x*
50	.	.	.	.	.	x	x	x.
60	.	.	.	.	.	.	.	.
100	.	.	.	.	.	.	.	.
200	.	.	.	.	.	.	.	.

*Sample depth will be at the thermocline if present

Sampling plan for dissolved nutrients DRP, NH4, NO3, 208 samples (26 per transect)

Sample				**Sampling Station** (depth contour m)				
Depth (m)			10	20	30	50	100	200
0	.	.	x	x	x	x	x	x
5	.	.	x	x	x	x	x	x
10	.	.	x	x	.	.	.	.
20	.	.	.	x	x*	.	.	.
30	.	.	.	.	x	x*	x*	x*
50	.	.	.	.	.	x	x	x
60	.	.	.	.	.	.	.	.
100	.	.	.	.	.	.	x	x
200	.	.	.	.	.	.	.	x

Sampling plan for particulate N,&P, TN, TP, SS, Turb, 128 samples (13 per transect)

Sample				**Sampling Station** (depth contour m)				
Depth (m)			10	20	30	50	100	200
0	.	.	x	x	x	x	x	x
5	.	.	.	.	.	.	.	.
10	.	.	x	.	.	.	.	.
20	.	.	.	x	x*	.	.	.
30	.	.	.	.	x	x*	x*	x*
50	.	.	.	.	.	.	.	.
60	.	.	.	.	.	.	.	.
100	.	.	.	.	.	.	.	.
200	.	.	.	.	.	.	.	.

Sampling plan for dissolved reactive silica and Enterococci bacteria, 48 samples (6 per transect).

Sample				**Sampling Station** (depth contour m)				
Depth (m)			10	20	30	50	100	200
0	.	.	x	x	x	x	x	x
5	.	.	.	.	.	.	.	.
10	.	.	.	.	.	.	.	.
20	.	.	.	.	.	.	.	.
30	.	.	.	.	.	.	.	.
50	.	.	.	.	.	.	.	.
60	.	.	.	.	.	.	.	.
100	.	.	.	.	.	.	.	.
200	.	.	.	.	.	.	.	.

Sampling Sites

Tauranga Transect

	Latitude	Longitude		NZMS 260 Grid ref. (m)		labstar #
10 m depth	37 35 40.9	176 08 34.8*	U14	2787737.4	6395999.1	730031
20 m	37 34 53.4	176 09 54.0*	U14	2789730.8	6397393.8	730032
30m	37 34 05.5	176 11 13.2*	U14	2791725.2	6398800.4	730033
50m	37 31 00.0	176 16 00.0	U13	2798966.4	6404260.9	730034
100m	37 27 45.0	176 22 21.0	U13	2808542.3	6409920.7	730035
200m	37 25 12.0	176 25 43.0	V13	2813682.0	6414445.5	730036
Whakatane Transect						
10m	37 56 02.0	177 00 53.3	W15	2862981.8	6355319.2	730037
20 m	37 55 35.4	177 01 17.3	W15	2863604.2	6356112.1	730038
30m	37 53 43.1	177 02 22.4	W15	2865348.4	6359499.5	730039
50m	37 51 41.9	177 04 00.0	W15	2867899.3	6363124.8	730040
100m	37 44 12.9	177 08 30.5	W15	2875140.6	6376649.1	730041
200m	37 41 51.9	177 10 02.0	W15	2877580.2	6380890.6	730042

*Sites are in same location as dinoflagellate cyst monitoring sites.

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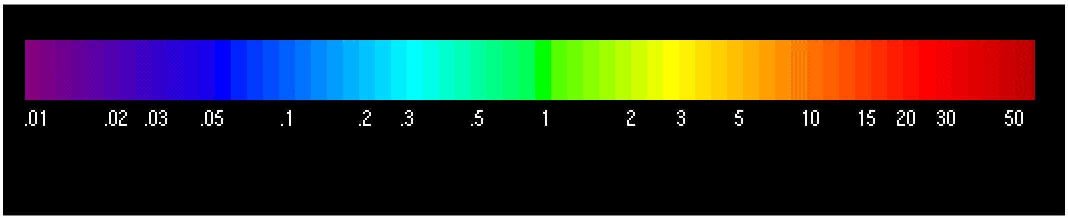
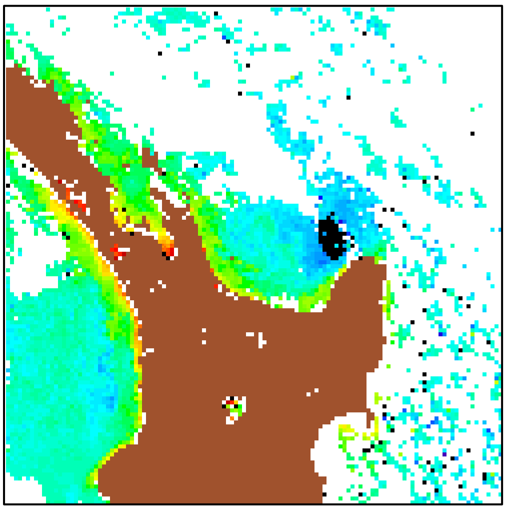
Appendix 2

Sea Wif Remote Sensing Satellite Images of Northeastern New Zealand

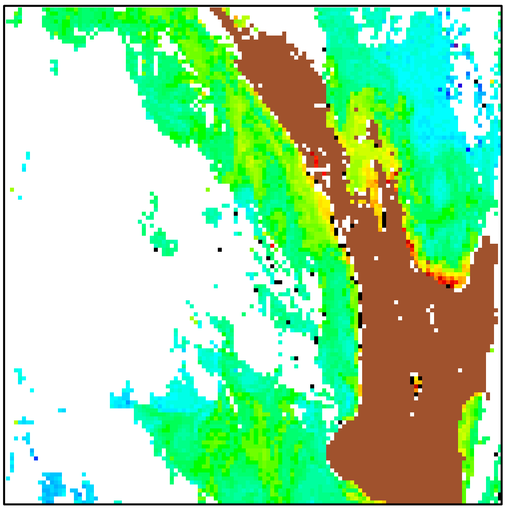
Scale bar for Sea Wif satelite images



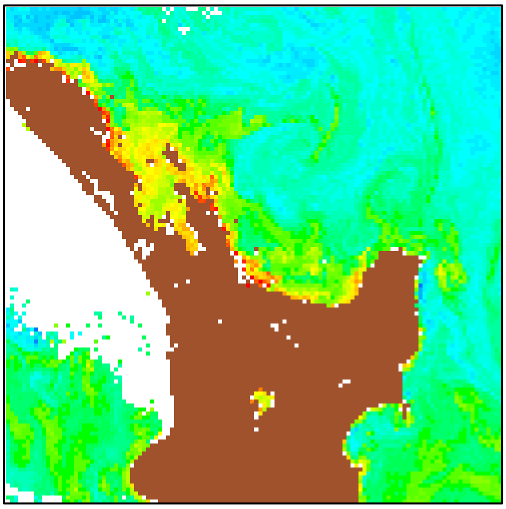
Chlorophyll a mg/m^3



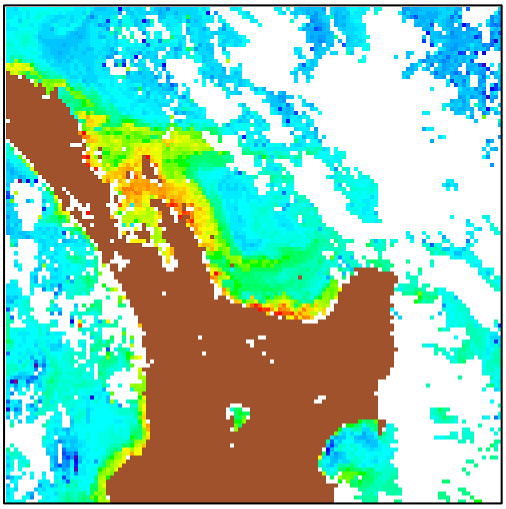
18th Sep 1997



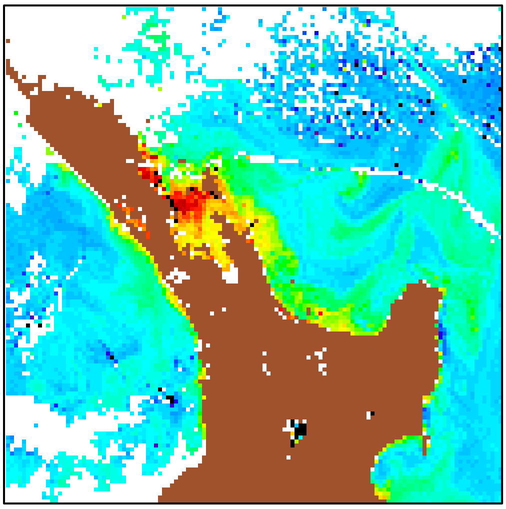
26th Oct 1997



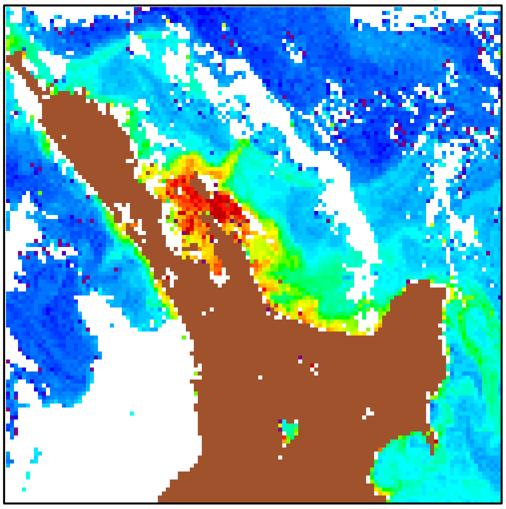
23rd Nov 1997



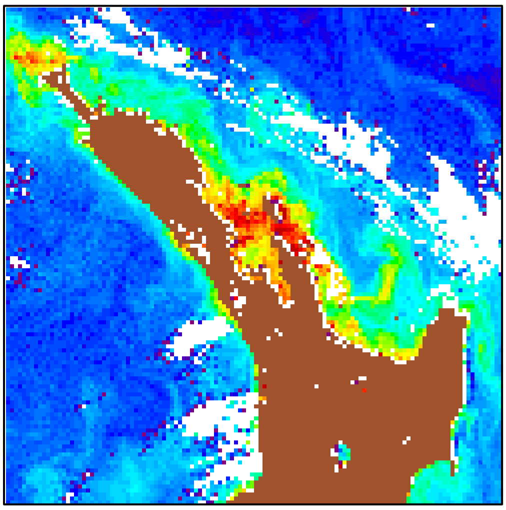
4th Dec 1997



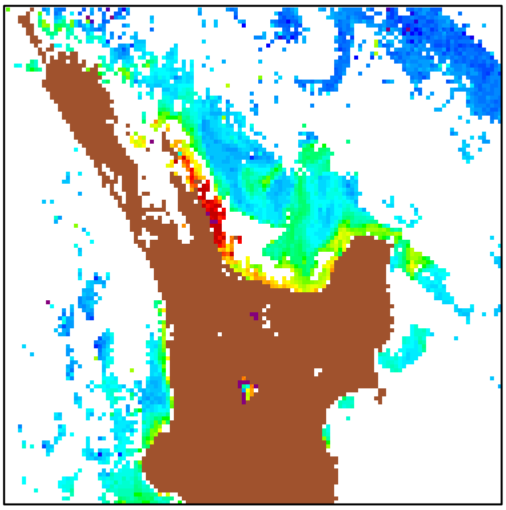
13th Dec 1997



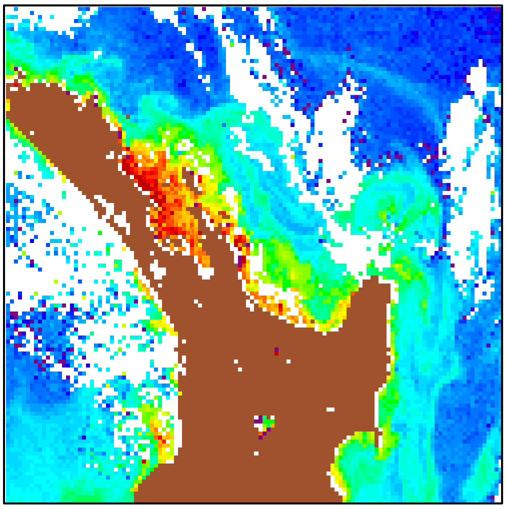
26th Dec 1997



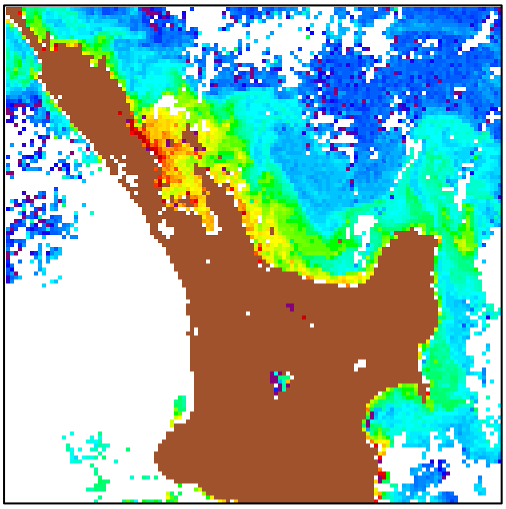
2nd Jan 1998



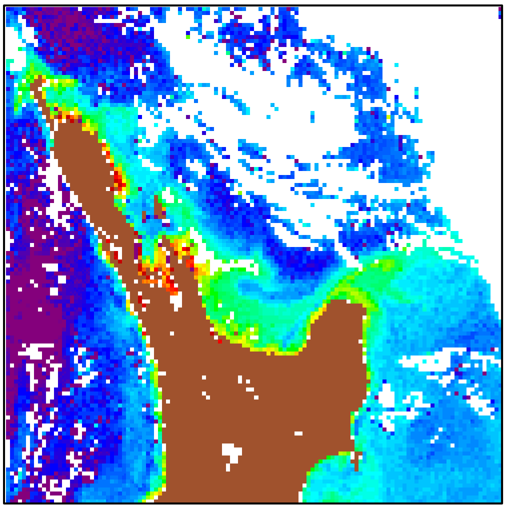
8th Jan 1998

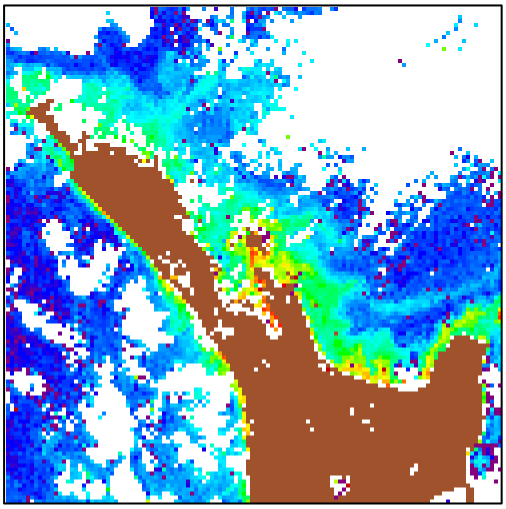


13th Jan 1998



17th Jan 1998





21st Feb 1998

20th Mar 1998

Appendix 3

Pearson correlation matrix and probabilities of all data combined from both transects

```
                 DISTANCE        DEPTH         TEMP           PH        DOSAT
DISTANCE            1.000
DEPTH               0.407        1.000
TEMP               -0.009       -0.239        1.000
PH                  0.088       -0.073        0.019        1.000
DOSAT              -0.077       -0.552        0.385        0.059        1.000
COND                0.405        0.314        0.492       -0.152        0.020
SALN                0.389        0.273        0.544       -0.134        0.065
VLEC               -0.691         .          -0.421        0.142       -0.300
SECCHI              0.662         .           0.607       -0.180        0.056
TURB               -0.489       -0.017       -0.025        0.075       -0.179
SS                 -0.340        0.003       -0.055        0.121       -0.143
CHLA               -0.251       -0.163       -0.529        0.102       -0.006
NO3                 0.281        0.777       -0.583       -0.155       -0.854
NH4                -0.207       -0.041       -0.045       -0.089       -0.256
TN                 -0.328        0.112       -0.514       -0.064       -0.605
PNMGM3             -0.434       -0.133       -0.189        0.155       -0.245
DRP                 0.234        0.766       -0.516       -0.175       -0.865
TP                 -0.465        0.156       -0.471       -0.041       -0.657
PPMGM3             -0.567       -0.073       -0.214        0.104       -0.209
DRSI               -0.594         .           0.069        0.018       -0.444
NPRATIO             0.201        0.304       -0.478       -0.082       -0.425
                     COND         SALN         VLEC       SECCHI         TURB
COND                1.000
SALN                0.985        1.000
VLEC               -0.694       -0.687        1.000
SECCHI              0.676        0.695       -0.766        1.000
TURB               -0.174       -0.158        0.768       -0.696        1.000
SS                 -0.220       -0.203        0.408       -0.355        0.790
CHLA               -0.458       -0.480        0.616       -0.493        0.217
NO3                 0.108        0.049        0.481       -0.376        0.075
NH4                -0.066       -0.073        0.519       -0.289        0.397
TN                 -0.286       -0.319        0.639       -0.558        0.361
PNMGM3             -0.395       -0.389        0.464       -0.251        0.514
DRP                 0.169        0.112        0.599       -0.406        0.203
TP                 -0.284       -0.315        0.708       -0.584        0.609
PPMGM3             -0.350       -0.341        0.820       -0.717        0.792
DRSI               -0.601       -0.585        0.661       -0.361        0.719
NPRATIO            -0.143       -0.173        0.163       -0.204       -0.047
                       SS         CHLA          NO3          NH4           TN
SS                  1.000
CHLA                0.268        1.000
NO3                 0.033        0.090        1.000
NH4                 0.319        0.209        0.090        1.000
TN                  0.356        0.560        0.737        0.441        1.000
PNMGM3              0.537        0.686        0.159        0.470        0.478
DRP                 0.167        0.142        0.963        0.226        0.748
TP                  0.523        0.570        0.717        0.550        0.885
PPMGM3              0.766        0.624        0.145        0.501        0.531
DRSI                0.318        0.234        0.413        0.615        0.472
NPRATIO            -0.135        0.095        0.541        0.156        0.456
                   PNMGM3          DRP           TP       PPMGM3         DRSI
PNMGM3              1.000
DRP                 0.297        1.000
TP                  0.594        0.810        1.000
PPMGM3              0.842        0.308        0.709        1.000
DRSI                0.436        0.476        0.552        0.593        1.000
NPRATIO             0.027        0.402        0.335       -0.013        0.233
                  NPRATIO
NPRATIO             1.000
```

```
Matrix of Bonferroni Probabilities

                  DISTANCE        DEPTH         TEMP           PH        DOSAT
 DISTANCE            0.0
 DEPTH               0.000        0.0
 TEMP                1.000        0.000        0.0
 PH                  1.000        1.000        1.000        0.0
 DOSAT               1.000        0.000        0.000        1.000        0.0
 COND                0.000        0.000        0.000        0.427        1.000
 SALN                0.000        0.000        0.000        1.000        1.000
 VLEC                0.000         .           0.750        1.000        1.000
 SECCHI              0.000         .           0.002        1.000        1.000
 TURB                0.000        1.000        1.000        1.000        1.000
 SS                  0.112        1.000        1.000        1.000        1.000
 CHLA                0.095        1.000        0.000        1.000        1.000
 NO3                 0.016        0.000        0.000        1.000        0.000
 NH4                 0.759        1.000        1.000        1.000        0.160
 TN                  0.182        1.000        0.000        1.000        0.000
 PNMGM3              0.001        1.000        1.000        1.000        1.000
 DRP                 0.210        0.000        0.000        1.000        0.000
 TP                  0.000        1.000        0.000        1.000        0.000
 PPMGM3              0.000        1.000        1.000        1.000        1.000
 DRSI                0.003         .           1.000        1.000        0.861
 NPRATIO             1.000        0.004        0.000        1.000        0.000
                      COND         SALN         VLEC       SECCHI         TURB
 COND                0.0
 SALN                0.000        0.0
 VLEC                0.000        0.000        0.0
 SECCHI              0.000        0.000        0.000        0.0
 TURB                1.000        1.000        0.000        0.000        0.0
 SS                  1.000        1.000        1.000        1.000        0.000
 CHLA                0.000        0.000        0.001        0.105        1.000
 NO3                 1.000        1.000        0.174        1.000        1.000
 NH4                 1.000        1.000        0.047        1.000        0.009
 TN                  0.814        0.257        0.000        0.012        0.048
 PNMGM3              0.009        0.012        0.242        1.000        0.000
 DRP                 1.000        1.000        0.002        1.000        1.000
 TP                  0.883        0.298        0.000        0.004        0.000
 PPMGM3              0.075        0.111        0.000        0.000        0.000
 DRSI                0.002        0.004        0.000        1.000        0.000
 NPRATIO             1.000        1.000        1.000        1.000        1.000
                        SS         CHLA          NO3          NH4           TN
 SS                  0.0
 CHLA                1.000        0.0
 NO3                 1.000        1.000        0.0
 NH4                 0.255        1.000        1.000        0.0
 TN                  0.059        0.000        0.000        0.001        0.0
 PNMGM3              0.000        0.000        1.000        0.000        0.000
 DRP                 1.000        1.000        0.000        0.313        0.000
 TP                  0.000        0.000        0.000        0.000        0.000
 PPMGM3              0.000        0.000        1.000        0.000        0.000
 DRSI                1.000        1.000        1.000        0.001        0.195
 NPRATIO             1.000        1.000        0.000        1.000        0.000
                    PNMGM3          DRP           TP       PPMGM3         DRSI
 PNMGM3              0.0
 DRP                 0.557        0.0
 TP                  0.000        0.000        0.0
 PPMGM3              0.000        0.411        0.000        0.0
 DRSI                0.521        0.174        0.015        0.003        0.0
 NPRATIO             1.000        0.000        0.154        1.000        1.000
                   NPRATIO
 NPRATIO             0.0
```

```
Pairwise frequency table

                  DISTANCE        DEPTH         TEMP           PH        DOSAT
 DISTANCE          440
 DEPTH             440          440
 TEMP              407          407          407
 PH                407          407          407          407
 DOSAT             352          352          352          352          352
 COND              407          407          407          407          352
 SALN              407          407          407          407          352
 VLEC               46           46           46           46           40
 SECCHI             46           46           46           46           40
 TURB              100          100          100          100           87
 SS                100          100          100          100           87
 CHLA              191          191          191          191          166
 NO3               193          193          193          193          167
 NH4               196          196          196          196          170
 TN                100          100          100          100           87
 PNMGM3            101          101          101          101           88
 DRP               195          195          195          195          169
 TP                100          100          100          100           87
 PPMGM3            100          100          100          100           87
 DRSI               46           46           46           46           40
 NPRATIO           193          193          193          193          167
                      COND         SALN         VLEC       SECCHI         TURB
 COND              407
 SALN              407          407
 VLEC               46           46           46
 SECCHI             46           46           46           46
 TURB              100          100           46           46          100
 SS                100          100           46           46          100
 CHLA              191          191           46           46           92
 NO3               193          193           45           45           98
 NH4               196          196           46           46          100
 TN                100          100           46           46          100
 PNMGM3            101          101           46           46          100
 DRP               195          195           46           46           99
 TP                100          100           46           46          100
 PPMGM3            100          100           46           46          100
 DRSI               46           46           46           46           46
 NPRATIO           193          193           45           45           98
                        SS         CHLA          NO3          NH4           TN
 SS                100
 CHLA               92          191
 NO3                98          158          193
 NH4               100          161          193          196
 TN                100           92           98          100          100
 PNMGM3            100           93           99          101          100
 DRP                99          160          193          195           99
 TP                100           92           98          100          100
 PPMGM3            100           92           98          100          100
 DRSI               46           46           45           46           46
 NPRATIO            98          158          193          193           98
                    PNMGM3          DRP           TP       PPMGM3         DRSI
 PNMGM3            101
 DRP               100          195
 TP                100           99          100
 PPMGM3            100           99          100          100
 DRSI               46           46           46           46           46
 NPRATIO            99          193           98           98           45
                   NPRATIO
 NPRATIO           193
```