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Nutrient Status of the Water in Port Phillip Bay

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EXECUTIVE SUMMARY

This study had several objectives, the most important of which was to determine the distribution of nitrogen and phosphorus species in Port Phillip Bay waters under normal and extreme climatic and hydrologic influences over diurnal, seasonal and annual periods.

Fieldwork over two years (1993-95) using a system of continuous analysis whilst underway has provided a large database from which horizontal and vertical distributions may be derived. The underway system measured the nutrients ammonium, nitrite, nitrate, phosphate and silicate, the phytoplankton pigment chlorophyll *a*, and salinity, temperature and dissolved oxygen, in water drawn from 1.5 m below the surface. Light attenuation and vertical profiles of the above characteristics were measured at 10 fixed sites from which samples were also collected for analysis of particulate and dissolved organic nitrogen, phosphorus and carbon, and suspended solids. Pool sizes were calculated for each of the 25 cruises at approximately four week intervals. Short-term variations were addressed by intensive sampling over five-day periods off both the Werribee and Hobsons Bay coasts, while long-term (interannual) variations were addressed by analysis of the VFRI database from six fixed sites sampled every 14 days since February 1990.

The study period (May 1993 - March 1995) was characterised by decreasing rainfall and freshwater input and relatively little data was gathered under high run-off conditions. However, heavy rains in September 1993 led to remarkable changes in nutrient distribution in the northern part of the Bay. In accord with all previous studies, for most of the period the highest nutrient and chlorophyll concentrations were found close to nutrient discharges (the Western Treatment Plant and the Yarra River). The Western Treatment Plant was the major source of ammonium and phosphate while the Yarra River was an important source of nitrate and silicate.

Rather than being radially dispersed from the sources, nutrients and chlorophyll appeared as cells of variable size. During winter cells of high nutrient and chlorophyll concentration up to 25 x 10 km in size traversed the Geelong Arm, while in summer such cells less than 5 km in size followed the Yarra plume. Under the unusual conditions observed in September 1993, floods in the Werribee River introduced a further large nutrient supply to the Bay (although ammonium discharge from the Werribee River was observed on 8 of the 25 cruises). By extrapolating observations in the Bay back to freshwater (zero salinity), we estimate that the Werribee River discharged 75-120 tonnes of ammonium-N, 30 tonnes of nitrate-N and 220 tonnes of silicate-Si to the Bay during this single flood event, 30% of which was discharged in a single day. This is small in comparison to the annual input from other sources but it did nonetheless have the potential to increase the phytoplankton standing crop by 70%.

Vertical variations were observed in most characteristics, particularly for silicate and chlorophyll *a*, but there were no consistent patterns of surface or bottom maxima. Vertical variations were generally so small that they could be ignored in calculating pool sizes. The exception was in Hobsons Bay where surface waters were enriched in nutrients from the Yarra River fresh water plume.

The five-day intensive sampling showed that under low discharge conditions typical of a dry spring-summer, salinity, phosphate and silicate distributions changed little over five days offshore from both the Werribee and Hobsons Bay coasts. Ammonium and oxidised nitrogen concentrations also varied little. There were pools of higher concentration in parts of the study areas which persisted but for less than six hours. If the pools disappeared because of planktonic uptake, it was not reflected in increased chlorophyll concentration within the time of the study (five days). Some nutrient patches moved in a direction consistent with wind-driven transport, but others did not.

Over the longer term, annual cycles were observed for many variables super-imposed on an apparent decline in concentration for some variables from 1990 to 1995. Bay-wide nutrient pool sizes were similar in 1993-95 to those estimated for the period 1980-84, though much smaller than those estimated for ammonium and total nitrogen during 1969-70. We believe this difference is due to analytical deficiencies in the earlier study rather than real changes in pool size.

On many cruises patches of high chlorophyll concentration coincided with high silicate concentrations, underlining the importance of this nutrient to the growth of the diatom-dominated phytoplankton in Port Phillip Bay. Nutrient concentrations and concentration ratios indicated that nitrogen limitation of plankton growth was probable, as was silicate limitation (to a lesser extent), even though cellular pigment ratios suggested growth under non-limiting conditions.

TABLE OF CONTENTS

Page No.

LIST OF TABLES

Page No.

LIST OF FIGURES

Page No.

1. INTRODUCTION

Port Phillip Bay, the largest water body in Victoria, is extremely important to the social and economic well-being of Victorians specifically, and Australians in general. It is an important recreational attraction, with about 30 million visits per year, is host to two of Australia's busiest shipping terminals, and supports significant recreational and commercial fisheries. About 2.6 million angler-hours are spent on the Bay each year and commercial and recreational fishers remove about 3,000 tonnes of fish per annum.

Port Phillip Bay receives waste discharges from many point and diffuse sources. Waste discharges add nutrients (among other chemicals) to the Bay. The effects of nutrient discharges may be beneficial, enhancing primary production, and the potential for increased fish stocks, or detrimental, leading to increased occurrence of nuisance algal blooms, and to ecosystem changes harmful to fish. One objective of the Port Phillip Bay Environmental Study was to determine what impact current nutrient discharges have on the Bay (Crossland 1992). Task N2.1 was designed to provide information on the status of nutrients in the water column.

1.1. Physical setting

Port Phillip Bay was formed about 8,000 years ago, at the end of the last Ice Age, when sea level rose and drowned the Yarra River valley. It has a surface area of 1930 km^2, a mean depth of 14 m and a maximum depth of 24 m (Figure 1). The bottom slopes gradually on the western side and depths of less than 15 m exist up to 10 km from shore. The 15 m contour is within 2 km of shore on the eastern side. About 73% of the total volume of about 26 km^3 is contained in the deeper (>15 m) central section (MMBW & FWD 1973).

The Bay is nearly oval in shape (58 km north-south, 48 km east-west) and includes two smaller bays: Hobsons Bay in the north and Corio Bay in the west. Exchange of water with Bass Strait is restricted by the Great Sands at the southern end of the Bay. Exchange of Bay water with Corio Bay is restricted by a sand bar on the eastern side of Corio Bay.

The Port Phillip Bay catchment is nearly 10,000 km^2 in area, about 11% of which is urban. It is the most populated catchment in Australia with 3.2 million residents (20% of Australia's population). Fresh water enters the Bay from five rivers, the Yarra and Maribyrnong in the north, the Werribee and Little Rivers in the west, and Patterson River in the east. There is also input from the Western Treatment Plant, several small creeks and about 350 storm water drains. The Maribyrnong and Werribee catchments receive substantially less rainfall than the Yarra and hence the Yarra River dominates riverine inflow. In a typical year, as much fresh water falls on the Bay surface in rainfall as is discharged by the gauged rivers, and it is thought that as much is lost by evaporation as enters both from the catchment and as direct rainfall (Hunter 1992). Net freshwater input may therefore be quite low and nominal flushing times accordingly long (12 to 16 months, Hunter 1992). Bay salinity is usually slightly below that of Bass Strait although the waters of Corio Bay are seasonally hypersaline (Longmore *et al*. 1990).

Circulation in the Bay is driven by tides, meteorological forcing (e.g. winds, barometric pressure) and density gradients. Tidal currents vary from about 0.8 m s^{-1} in the region south of the Great Sands, to less than 0.02 m s^{-1} at the northern end of the Bay. Wind-driven currents typically reach 0.05 m s^{-1} (Black and Mourtikas 1992). Density-driven currents are only likely to be important along the east coast near the Yarra River plume and, following a high flow event, offshore from the Werribee River when the localised effect may be equivalent to that of a 2 m s^{-1} (7 km h^{-1}) wind (Hunter 1992). Net horizontal circulation in the Bay occurs as gyres in which the current follows the wind direction in shallow water and opposes it in deeper waters (Black and Mourtikas 1992).

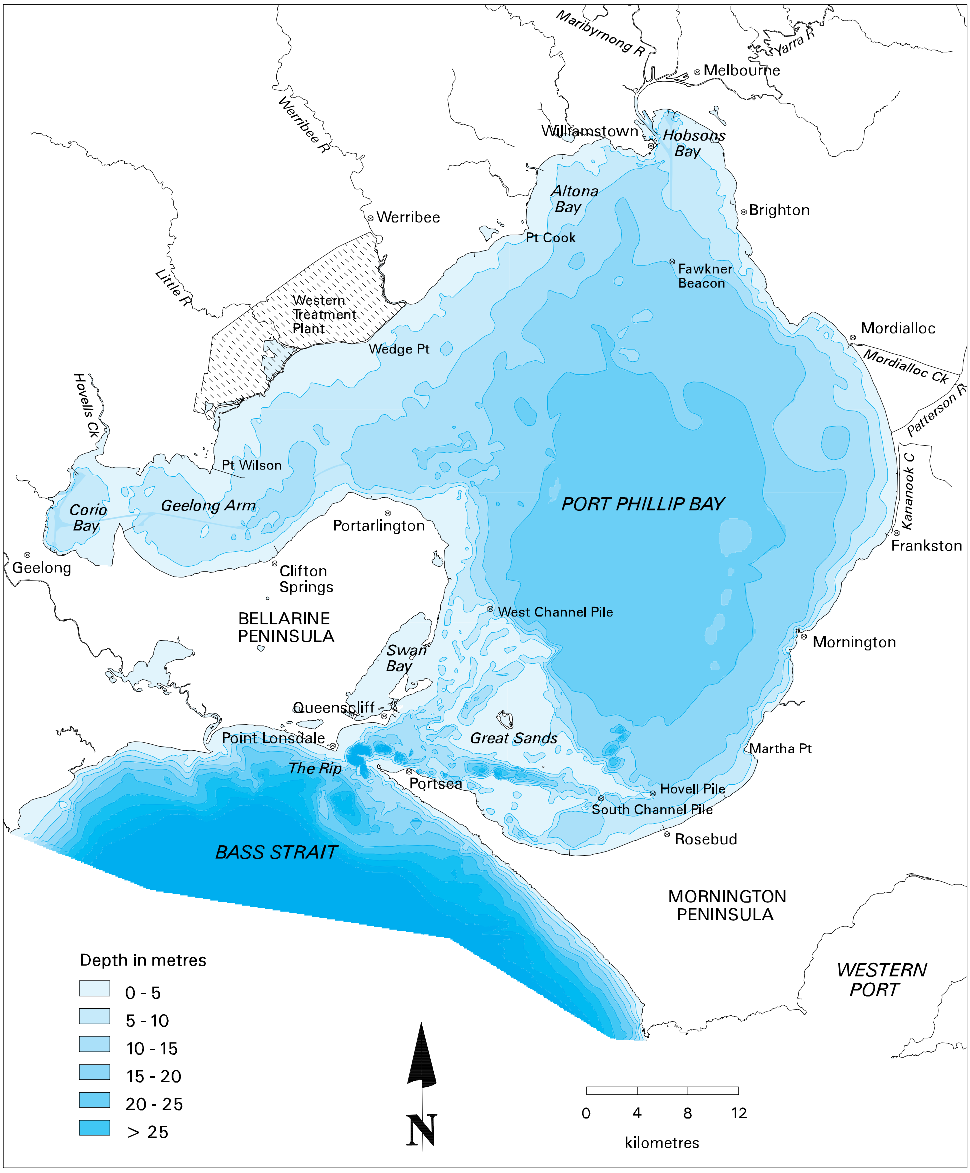

Figure 1: Locality map of Port Phillip Bay with bathymetry.

Vertical mixing is hindered by thermal and salinity gradients and enhanced by wind-driven overturning. Along the north western coast the freshwater plume from the Western Treatment Plant mixes completely with Bay water at wind speeds greater than 5.5 m s^{-1} and forms multiple fronts at lower speeds (Pattiaratchi *et al.* 1989). Since the wind regime over the Bay is highly variable in space and time (Hunter 1992) the direction of net circulation and degree of vertical mixing may also be highly variable.

Measurements to date indicate very effective exchange between water south of the Great Sands and Bass Strait. However, the restrictions imposed by the Great Sands means that very little water from the rest of the Bay actually exchanges with Bass Strait (Walker 1996, Prytz and Heron 1995). This low exchange rate has extremely important implications for the ability of biological and physico-chemical processes in the Bay to effectively mineralise or sequester increased nutrient discharges.

1.2. Nutrient inputs

Nutrient inputs from the catchment include rural runoff, urban runoff and discharges from sewage treatment plants. Estimated contributions of each source are listed in Table 1. The atmosphere may also be a significant source of nitrogen under both wet and dry conditions (Carnovale *et al.* 1992). Nutrient discharges to the Bay are currently thought to total about 7,000 t N and 1,500 t P but with considerable interannual variation.

Nutrient (tonne y^{-1})	WTP	Yarra	Other*	Total
Ammonium	2400			2400
Nitrate	200	460	540	1200
Nitrite	60			60
Organic nitrogen	1020	600	1100	2720
Total nitrogen	3680	1060	1640	6380
Phosphate	760			760
Organic phosphorus	180			180
Total phosphorus	940	120	380	1440

* Other includes rivers, streams and drains other than the Yarra.

Table 1: Averaged surface nutrient discharges to Port Phillip Bay (adapted from Murray 1994).

The largest single source of nutrients to the Bay is the Western Treatment Plant (WTP, Figure 1 and Table 1) which treats about half of Melbourne's domestic wastewater and 90% of its liquid industrial waste. Since 1897 the WTP has treated Melbourne's waste principally by lagooning supplemented by land irrigation in summer and grass filtration in cooler months. The discharge enters the Bay through four outlets (Figure 2) following a retention time in the lagoons of 60-90 days (Murray 1994). Flows are highest and retention times lowest (3-4 days for grass filtration) in winter and spring. Nutrients are discharged principally as dissolved inorganic nitrogen (ammonium and nitrate) and dissolved inorganic phosphate. There is a large seasonal variation in ammonium discharge from the WTP, from less than 2 tonnes N d^{-1} in summer to more than 11 tonnes N d^{-1} in winter. Phosphate discharge is also greater in winter than summer (about 3 tonnes P d^{-1} and 1 tonne P d^{-1} respectively, Murray 1994).

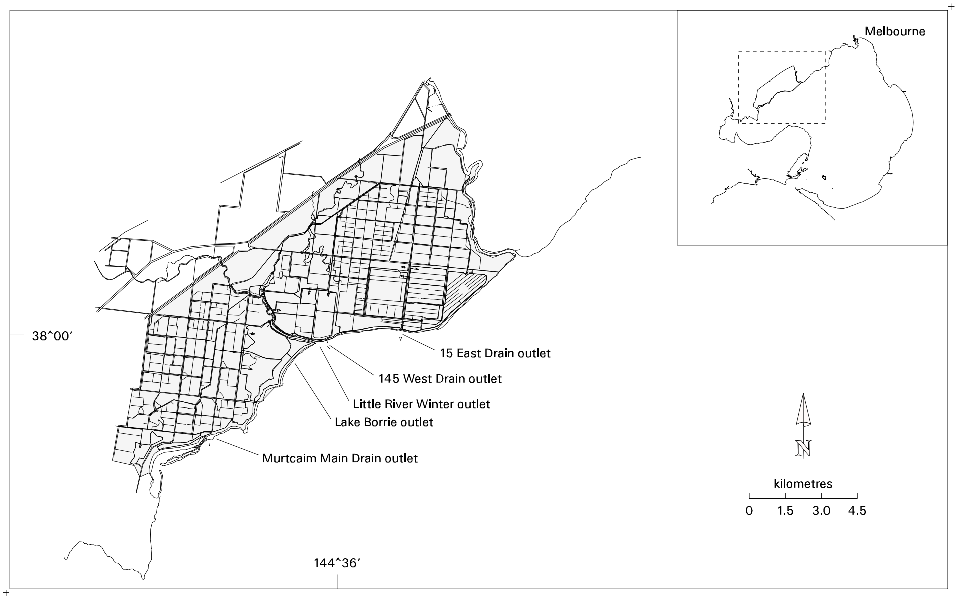

Figure 2: Map of WTP, showing outlets to Port Phillip Bay.

Changes in the catchment over the past 25 years have resulted in decreased nitrogen loads from sullage and trade waste discharges, but increased discharges from regional sewage authorities, urban run-off and atmospheric deposition. This may have led to an increased loading to the northern and eastern areas of the Bay (Skyring *et al.* 1992). Ground water discharges of nutrients are thought to be negligible in comparison to the surface inputs (HydroTechnology 1993).

The Yarra/Maribyrnong catchments contribute about 17% of the nitrogen and 8% of the phosphorus entering the Bay in surface runoff (Murray 1994). The Patterson River/Mordialloc Creek and Werribee River nutrient discharges are also significant (Table 1). River nutrient inputs may be strongly related to flow, but the relationships are complex. For example, total phosphorus, total nitrogen and oxidised nitrogen concentrations increase with rising initial flow, and then either stay constant or decrease with further flow increases (NSR 1993).

1.3. Previous studies of nutrient status

There have been seven major surveys of nutrient concentrations in Bay waters in the past 25 years (summarised in Longmore 1992), all of which have concluded that concentrations of nutrients are highest near shoreline discharges (WTP, Yarra River, Patterson River, Werribee River) and decline toward the centre of the Bay and south of the Great Sands toward Bass Strait. The Phase One Study (MMBW & FWD 1973) identified nine "environmental zones" within which water quality was thought to be fairly uniform. This has not been borne out by subsequent studies (EPA 1979, Cowdell *et al.* 1985) which have shown that spatial variance within a segment at one time is often larger than temporal variance for that segment. Vertical variations in nutrient concentration have been insignificant, except near the WTP and in Hobsons Bay (MMBW & FWD 1973, EPA 1979), suggesting that the water column is usually well-mixed at most sites. Diurnal variations at one site in Corio Bay were negligible in summer and winter (Longmore *et al.* 1990).

Most previous studies have not observed strong seasonal signals in nutrient concentrations except where the discharge has a seasonal signal (e.g. WTP). Several have observed higher nitrogen and phosphorus concentrations during winter in the Werribee and Hobsons Bay areas.

Except for the Phase One Study there has never been an attempt to link concentrations found in the Bay to estimates of loads entering the Bay. Dissolved and particulate nutrients discharged to the Bay from point and diffuse sources are transported in the water column. As noted above, mixing, dispersion and uptake of nutrients may be affected by physical, biological and chemical processes (e.g. wind mixing, phytoplankton uptake, trapping of phosphate by ferric iron). In order to model these processes and extrapolate to future nutrient loads, quantitative estimates of nutrients in varying chemical and physical forms in Bay waters were required. Task N2.1 (Nutrient status of Bay water) was developed to provide this data.

Task N2.1 had the following objectives:

- **i.** To determine the distribution of nitrogen and phosphorus species in Bay waters under normal and extreme climatic and hydrologic influences, over diurnal, seasonal and annual periods.
- **ii.** To determine physico-chemical variables (salinity, temperature, light attenuation, suspended solids, chlorophyll fluorescence) in Bay waters concurrently with sampling for (i).
- **iii.** To provide a description of the nutrient gradients (horizontal and vertical) existing in the Bay to allow the identification of compartments for numeric modelling.

2. METHODS

2.1. Sampling procedures

We chose to meet the objectives of this task by sampling over various time scales at a range of fixed sites, by continuously monitoring along transects and by event-driven sampling over small areas of the Bay. Short-term (four-hourly to five-day) variations in nutrients and associated physico-chemical variables were determined once near Hobsons Bay and twice offshore from the WTP. Longer-term temporal variations (seasonal, climatic and hydrologic) were determined from a previous Victorian Fisheries Research Institute (VFRI) study (see below).

Most of the previous sampling of Port Phillip Bay waters has been from the surface at fixed sites, followed by analysis in land-based laboratories. This traditional approach has several shortcomings, including:

- High staff and boat costs per unit sample;
- No knowledge of vertical structure;
- Imperfect preservation of samples;
- Large sample storage volume needed;
- Limited number of samples from which to draw conclusions about spatial patterns and
- Delays of days to weeks between sampling and analysis.

By coupling salinity, temperature, depth, dissolved oxygen and fluorometric sensors with continuous-flow nutrient analytical systems, it is possible to obtain far greater sample density than with discrete samples. This approach is not novel, having been used for many years to collect vertical profiles (Armstrong *et al.* 1967, Strickland 1968, Anderson and Okubo 1982, Moll *et al.* 1984, Jones *et al.* 1991, Yin *et al.* 1995), but has seldom been used for collecting horizontal transects (Morris *et al.* 1981, Morris *et al*. 1995) and has been reported only once before in Australia (Longmore *et al.* 1990). The spatial resolution of such systems depends on several factors including digitising interval, pump lowering speed (for vertical profiles), and boat speed (for horizontal transects), degree of peak spreading in the water transmission system and response time of sensors (Anderson and Okubo 1982, Mackas and Owen 1982). A simplified diagram of the system is shown in Figure 3.

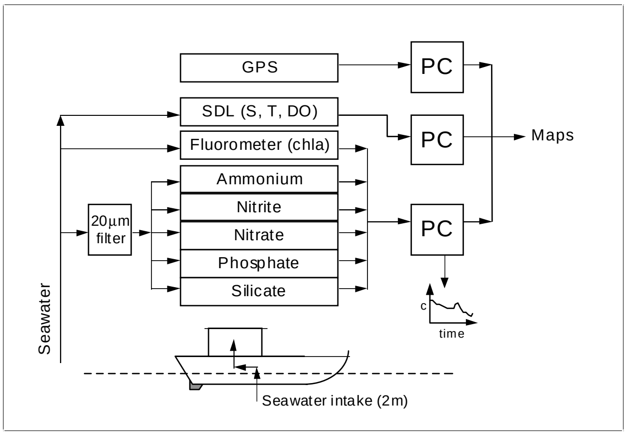

Figure 3: Underway analysis system.

The VFRI have been sampling six near-shore sites in areas of high fishing interest every 14 days since February 1990 (sites 1, 4, 6, 9, 11 and 13, Figure 4). Five additional sites were investigated to provide better coverage of the Bay for the Port Phillip Bay Environmental Study (sites N1, N2, N3, MW1 and MW2, Figure 4) and were sampled once every four weeks between May 1993 and March 1995. The N1 site in The Rip (the confluence of the Bay and Bass Strait) was sampled at the end of the flood and ebb tides in order to distinguish Bass Strait water from Bay water. Temporal trends in nutrient and other characteristics will be determined later by time-series analysis of the VFRI data using a range of spectral and ARMA models (SAS 1986, Chatfield 1989), but simple linear regression was used here to describe trends. The VFRI data set can be used to indicate seasonal and interannual variation.

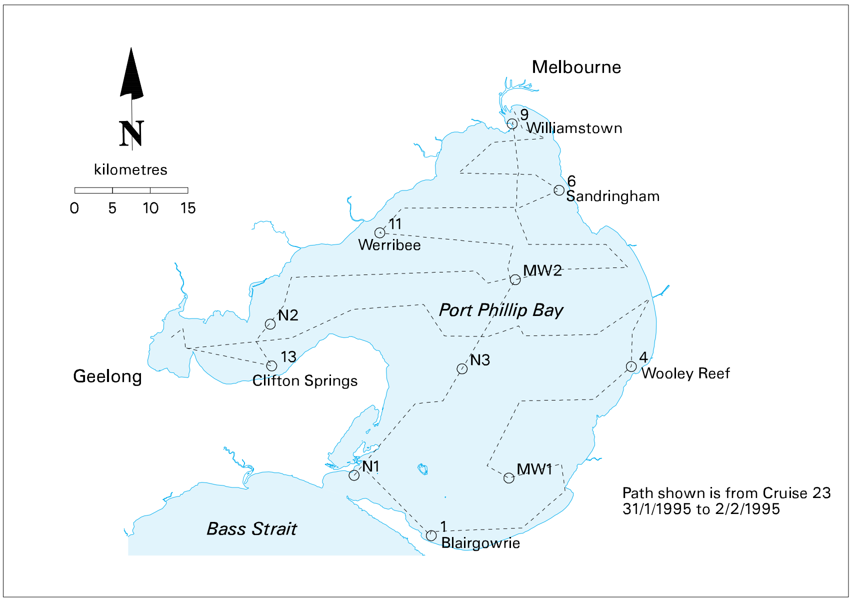

Figure 4: Typical cruise path and station locations for sampling.

Spatial gradients of temperature, salinity, dissolved oxygen, nitrate, nitrite, ammonium, phosphate, silicate and chlorophyll fluorescence were determined each month by continuous underway sampling of near-surface water along transects between the fixed sites and in "zigzags" away from shore (Figure 4). Inorganic nutrients were determined using an on-board AutoAnalyser linked to a datalogger and global positioning system (GPS). Data are presented as maps of concentration isopleths for each characteristic, in a series of figures in this report.

Vertical profiles were obtained at the fixed sites by lowering to surface, midwater and bottom depths a salinity/temperature/dissolved oxygen/depth probe, a fluorometer and a pump. Photosynthetically active radiation (PAR) depth profiles were measured at the fixed sites, from which depth-integrated samples were also collected for particulate and dissolved organic nitrogen, phosphorus, carbon and suspended solids.

2.2. Analytical procedures

Salinity, temperature, dissolved oxygen concentration and depth were measured with a Yeo-Kal SDL submersible data logger run in direct reading mode. Data were fed to a computer for display and storage. Samples were collected from specific depths by Niskin bottle for calibration of salinity and dissolved oxygen. Salinity calibration samples were measured by a Yeo-Kal model 601 mark IV bench salinometer to a precision of 0.01. DO samples were measured by Winkler titration with amperometric end-point detection (Strickland and Parsons 1972) to a precision of 0.05 mL L^{-1} (about 1% saturation).

Temperature was calibrated in the laboratory to 0.01^{o}C against a certified Sensoren Instrument Systems digital reversing thermometer. Despite heavy thermal insulation of the boat pumped water supply, some heating of the flowing stream occurred as it passed through the engine room. Corrections were made to transect temperatures for the effect of heating, by comparison of temperatures measured in depth profiles at fixed sites to those measured from the same sites in the flowing stream.

Chlorophyll fluorescence was measured using either a Seatech submersible fluorometer or a Turner Designs model 10 fluorometer fitted with a flow-through cell. Data were digitised with a Data Electronics DT 200 data logger and stored on computer. Fluorescence was converted to chlorophyll *a* by least-squares linear regression against chlorophyll samples collected by gravity filtration through Whatman GF/C glass fibre filters. These were stored frozen and then extracted by ultrasonication in ice-cold 90% acetone followed by polychromatic spectrophotometric determination (Strickland and Parsons 1972) with the equations of Jeffrey and Humphrey (1975). Comparison of chlorophyll collected on GF/C filters with those on 0.2 μm membrane filters indicated that the concentrations reported here may underestimate the true chlorophyll concentration by 10-40%, representing the fraction of plankton which passes through GF/C filters with a nominal pore size of 1 μm.

The inorganic nutrients ammonium, nitrite, nitrate, phosphate and silicate were measured by continuous-flow colorimetry on water passed through a 20 μm nylon mesh. Ammonium (NH_4) was measured using the phenol-hypochlorite method of Solorzano (1969) as automated by Technicon (1973a). This method has been significantly modified by VFRI to eliminate salinity-dependent sensitivity. Nitrite (NO_2) was measured by the method of Bendschneider and Robinson (1952) as automated by Technicon (1972). Nitrate (NO_3) was measured as nitrite after reduction with a cadmium coil (Morris and Riley 1963) as automated by Technicon (1972). Phosphate (PO_4) was measured using the molybdenum blue method of Murphy and Riley (1962) as automated by Technicon (1973b). Monomeric reactive silicate (SiO_4) was measured using the method of Koroleff (1972) as automated by Technicon (1973c). Nutrient concentrations measured in the field were digitised and recorded on computer. Standards and system blanks were analysed frequently to detect drift and changes in sensitivity.

By measuring the time a spiked sample took to travel through the system, and the degree to which the spike broadened, we were able to estimate that the system deployed by VFRI is capable of resolving features no smaller than 60 sec, or about 200-300 m horizontally at a cruising speed of 8-10 knots.

Total phosphorus (TotP) and Kjeldahl nitrogen (KjlN) were determined by H_2SO_4/H_2O_2 digestion (Nicholls 1975). Particulate nitrogen (PN) and particulate phosphorus (PP) were determined by the same method on samples collected on distilled, deionised water-washed glass fibre filters. Total organic carbon (TOC) was measured by a low-temperature UV/NDIR method on an Astra 1000 analyser, while particulate organic carbon (POC) was measured by high-temperature combustion/NDIR detection of samples on combusted glass fibre filters. Suspended solids (NFR) were measured by gravimetric analysis on glass fibre filters (Anon. 1979).

Photosynthetically-active radiation (PAR) was measured using a Licor LI 192SB submersible sensor connected to a Licor LI 1000 logger. An integration time of three seconds was used to smooth the output, while variations in incident radiation were accounted for by a deck-mounted sensor. Readings were collected from just above and below the water surface and at depths of 0.5, 1, 2, 5, 10, 15 and 20 m. An attenuation coefficient was calculated from the slope of log PAR against depth.

Oxidised nitrogen (N_{ox}) was calculated as the sum of nitrite and nitrate, dissolved inorganic nitrogen (DIN) as [NH_4 + N_{ox}], dissolved organic nitrogen (DON) as [KjlN-NH_4-PN], dissolved organic phosphorus (DOP) as [TotP-PO_4-PP] and dissolved organic carbon (DOC) as [TOC-POC].

Precision and/or accuracy for the various methods used is given in Tables 2 and 3 below.

Salinity	0.02
Temperature	0.02 ^{o}C
Photosynthetically active radiation (PAR)	3%
Chlorophyll fluorescence	~0.1 µg L^{-1} chlorophyll *a* equivalent
Dissolved oxygen	1% saturation
Nitrate	0.05 µM
Nitrite	0.03 µM
Ammonium	0.08 µM
Phosphate	0.05 µM
Silicate	0.10 µM

Table 2: Estimated accuracy of underway analyses.

Salinity	0.006
Dissolved oxygen	0.02 mL L^{-1}
Nitrate	0.05 µM
Nitrite	0.02 µM
Ammonium	0.04 µM
Phosphate	0.02 µM
Silicate	0.06 µM
Kjeldahl nitrogen	0.25 µM
Total phosphorus	0.05 µM
Particulate nitrogen	0.10 µM
Particulate phosphorus	0.02 µM
Total organic carbon	0.2 mg L^{-1}
Particulate organic carbon	0.03 mg L^{-1}
Chlorophyll pigments	0.05 µg L^{-1}
Suspended solids	0.2 mg L^{-1}

Table 3: Estimated precision of laboratory analyses.

In Port Phillip Bay most ammonium, nitrite, nitrate and silicate are "dissolved" (filtration through a Whatman GF/C filter with nominal pore size of 1 µm does not reduce their concentrations) whereas up to 20% of the phosphate detected by the colorimetric method is associated with particles (A. Longmore, unpublished). In the absence of storage effects we could therefore expect similar results for unfiltered frozen samples and directly analysed samples for ammonium, nitrite, nitrate and silicate, while phosphate samples measured in the field may have a slightly lower concentration than those measured in the laboratory because the field samples pass through a coarse (20 µm) filter.

Experiments at VFRI have indicated that freezing of Port Phillip Bay water is normally an adequate preservation method for both short-term (<24 hours) and longer-term (3-9 months) storage of unfiltered samples for subsequent analysis of ammonium, nitrite, nitrate, phosphate and silicate (A. Longmore, unpublished). Turbid samples require filtration before freezing to prevent over-estimation of ammonium concentration.

3. RESULTS

3.1. Chemical and physical forms of nutrients

The depth-integrated fixed site data gathered by VFRI since 1990 (six sites, Figure 4) and by this study during 1993-95 (11 sites, locations given in Table 4 and shown in Figure 4) have been analysed to indicate the chemical and physical forms of nutrients found in the Bay and how these vary from site to site. Table 5 outlines measured concentration ranges and Table 6 describes the percentage composition of various forms of nitrogen, phosphorus and carbon in Bay waters.

Site code	Descriptive name	Latitude (deg, min)	Longitude (deg, min)
1	Blairgowrie	38, 21.240	144, 46.540
4	Wooley Reef	38, 09.015	145, 04.796
6	Sandringham	37, 56.710	144, 58.940
9	Williamstown	37, 51.720	144, 54.790
11	Werribee River	37, 59.480	144, 42.660
13	Clifton Springs	38, 08.630	144, 32.300
MW1	Southern central Bay	38, 17.170	144, 53.710
MW2	Central Bay	38, 03.355	144, 54.522
N1	Rip	38, 16.560	144, 40.356
N1E	Rip (ebb tide)	38, 16.560	144, 40.356
N1F	Rip (flood tide)	38, 16.560	144, 40.356
N2	Point Wilson	38, 05.755	144, 32.433
N3	Western central Bay	38, 09.256	144, 49.630

Table 4: Geographic coordinates for sampling sites.

Dissolved organic nitrogen was the dominant nitrogen form in Bay waters at all sites and varied from about 7 µM equivalent in the south to 11-12 µM near the WTP and Yarra River. The proportion of mean DON to total N decreased in an anticlockwise direction from 79% at the Rip to 67% at the Yarra mouth and then increased again to 79-84% in the west and south. Particulate nitrogen (1.3-3.5 µM equivalent) accounted for 13-20% of the total, decreasing toward the centre of the Bay. Dissolved inorganic nitrogen (0.3-3 µM) accounted for 3-5% of the total at sites distant from nutrient discharges, increasing to 12-13% of the total near the WTP and Hobsons Bay. Ammonium dominated the DIN at most sites, although oxidised nitrogen accounted for up to 54% of the DIN in Hobsons Bay.

Phosphate (0.3-3.3 µM) dominated the phosphorus distribution at all sites and varied from 60% of the total in Bass Strait water to 81-86% elsewhere. Particulate phosphorus (0.09-0.36 µM) accounted for 5-11% of the total at every site except in Bass Strait water at the Rip where it constituted 18% of the total. Dissolved organic phosphate (0.11-0.36 µM) varied from 7-10% of the total at every site except the Rip where it comprised 22% of the total.

Organic carbon (1.1-2.4 mg L^{-1}) was dominated by the dissolved fraction at all sites. POC varied with distance from shore, from 13% of the total in Hobsons Bay to 10% at other coastal sites and 5% in the centre of the Bay.

Table 5: Variation in concentration of chemical and physical forms of nutrients by site.

All values are µM except DOC and POC (mg L^{-1}).
DON = Total N - NH4 - (NO_2+NO_3) - Particulate N;
DOP = Total P - PO_4 - Particulate P;
DOC = TOC - POC

Site	Variable	n. obs.	Mean	Std Dev	Minimum	Maximum
1 (Blairgowrie)	**NH_4**	136	0.42	0.23	0.05	1.78
	NO_2+NO_3	136	0.08	0.14	0	0.92
	DIN	136	0.51	0.28	0.07	1.83
	DON	132	7.57	1.26	4.57	11.11
	PrtN	132	1.52	0.5	0.63	3.28
	PO_4	136	1.16	0.23	0.67	1.67
	DOP	132	0.15	0.13	0.00	0.76
	PrtP	132	0.12	0.05	0.06	0.36
	SiO_4	136	2.9	1.73	0.18	8.91
	DOC	121	1.34	0.35	0.58	3.24
	POC	129	0.15	0.07	0.03	0.37
4 (Wooley Reef)	**NH_4**	131	0.49	0.37	0.01	2.88
	NO_2+NO_3	131	0.18	0.36	0.00	2.15
	DIN	131	0.67	0.65	0.02	3.96
	DON	128	9.62	1.33	6.09	14.25
	PrtN	128	2.09	0.66	0.85	4.09
	PO_4	131	2.13	0.31	0.97	2.89
	DOP	128	0.22	0.18	0.00	0.74
	PrtP	128	0.19	0.07	0.08	0.48
	SiO_4	131	6.59	3.78	0.04	19.43
	DOC	118	1.78	0.39	1.04	3.94
	POC	124	0.19	0.1	0.02	0.52
6 (Sandringham)	**NH_4**	134	0.55	0.5	0	3.86
	NO_2+NO_3	134	0.44	0.92	0.00	6.46
	DIN	134	1	1.32	0.04	10.32
	DON	130	10.25	1.45	4.69	16.15
	PrtN	131	2.52	1.06	0.73	6
	PO_4	134	2.39	0.39	1.71	4.33
	DOP	130	0.22	0.16	0	0.75
	PrtP	131	0.24	0.12	0.07	0.61
	SiO_4	134	7.03	4.14	0.31	25.15
	DOC	125	1.96	0.47	0.98	4.58
	POC	128	0.22	0.11	0.07	0.58

9 (Williamstown)	**NH_4**	134	1.08	0.75	0.07	4.59
	NO_2+NO_3	134	1.28	1.55	0.04	11.84
	DIN	134	2.35	2.14	0.15	16.39
	DON	128	10.97	2.09	7.38	18.7
	PrtN	128	3.38	1.46	0.14	8.82
	PO_4	134	2.65	0.48	1.82	4.92
	DOP	128	0.24	0.36	0	3.57
	PrtP	128	0.36	0.16	0	1.04
	SiO_4	134	9.81	4.86	1.33	31.63
	DOC	125	2.03	0.62	0.95	5.19
	POC	127	0.3	0.14	0.09	0.94
11 (Werribee River)	**NH_4**	134	2.04	3.46	0	18.79
	NO_2+NO_3	134	0.78	1.3	0	6.49
	DIN	134	2.81	4.63	0.04	24.93
	DON	129	11.38	2.16	7.87	19.4
	PrtN	129	2.8	1.62	0.52	8.43
	PO_4	134	3.2	1.21	1.48	7.65
	DOP	128	0.36	0.45	0	3.81
	PrtP	128	0.24	0.16	0.04	0.85
	SiO_4	134	4.2	2.72	0.13	12.7
	DOC	121	2	0.54	0.3	5.17
	POC	123	0.23	0.13	0.06	0.72
13 (Clifton Springs)	**NH_4**	135	0.6	0.8	0	6.87
	NO_2+NO_3	135	0.17	0.44	0	3.07
	DIN	135	0.77	1.17	0.03	9.94
	DON	131	11.4	1.63	7	16.64
	PrtN	131	2.34	1.09	0.36	10.03
	PO_4	135	2.78	0.54	1.3	4.09
	DOP	130	0.29	0.35	0	3.57
	PrtP	130	0.2	0.1	0.04	0.63
	SiO_4	135	4.75	3.12	0.09	16.15
	DOC	124	1.97	0.43	1.06	4.81
	POC	128	0.21	0.12	0.06	0.88
MW1 (Southern Central Bay)	**NH_4**	24	0.51	0.59	0.05	2.92
	NO_2+NO_3	24	0.13	0.51	0	2.54
	DIN	24	0.64	1.06	0.06	5.45
	DON	23	8.91	1.55	3.4	11.04
	PrtN	23	1.59	0.35	0.81	2.12
	PO_4	24	1.76	0.4	1.19	3.31
	DOP	23	0.17	0.21	0	0.58
	PrtP	23	0.12	0.03	0.07	0.17
	SiO_4	24	5.12	4.19	0.24	20.03
	DOC	21	1.56	0.28	1.02	2.03
	POC	21	0.09	0.03	0.05	0.15
MW2 (Central Bay)	**NH_4**	24	0.48	0.27	0.11	0.96
	NO_2+NO_3	24	0.03	0.03	0	0.14
	DIN	24	0.5	0.28	0.12	0.97
	DON	23	9.73	1.42	6.66	12.5
	PrtN	24	1.61	0.51	0.57	2.5
	PO_4	24	2	0.19	1.78	2.37
	DOP	23	0.2	0.13	0	0.36
	PrtP	24	0.13	0.04	0.05	0.23
	SiO_4	24	5.22	3.22	0.11	11.18
	DOC	21	1.7	0.3	1.12	2.31
	POC	22	0.11	0.04	0.05	0.19

N1E (Rip ebb)	**NH_4**	21	0.43	0.27	0.05	1.07
	NO_2+NO_3	21	0.34	0.38	0.04	1.57
	DIN	21	0.77	0.59	0.21	2.64
	DON	21	7.07	2.21	3.4	12.55
	PrtN	21	1.41	0.68	0.81	3.77
	PO_4	21	0.59	0.47	0.15	1.72
	DOP	21	0.11	0.1	0	0.34
	PrtP	21	0.11	0.05	0.05	0.27
	SiO_4	21	1.32	1.43	0.14	7
	DOC	15	1.13	0.46	0.45	2.35
	POC	15	0.12	0.06	0.05	0.25
N1F (Rip flood)	**NH_4**	17	0.38	0.19	0.13	0.85
	NO_2+NO_3	17	0.23	0.17	0.06	0.58
	DIN	17	0.6	0.23	0.27	1
	DON	17	6.12	1.19	4.16	8.92
	PrtN	17	1.26	0.6	0.75	3.22
	PO_4	17	0.33	0.24	0.17	1.13
	DOP	17	0.12	0.1	0	0.39
	PrtP	17	0.09	0.05	0.05	0.26
	SiO_4	17	1.03	1.03	0.06	4.61
	DOC	15	0.98	0.28	0.53	1.53
	POC	15	0.09	0.06	0.04	0.28
N2 (Pt. Wilson)	**NH_4**	9	2.18	3.17	0.41	8.16
	NO_2+NO_3	9	0.76	1.37	0	3.49
	DIN	9	2.94	4.54	0.43	11.65
	DON	9	12.86	2.34	9.25	15.76
	PrtN	9	2.48	0.91	1.32	3.72
	PO_4	9	3.3	0.99	1.6	4.97
	DOP	9	0.34	0.19	0.02	0.73
	PrtP	9	0.19	0.08	0.1	0.35
	SiO_4	9	4.8	2.16	0.37	7.8
	DOC	9	2.19	0.23	1.76	2.44
	POC	9	0.19	0.12	0.07	0.46
N3 (Western central Bay)	**NH_4**	14	0.29	0.1	0.16	0.45
	NO_2+NO_3	14	0.03	0.01	0.01	0.05
	DIN	14	0.32	0.09	0.19	0.48
	DON	14	9.72	1.16	8.26	11.46
	PrtN	14	1.45	0.37	0.85	1.91
	PO_4	14	1.79	0.13	1.51	2.06
	DOP	14	0.21	0.1	0	0.34
	PrtP	14	0.11	0.04	0.06	0.2
	SiO_4	14	3.81	2.46	0.57	7.99
	DOC	10	1.64	0.25	1.24	1.96
	POC	10	0.08	0.02	0.06	0.12

Table 6: Mean percentage distribution of physical and chemical forms of N, P and C, by site.

DON = Total N - NH4 - (NO_2+NO_3) - Particulate N;
DOP = Total P - PO_4 - Particulate P;
DOC = TOC - POC

Site	Variable	n. obs.	Mean % of total	Std Dev	Minimum % of total	Maximum % of total
1 (Blairgowrie)	**DON**	132	79	6	57	92
	DIN	136	5	3	1	23
	PrtN	132	16	5	5	38
	DIP	136	81	8	54	105
	DOP	132	10	8	0	33
	PrtP	132	9	3	4	23
	DOC	121	90	6	64	97
	POC	121	10	6	3	36
4 (Wooley Reef)	**DON**	128	78	7	58	90
	DIN	131	5	5	0	28
	PrtN	128	17	5	7	30
	DIP	131	84	7	64	114
	DOP	128	9	7	0	27
	PrtP	128	7	3	3	22
	DOC	118	90	5	73	99
	POC	118	10	5	1	27
6 (Sandringham)	**DON**	130	75	8	48	92
	DIN	133	7	6	0	40
	PrtN	130	18	6	5	35
	DIP	133	84	7	58	106
	DOP	130	8	6	0	26
	PrtP	130	8	4	3	21
	DOC	125	90	4	71	96
	POC	125	10	4	4	29
9 (Williamstown)	**DON**	128	67	8	38	92
	DIN	134	13	8	1	42
	PrtN	128	20	7	1	43
	DIP	134	82	7	43	95
	DOP	128	7	7	0	52
	PrtP	128	11	4	0	28
	DOC	125	87	5	62	96
	POC	125	13	5	4	38
11 (Werribee R.)	**DON**	129	71	14	36	94
	DIN	134	12	14	0	56
	PrtN	129	17	8	4	45
	DIP	134	84	8	45	98
	DOP	128	9	7	0	54
	PrtP	128	7	4	1	27
	DOC	121	89	7	48	97
	POC	121	11	7	3	52
13 (Clifton Springs)	**DON**	131	79	8	41	92
	DIN	135	5	5	0	40
	PrtN	131	16	6	2	58
	DIP	135	85	7	42	103
	DOP	130	9	7	0	55

	PrtP	130	6	3	1	24
	DOC	124	90	6	56	97
	POC	124	10	6	3	44
MW1 (Southern central Bay)	**DON**	23	81	6	64	89
	DIN	23	4	3	1	12
	PrtN	23	15	3	9	24
	DIP	23	85	10	64	120
	DOP	23	8	11	0	31
	PrtP	23	6	2	4	10
	DOC	21	94	2	90	97
	POC	21	6	2	3	10
MW2 (Central Bay)	**DON**	23	82	5	72	89
	DIN	24	4	2	1	9
	PrtN	23	13	4	6	19
	DIP	24	86	7	75	105
	DOP	23	9	6	0	15
	PrtP	23	5	2	3	10
	DOC	21	94	2	90	97
	POC	21	6	2	3	10
N1E (Rip ebb)	**DON**	21	76	9	49	90
	DIN	21	9	7	2	28
	PrtN	21	15	4	8	23
	DIP	21	68	17	26	95
	DOP	21	16	14	0	42
	PrtP	21	16	9	5	32
	DOC	15	90	6	73	94
	POC	15	10	6	6	27
N1F (Rip flood)	**DON**	17	77	7	55	83
	DIN	17	8	3	3	13
	PrtN	17	16	6	10	35
	DIP	17	60	12	40	87
	DOP	17	22	14	0	44
	PrtP	17	18	9	7	39
	DOC	15	92	5	77	97
	POC	15	8	5	3	23
N2 (Pt. Wilson)	**DON**	9	74	15	49	88
	DIN	9	12	16	3	40
	PrtN	9	14	6	7	27
	DIP	9	85	7	72	96
	DOP	9	10	6	1	23
	PrtP	9	5	2	3	8
	DOC	9	93	4	84	97
	POC	9	7	4	3	16
N3 (Western central Bay)	**DON**	14	84	3	78	91
	DIN	14	3	1	2	5
	PrtN	14	13	3	7	17
	DIP	14	85	5	79	96
	DOP	14	10	5	0	16
	PrtP	14	5	2	3	10
	DOC	10	95	1	93	97
	POC	10	5	1	3	7

3.2. Spatial scales and temporal scales

Twenty-five Bay-wide cruises at four-weekly intervals and three small area short term studies were completed between May 1993 and April 1995 (see Table 7 for cruise dates). The short term studies were intended to occur following significant events in 1994, such as high river flows, but unfortunately no such events occurred (Figures 5 and 6). Small-scale cruises were therefore carried out in spring and summer 1994-95 under relatively low-flow conditions.

Bay-wide Cruises	
Cruise no.	**Dates**
1	25, 26 May 1993
2	22, 23, 24, 25 June 1993
3	20, 21 July 1993
4	3, 4 August 1993
5	14, 15, 16 September 1993
6	12, 13 October 1993
7	9, 10, 11 November 1993
8	7, 8 December 1993
9	4, 5, 7 January 1994
10	1, 2, 3 February 1994
11	1, 2, 3 March 1994
12	28, 29, 30 March 1994
13	26, 27, 28, 29 April 1994
14	31 May, 1, 2, 3 June 1994
15	22, 27, 28, 29 June 1994
16	19, 20, 21 July 1994
17	16, 17, 18 August 1994
18	14, 15, 16 September 1994
19	12, 13, 14 October 1994
20	9, 10, 11 November 1994
21	6, 7, 8, 10 December 1994
22	3, 4, 5 January 1995
23	31 January, 1, 2, 3 February 1995
24	27, 28 February, 1, 2, 3 March 1995
25	27, 28, 29 March 1995

Short Term Studies		
Cruise no.	**Area**	**Dates**
1	Werribee	5-9 September 1994
2	Northern Port Phillip	23-27 January 1995
3	Werribee	6-10 February 1995

Table 7: Cruise dates for under-way sampling.

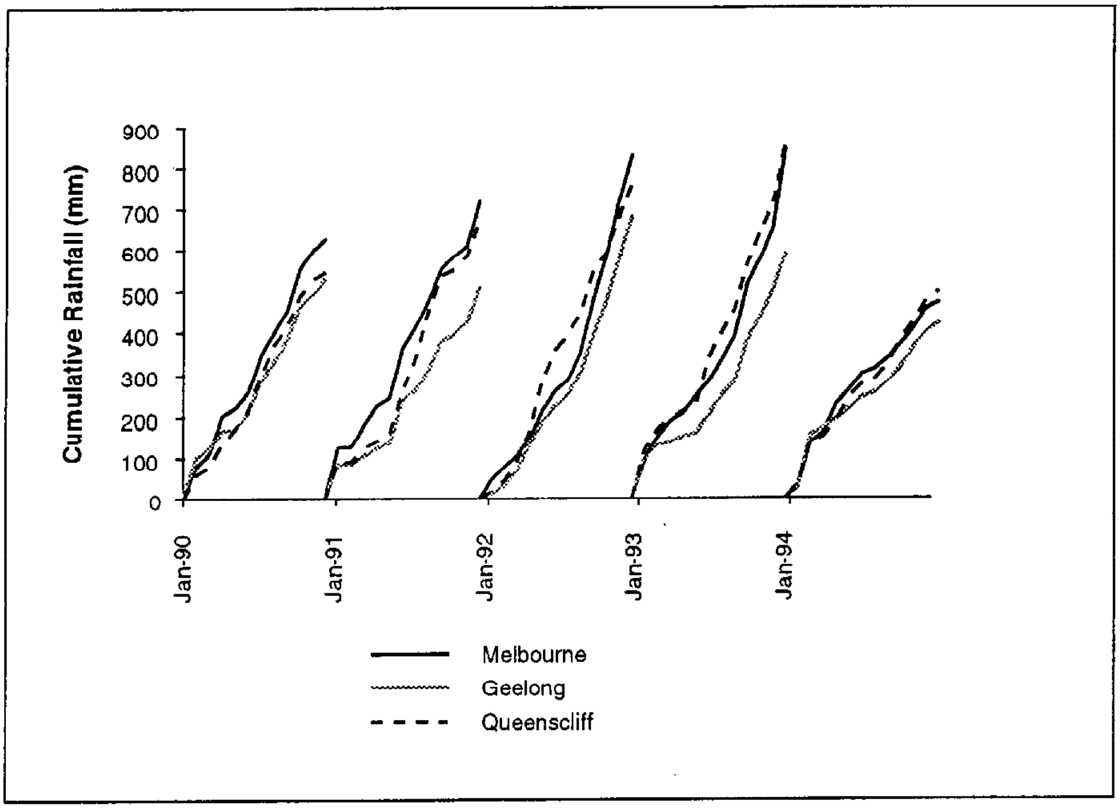

Figure 5: Cumulative Rainfall measured at Melbourne, Geelong and Queenscliff, 1990-95.

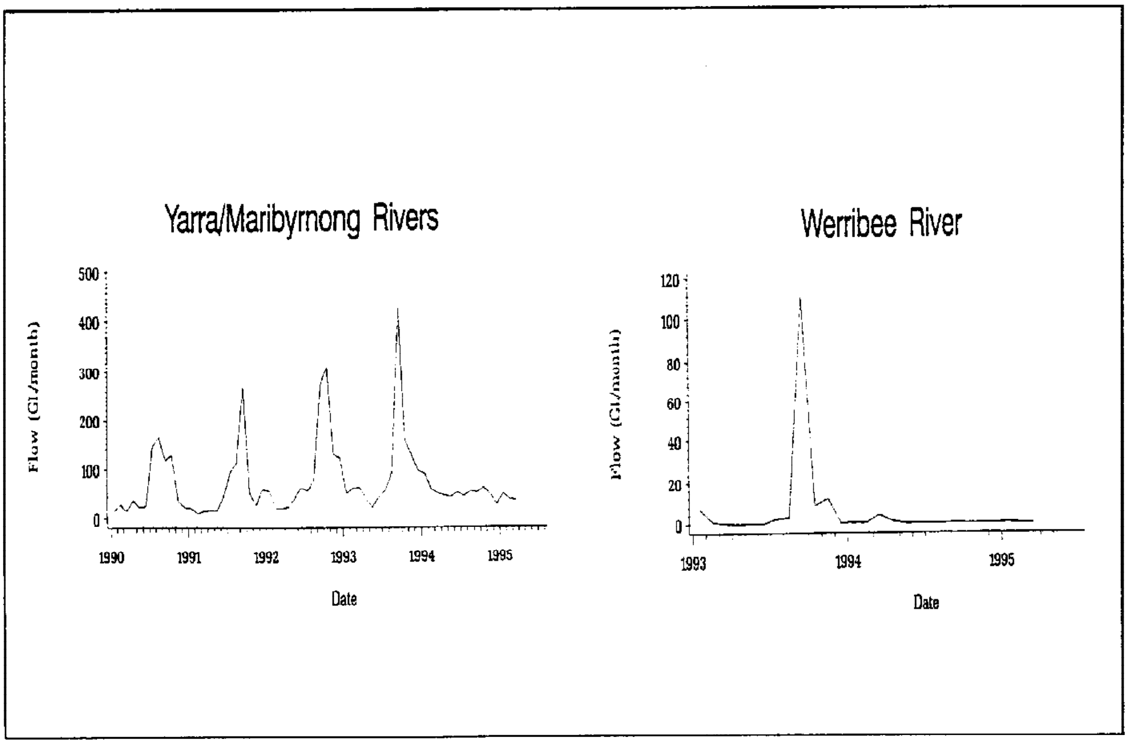

Figure 6: Flows for the Werribee River and the Yarra/Maribyrnong Rivers, 1990-95.

3.2.1. Short term study - Werribee September 5-9, 1994

Surface distributions

Figures 7 to 14 display surface concentrations measured during nine circuits off the Werribee coast over five days in September 1994. Only 2.2 mm of rain was recorded during the period. Wind speed was 6-11 m s^{-1} on the first two days and then abated to 2 m s^{-1} by the last day. Wind direction was consistently in the arc SW-WNW.

Salinity offshore of the WTP decreased on lap 5 by about 0.5 (Figure 7). Low salinity water moved north along the coast over the next day and then reoccurred over the whole study area during the last two laps. Temperature distribution (Figure 8) was similar on all laps with the exception of patches of warmer water in the southern part of the area on the first, eighth and ninth laps.

Ammonium concentrations (Figure 9) were low (<0.5 µM) on most laps throughout the area. A patch of higher concentration less than 5 km in diameter appeared off the Werribee River on lap 4 but disappeared within four hours. Two patches (2 km diameter and 5 km x 15 km) of high concentration (4-18 µM) appeared on lap 8 offshore from the WTP and Werribee River but disappeared by the next day.

Oxidised nitrogen concentrations (Figure 10) were less than 0.2 µM over most of the area on each lap. A small (<2 km diameter) patch of more than 2 µM offshore from the Werribee River was recorded on lap 4 but disappeared within the next four hours. Most of the near-shore area had high oxidised nitrogen concentrations on lap 8, but these disappeared within 24 hours.

Phosphate concentrations (Figure 11) were fairly uniform over the first 20 hours and then increased from <3 to >4 µM over most of the area in the next four hours (lap 6). After a further 24 hours (lap 7) concentrations dropped everywhere except near-shore north of the Werribee River. By the fourth day (lap 8) phosphate concentrations in most of the near-shore area were high (4-7 µM) but then returned to background (<3 µM) before the fifth day.

Silicate (Figure 12) was uniformly low (<1 µM) on all laps for which data was obtained.

Chlorophyll *a* concentration (Figure 13) generally increased to a peak on lap 6 and declined thereafter on all laps except the last. Patches offshore from the WTP and Werribee River moved by less than 1 km during the first two days.

Dissolved oxygen (Figure 14) was above saturation on all laps with concentrations up to 120% along the inshore leg and more than 110% elsewhere on the afternoons of days 1, 4 and 5 (laps 2, 8 and 9). Concentrations declined slightly at night (lap 3) but increased again before daylight (lap 4). Areas with 110% saturation or more generally coincided with areas of high chlorophyll *a* concentration.

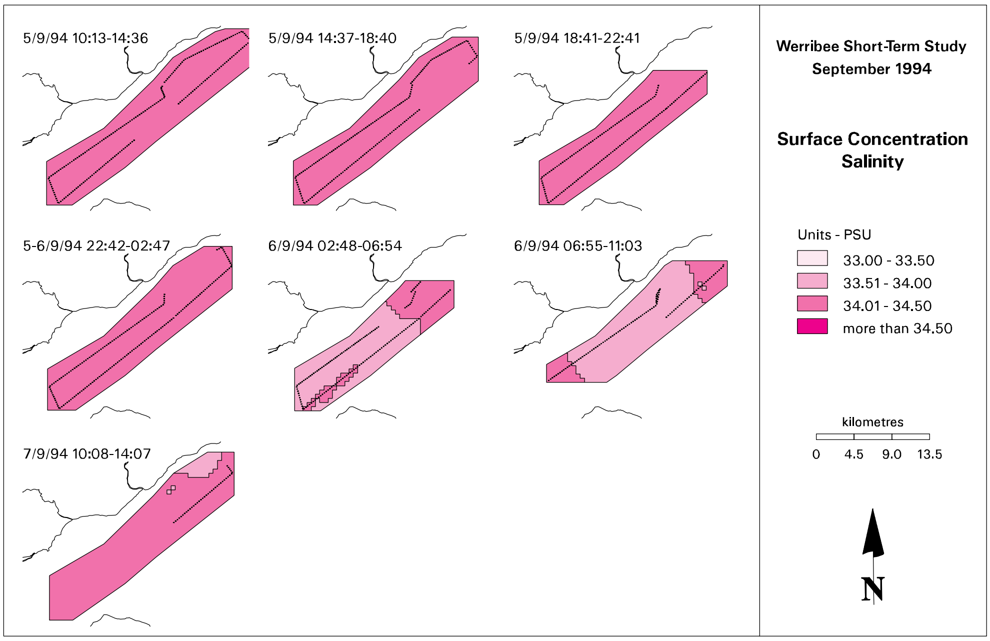

Figure 7: Surface salinity distributions, Werribee, September 1994.

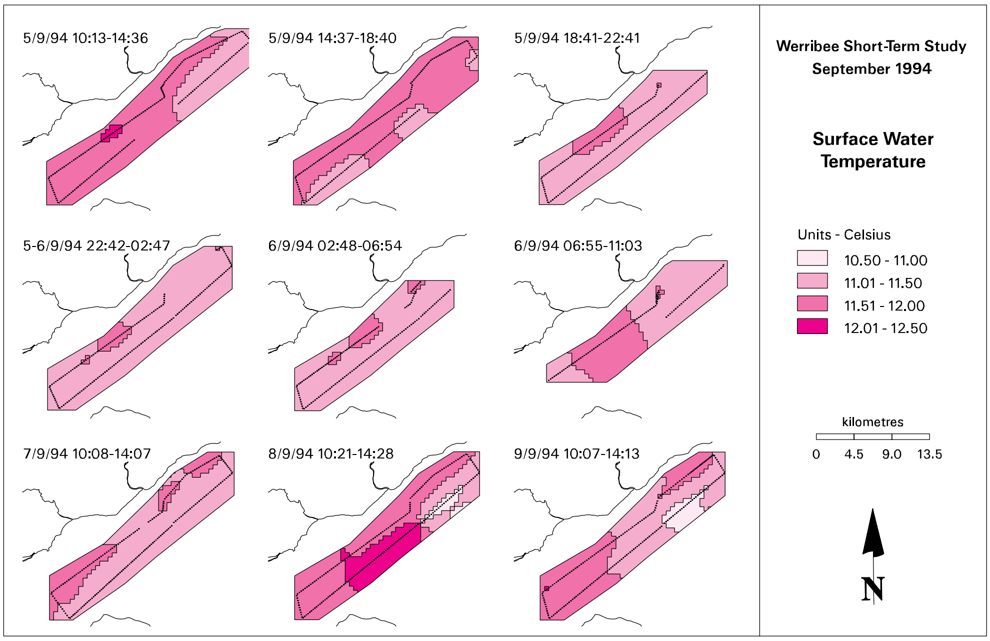

Figure 8: Surface temperature distributions, Werribee, September 1994.

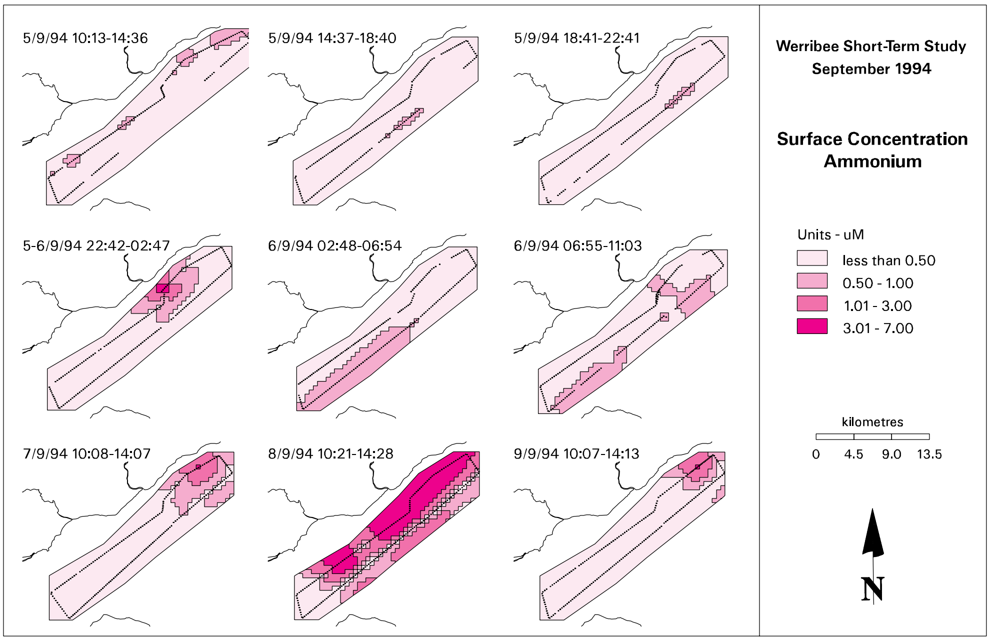

Figure 9: Surface ammonium distributions, Werribee, September 1994.

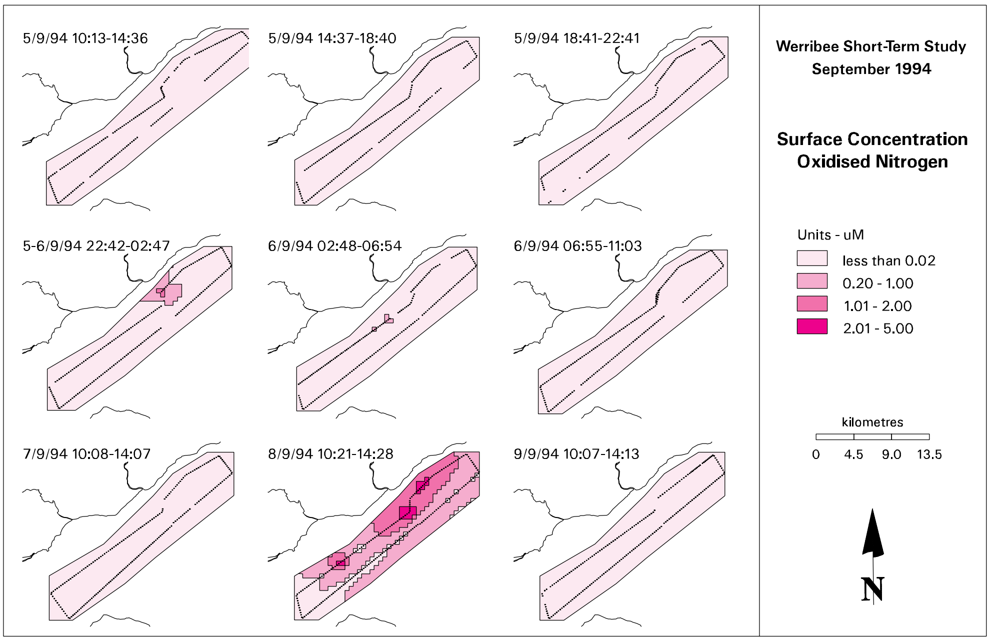

Figure 10: Surface oxidised nitrogen distributions, Werribee, September 1994.

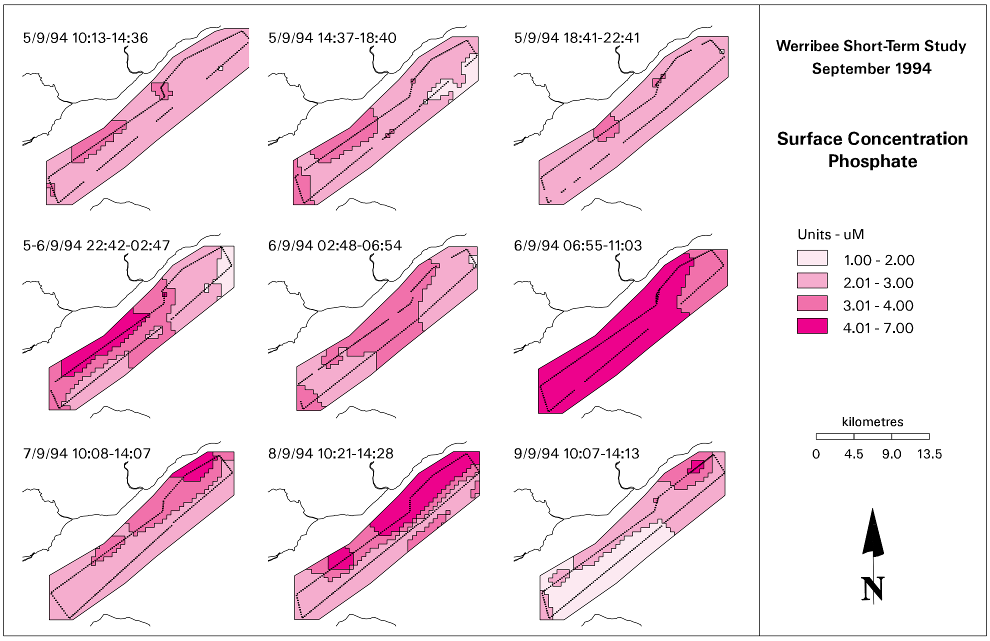

Figure 11: Surface phosphate distributions, Werribee, September 1994.

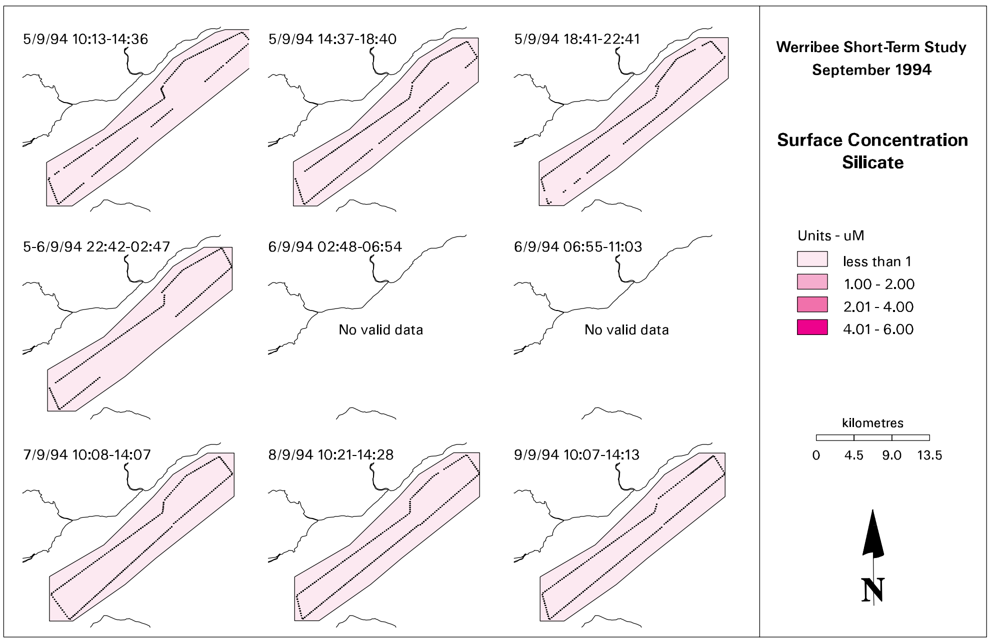

Figure 12: Surface silicate distributions, Werribee, September 1994.

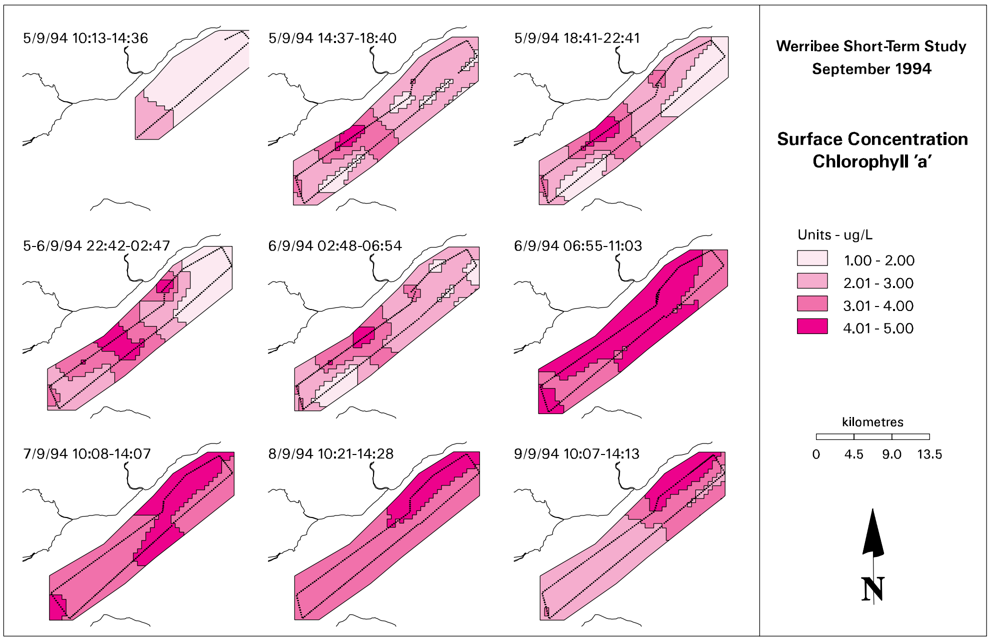

Figure 13: Surface chlorophyll *a* distributions, Werribee, September 1994.

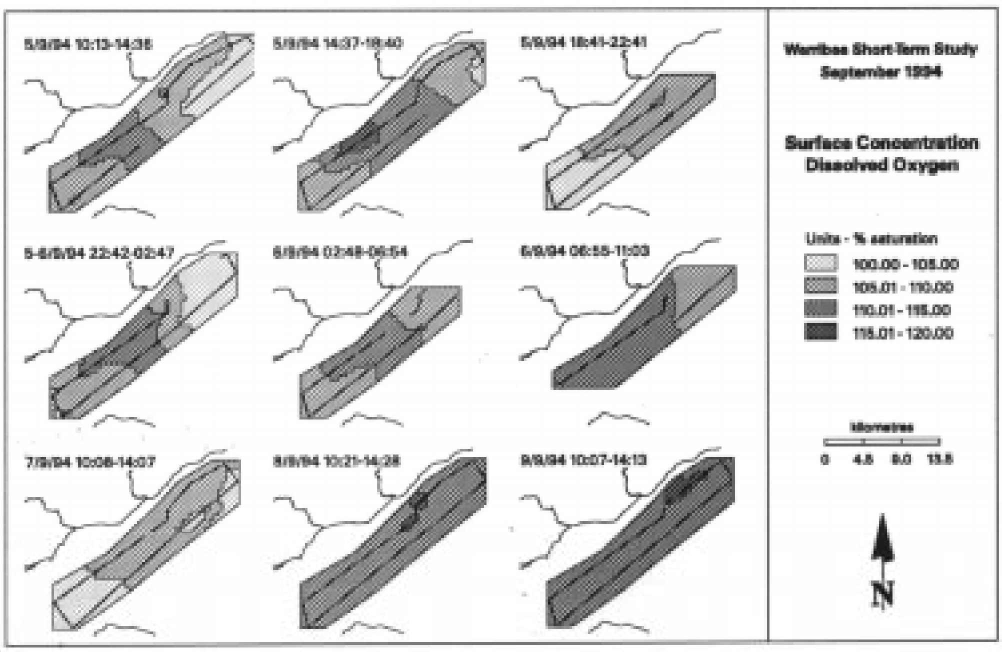

Figure 14: Surface disolved oxygen distributions, Werribee, September 1994.

Vertical structure was only measured at site 11 offshore from the Werribee River (Figure 15). A fresh water input reduced salinity by 0.2 PSU in the surface 3 m on lap 8 and greatly increased ammonium, oxidised nitrogen and phosphate concentrations. Silicate concentrations doubled with depth on lap 9. Vertical distributions of chlorophyll and dissolved oxygen were rather erratic with no clear trends.

Figure 15: Vertical structure at site 11 (Figure 4), Werribee, September 1994.

3.2.2. Short term study - Werribee February 6-10, 1995

Surface concentrations measured on seven laps offshore from the Werribee coast over five days are shown in Figures 16 to 23. Rain (0.8 mm) was recorded on the last lap. Wind speed varied between 4 and 8 m s^{-1} and the direction veered from NE to E to SE to SW then backed from SW to E.

Discharges from the four WTP drains during the study period are listed in Table 8. About half of the total flow originated from 15E and most of the nutrients discharged emanated from 15E and Lake Borrie. Total flow and both total phosphorus and phosphate discharges declined by about 30% over the five days. Ammonium discharge increased by 30% over the first three days and then declined over the last two days. Oxidised nitrogen discharge peaked on day two and declined thereafter. Organic nitrogen discharge varied greatly owing mainly to changes in the discharge from 15E and appeared to be unrelated to variations in flow.

6/2/95	**15E**	**145W**	**L. Borrie**	**Murtcaim**	**Total**
Flow	200	73	107	7	387
NO_2+NO_3	474	37	95	<1	608
NH_4	340	73	332	6	751
Org N	660	730	1819	41	3250
PO_4	1400	183	567	60	2210
Total P	1520	270	867	68	2725
7/2/95	**15E**	**145W**	**L. Borrie**	**Murtcaim**	**Total**
Flow	179	66	93	7	345
NO_2+NO_3	558	46	65	<1	671
NH_4	376	112	428	10	926
Org N	322	284	1209	33	1848
PO_4	1343	165	502	62	2072
Total P	1343	218	762	64	2387
8/2/95	**15E**	**145W**	**L. Borrie**	**Murtcaim**	**Total**
Flow	189	54	92	7	342
NO_2+NO_3	387	30	86	<1	505
NH_4	435	211	478	11	1135
Org N	2079	383	1380	41	3883
PO_4	1489	146	432	64	2135
Total P	1625	194	800	70	2689
9/2/95	**15E**	**145W**	**L. Borrie**	**Murtcaim**	**Total**
Flow	124	42	80	7	253
NO_2+NO_3	251	20	72	<1	345
NH_4	149	113	216	11	489
Org N	1364	126	1200	51	2741
PO_4	967	110	320	64	1461
Total P	1104	139	680	65	1988
10/2/95	**15E**	**145W**	**L. Borrie**	**Murtcaim**	**Total**
Flow	121	37	67	7	232
NO_2+NO_3	262	10	61	<1	335
NH_4	254	59	308	15	636
Org N	315	122	1943	38	2418
PO_4	920	78	288	64	1350
Total P	1101	107	570	70	1848

Units are kg d^{-1} for nutrients and ML d^{-1} for flow.

Table 8: Daily discharges from WTP, during the five day short term study, 6/2/95 - 10/2/95.

Surface salinity (Figure 16) was reasonably uniform during February (range 0.6 PSU) probably reflecting negligible discharge from the Werribee River and thorough mixing of WTP discharge by the prevailing winds. Surface water temperature (Figure 17) varied by less than 1.5 ^{o}C during the study and was lowest in the early morning (lap 4).

Ammonium concentrations (Figure 18) were low (<0.6 µM) over the whole area on every lap with the exception of a 2 km diameter patch (up to 2 µM) north-east of the Werribee River on lap 1. Oxidised nitrogen concentrations (Figure 19) were uniformly less than 0.1 µM except for a small (< 1 km diameter) patch of 0.2 µM north of the WTP on lap 1 which disappeared within 6 hours.

Phosphate concentrations (Figure 20) varied considerably over the study area on each lap (1-7 µM). A 3-5 km diameter patch of up to 9 µM on lap 1 moved northward along the coast over the next five days.

A patch of water 5-10 km in size with high silicate concentration (Figure 21) associated with less saline water to the north of the study area did not move far during the study period, though it moved offshore on laps 5 and 6 while the wind was from the south-west. An area of very low (<1 µM) concentration was observed offshore from the WTP on laps 2, 4 and 6.

Chlorophyll *a* concentrations (Figure 22) were low (<1 µg L^{-1}) over the whole area on each lap with the exception of a patch of higher concentration (1-2 µg L^{-1}) coincident with the phosphate patch on laps 1, 2, 3 and 5.

Dissolved oxygen (Figure 23) was below saturation (94-98%) for most of the study period. Small episodes of > 100% saturation occurred on laps 2 and 5 and nearshore on all laps.

Vertical distributions of salinity, temperature and dissolved oxygen were measured at 10 sites and nutrient distributions were also measured at three of those sites (11, 11B, 11C). The locations of the 10 sites are given in Figure 24.

Figure 24: Sampling sites and cruise track , Werribee short term study, February 1995.

Salinity (Figure 25), temperature (Figure 26), dissolved oxygen (Figure 27) and density (Figure 28) were relatively uniform with depth on each lap at each of the 10 profile sites. Variations with time were generally larger than variations with depth. Fourteen of the 58 profiles indicated a slightly cooler (>0.1 ^{o}C) temperature at depth, while only four profiles demonstrated a salinity (and density) increase with depth of more than 0.1 units. Dissolved oxygen concentration varied by more than 5% with depth at only four sites (two increasing, two decreasing with depth), and fell at night (lap 2) at only one site (11C), but increased again before daylight (lap 4). At all other sites diurnal changes were negligible.

Nutrient concentrations were also generally uniform with depth (Figures 29 and 30). Exceptions included a large increase in ammonium concentration to 20 μM in a narrow depth band (4-6 m) on lap 6 at site 11C which was coincident with smaller increases in oxidised nitrogen and phosphate (but not silicate) concentrations. These peaks disappeared within 24 hours. Salinity, temperature and density distributions at the same site were relatively uniform with depth, and did not indicate an input of either fresher or more saline water. Chlorophyll concentrations (Figure 31) were mostly uniform or increased slightly with depth on most of the profiles. However there were large increases on lap 3 at site SDL 1 (from 1 to 5 μg L^{-1} over 5 m), on lap 5 at site 11 (from 3 to more than 6 μg L^{-1} over 7 m) and on lap 7 at site 11C (from 1 to 6 μg L^{-1} over 6 to 12 m).

3.2.3. Short term study - Northern Port Phillip Bay January 23-27, 1995

Surface concentrations were measured over seven laps off Hobsons Bay during 5 days in January, including four laps in 28 hours. Depth profiles of salinity, temperature, dissolved oxygen concentration and chlorophyll fluorescence were obtained at 10 sites (SDL 1 - 10, Figure 32). Depth profiles of inorganic nutrient concentrations were obtained at a further three sites (Sites 6, 7 and 9, Figure 32). The cruise track is also shown in Figure 32.

Figure 32: Sampling sites and cruise track, Northern Port Phillip Bay short term study, January 1995.

Rain (28 mm) was recorded on January 6 1995 but river flow (Figure 6) was below average 17 days later when this study began. Rain (0.6 mm) fell during the last lap of the study. Wind for the first day was about 8-10 m s^{-1} from the SW-NW. It abated to 4.5-6 m s^{-1} for the rest of the study. Typical tidal range in this part of the Bay is 0.5 m. The tides on each lap are given in Table 9.

Lap	Tidal state
1	Flood
2	Ebb
3	Flood
4	Ebb
5	Ebb
6	Ebb
7	2 hrs flood, then ebb

Table 9: Tidal state for each lap of the short term study, January 1995.

Nutrient and chlorophyll concentrations recorded in this study were lower than the average observed at Williamstown and Sandringham during summer over the past five years (see 'Seasonal and Interannual Time Scales' below, Figures 51 to 63).

Surface salinity distribution was similar on each lap with the Yarra freshwater plume evident along the north eastern coast of the Bay (Figure 33). Stratification of the water column was evident in the north near the Yarra mouth (sites 9, SDL9 and SDL10) and in the east (sites SDL2, 4, 5 and 6) whereas no stratification was evident at the more westerly sites (sites SDL1, 3, 7 and site 7; Figure 34). The depth of the mixed layer increased with distance from the Yarra mouth. Stratification was broken down at the Yarra mouth (site 9) on lap 4 during an ebb tide.

Surface temperatures varied by less than 1^{o}C on any one lap but ranged over 2^{o}C during the study period (Figure 35). The water column was thermally stratified by up to 0.5^{o}C on most laps in the Yarra mouth (site 9), and by 0.4-2^{o}C on some laps at the other sites (Figure 36).

There were significant density differences between surface and bottom waters at most sites on one or more laps, particularly those on the eastern side, reflecting the salinity and thermal stratification noted above (Figure 37).

Surface ammonium concentrations were low (<0.5 µM) for most of the 7 laps (Figure 38). However, there is some evidence of a weak input from the Yarra on laps 2, 3, 4 and 7, and an increase to more than 0.5 µM over a relatively large part of the study area on lap 4. High ammonium concentrations appeared on lap 4 in the top 8 m at site 7 (Figure 40) even though salinity and temperature depth profiles indicated complete mixing. There is some evidence of enrichment in bottom waters within Hobsons Bay (site 9), possibly from benthic fluxes which are large in Hobsons Bay (Nicholson *et al.*, 1996), and on one lap at site 6.

Surface oxidised nitrogen concentrations were near detection limit for much of the study (Figure 39). A pool of 0.2-0.3 µM in the northern half of the area on lap 2 persisted for less than 6 hours. Little discharge was evident from the Yarra except on the last lap. There was no vertical structure in nitrate concentration at any site, except for higher concentrations in the top 7 m in the Yarra mouth (site 9) on the last lap (Figure 40).

Only small changes in phosphate concentrations were observed with depth and over time (Figures 41 and 43). However, a pool of higher concentration in the northern part of the area persisted for 4 days.

Silicate concentrations were moderate (6-10 µM) throughout the study area on each lap (Figure 42). An area of slightly higher concentration was observed in Hobsons Bay on laps one and three. The high concentration found in Hobsons Bay on the last lap formed a surface layer 7 m deep, however there was little vertical structure on other laps or at the other two sites (Figure 43). A patch of 10-11 µM less than 1 km in diameter in the southern part of the study area on the sixth lap moved further south over the next 24 hours.

Surface chlorophyll concentrations were low (<3 µg L^{-1}) over most of the study area, except near the Yarra mouth over the first 18 hours, and varied by less than 1 µg L^{-1}

during the rest of the study (Figure 44). There was little vertical structure except near the Yarra mouth (site 9) during the first three laps (Figure 46).

Dissolved oxygen was above saturation over much of the study area on most laps, but was less than 95% over a large part of the study area on the sixth lap (Figure 45). Areas of supersaturation corresponded to chlorophyll concentrations of greater than 2 $\mu g\ L^{-1}$. Diurnal response varied between sites. Decreases in concentration by about 5% after nightfall (laps 2-3) and subsequent increases after daylight the next day (lap 4) were observed at sites SDL6-10 and site 9, all from the northern part of the study area. At sites SDL1-3 and sites 6-7 concentrations increased by about 5% at night and decreased the next day. Dissolved oxygen concentrations at site SDL 5 decreased through the night and over the next day. Dissolved oxygen depth profiles generally showed a decline of 5-15% near the bottom, particularly from sites near Hobsons Bay, however shapes did not change greatly during the study (Figure 47).

Figure 33: Surface salinity distribution, Northern Port Phillip Bay, January 1995.

Mean values of all near-surface observations on each lap of the short term studies are given in Table 10.

Werribee, September 5 - 9, 1994

Lap	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
NH_4 (µM)	0.43	0.30	0.41	0.49	0.46	0.44	0.54	2.68	0.41
NO_2 (µM)	0.03	0.04	0.03	0.03	0.03	0.07	0.04	0.11	0.04
NO_2+NO_3 (µM)	0.06	0.02	0.02	0.10	0.14	0.08	0.02	0.67	0.05
PO_4 (µM)	2.60	2.69	2.62	3.04	2.91	4.33	3.00	3.65	2.21
SiO_4 (µM)	0.34	0.40	0.25	0.33	.	.	0.28	0.21	0.42
Chl *a* (µg L^{-1})	1.35	2.60	2.48	2.68	2.62	4.12	4.05	3.87	3.20
Salinity	34.20	34.18	34.21	34.21	33.96	33.95	34.11	33.72	33.70
Temp (^{o}C)	11.63	11.59	11.41	11.36	11.40	11.43	11.42	11.75	11.46
Dosat (%)	107.8	110.3	104.4	107.0	109.4	110.9	105.3	113.0	112.5

Werribee, February 6 - 10, 1994

Lap	**1**	**2**	**3**	**4**	**5**	**6**	**7**
NH_4 (µM)	0.47	0.24	0.23	0.26	0.16	0.27	0.30
NO_2 (µM)	0.03	0.02	0.03	0.02	0.02	0.02	0.01
NO_2+NO_3 (µM)	0.04	0.03	0.03	0.03	0.03	0.03	0.02
PO_4 (µM)	2.65	2.54	2.54	2.72	2.79	2.51	2.10
SiO_4 (µM)	3.60	3.35	3.74	3.41	3.35	3.11	3.45
Chl *a* (µg L^{-1})	0.79	1.03	0.88	0.68	0.60	0.56	0.54
Salinity	35.07	35.08	35.10	35.04	35.03	35.11	35.15
Temp (^{o}C)	20.32	20.32	19.99	19.98	20.36	20.12	20.06
Dosat (%)	96.9	98.6	96.2	95.4	99.8	98.1	95.5

Northern Port Phillip Bay, January 23 - 27, 1995

Lap	**1**	**2**	**3**	**4**	**5**	**6**	**7**
NH_4 (µM)	0.16	0.21	0.23	0.36	0.25	0.19	0.43
NO_2 (µM)	0.02	0.02	0.02	0.01	0.03	0.01	0.03
NO_2+NO_3 (µM)	0.04	0.12	0.05	0.04	0.05	0.04	0.13
PO_4 (µM)	2.23	2.12	2.19	2.24	2.20	2.28	2.28
SiO_4 (µM)	8.42	8.21	8.26	8.09	6.89	8.53	8.94
Chl *a* (µg L^{-1})	2.14	2.44	2.38	1.53	1.79	1.88	1.19
Salinity	34.24	34.19	34.10	34.37	34.50	34.45	34.05
Temp (^{o}C)	21.97	21.64	20.76	21.14	21.58	21.29	21.60
Dosat (%)	105.8	107.1	101.9	103.1	107.1	95.7	100.6

Table 10: Mean near-surface concentrations for each lap of the short term studies.

3.3. Seasonal and interannual time scales

Water quality data collected at 14-day intervals at six sites in Port Phillip Bay from February 1990 to May 1995 were analysed for trends in time by simple linear regression. Station locations are given in Table 4 and Figure 4. The water column at Sandringham, Williamstown and Wooley Reef was thermally and salt-stratified on several occasions (Figures 48 and 49). Spring minima in salinity were observed at most sites, but the major feature was an almost Bay-wide decline in salinity from spring 1992 until early 1994, followed by a steady increase in salinity throughout the remainder of 1994 and 1995. No clear changes with time were observed for dissolved oxygen (Figure 50).

More than 40% of the linear regressions were significant at the 0.05 level. Most of these were also significant at the 0.01 level (Table 11, Figures 51-65). Most of the statistically non-significant trends (not shown in the table) also appeared to be downward with time.

Site	Blairgowrie	Wooley Reef	Sandring-ham	Williams-town	Werribee River	Clifton Springs
NH_4	*-6%*	*-11%*	*-16%*			
$NO_2 + NO_3$		*-21%*	*-17%*			
PO_4		*-4%*	*-4%*	*-4%*		
SiO_4	*-7%*	*-9%*	**-6%**		**-6%**	
Total N	*+3%*					
DON	*+5%*	*+3%*	*+2%*	*+3%*	*+4%*	*+4%*
Total P		*-4%*	*-3%*	*-4%*		**-3%**
DOP						
Particulate N		*-5%*				
Particulate P		*-5%*				**-10%**
Chl *a*	**-5%**	*-11%*				
TOC			**-9%**			
POC	*-10%*	*-12%*	*-10%*	*-10%*	*-10%*	*-14%*
NFR						
Secchi depth	*+22%*	*+46%*	*+17%*			
Attenuation	*-3%*	*-6%*		*-5%*	*-5%*	*-6%*

Trends are shown as percentage change in the mean value per year. Trends not significant at the 0.05 level are not shown; trends significant at the 0.05 level are in bold script, while trends significant at the 0.01 level are shown in italic.
Organic N=Total N-NH_4-NO_{23}-Particulate N;
Organic P=Total P-PO_4-Particulate P;
TOC=total organic carbon;
NFR=suspended solids;
Secchi=Secchi disk depth;
Attenuation =attenuation of photosynthetically active radiation (PAR).

Table 11: Linear trends in measured characteristics over the period 1990-95.

List of Figures for this section:

Few of the trends applied Bay-wide with the exception of DON, POC and attenuation. Most of the trends occurred on the eastern side of the Bay and indicated decreasing inorganic nutrient concentrations with time. Few trends were detected on the western side of the Bay. Phytoplankton biomass (chlorophyll *a*) declined or stayed unchanged, while POC (food for deposit feeders and filter feeders) declined Bay-wide. Water clarity improved Bay-wide as is indicated by declining PAR attenuation with a marked increase in Secchi depth in the east. Trends in total P were due to domination of total P by phosphate. However, trends in total N were the result of two opposing trends which were an increase Bay-wide in organic N and a decrease at three sites in ammonium.

Changes over the period 1990-95 were also observed for various nutrient ratios (Figures 66 to 74) including increases in the DOC:DIN and DOC:DIP ratios and decreases in the particulate C:N and C:P ratios.

There was appreciable seasonality in many of the variables at one or more sites (e.g. all variables at Werribee River, Figures 51 to 65; silicate all sites except Williamstown, Figure 55). Some are undoubtedly related to the seasonality in inputs from the WTP and the Yarra River, while others (e.g. silicate at Wooley Reef) may indicate a complex balancing between external input, planktonic consumption and benthic remineralisation. It was a reduction in scatter and seasonal variability during 1990-95, rather than changes in the baseline, that produced some of the trends observed (e.g. nitrate plus nitrite, Figure 52).

Spectral analysis is a statistical tool which can be applied to data collected as a time series. It is designed to extract regularly recurring signals from a “noisy” background. The size of peaks in a spectral plot indicate the relative significance of regularly recurring cycles. Preliminary spectral analysis confirms the seasonality of some of the fixed site data. Figure 75 portrays the spectra of a range of nutrients from different sites. The largest peak is at about 52 weeks and indicates a strong annual signal for three of the examples. The exception shown is ammonium at Blairgowrie, where the largest variation is longer than 70 weeks (i.e. interannual variation is greater than annual cycles).

Correlation of PAR attenuation with suspended solids (NFR) and chlorophyll concentrations indicated that at all sites (except Williamstown), suspended solids and chlorophyll together are responsible for less than half (18-43%) of the observed attenuation (Table 12). At the chlorophyll concentrations observed in Port Phillip Bay, other than during exceptional blooms, only a small proportion (3-18%) of the incident radiation is absorbed by cells (and self-shading is therefore unlikely to limit growth). It appears that Bay water has a significant intrinsic attenuation (0.15-0.26 m^{-1}), perhaps due to dissolved organic matter, to which turbidity and cellular absorption effects are added.

Site	**Intercept**	**a (NFR)**	**b (Chlor)**	r^2	**% of attenuation due to NFR**	**% of attenuation due to chlor *a***
Blairgowrie (1)	0.15	0.01	0.04	0.12	14	14
Wooley Reef (4)	0.21	0.01	0.05	0.17	7	18
Sandringham (6)	0.23	0.04	0.03	0.38	30	13
Williamstown (9)	0.17	0.07	0.01	0.47	72	3
Werribee River (11)	0.23	0.03	0.02	0.38	25	11
Clifton Springs (13)	0.26	0.01	0.04	0.07	6	12
All sites	0.22	0.02	0.04	0.26		
The model is: Attenuation= intercept + a * NFR + b * Chlorophyll *a*.						

Table 12: Linear model fit to the attenuation-NFR-chlorophyll *a* data.

Rainfall over Port Phillip Bay was near average in 1990 and 1991, 25% above average in 1992 and 1993, and about 20% below average in 1994 (rainfall records from Queenscliff, Geelong and Melbourne, Figure 5). This pattern is reflected in the river flow records (Figure 6) but is not reflected by any of the variables shown in Figures 51-74 even though many variables peaked in summer 1992-93. Further study of the relationships between rainfall, river flow, WTP input and nutrient concentrations is underway.

3.4. Spatial scales: horizontal scales

The underway data gathered on 25 cruises over two years were collected along transect lines and therefore necessarily sampled only a small proportion of the Bay surface. In order to improve our understanding of spatial scales, and for estimation of pool sizes, the data were processed by an inverse-distance weighting method to produce surface distribution maps (Figures 76 to 83). In this procedure, a hypothetical grid of cells 250 m by 250 m in size is laid across the Bay. At each grid intersection a search is made for valid data within a specified radius. Data from all valid data points within the search radius are weighted by the inverse of their distance from the grid point to produce an interpolated value for the grid intersection (Molloy 1996). The horizontal scale of discrimination can be varied arbitrarily, but using a search radius of 5 km to produce interpolations on the 250 m grid allowed us to reach the following conclusions.

Salinity (Figure 76): The physical characteristics (salinity, temperature and dissolved oxygen) showed much smoother patterns of distribution than did the nutrients. Relatively low salinities were always found in Hobsons Bay during winter and were also evident during winter offshore from the WTP and the Werribee River. The Yarra plume was observed as a thin (< 5 km wide) strip down the eastern coast as far as Dromana in winter but was restricted to within 15 km of Hobsons Bay in summer. A plume from the Werribee River toward the centre of the Bay could be detected on a few occasions. Low salinities were observed offshore from the Patterson River (as distinct from the Yarra plume) in September and November 1994. Hypersaline water was observed in Corio Bay in January 1994, extending into the Geelong Arm during February and March. The mixing of Bay and higher salinity Bass Strait water was always observed near the Sands. The shape of high-salinity features in April and June 1994 in the south may indicate a clockwise gyre of about 30 km diameter.

Temperature (Figure 77): Temperature differences of up to 2.5^{o}C were observed over the Bay surface on most cruises, although the effects of surface heating and cooling during the day may have obscured the underlying pattern. The influence of Bass Strait water was observed on many cruises in the region of and south of the Sands. Flood waters reduced temperatures in the north by up to 2^{o}C in September 1993.

Ammonium (Figure 78): Occasional concentrations of up to 40 µM were observed against a background of less than 0.5 µM. Typical patch size (area of uniform concentration) varied with discharge and distance from source. Highest concentrations often, but not always, occurred in areas of reduced salinity. Under flood conditions (September 1993) concentrations of more than 1 µM occurred in a patch in the north-west up to 25 km long and 10 km wide. During winter virtually all of the Geelong Arm was affected by the WTP discharge plume (about 45 km long by 10 km wide). In summer, zones of high ammonium concentration were generally less than 5 km in diameter. Ammonium concentrations in the Exchange zone were usually less than 0.2 µM. Small areas of increased concentration were observed offshore from the Werribee River mouth on 16 of the 25 cruises in all seasons, though 8 of these patches originated from the WTP. Some cruise paths did not go within 5 km of the Patterson River and high ammonium concentrations were observed in this area only once during August 1994.

Oxidised nitrogen (Figure 79): The distribution patterns for nitrite mirrored those for nitrite plus nitrate on every cruise and therefore nitrite will not be discussed separately. The largest single zone of high concentration occurred in the north-west in September 1993 following flooding of the Yarra and Werribee Rivers. The patch was about 25 km long and 10 km wide with concentrations exceeding 5 µM. During winter patches up to 15 km long and 5 km wide with concentrations greater than 1 µM were observed along and offshore from the WTP and extending toward Corio Bay. High concentrations during summer were restricted to patches less than 2 km diameter within 10 km of the discharges (Yarra River and WTP). Moderate oxidised nitrogen concentrations (>0.5 µM) were often observed close to the Rip while concentrations over a large proportion of the Bay surface were below 0.1 µM, indicating that Bass Strait may contribute oxidised nitrogen to the Bay.

Phosphate (Figure 80):. Zones of high (>3 µM) phosphate concentration occurred offshore from the WTP during winter in patches up to 15 km long and 5 km wide and extended into the Geelong Arm. Patches at other times of the year were usually restricted to less than 5 km diameter along the western coast and always coincided with areas of reduced salinity. High concentrations were observed in Hobsons Bay on only one occasion (November 1994) and offshore from the Patterson River only twice (July and August 1994). The Exchange zone was always an area of significant dilution of phosphate, with concentrations almost always less than 1 µM in the region of and south of the Sands. Phosphate concentration varied less over time than the other nutrients with concentrations in the range 1.5-2.5 µM for most of the Bay.

Silicate (Figure 81): Silicate concentrations varied differently to the other nutrients. Zones of high concentration affected large areas of the Bay on occasions but concentrations Bay-wide varied markedly from season to season. Significant sources of silicate included the Yarra and Werribee Rivers. Concentrations were generally lowest in spring and highest in autumn. In summer-autumn, silicate concentrations in nearly the entire Bay were greater than 5 µM. In late autumn 1993, patches of high concentration (>5 µM) occupied the northern 70% of the Bay. Curiously, during the flood in September 1993 higher concentrations were observed offshore from the Werribee River than off the Yarra. In winter 1994, high concentrations occurred in the Geelong Arm (up to 20 km by 10 km) and along the north-east coast (up to 15 km in diameter, but usually less than 5 km in diameter). The Sands were usually a zone of significant dilution.

Chlorophyll *a* (Figure 82): Patches of chlorophyll *a* concentration greater than 5 µg L^{-1} were observed against a background of usually less than 1 µg L^{-1}. Patches up to 15 km long by 5 km wide were observed offshore from the Werribee coast and into the Geelong Arm in winter and early spring while high chlorophyll concentrations during summer were restricted to the north-east within 15 km of the Yarra. Patches of moderate concentration (2-5 µg L^{-1}) up to 30 km by 30 km in size were observed in the south-east in June 1993 and off the Werribee coast in July 1993. On many cruises patches of high chlorophyll concentration coincided with high silicate concentrations.

Dissolved oxygen (Figure 83): Surface values were generally between 90 and 110% saturation except for patches up to 120% measured on six cruises. Patches of high oxygen less than 10 km in diameter coincided with areas of high chlorophyll concentration in the north in November 1993, and off the western coast in October and December 1994. However, very large patches of high oxygen in October 1993 and January 1994, which occupied the eastern half of the Bay, covered areas in which chlorophyll was not elevated.

Few of the nutrient patch shapes indicated concentric zones of increasing concentration, suggesting that wind speed and direction influence patch integrity and distribution, rather than simple radial dilution from the source. These observations emphasise the need for hydrodynamic modelling of water transport and mixing before an understanding of nutrient distribution patterns can be achieved. However, a conceptually simple technique for distinguishing mixing from biological and chemical transformations is applied below.

3.5. Spatial scales: conservative mixing

We may treat the whole of Port Phillip Bay as an estuary and attempt to understand the relative importance of physical and biological factors in altering nutrient distribution by observing how nutrient concentrations change with increasing salinity. This approach is based on the concept of conservative mixing. When a high-nutrient fresh water discharge mixes with low-nutrient seawater, in the absence of biological, chemical or physical transformations, nutrient concentrations will decrease linearly with increasing salinity (Boyle *et al.* 1974). Deviations from a straight line between fresh water input and seawater concentrations are interpreted as non-conservative behaviour, and may be due to a number of factors (see Discussion below).

When nutrient concentrations from each cruise were plotted against salinity, apparent conservative behaviour was evident for each nutrient and chlorophyll. Conservative behaviour was most often observed near fresh water inputs (the Yarra and WTP) under high flow. However we also observed instances for all nutrients and chlorophyll of non-conservative behaviour, particularly at low concentrations under low-flow conditions. The various shapes of the mixing curves observed are listed in Table 13 and an example from October 1994 is shown in Figure 84.

Curve type	Ammonium	Oxidised nitrogen	Phosphate	Silicate	Chlorophyll
I	11	22	6	1	8
3C	0	4	0	0	0
2C	17	3	3	6	9
C	17	12	24	21	19
U	9	9	4	21	16
R	6	1	13	8	3
L	4	16	27	30	34
H	37	41	21	18	10

Numbers indicate the number of times the mixing curve was observed, during 77 separate cruise days. Curve types are: **I**=inverse (concentration increases with increasing salinity); **C**=conservative (concentration decreases with increasing salinity); **2C**=conservative, with two nutrient sources; **3C**=conservative with three nutrient sources; **U**=uptake (concentration decreases more rapidly than salinity increases- curve dips toward the salinity axis); **R**=release (concentration decreases more slowly than salinity increases-curve bows from the salinity axis); **L**=loops, indicating non-steady state; **H**=horizontal (concentration does not change with increasing salinity).
Note that more than one behaviour may be observed for the one day.

Table 13: Frequency distribution of types of mixing curve observed for each nutrient.

Over all cruises, ammonium and oxidised nitrogen showed conservative behaviour relatively infrequently, and only if concentrations exceeded 0.5 µM for ammonium or 0.2 µM for oxidised nitrogen. The most frequently observed behaviour for both nitrogenous nutrients was one of no concentration change with increasing salinity. Phosphate and silicate showed conservative behaviour more often than nitrogen, but were more likely still to show loops indicating non-steady state (see Discussion below). Chlorophyll also exhibited non-steady state as the most frequent occurrence.

During the dry part of the study (October 1994), two sources of ammonium, the WTP and Yarra/Maribyrnong Rivers, could be distinguished (Figure 84). However, only one source of phosphate (the WTP) and one source of silicate (the Yarra/Maribyrnong Rivers) could be distinguished. Water from Hobsons Bay actually had a slightly lower phosphate concentration than the Bay water it mixed with. By extrapolating the observations for waters offshore from the WTP back to zero salinity, ammonium and phosphate concentration in the WTP discharge could be estimated at about 1100 and 85 µM respectively. However, actual WTP discharge concentrations for this time of the year would be about 1700 µM ammonium and 190 µM phosphate (Murray 1994), indicating a loss of about 35% of the discharged ammonium, and 50% of the phosphate, at salinity below 18 and within 2 km of shore.

A detailed study of the data from September 1993 (Longmore *et al*. 1996) indicated that the Werribee River, then in flood and at its highest flow rate for the study period, could be distinguished as a separate and significant source of ammonium to the Bay (although ammonium discharge from the Werribee River was observed on only 8 of the 25 cruises).

Figure 84: Identification of multiple nutrient sources from property/property plots (October 1994).

3.6. Spatial scales: vertical scales

Data from depth profiles at the fixed sites were pooled to calculate mean concentrations at each site for the depth intervals surface, midwater and bottom. The variations in mean value with depth interval for measured variables are listed for each site in Tables 14 to 26. Because of the large number of analyses carried out during the study (about 2,000 per depth interval, per site) and because of the high precision of the measurements, statistical tests (e.g. Tukey's Studentized Range Test) indicated that differences in mean value per depth interval were almost all highly significant ($p<0.0001$). However, the differences were often much less than the estimated accuracy of the measurements (Table 2). Therefore accuracy, rather than precision, will have the greater effect on errors in loads calculated from this data set. The criterion adopted to determine whether differences between depths would make a practical difference to calculated budgets was as follows: if differences between depth intervals were less than the estimated accuracy they were ignored. The frequency of occurrence of significant differences with depth for each variable is shown at the foot of Tables 14 to 26.

Overall, the water column was well-mixed chemically at most sites more than half the time. However thermal stratification was observed Bay-wide on many occasions. Mean chlorophyll *a* was higher in bottom waters at Blairgowrie, Wooley Reef, Werribee River, Clifton Springs, southern central Bay and western central Bay sites. Mean dissolved oxygen was supersaturated by up to 3% in surface waters at Wooley Reef, Sandringham, Werribee River and southern central Bay sites, and reduced in bottom waters by an average of 1% at Sandringham, Williamstown, northern central Bay, western central Bay and the Rip sites. The entire water column mean at the Werribee River site was supersaturated, while that at Williamstown was under-saturated by about 3%. The water column at Williamstown was chemically and physically stratified most of the time by a nutrient-rich fresh water surface layer. During times of highest stratification (with high river flow), nutrient enrichment in the surface layer of Hobsons Bay was substantial (e.g. silicate up to 50 µM, and nitrate up to 10 µM). Almost half the surface samples from the Werribee River site were enriched in silicate, presumably as a result of Werribee River input rather than the WTP. Ammonium and silicate were enriched by about 10% in bottom waters at the central Bay site in 30-40% of samples.

On only one occasion (March 1995) was there a significant difference between mean oxidised nitrogen concentrations on ebb and flood tides at the Rip station (N1E and N1F).

List of Tables for this section:

3.7. Nutrient limitation

There have been many studies on phytoplankton growth limitation based on two approaches:

i. Limitation by physical factors (light, temperature, salinity, turbulence).
ii. Limitation by nutrient availability.

Studies elsewhere on nutrient limitation have included measurements of ambient dissolved nutrients (Fisher *et al*. 1992), nutrients bound in cells or particulate matter (Lebo *et al*. 1994) and other intracellular chemicals required for (or produced during) growth. These have included carbohydrates, proteins, lipids, nucleic acids, enzymes and phytoplankton pigments (Heath *et al*. 1990, Latasa and Berdalet 1994).

The nutrient concentration approach is based on the assumption that under optimal conditions, diatomaceous phytoplankton will take up nutrients in the ratio C:N:P:Si as 106:16:1:18 (Redfield *et al*. 1963, Brockmann *et al*. 1990). Waters with nutrients in these concentration ratios should therefore not be limiting to phytoplankton growth. Cells containing nutrients in these ratios may have grown without nutrient limitation. Furthermore, while dissolved nutrients may be readily taken up by plankton, organic and particulate nutrients may also be ultimately available for phytoplankton growth *via* mineralisation processes. Both dissolved and total nutrient ratios may therefore be important in nutrient limitation. The half-saturation constants for phytoplankton uptake of dissolved inorganic nitrogen (ammonium, nitrate), phosphate and silicate (2, 0.2 and 2 μM respectively) indicate nutrient concentrations which are potentially limiting to algal growth (Fisher *et al.* 1992).

Phytoplankton contain many pigments, including chlorophylls and carotenoids, which enable them to utilize light energy. Under nutrient-rich conditions both pigment types accumulate in cells. However, under nitrogen limitation chlorophyll production ceases while carotenoid production continues. The ratio carotenoid:chlorophyll *a* could therefore be used to infer nitrogen limitation. Heath *et al*. (1990) suggest that a ratio less than 1.4 indicates growth with excess nitrogen, while a ratio greater than 2.4 indicates extreme nitrogen deficiency. In the Kattegat (Baltic Sea), Richardson and Christoffersen (1991) observed that the carotenoid:chlorophyll ratio increased from 1.1 to more than 2 as nitrate disappeared during a diatom bloom.

In this report we analysed data collected from both fixed sites and transects in Port Phillip Bay over the period February 1990 to May 1995 for the nutrient and pigment ratios and concentrations shown in Table 27. Nutrients studied include dissolved inorganic nitrogen (DIN; the sum of ammonium, nitrite and nitrate), dissolved inorganic phosphorus (DIP), silicate, total nitrogen (TN), total phosphorus (TP), particulate organic carbon (POC), particulate nitrogen (PN) and particulate phosphorus (PP). Carotenoid:chlorophyll *a* ratios were also calculated. Though the water in this study was only coarsely filtered (~ 20 μm) prior to analysis, as noted above, all of the ammonium, nitrate and silicate, and most of the phosphate detected is assumed "dissolved".

Nutrients	Key ratio / conc.	Limitation inferred
DIN	<2 µM	Nitrogen
PO_4	<0.2 µM	Phosphate
SiO_4	<2 µM	Silicate
DIN:DIP	<16:1	Nitrogen
SiO_4:DIN	<18:16	Silicate
TN:TP	<16:1	Nitrogen
POC:PN	>106:16	Nitrogen
POC:PP	>106:1	Phosphorus
PN:PP	<16:1	Nitrogen
carotenoid:chlorophyll *a*	>2.4	Nitrogen

Table 27: Nutrient concentrations and ratios used to infer nutrient limitation.

3.8. Growth limitation

3.8.1. Light limitation

There is a well-defined minimum depth-averaged light intensity below which phytoplankton will not bloom (Perry *et al*. 1989). Attenuation coefficients from this study will be combined with simultaneous global radiation data and compared to the minimum, in a subsequent publication, to calculate the likelihood of light limitation.

PAR attenuation varied between 0.2 and 0.6 m^{-1} for most samples from most sites (Figure 65). The depth at which 1% of the incident PAR is available (the compensation depth) has been taken by some as an indication of the depth to which net primary production is possible. The compensation depth decreased from 20 m at an attenuation of 0.2 m^{-1} to 9 m at 0.4 m^{-1}, indicating that a significant volume of the Bay may not support net primary production at the higher attenuation coefficient. A better estimate of the compensation depth will be obtained from carbon fixation studies. Field data from these studies will also be compared to the light compensation point (at which carbon production is balanced by consumption) to calculate the proportion of samples limited by light. Such data should be available in late 1996. However, because Port Phillip Bay is shallow for its surface area, and easily mixed by wind, it is likely that plankton are regularly transported to the surface thereby reducing the probability of light limitation (Kirk 1983, p 257).

3.8.2. Nutrient concentrations

Table 28 lists the proportion of samples from all sites and transects in which nutrient concentrations were less than the concentration limits listed in Table 27. From nutrient concentrations alone, nitrogen limitation was indicated in almost all of the samples from all sites with the exception of Williamstown where nitrogen limitation was unlikely nearly half of the time. Phosphate limitation was extremely unlikely for any sample with the exception of a relatively small number of transect observations in the West and South Channels. Silicate limitation was possible for up to 40% of samples from Blairgowrie and for less than 2% for samples from Williamstown. The nearly

30% of transect observations with potentially limiting silicate concentrations were from all over the Bay, not any particular locations.

Site/ratio	DIN<2 µM	PO4<0.2 µM	SiO4<2 µM
1 (Blairgowrie)	100%	0% (min 0.7 µM)	40%
4 (Wooley Reef)	96%	0% (min 1.0 µM)	15%
6 (Sandringham)	89%	0% (min 1.7 µM)	12%
9 (Williamstown)	55%	0% (min 1.8 µM)	2%
11 (Werribee R.)	70%	0% (min 1.5 µM)	25%
13 (Clifton Springs)	93%	0% (min 1.3 µM)	20%
Transects	94%	0.8%	28%

Table 28: The proportion of samples from each site with nutrient concentrations less than the concentration limits shown.

3.8.3. Nutrient concentration ratios

Table 29 lists the proportion of samples in which nutrient concentration ratios were less than the limits listed in Table 27. Ratios from all fixed sites, but not the transects, are shown in Figures 68 to 76. The inorganic nutrient ratios indicate that phosphate limitation was never likely. Nitrogen limitation was always likely Bay-wide.

Site/ratio	DIN:DIP <16	SiO_4:DIN<1.1	TN:TP<16	SiO_4:TN<1.1
1 (Blairgowrie)	100% (max. 0.4)	5%	100% (max. 10.8)	100% (max. 0.8)
4 (Wooley Reef)	100% (max. 1.7)	3%	100% (max. 7.7)	92%
6 (Sandringham)	100% (max. 3.0)	1%	100% (max. 9.1)	95%
9 (Williamstown)	100% (max. 3.5)	0% (min 1.6)	100% (max. 9.5)	90%
11 (Werribee R.)	100% (max. 4.1)	30%	100% (max. 6.7)	100% (max. 0.8)
13 (Clifton Springs)	100% (max. 2.5)	6%	100% (max. 5.7)	95%
Transects	99.99%	6.4%	--------	-------

Table 29: The proportion of samples from each site with concentrations less than the ratios shown.

Silicate limitation was rarely likely at fixed sites with the exception of near the Werribee River where about 30% of samples had a low silicate:DIN ratio. However given the proximity of the Werribee River site to two nutrient sources (the river and the WTP), a low silicate:DIN ratio could indicate relatively high DIN concentrations as opposed to low silicate concentrations. About half of the samples with a low silicate:DIN ratio had both a silicate concentration of less than 2 µM and a silicate:DIN ratio of less than 1.1 thereby indicating silicate limitation rather than DIN limitation. Therefore growth of diatomaceous phytoplankton in about 15% of samples from the Werribee River fixed site may have been silicate-limited. The 6% of transect observations with silicate:DIN<1.1 were from all over the Bay, but tended to be most prevalent in the western half including the Geelong Arm. Nearly all such samples occurred in winter or spring.

Even when organic nutrients were included in the ratios, phosphorus limitation was never likely, though the N:P ratio did increase by differing amounts at each site (Figure 74). Exactly how much of the organic nutrients are available for phytoplankton uptake is impossible to tell without laboratory or *in situ* incubations, but the probability is that if any of the organic N were available, the ratio silicate:N would decrease, making silicate limitation even more likely.

3.8.4. Particulate nutrient concentration ratios

Table 30 lists the proportion of particulate samples for which concentration ratios fell below the limits listed in Table 27. A scatter plot from all sites is shown in Figure 85, while trends in time for each fixed site are shown in Figures 69 to 71. Almost all of the samples from all sites were rich in phosphorus compared to carbon and nitrogen and about half at each site were deficient in nitrogen compared to carbon. Nitrogen limitation was therefore more likely than phosphorus limitation, but no limitation is indicated for more than half the samples. The POC:PN and POC:PP ratios declined at each site during the period 1990-95 whereas the PN:PP ratio increased from about 11 to 13 thereby approaching the Redfield ratio of 16:1.

Site/ratio	POC:PN<106:16	POC:PP<106:1	PN:PP<16:1
1 (Blairgowrie)	45%	70%	96%
4 (Wooley Reef)	45%	75%	100%
6 (Sandringham)	45%	90%	100%
9 (Williamstown)	40%	95%	100%
11 (Werribee R.)	50%	75%	98%
13 (Clifton Springs)	45%	75%	98%

Table 30: The proportion of particulate samples from each site with concentrations less than the ratios shown.

3.8.5. Pigment ratios

Table 31 lists the proportion of samples for which pigment concentration ratios fell outside the ranges shown. If those samples with a ratio of carotenoid:chlorophyll *a* >2.4 are nitrogen deficient, then nitrogen deficiency was a rare occurrence. Very few samples had ratio values in the range of 1.4 to 2.4, within which N-replete cells become severely N-deficient. Most samples had carotenoid:chlorophyll *a* values <1.4 indicating N-sufficiency (Figure 85).

Site/ratio	Ratio >2.4	Ratio <1.4
1 (Blairgowrie)	0%	99%
4 (Wooley Reef)	0%	93%
6 (Sandringham)	0%	97%
9 (Williamstown)	0%	99%
11 (Werribee R.)	3%	96%
13 (Clifton Springs)	0%	90%

Table 31: The proportion of samples for which the pigment concentration ratio carotenoid:chlorophyll *a* fell outside the ranges shown.

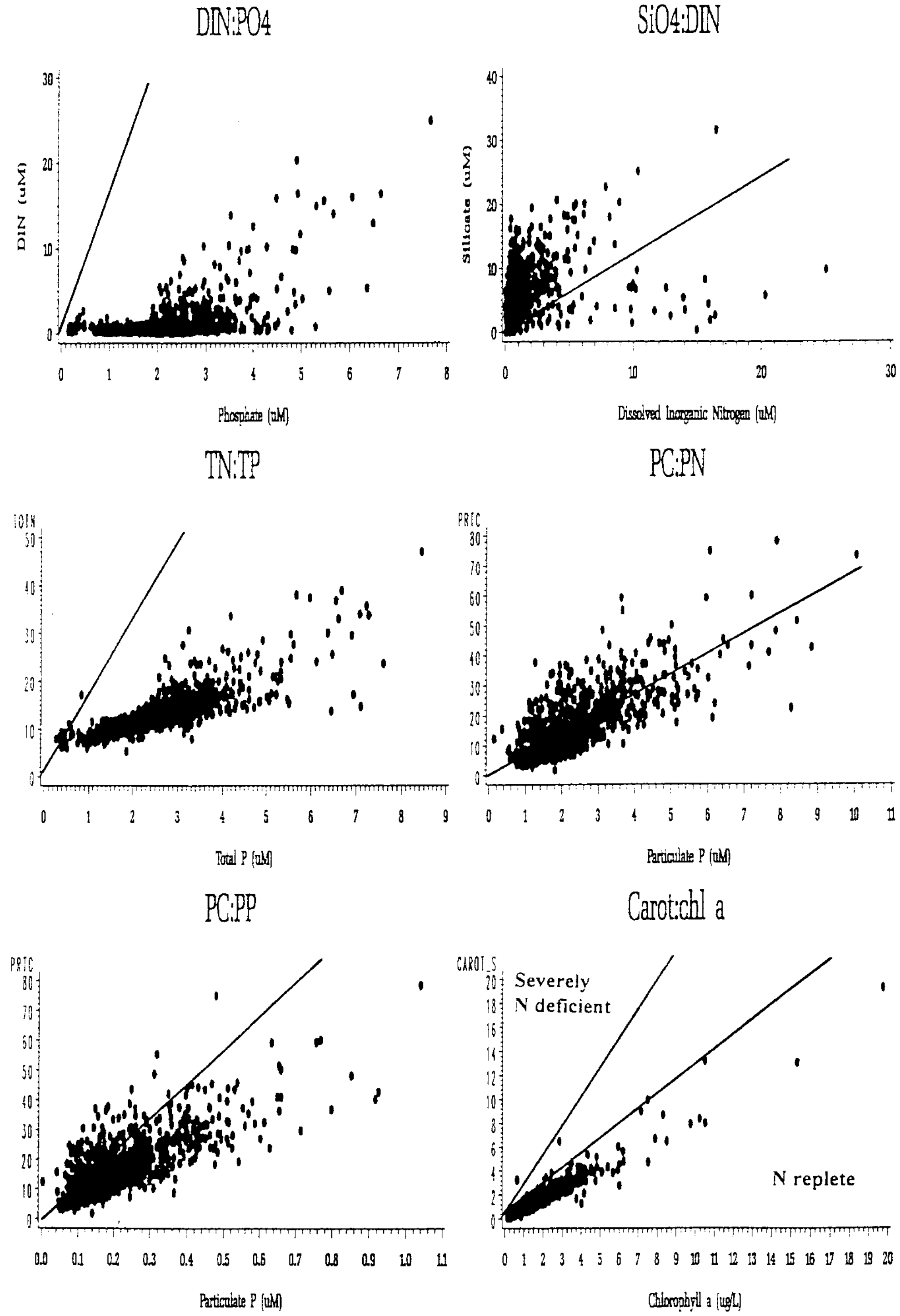

Figure 85: Concentration ratios indicating nutrient deficiency. Points to the right of the solid line are potentially deficient in the first-named of each pair.

3.9. Nutrient pool sizes

The data sampled while underway together with the organic and particulate data from the fixed sites were processed to provide Bay-wide mean concentrations for each cruise and over the whole study (Table 32). The mean concentrations were then converted to mean pool sizes by assuming a constant concentration with depth and a total Bay water volume of 25 km^3 (Table 33).

It is apparent from Tables 14-26 that pool sizes calculated from surface concentrations will be in error because of vertical differences in concentrations. Measurements of organic and particulate nutrients were obtained from depth-integrated samples and are therefore not subject to the same errors. It is possible that use of surface concentrations would lead to under-estimates of ammonium and chlorophyll pool sizes (by 5 and 20% respectively) and over-estimates of oxidised nitrogen, phosphate and silicate pool sizes (by 20%, 1% and 5% respectively). Similarly, ignoring horizontal gradients will lead to errors in estimated pool sizes. However, because there are no conspicuous and persistent spatial "compartments" it is difficult to estimate the extent of these errors. Nevertheless, it is clear from Table 33 that the calculated mean pool size for phosphorus (PO_4 + DOP + PP=1882 t P) is of the same order as the estimated annual input, while the nitrogen pool size (DIN + DON + PN=4340 t N) is much less than the estimated annual input of about 7000 t (Skyring *et al.* 1992).

Since DON dominates the N pool the fixed site (depth-integrated) data are probably adequate to use in the calculation of an overall nitrogen budget, but it must be borne in mind that the mean DON concentration is based on only 11 samples per month.

A second approach to budget calculation is to take advantage of the interpolation used to create the surface distribution maps (Figures 78-82). By multiplying the interpolated concentration in each grid cell by the water depth below it, and summing across all cells, a budget can be constructed for those variables measured underway.

A third approach, that of double-spline interpolation, forces a two-dimensional surface through all existing data points, and interpolates all other points on the surface. This approach has been used to estimate the accuracy of calculated pool sizes. Annual pool sizes calculated by each of these three methods are given in Table 34.

Bay-wide average annual pool sizes have been calculated for the periods 1969-70, 1980-84 and 1993-95 (Table 35) by the methods indicated.

Table32. Bay-wide mean concentrations by cruise, May 1993-March 1995.

Particulate and dissolved organic nutrients are from fixed sites (11 per cruise), while all other measurements are from transect data (about 3,000 per cruise).

Cruise	Date	NH_4 (µM)	NO_2 (µM)	NO_2+NO_3 (µM)	PO_4 (µM)	SIO_4 (µM)	Chl *a* (µg L^{-1})	DON (µM)	DOP (µM)	PRTN (µM)	PRTP (µM)	DOC (mg L^{-1})	POC (mg L^{-1})	Salinity	Temp (°C)	D.O. (% sat)
1	May-93	0.68	0.06	0.39	2.47	8.47	1.13	11.17	0.10	1.82	0.14	1.78	0.10	34.09	14.45	101.3
2	Jun-93	1.11	0.10	0.44	2.59	8.34	1.34	12.27	0.06	1.49	0.12	1.69	0.14	34.10	11.47	99.4
3	Jul-93	2.00	0.10	1.10	2.46	6.43	1.35	8.87	0.19	1.90	0.15	1.50	0.19	33.84	10.96	102.9
4	Aug-93	0.96	0.15	0.59	2.27	2.74	1.26	9.55	0.21	2.36	0.20	1.68	0.16	33.19	11.00	100.6
5	Sep-93	2.05	0.14	1.08	1.96	5.79	1.74	7.37	-0.03	2.31	0.24	1.95	0.22	31.71	12.39	99.0
6	Oct-93	0.72	0.07	0.27	2.03	2.16	1.35	10.95	0.32	2.67	0.25	2.09	0.23	33.02	14.26	110.1
7	Nov-93	0.79	0.02	0.23	1.79	5.78	1.38	11.11	0.30	2.66	0.23	2.25	0.17	32.57	15.34	104.9
8	Dec-93	0.58	0.03	0.09	1.89	6.37	0.62	9.49	0.28	2.38	0.17	1.89	0.13	33.04	18.07	103.5
9	Jan-94	0.48	0.07	0.49	1.85	9.51	1.48	9.25	0.33	3.35	0.29	1.95	0.21	32.28	18.11	107.1
10	Feb-94	0.40	0.06	0.13	1.77	6.51	0.89	9.54	0.16	1.86	0.14	1.85	0.10	33.40	20.33	102.5
11	Mar-94	0.45	0.05	0.32	1.92	.	1.17	9.89	0.32	2.15	0.18	1.74	0.13	32.97	19.73	102.5
12	Mar-94-2	0.37	0.02	0.10	2.03	3.08	0.52	8.80	0.29	2.10	0.15	1.68	0.11	33.28	19.36	103.7
13	Apr-94	0.37	0.05	0.12	2.05	8.23	0.99	8.45	0.28	1.29	0.10	1.83	0.08	33.75	16.63	98.8
14	May-94	0.35	0.07	0.23	2.00	5.02	1.44	8.17	0.21	1.40	0.12	1.43	0.10	33.86	12.86	101.0
15	Jun-94	0.87	0.09	0.50	2.16	2.16	0.96	9.61	0.25	1.71	0.17	1.35	0.11	33.88	11.30	99.7
16	Jul-94	0.65	0.08	0.33	2.11	2.28	1.02	9.00	0.26	1.51	0.11	1.23	0.08	34.16	10.99	98.3
17	Aug-94	0.53	0.05	0.32	1.86	1.85	0.64	7.69	0.08	1.37	0.10	1.50	0.09	34.24	9.92	100.8
18	Sep-94	0.23	0.02	0.03	1.92	1.46	1.05	7.90	0.30	1.73	0.14	1.72	0.15	34.32	11.96	101.7
19	Oct-94	0.57	0.03	0.27	1.98	2.48	0.58	9.68	0.29	1.28	0.11	1.63	0.07	33.96	12.94	104.7
20	Nov-94	0.39	0.04	0.23	1.98	4.75	0.82	9.31	0.18	1.85	0.18	1.50	0.14	34.20	15.23	101.0
21	Dec-94	0.36	0.02	0.04	1.98	4.73	0.68	8.86	0.16	1.82	0.14	1.59	0.09	34.47	18.99	104.2
22	Jan-95	0.26	0.03	0.09	1.86	4.13	0.58	9.88	0.11	2.20	0.17	1.50	0.09	34.81	20.21	99.2
23	Feb-95	0.39	0.02	0.11	1.98	5.49	0.96	10.27	0.22	2.21	0.17	1.94	0.18	34.78	21.19	98.1
24	Mar-95	0.27	0.04	0.13	2.06	5.93	1.11	9.99	0.27	2.29	0.17	1.77	0.14	35.15	21.23	98.2
25	Mar-95-2	0.26	0.03	0.13	2.20	1.82	1.06	9.71	0.17	1.75	0.16	1.73	0.12	35.33	18.31	97.6
Overall mean:		**0.64**	**0.06**	**0.31**	**2.05**	**4.81**	**1.04**	**9.46**	**0.21**	**1.99**	**0.16**	**1.71**	**0.13**	**33.78**	**15.49**	**101.6**

Table 32: Bay-wide mean concentrations by cruise, May 1993 - March 1995.

Table 33. Estimated Bay-wide nutrient pool size (tonnes) by cruise, assuming a volume of 25 km^3.

Cruise	Date	NH_4	NO_2	NO_2+NO_3	DIN	PO_4	SIO_4	DON	DOP	PRTN	PRTP	DOC	POC	Chl *a*
1	May-93	238	19	135	373	1917	5929	3908	76	639	109	44411	2479	28
2	Jun-93	387	34	155	542	2010	5835	4294	46	521	94	42138	3590	33
3	Jul-93	699	35	384	1084	1910	4503	3106	145	665	115	37414	4772	34
4	Aug-93	336	54	205	541	1757	1916	3342	159	824	154	42008	4115	32
5	Sep-93	718	49	378	1096	1516	4050	2578	-22	810	184	48668	5446	44
6	Oct-93	251	24	96	347	1572	1510	3833	249	936	196	52225	5762	34
7	Nov-93	276	9	81	357	1385	4043	3890	233	930	176	56181	4199	35
8	Dec-93	203	11	30	233	1466	4462	3323	221	833	135	47283	3188	16
9	Jan-94	169	24	173	341	1433	6658	3237	257	1172	223	48677	5244	37
10	Feb-94	140	22	46	187	1368	4554	3340	127	650	111	46209	2388	22
11	Mar-94	156	18	114	270	1485		3462	245	753	143	43500	3294	29
12	Mar-94-2	131	9	34	165	1577	2156	3079	223	735	119	41966	2782	13
13	Apr-94	129	19	41	171	1586	5761	2956	214	452	74	45800	2042	25
14	May-94	124	24	81	205	1549	3512	2858	160	491	95	35805	2437	36
15	Jun-94	303	30	176	479	1673	1515	3362	190	599	131	33679	2869	24
16	Jul-94	228	26	114	342	1634	1597	3150	205	528	88	30771	2108	25
17	Aug-94	184	18	114	298	1442	1294	2690	59	479	81	37622	2254	16
18	Sep-94	80	8	11	91	1488	1025	2765	233	606	109	42963	3675	26
19	Oct-94	200	10	93	292	1538	1736	3389	227	447	82	40777	1821	15
20	Nov-94	138	16	79	217	1533	3328	3257	138	649	137	37565	3442	21
21	Dec-94	126	5	13	138	1534	3308	3100	126	636	109	39736	2247	17
22	Jan-95	89	11	30	120	1439	2888	3460	83	770	131	37425	2227	15
23	Feb-95	136	7	39	175	1537	3846	3595	167	774	128	48376	4375	24
24	Mar-95	93	14	46	139	1597	4154	3495	213	800	130	44182	3449	28
25	Mar-95-2	92	10	47	138	1708	1275	3398	129	612	127	43239	3062	26
Overall mean:		**224**	**21**	**109**	**333**	**1589**	**3367**	**3311**	**166**	**696**	**127**	**42724**	**3342**	**21**

Table 33: Estimated Bay-wide nutrient pool size (tonnes) by cruise, assuming a Bay volume of 25 km

Year/method	**NH_4**	**NO_2**	**NO_3**	**PO_4**	**SiO_4**	**Chl *a***
May 1993-April 1994:						
Simple average	284	24.2	134	1612	4100	28.5
Inverse-distance	249	18.8		1651	4304	26.5
Double spline	208	17.7	89	1500	4263	22.5
May 1994- March 1995:						
Simple average	151	14.0	74	1558	2478	22.7
Inverse-distance	130	11.8		1549	2436	21.1
Double spline	118	11.6	60	1420	2342	19.6

Table 34: Bay-wide annual nutrient pool sizes (tonnes), from simple averages (Table 33), inverse-distance weighting interpolation, and double spline interpolation.

Variable/period	**1969-70**	**1980-84**	**1993-95**
Ammonium	1250	140	163
Nitrite	49	21	15
Nitrate	74	70	75
Total N	8505	4165	3025
Phosphate	1891	1473	1460
Silicate	3640	2520	3303
Chlorophyll *a*	~33	24.0	21.1
Method	Simple average of data from 40-60 stations at 6-week intervals	Depth-weighted average from 16 samples (one sample randomly chosen within each of 16 strata) each 6 weeks	Double-spline interpolation onto 300 m grid of about 2,000-3,000 surface measurements every 4 weeks, except Total N: 12 samples per 4 weeks.

Table 35: Bay-wide annual average pool sizes (tonnes), 1969-1995.
1969-70 data is drawn from MMBW & FWD (1973), 1980-84 data from Cowdell *et al.* (1985) and 1993-95 from the present study.

4. DISCUSSION

4.1. Spatial scales: defining model compartments

We found no obvious and persistent zones in the Bay which apply to all nutrients and for all sampling occasions. However, on a long term basis the highest mean concentrations of ammonium and phosphate were observed offshore from the WTP. Highest oxidised nitrogen concentrations occurred offshore from the WTP and Hobsons Bay during winter and in Hobsons Bay during summer. Highest silicate concentrations occurred in the Hobsons Bay area. Areas of high chlorophyll concentration occurred off both the WTP and Hobsons Bay. This pattern is consistent with those observed previously (MMBW & FWD 1973, Cowdell *et al.* 1985, Longmore *et al.* 1990). From the variability observed in this study it is difficult to justify division of the Bay into more than four compartments: Hobsons Bay and the north-eastern near-shore; WTP coastal area; on and south of the Sands; and the rest of the Bay.

4.2. Spatial scales: conservative mixing

Mixing curves are easiest to interpret if there is only one nutrient input (fresh water source) and only one salt water source. Mixing curve shapes become more complex with increasing numbers of inputs, and as biological and physical transformations also take place. In this study we have observed:

- curves that could be interpreted as conservative;
- curves indicating two nutrient sources (e.g. WTP and Yarra River for ammonium);
- curves indicating three nutrient sources (e.g. WTP, Yarra River and Bass Strait for oxidised nitrogen);
- curves indicating a nutrient source within the Bay itself (e.g. silicate from benthic remineralisation);
- curves indicating biological uptake (silicate), physical settling or grazing (chlorophyll);
- distributions that do not vary with salinity.

Multiple sources could be identified for all nutrients. Biological uptake was observed for all nutrients but was especially evident for silicate at concentrations below 10 µM. Inverse mixing (where concentration increases with increasing salinity) was observed about 30% of the time for oxidised nitrogen, usually within the Great Sands, indicating the potential of Bass Strait as a source to the Bay. However, although patches of high oxidised nitrogen concentration were often observed in the area of the Great Sands they may in fact have just have moved back and forth in this area with the tide, with little impact on the rest of the Bay (Prytz and Heron 1995). Mixing of all nutrients in the channels through the Great Sands was usually conservative.

No nutrient behaved in the same way from one cruise to the next (or even from one part of the Bay to another on the same cruise). Conservative mixing was most often observed under high-flow conditions when low salinity water with high nutrient concentrations mixed with Bay water. Such examples could be found for each nutrient and chlorophyll (Table 13). Phosphate distribution was conservative with salinity more often than the other nutrients but was usually split into three sections with increasing salinity: a conservative section near the nutrient source, a non-conservative area in the centre of the Bay where phosphate concentration changed little with increasing salinity and a conservative section through the Great Sands in which central Bay water mixes with Bass Strait. This distribution reflects the impact time scales have on the mixing process: transport through the salinity gradient near the discharge and also through the Great Sands is rapid by comparison with transport across the centre of the Bay. Mixing in the shallow areas occurs at a faster rate than biological processes so that conservation is observed. However in the deep centre of the Bay, where mixing is slower, biological and physical processes have time to affect phosphate distribution.

Another reason for observing non-conservative mixing in a Bay as large as Port Phillip also has to do with relative time scales. Where the concentration of end-members changes more rapidly than the speed of transport along the gradient, a straight line will not be observed. For example, if phosphate discharge from the Yarra declined by 50% in the time it took a volume of water to reach the middle of the Bay, even with no biological or physical transformations a curved distribution with salinity would be observed. This is one of the limitations of the mixing curve approach, which assumes a steady-state, and could only be overcome by monitoring a pool of water as it moved along the salinity gradient. As noted above, non-steady state was the most frequently observed shape for phosphate, silicate and chlorophyll. Our short-term studies, undertaken at times of low flow, generally did not indicate conservative mixing for two reasons: the salinity range was usually less than 1, and the concentration changes were often near the limit of accuracy. The mixing curve approach works best when both salinity and nutrient changes are large (Morris *et al.* 1995).

A further feature of the Bay which confounds the mixing curve approach is seasonal hypersalinity in the Geelong Arm and Corio Bay, producing two saline end-members and often two separate mixing curves. This was most apparent for phosphate.

One reason for the observations of conservative mixing for chlorophyll could be that production occurs in patches of relatively low salinity, but production ceases as the patches mix with the surrounding water.

When the data in Figure 84 were extrapolated back to zero salinity in order to estimate concentrations in the freshwater input from WTP, the extrapolated WTP end-member concentrations were much less than those expected for WTP effluent. There was a greater proportional loss of phosphate than of ammonium. From the ammonium lost as the salinity increased from 0 to 18 (600 μM), we would predict a biological removal of 1:16, or 38 μM phosphate. The inferred removal is 85 μM phosphate. This contradicts Kelly *et al.* (1987) who concluded that loss rates of phosphorus and nitrogen were the same off the WTP drains and were probably due to dilution. It is likely that both nutrients are biologically assimilated to some extent in the area directly off the WTP coast, but the additional loss of phosphate could be attributed to the trapping of phosphate in organic and inorganic flocs which form in and settle from the water column as fresh water meets salt (Smith and Longmore 1980, Froelich *et al.* 1985). Since the near-shore is so shallow, the flocs have no opportunity to build up and enrich the sediment but are presumably transported to deeper water. The generally low N:P and C:P ratios in particulate matter support the notion of P-enrichment, especially in 1994-95.

Assuming conservative mixing, we can extrapolate nutrient concentrations observed in the Werribee River plume in September 1993 to the freshwater end-member concentration (50-80μM NH_4, 20 μM NO_2+NO_3, 70 μM SiO_4). Further assuming that nutrient concentrations are constant with discharge, and multiplying concentration by discharge volume (Figure 6), we estimate the nutrient load discharged to the Bay from the Werribee River in September 1993 at 75-120 t NH_4-N, 30 t (NO_2+NO_3)-N, and 220 t SiO_4-Si, 30% of which was discharged in a single day. The estimated end-member concentration is only about one-tenth of that measured (under much lower flow) for NO_2+NO_3 in the Werribee River (NSR 1993) and may indicate dilution of concentration under high flow. If that is the case our estimates above are likely to be conservative. Whilst they exceed those calculated previously for the Werribee River (NSR 1993) they are still only a minor proportion of the total annual load to the Bay from other known sources. However, if all of the nitrogen was assimilated by phytoplankton (C:N=106:16 atoms and C:chl=50:1w/w) it could have led to an increased biomass of 15 t chlorophyll *a*, or close to 70% of the standing crop.

It is difficult to believe that the high chlorophyll concentrations observed off the Werribee River at that time would have had sufficient time (<2 days) to develop *in situ*, but the inverse relationship observed of chlorophyll with salinity indicates production at salinities below 15 being diluted at higher salinities. Froelich et al. (1985) observed a peak in chlorophyll concentration at a salinity of about 10 in the Charlotte Harbour, Florida, and concluded that the location of the chlorophyll maximum along the salinity gradient was a balance between turbulence at high flow near the river mouth which prevented production, and lack of nutrients at high salinity. The same process may have operated off the Werribee River in September, but we have no observations at low salinity for verification.

We may speculate on the fate of the nutrient load brought in by the Werribee River flood. Inspection of Table 33 (monthly pool sizes) leads to the following analysis. Over the month following the flood (September-October 1993) the Bay-wide DIN pool decreased by 750 t, silicate by 2500 t and chlorophyll by 10 t. Converting chlorophyll to nitrogen equivalents, the DIN and chlorophyll pool size decreased by about 840 t N. However, DON and PrtN pools increased over the month by about 1300 and 126 t respectively. Hence, the increase in organic forms of nitrogen is more than enough to account for the loss of DIN. This is consistent with the view that the DIN input was converted to organic matter, presumably by rapid phytoplanktonic uptake and partial remineralisation. The loss of silicate greatly exceeds that held in diatom cells and suggests that substantial deposition of cell frustules occurred.

Given the high nutrient concentrations in the WTP discharge, the question may rise as to why we did not always observe much higher concentrations offshore from the

WTP. We believe this is due to the combined effects of dilution, wind and biological uptake. The sampling vessel could not approach within 2 km of the WTP discharges because the water is too shallow. Assuming a 75 ML d^{-1} freshwater discharge from each of four outlets (Murray 1994) radially diluted into a 2 km radius half-circle, with an average depth of 3 m, the ratio of receiving volume to discharge is 500:1. Assuming complete mixing, we can then calculate the expected nutrient concentration following such dilution (Table 36). At a dilution of 500:1, we could expect to be able to detect ammonium from the WTP in winter, while detection of oxidised nitrogen and phosphate discharges would be more difficult. Biological uptake would make the detection of the WTP plume even more difficult, and on-shore winds (with an easterly component) would tend to force the plume back toward the shore. In concert these factors may be sufficient to prevent detection of the WTP plume more than 2 km offshore, except in winter or under very calm conditions.

Assumptions:
1. WTP effluent is fresh water, with nutrient concentrations of :
   NH_4 : 360 µM (summer) and 1785 µM (winter);
   $NO_2 + NO_3$: 160 µM;
   PO_4: 190 µM;
   SiO_4: 250 µM;
2. Central Bay water has a salinity of 34, with nutrient concentrations of:
   NH_4: 0.4 µM;
   $NO_2 + NO_3$: 0.2 µM;
   PO_4: 2 µM;
   SiO_4: 2 (summer)- 8 µM.

Dilution factor	Salinity	NH_4 (µM) summer	NH_4 (µM) winter	$NO_2 + NO_3$ (µM)	PO_4 (µM)	SiO_4 (µM) summer	SiO_4 (µM) rest of year
0	0.00	360	1785	160	190	250	250
1	17.00	180.2	892.7	80.1	96.0	126.0	129.0
2	25.50	90.3	446.6	40.2	49.0	64.0	68.5
4	29.75	45.3	223.5	20.2	25.5	33.0	38.3
8	31.88	22.9	111.9	10.2	13.8	17.5	23.1
16	32.4	11.6	56.2	5.2	7.9	9.8	15.6
32	33.47	6.0	28.3	2.7	4.9	5.9	11.8
64	33.73	3.2	14.3	1.5	3.5	3.9	9.9
128	33.87	1.8	7.4	0.8	2.7	3.0	9.0
256	33.93	1.1	3.9	0.5	2.4	2.5	8.5
512	33.97	0.8	2.1	0.4	2.2	2.2	8.2
1024	33.98	0.6	1.3	0.3	2.1	2.1	8.1
infinity	34.00	0.4	0.4	0.2	2.0	2.0	8.0

Table 36: Conservative mixing of Western Treatment Plant effluent with central Bay water.

Each of these observations emphasises the dynamic nature of nutrient distribution in the Bay - there is no general rule! The Bay may be well-mixed vertically but is often very patchy horizontally.

4.3. Temporal scales

Changes in nutrient concentration with time are more dramatic in Port Phillip Bay than changes with depth.

4.3.1. Short term (<5 days)

The short-term studies took place under low-flow conditions, and the changes observed were slight compared to those observed over the whole study period.

Pattiaratchi *et al* (1989) have argued that discharges from the WTP mix completely with Bay water under wind speeds of more than 5.5 m s^{-1} while multiple fronts form at lower wind speeds. The lack of stratification during the first three days of the September 1994 Werribee study, when wind speeds exceeded 6 m s^{-1}, is consistent with this. The general movement of water, indicated by north-east drift of ammonium, oxidised nitrogen and phosphate patches, is also consistent with wind-driven motion. Wind-driven surface currents move at about 3% of the wind speed, which leads to an expected transport of surface water downwind at 3-6 km per lap for wind in the range 5-10 m s^{-1}. This exceeds the water movement calculated from patch movement.

During the February, 1995, Werribee study, winds from the north-east over the first three days and the fifth day should have forced WTP water to remain near the shore and move toward the south-west. We would not expect to see the impact of discharges in this period but we could expect to have seen a plume on the fourth day. However, we observed phosphate and chlorophyll patches moving north-east over the five days, against the wind, while a patch of high-silicate water on the north-eastern end of the study area did not move at all. This is the same area in which a subsurface increase in nutrients was observed on one lap, while the water column was not stratified. It is difficult to reconcile these three observations unless water motion itself is extremely patchy in the study area. The finding of higher chlorophyll concentrations at depth on some laps suggests either that wind speeds of 4-7.5 m s^{-1} were insufficient to keep phytoplankton suspended in the water column or that the phytoplankters actively migrate to specific depths (if motile). Measured changes in the WTP discharge of ammonium, oxidised nitrogen and phosphate were not reflected in changes in surface nutrient distributions.

Wind speed during the northern Bay study in January 1995 led to the expectation that the water column outside Hobsons Bay would be well-mixed on the first lap, but capable of stratifying on the other laps. The consistent wind direction (SW-NW) should have driven water toward the eastern shore. The movement of the Yarra fresh water plume, down the eastern coast, is consistent with this. The ammonium patch observed on the first lap may have travelled NE out of the study area. However, the small (<0.3 µM) increase in ammonium concentration over much of the study area to a depth of at least 7 m on lap 4, and its disappearance before the next lap, is inconsistent with either NE or southward movement of water. The apparent lack of movement of a phosphate patch over the last three laps is also inconsistent with wind-driven motion, unless it was part of a return current carrying a continuous supply of phosphate-rich (but nitrogen- and silicate-poor) Hobsons Bay water along the northern coast. This seems unlikely, since the Yarra discharge is usually rich in nitrate and silicate and relatively poor in phosphate. Density depth profiles indicate stratification at all sites on most laps. They do not support the notion of night-time overturning which could replace surface water with bottom water enriched in nutrients by benthic recycling.

Under low discharge conditions typical of a dry spring-summer, salinity, phosphate and silicate distributions changed little over 5 days off both the Werribee and Hobsons Bay coasts. Ammonium and oxidised nitrogen concentrations also exhibited limited variation but there were pools of higher concentration in parts of the study areas which persisted for less than 6 hours. If the pools disappeared because of planktonic uptake, it was not reflected in increased chlorophyll concentration within the time of the study (5 days). Relatively slow movement of pools of phosphate and silicate (Werribee February 1995, northern Port Phillip Bay January 1995) contrasted strongly with transient occurrence of pools of ammonium and oxidised nitrogen. Some movement of nutrient patches was consistent with wind-driven transport, but some others were not.

4.3.2. Seasonal

The use of linear regression to indicate trends in time ignores the existence of seasonal changes, which are extremely important for some of the variables at some sites. It is the variation in seasonal peaks for ammonium at Wooley Reef, oxidised nitrogen at Wooley Reef and Sandringham, and chlorophyll at Wooley Reef which cause these regressions to slope, rather than a change in the underlying baseline. Such samples will be better modelled by the time series analysis to be undertaken later in 1996. While many of the preliminary spectral analyses (Figure 75) indicate that an annual cycle is the single largest repeating pattern, some patterns clearly have changed between 1990 and 1995. For example, lowest concentrations of silicate at Wooley Reef (Figure 55) occurred in November 1990, 1991, and 1992, but shifted to September-October 1993 and July 1994. The lack of fresh water runoff in 1994 and early 1995 may have led to a reduction in the silicate input and consequently a more rapid draw-down of the silicate pool by diatoms. The seasonal pattern in this case would relate to fresh water input, phytoplankton growth rate and benthic remineralisation rather than a signal related to temperature or light.

4.3.3. Interannual

There is no clear reason why a linear trend of nutrient concentration with time should be expected and yet many statistically significant trends were observed over a period of five years. Cross-correlation with meteorological factors (river flow, wind forcing) may establish links between the trends and driving forces, but it is already clear that terrestrial inputs of storm water and river flow strongly affect the behaviour of the Bay.

Declining nutrient concentrations over several years could be expected to lead to lower phytoplankton biomass if the population were nutrient -limited. Similarly, improved water clarity could be expected to lead to increased phytoplankton biomass if light was limiting. The evidence we have indicates that nutrient limitation is more likely than light limitation because where nutrient concentrations declined and light penetration increased, we observed chlorophyll reductions or no change. Grazing may confound such a simple interpretation.

4.4. Statistics and pool sizes

Pool sizes calculated here are subject to several sources of error. The first is analytical error. We estimate the error in typical concentrations at about ±13% for ammonium, ±50% for nitrite, ±16% for oxidised nitrogen, ±5% for phosphate and ±4% for silicate. Chlorophyll concentrations given here may underestimate the true concentration by 10-40%. The second error arises because of variations in concentration with depth, which are ignored for all of the pool calculations given here. Using surface concentrations only may lead to underestimates in mean ammonium and chlorophyll concentrations of about 5% and 20% respectively, and overestimates for oxidised nitrogen, phosphate and silicate of 20%, 1% and 5% respectively. The third source of error is in spatial interpolation.

The method of interpolation has a significant effect on calculated pool sizes (Table 34). Simple averaging leads to an over-estimation of pool sizes by 6-50% (compared to double spline interpolation) in every case except for silicate in 1993-94. The error arises because simple averages of surface measurements multiplied by the total Bay volume do not take into account the volume weighting necessary to calculate pool sizes accurately. About 70% of the total Bay volume occurs in the centre, which is often the region of lowest nutrient concentration, but less than 30% of the measurements were made there (Figures 1 and 4). The error in silicate is lower than for the other nutrients and chlorophyll because its concentration appears to vary Bay-wide and not just near the inputs. The error in phosphate is likewise relatively small (7-10%) because its concentration is comparatively high throughout the Bay.

Depth-weighting is therefore essential if accurate pool sizes are to be obtained. The method of interpolation (inverse-distance, double-spline or other) may be less critical, and it can be shown (David Fox, CSIRO, personal comment) that the error in interpolation for annual pool size calculations is less than the combined analytical and depth-variation errors cited above.

Bay-wide pools appear to have declined in size over the past 25 years for all nutrients except nitrate and silicate (Table 35). The ammonium pool was about 1100 tonnes smaller in 1993-95 than it was in 1969-70 and the total nitrogen pool 5500 tonnes smaller. The phosphate pool was 430 tonnes (22%) smaller and chlorophyll 12 tonnes (36%) smaller. It is difficult to believe that ammonium and total nitrogen concentrations were 2-8 times greater in 1969-70 than those measured since, especially given the relatively small changes in estimated inputs (Skyring *et al.* 1992) and the relatively constant phosphate pool size. We believe that there were analytical problems unidentified in the Phase 1 study which render suspect the ammonium and total nitrogen concentrations measured during 1969-70. Changes since 1980-84 appear to be insignificant and are certainly less than the differences between 1993-94 and 1994-95 (Table 34). This emphasises the necessity to collect long-term data if we wish to interpret changes in pool sizes from one period to the next. Sampling for one year will inevitably lead to a biased estimate of long-term pool size, the bias depending on runoff and other factors.

4.5. Nutrient limitation

It has long been recognised that there is no single unambiguous indicator of nutrient limitation of phytoplankton growth. The results of *in vitro* assays and *in situ* enclosures are subject to interpretation difficulties, particularly as they isolate the water sample from many processes (wind mixing, benthic fluxes, grazing) of importance to plankton growth (Carignan and Planas 1994). Benthic nutrient fluxes are thought to have a major influence on water quality in Port Phillip Bay (Berelson et *al.* 1994, Nicholson *et al*. 1996).

Ambient nutrient concentrations are the result of many concurrent processes including external inputs, biological uptake, physical and chemical transformations in the water column, losses to and fluxes from the sediments and atmosphere. They may indicate what is left behind rather than what is needed, or lacking, for further growth. It is possible for high primary production to occur in waters with very low ambient nutrient concentrations if there is a close link between benthic fluxes and planktonic uptake, and rapid recycling. Nevertheless, some studies have identified nutrient concentrations which were considered growth-limiting. Egge and Aksnes (1992) considered nitrate concentrations less than 0.5 µM limited growth in marine mesocosms, while phosphate concentrations greater than 0.6 µM would not limit growth. Silicate concentrations less than 2 µM were believed to be limiting for diatom growth. Brockmann *et al*. (1990) stated that nutrient limitation in the North Sea occurred when phosphate concentrations fell below 0.2 µM. Note that some of these limits differ considerably from those in Table 27; these differences indicate the uncertainty in setting limits for populations of mixed plankton.

Conley *et al.* (1993) discussed the effect of increasing discharges of N and P on silicate. Their evidence, from lakes with long turnover times, was that eutrophication generally leads to increased primary production, particularly of large diatoms. These are sedimented, depleting the water column of silicate. Plankton other than diatoms are then favoured by the continued inputs of N and P, and these are often less desirable as a food source than diatoms. However, in a system like Port Phillip Bay where silicate is regularly resupplied from the catchment by river input and from benthic remineralisation (Nicholson *et al.,* 1996) silicate limitation may be, at most, a transient problem.

Furthermore, changes in nutrient concentration ratios may limit some phytoplankton species, but not others. Several workers (Egge and Aksnes 1992, Conley *et al*. 1993) have observed that diatoms dominate irrespective of season if silicate concentrations exceed 2-3 µM.

It has been argued that organic nitrogen turns over more slowly than organic phosphorus, perhaps leading to N limitation, as a proportion of the N is fixed in a slowly-cycling reservoir (Smith *et al*. 1986). The TN:TP ratios found in Port Phillip Bay are so far below 16 that N limitation is likely even if both N and P were recycled with the same efficiency.

Particulate matter is made up of a wide spectrum of particles with a range of origins and ages. It may include fresh (living) plankton, recently dead cells, macroalgal fragments, soils and other terrestrial runoff. As detritus ages, its C:N ratio increases from about 6 for fresh plankton to more than 10 for older material as a result of the preferential degradation of N (Brockmann *et al*. 1990). Without independent evidence it is not possible to indicate whether the 50% of Port Phillip Bay particulate samples with a high C:N ratio were N-deficient or simply dominated by old, partly degraded material. The particulate C:N ratio decreased at all sites during 1990-95 from >10 to <6 (Figure 69), suggesting that N deficiency, if present, would have been less likely in later years. The observation that nearly half of the particulate samples did not indicate N deficiency is important since it suggests nitrogen limitation may not always be the factor which controls biomass.

The independent evidence needed to test this hypothesis may be found in the pigment ratios, which indicated N-sufficiency for most samples. The ratios are not universally applicable: Latasa and Berdalet (1994) demonstrated that pigment ratios are not a good indicator of N limitation for a marine dinoflagellate. However several studies have now shown that it does apply to diatom-dominated systems (Heath *et al*. 1990, Richardson and Christoffersen 1991). Recent work (O'Leary *et al.* 1994, Magro *et al.* 1996) has indicated that the plankton in Port Phillip Bay is generally dominated by diatoms. Providing the photosynthetic pigment concentrations are not drastically affected by previous light history (Kirk 1983), our conclusions on the lack of N deficiency should hold.

There is always the possibility of other limiting factors (e.g. grazing), although Armstrong (1994) produced a multiple food chain model which showed that it is possible for each phytoplankton size class to be limited by its herbivores, while the overall biomass is nutrient-limited.

5. CONCLUSIONS.

5.1. Chemical and physical forms of nitrogen and phosphorus.

Dissolved organic nitrogen comprised 70-80% of the total nitrogen concentration. Particulate nitrogen accounted for 13-20% of the total and dissolved inorganic nitrogen comprised 3-13% of the total. Ammonium was the dominant form of DIN. Phosphate formed 60-86% of the total phosphorus concentration, dissolved organic phosphorus 7-22% and particulate phosphorus 5-18%.

5.2. Spatial variation.

Horizontal: In accord with all previous studies, nutrient concentrations were highest close to the known nutrient discharges (WTP and Hobsons Bay). Nutrients (particularly nitrogen species) occurred in patches of high concentration rather than smoothly declining concentration away from inputs. Few of the nutrient patch shapes indicated concentric zones of increasing concentration, suggesting that wind speed and direction influence patch integrity and distribution rather than simple radial dilution from the source. The distribution of each species was different and on many cruises patches of high chlorophyll concentration coincided with high silicate concentrations.

Vertical: The water column at Williamstown was chemically and physically stratified most of the time by a nutrient-rich fresh water surface layer. During times of highest stratification (with high river flow), nutrient enrichment in the surface layer of Hobsons Bay was substantial (e.g. silicate up to 50 μM and nitrate up to 10 μM). Almost half of the surface samples from Werribee River were enriched in silicate, presumably due to the Werribee River rather than the WTP input. Except near freshwater discharges (rivers and the WTP), variation of nutrient concentrations with depth was often less than the accuracy of our field measurements. Overall the water column was well-mixed chemically at most sites more than half the time.

5.3. Temporal variation.

Short term: The short-term studies took place under low-flow conditions and the changes observed were slight compared to those observed over the whole study period. Under low discharge conditions typical of a dry spring-summer, salinity, phosphate and silicate distributions changed little over 5 days off both the Werribee and Hobsons Bay coasts. Ammonium and oxidised nitrogen concentrations also varied little, though there were pools of higher concentration in parts of the study areas which persisted for less than 6 hours. If the pools disappeared because of planktonic uptake it was not reflected in increased chlorophyll concentration within the time of the study (5 days). Relatively slow movement of pools of phosphate and silicate (Werribee February 1995, Northern Port Phillip Bay January 1995) contrasted strongly with occurrence of pools of ammonium and oxidised nitrogen. Some movement of nutrient patches was consistent with wind-driven transport, but some others were not.

Though short-term variations in concentration were less than spatial variations, short-term variations in inorganic nitrogen concentrations were large enough to indicate that distributions measured four weeks apart cannot be used to infer changes over the four weeks. They are best used to indicate the extent of discharge plumes. However, variation in nutrient concentrations is probably less further away from the shore. Since 75% of the Bay volume occurs in the central region, nutrient pool calculations for the whole Bay may be relatively insensitive to the sorts of changes observed near-shore in these short-term studies.

Long term: Changes with time were observed for most nutrients at several sites during 1990-95. Most of the trends applied to sites on the eastern side of the Bay and indicated decreasing nutrient concentrations (especially phosphate, silicate, ammonium and nitrate) with time. Few trends were detected on the western side of the Bay. Phytoplankton biomass (chlorophyll *a*) declined or stayed unchanged while POC (food for deposit feeders and filter feeders) declined Bay-wide. Water clarity improved Bay-wide, as indicated by declining PAR attenuation.

5.4. Identification of model compartments.

There are no persistent zones in the Bay which apply for all nutrients and for all sampling occasions. However, on an annual basis highest mean concentrations of ammonium and phosphate occurred offshore from the WTP. Highest oxidised nitrogen concentrations occurred off the WTP and Hobsons Bay in winter, and in Hobsons Bay during summer. Highest silicate concentrations occurred in the Hobsons Bay area. Areas of high chlorophyll concentration occurred off both the WTP and Hobsons Bay.

5.5. Pool sizes.

Three different methods of calculation (from the same data) all indicate that pool sizes have not changed greatly since 1980-84, though ammonium and total nitrogen pools in 1993-95 were much smaller than those calculated in 1969-70. Changes in pool size between 1993-94 and 1994-95 were greater than the differences between 1980-84 and 1993-95.

5.6. Nutrient limitation.

The likelihood of nutrient limitation of phytoplankton growth was inferred from a study of dissolved and particulate nutrient concentrations, nutrient concentration ratios and pigment concentration ratios. Dissolved nutrient concentrations and concentration ratios indicated nitrogen limitation was possible in most samples. Silicate limitation was possible for up to 40% of samples from the southern sites, reducing to less than 2% for samples from Williamstown. Growth of diatomaceous phytoplankton in about 15% of samples from the Werribee River fixed site may have been silicate-limited. Particulate nutrient concentrations and ratios indicated nitrogen limitation was more likely than phosphorus limitation, but no limitation was indicated for more than half the samples. The PN:PP ratio increased from 10:1 to closer to the Redfield ratio of 16:1, and POC:PN decreased from >10 to <6 over the period 1990-95. However, phytoplankton pigment ratios indicated that nitrogen deficiency was a rare occurrence. These data suggest that nitrogen limitation may not always be as important a factor in controlling phytoplankton growth in the Bay as was previously thought.

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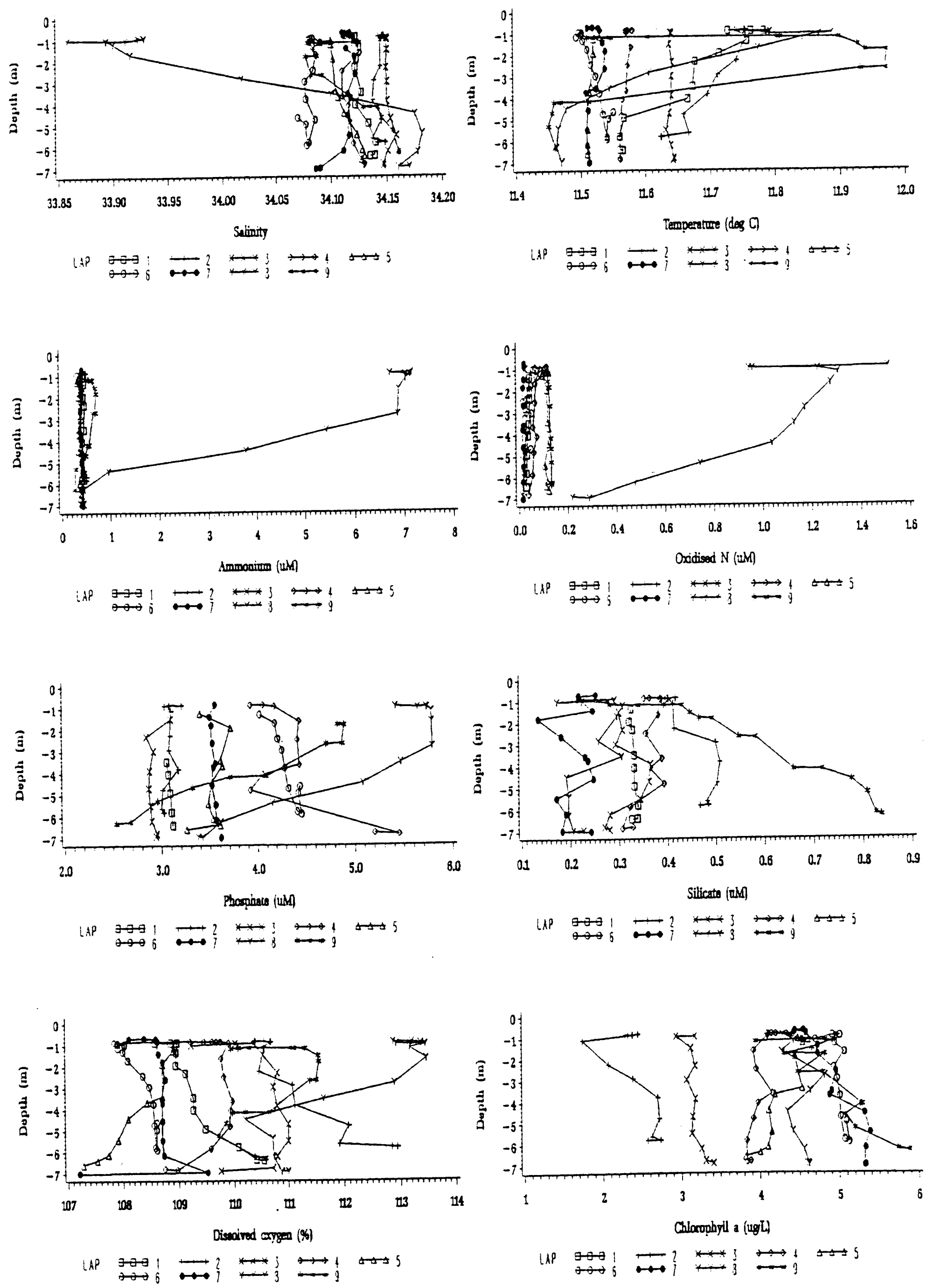
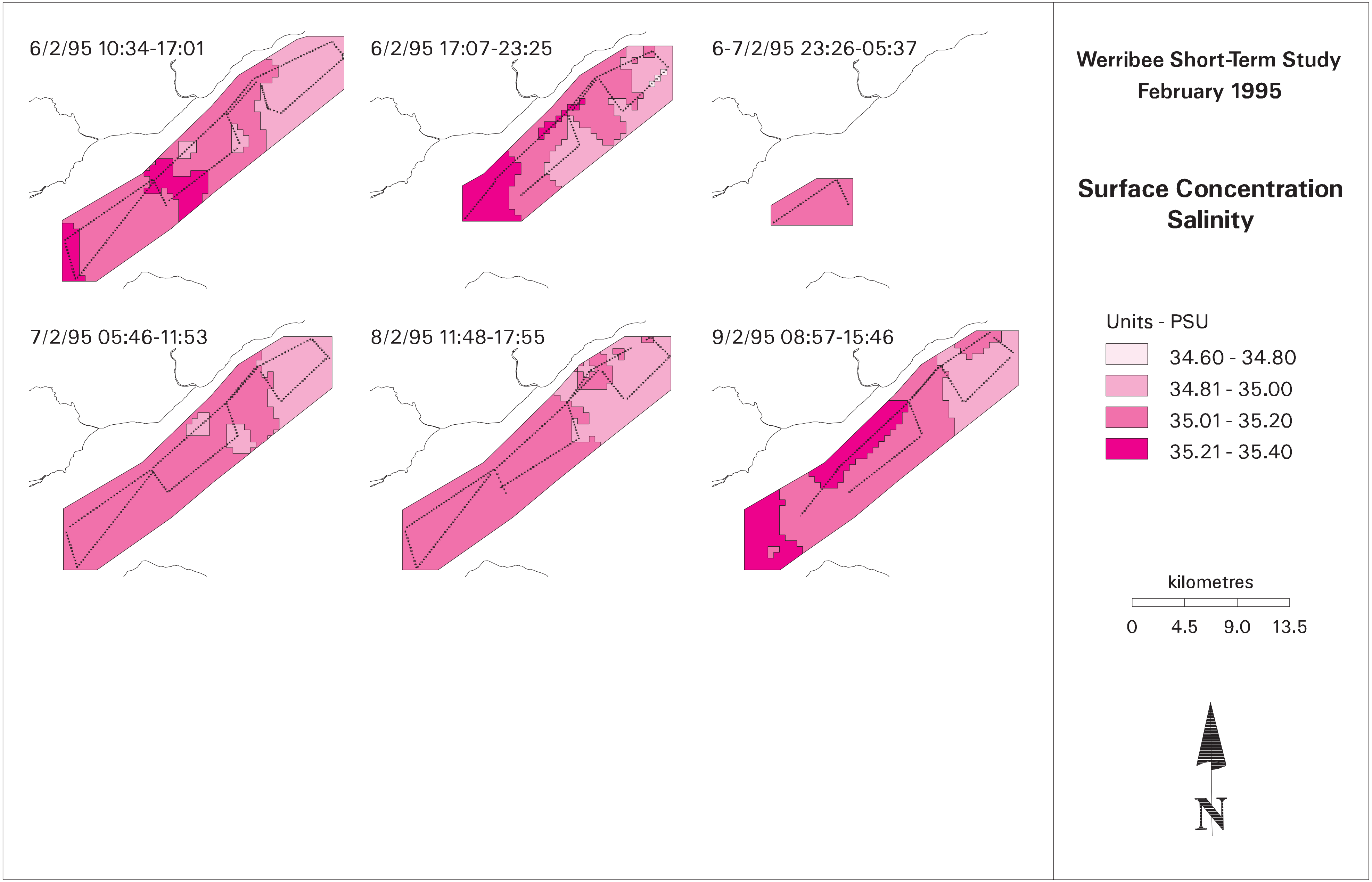
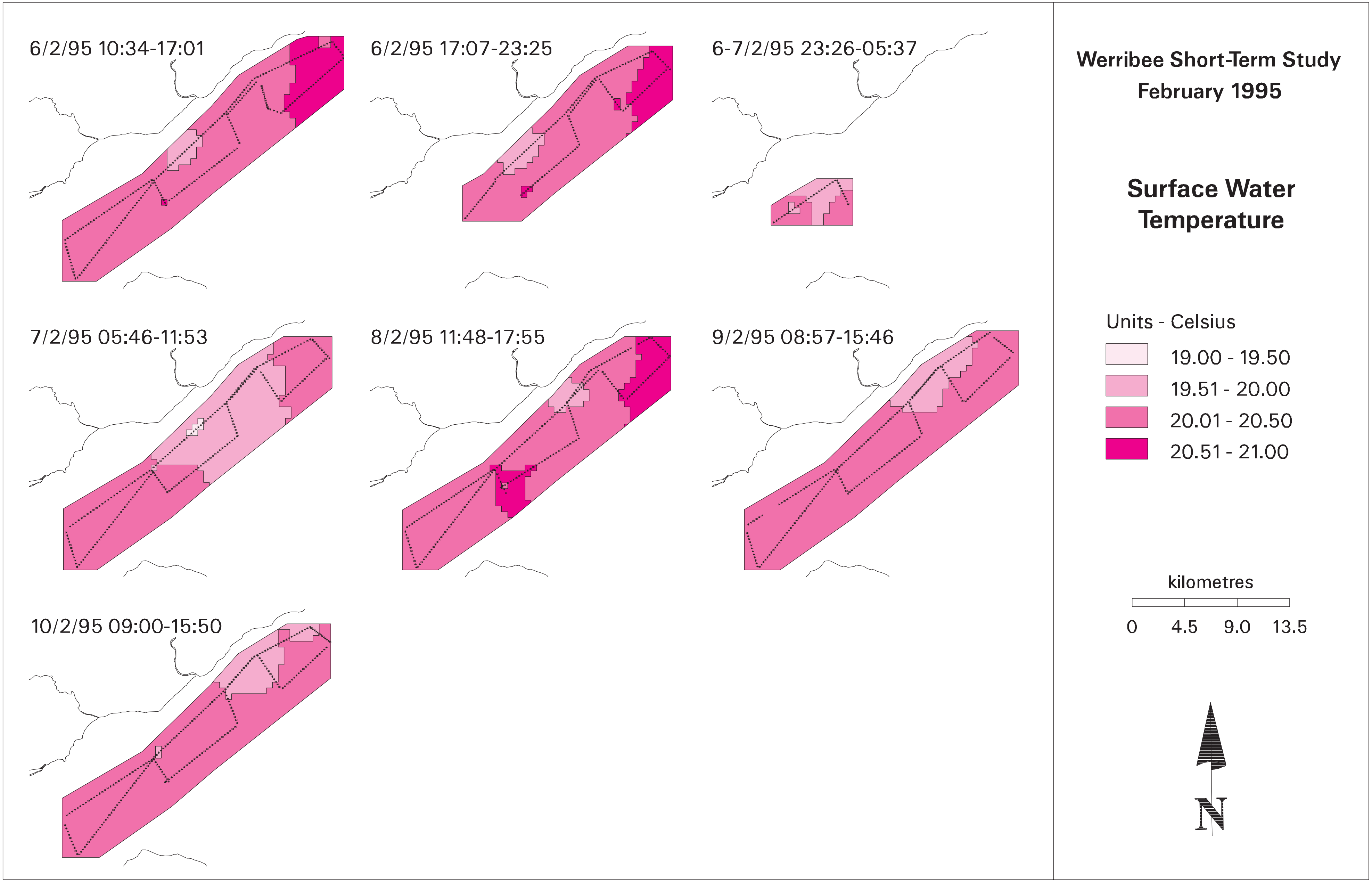
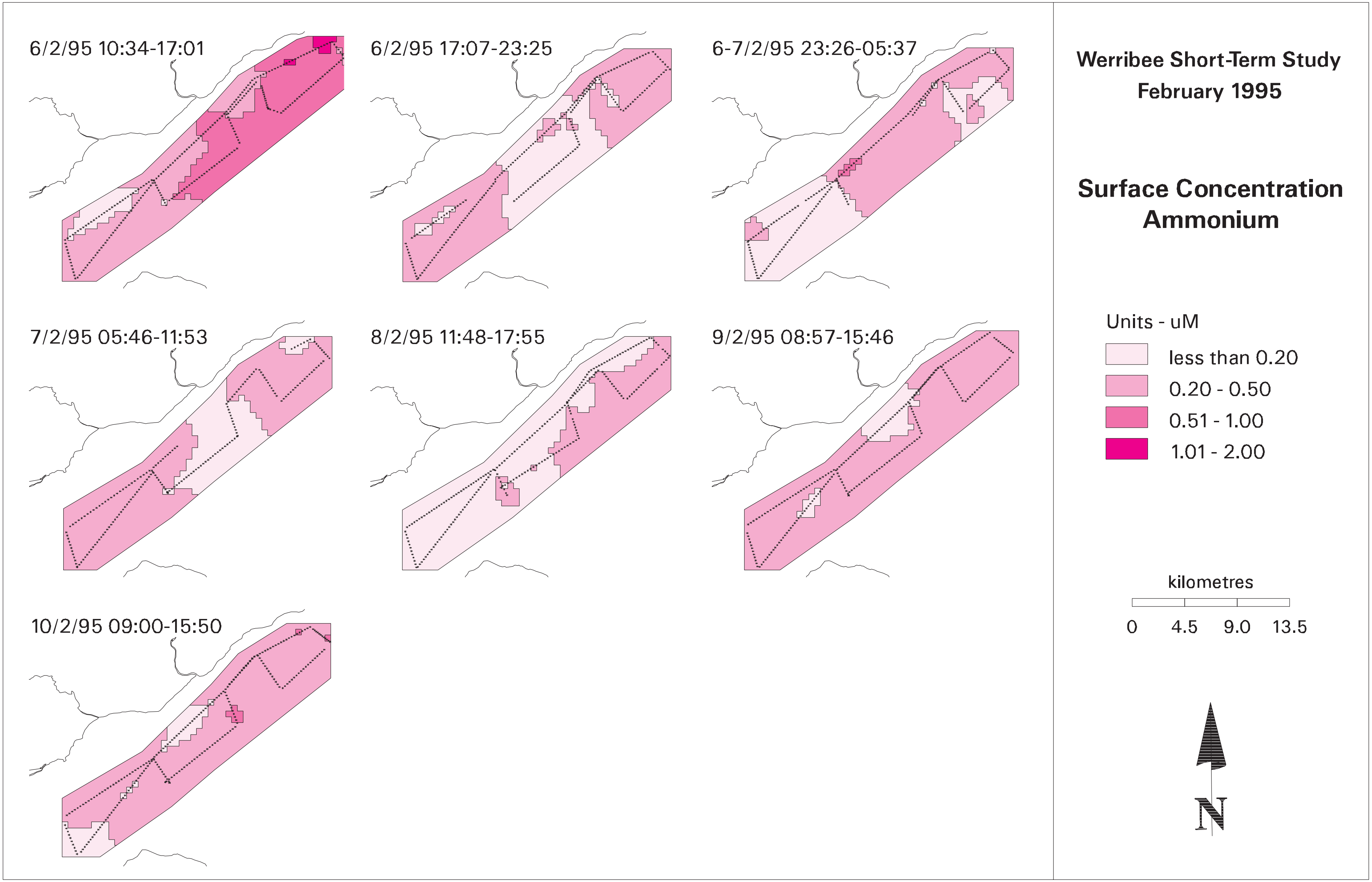
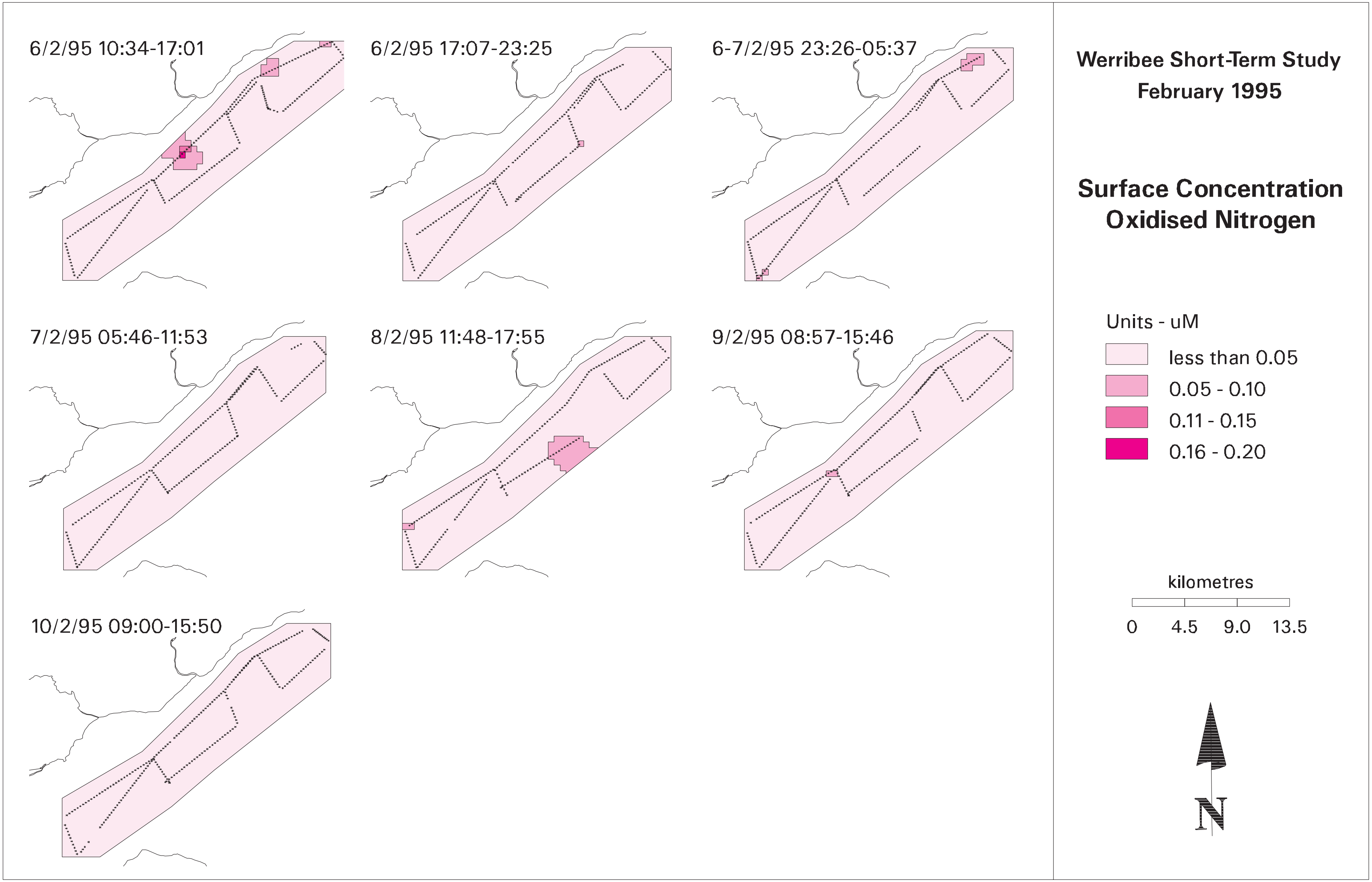


Figure 15: Vertical structure at site 11 (figure 4), Werribee, September 1994.


6/2/95 10:34-17:01
6/2/95 17:07-23:25
6-7/2/95 23:26-05:37
7/2/95 05:46-11:53
8/2/95 11:48-17:55
9/2/95 08:57-15:46
Werribee Short-Term Study
February 1995
Surface Concentration
Salinity
Units - PSU
34.60 - 34.80
34.81 - 35.00
35.01 - 35.20
35.21 - 35.40
kilometres
0
4.5
9.0
13.5
N


Werribee Short-Term Study
February 1995
Surface Water Temperature
6/2/95 10:34-17:01
6/2/95 17:07-23:25
6-7/2/95 23:26-05:37
7/2/95 05:46-11:53
8/2/95 11:48-17:55
9/2/95 08:57-15:46
10/2/95 09:00-15:50
Units - Celsius
19.00 - 19.50
19.51 - 20.00
20.01 - 20.50
20.51 - 21.00
kilometres
0
4.5
9.0
13.5
N


6/2/95 10:34-17:01
6/2/95 17:07-23:25
6-7/2/95 23:26-05:37
7/2/95 05:46-11:53
8/2/95 11:48-17:55
9/2/95 08:57-15:46
10/2/95 09:00-15:50
Werribee Short-Term Study
February 1995
Surface Concentration
Ammonium
Units - uM
less than 0.20
0.20 - 0.50
0.51 - 1.00
1.01 - 2.00
kilometres
0
4.5
9.0
13.5
N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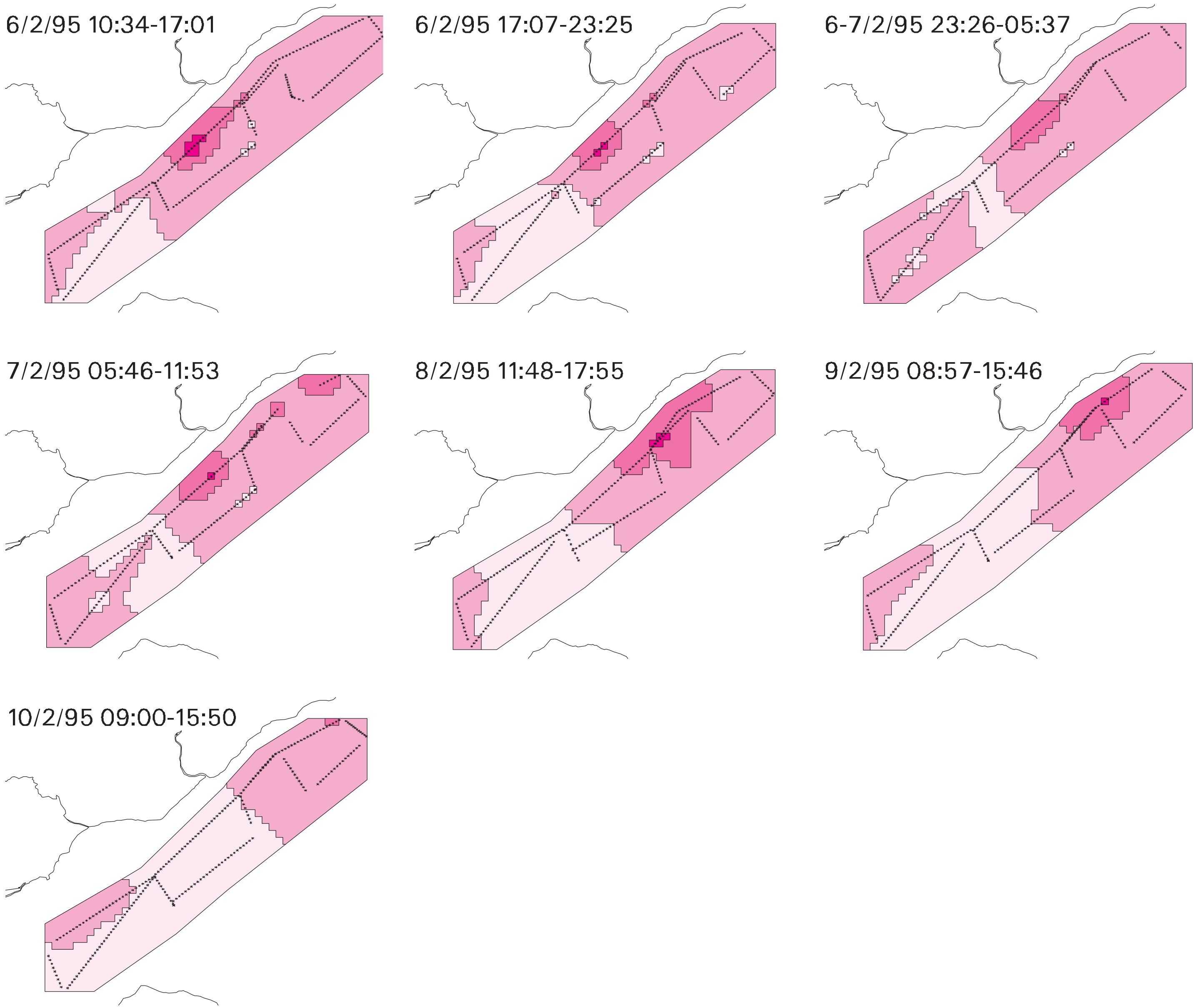
6/2/95 17:07-23:25
6-7/2/95 23:26-05:37
7/2/95 05:46-11:53
8/2/95 11:48-17:55
9/2/95 08:57-15:46
10/2/95 09:00-15:50
Werribee Short-Term Study
February 1995
Surface Concentration
Oxidised Nitrogen
Units - uM
less than 0.05
0.05 - 0.10
0.11 - 0.15
0.16 - 0.20
kilometres
0
4.5
9.0
13.5
N



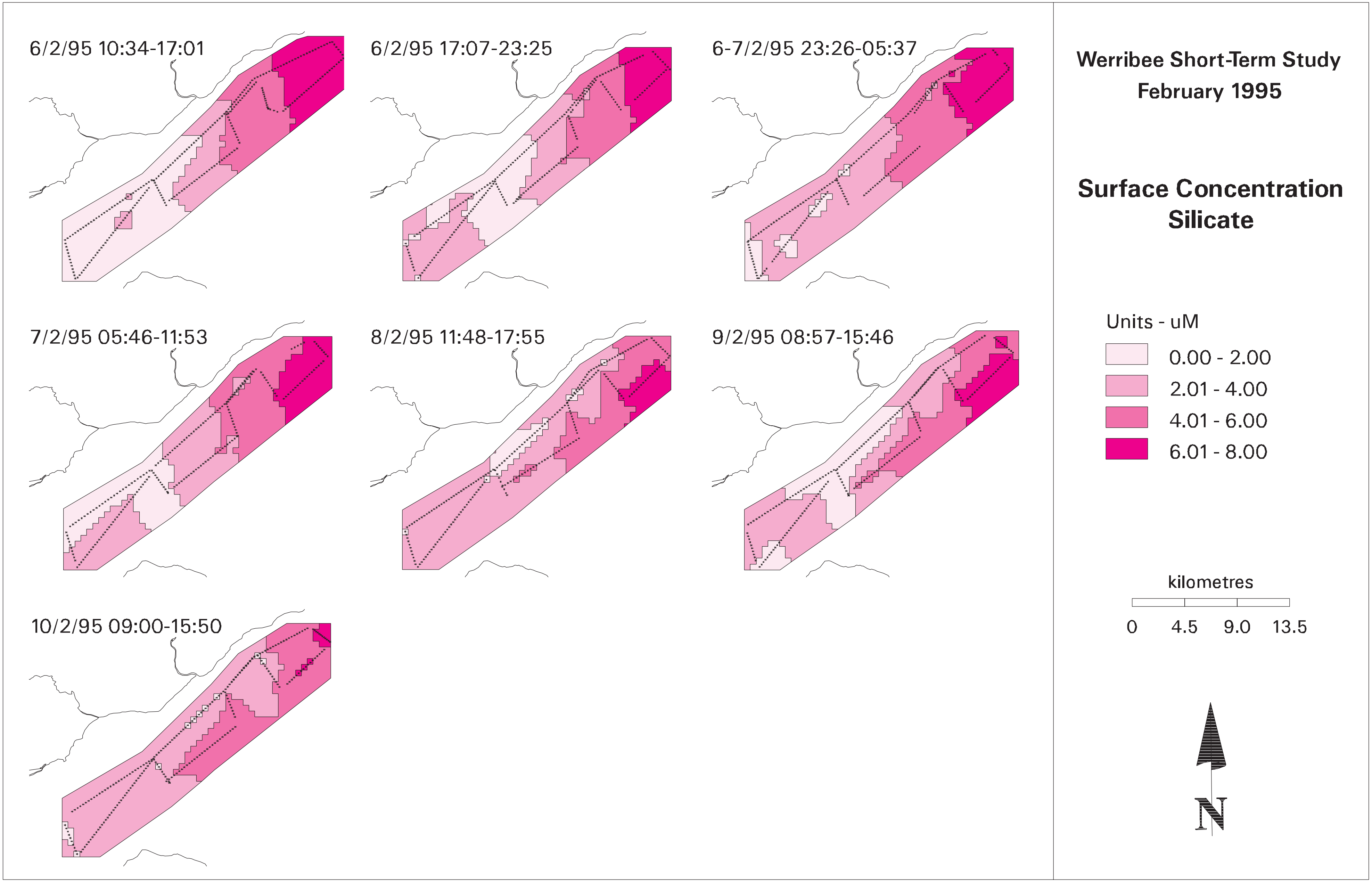
Werribee Short-Term Study
February 1995

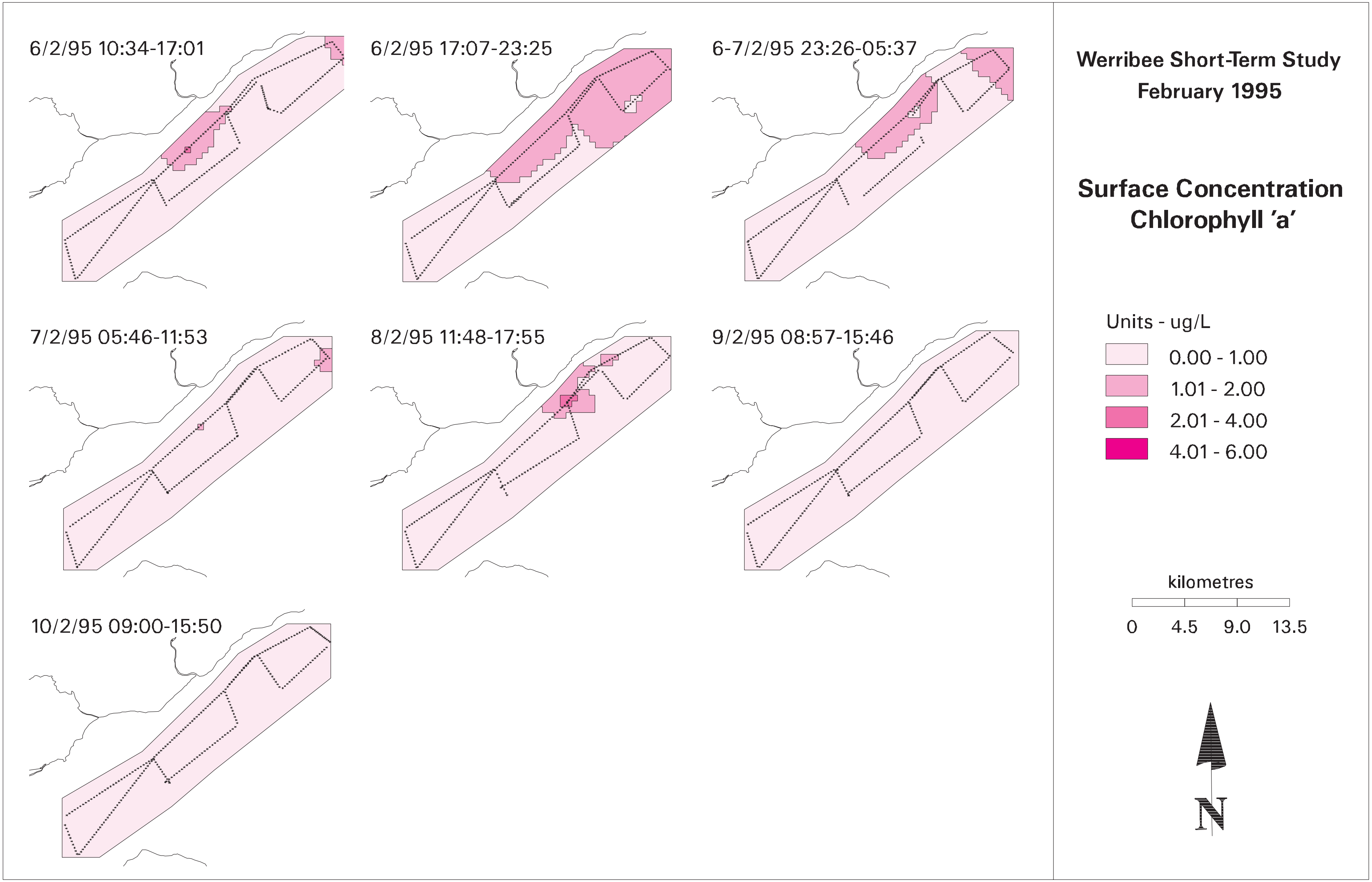
Surface Concentration
Phosphate

Units - uM
1.00 - 2.00
2.01 - 4.00
4.01 - 6.00
6.01 - 9.00

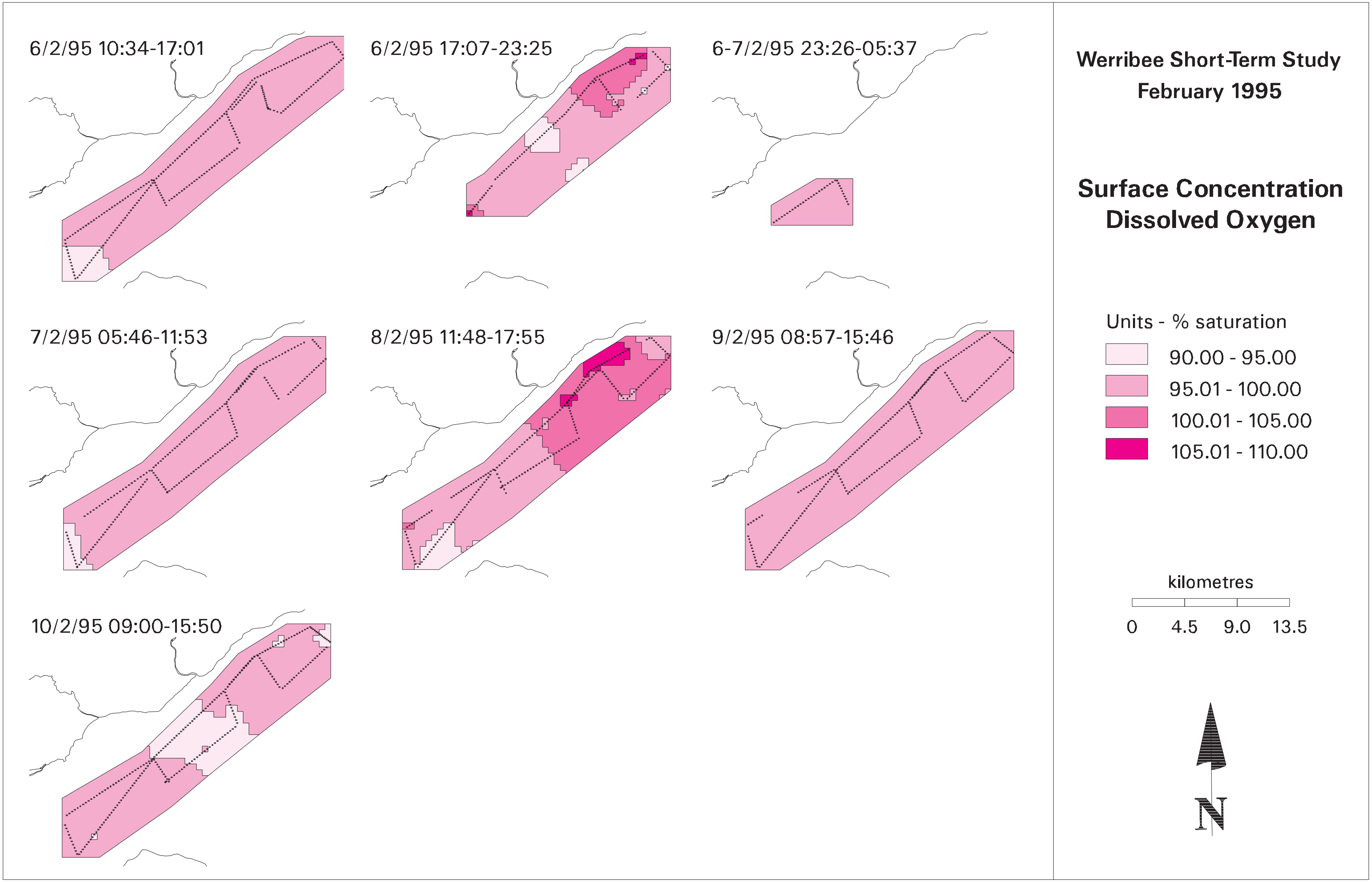
kilometres
0 4.5 9.0 13.5

N


Werribee Short-Term Study
February 1995
Surface Concentration
Silicate
6/2/95 10:34-17:01
6/2/95 17:07-23:25
6-7/2/95 23:26-05:37
7/2/95 05:46-11:53
8/2/95 11:48-17:55
9/2/95 08:57-15:46
10/2/95 09:00-15:50
Units - uM
0.00 - 2.00
2.01 - 4.00
4.01 - 6.00
6.01 - 8.00
kilometres
0
4.5
9.0
13.5
N



6/2/95 10:34-17:01
6/2/95 17:07-23:25
6-7/2/95 23:26-05:37
7/2/95 05:46-11:53
8/2/95 11:48-17:55
9/2/95 08:57-15:46
10/2/95 09:00-15:50
Werribee Short-Term Study
February 1995
Surface Concentration
Chlorophyll 'a'
Units - ug/L
0.00 - 1.00
1.01 - 2.00
2.01 - 4.00
4.01 - 6.00
kilometres
0
4.5
9.0
13.5
N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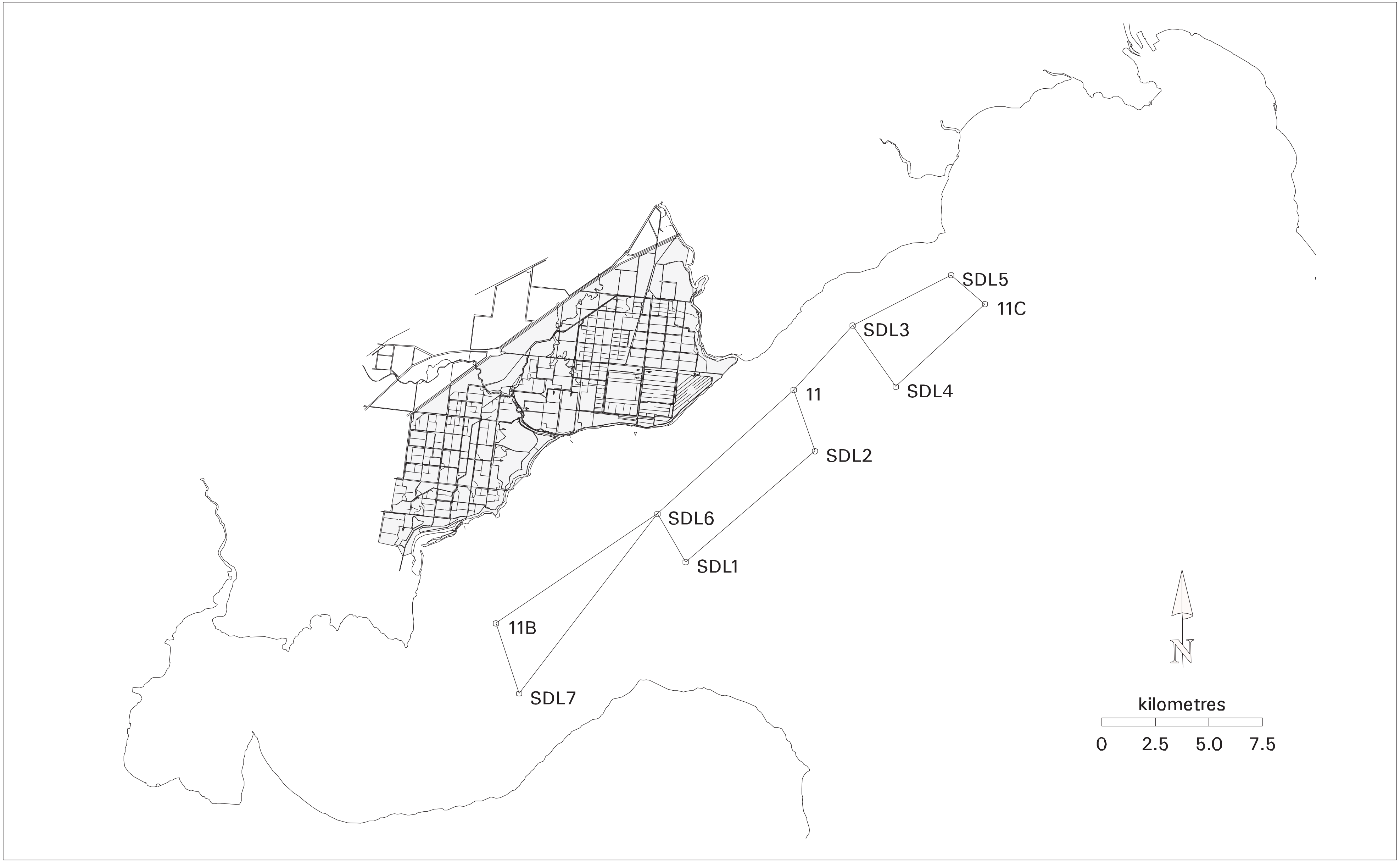
6/2/95 17:07-23:25
6-7/2/95 23:26-05:37
7/2/95 05:46-11:53
8/2/95 11:48-17:55
9/2/95 08:57-15:46
10/2/95 09:00-15:50
Werribee Short-Term Study
February 1995
Surface Concentration
Dissolved Oxygen
Units - % saturation
90.00 - 95.00
95.01 - 100.00
100.01 - 105.00
105.01 - 110.00
kilometres
0
4.5
9.0
13.5
N


SDL5
11C
SDL3
SDL4
11
SDL2
SDL6
SDL1
11B
SDL7
N
kilometres
0
2.5
5.0
7.5

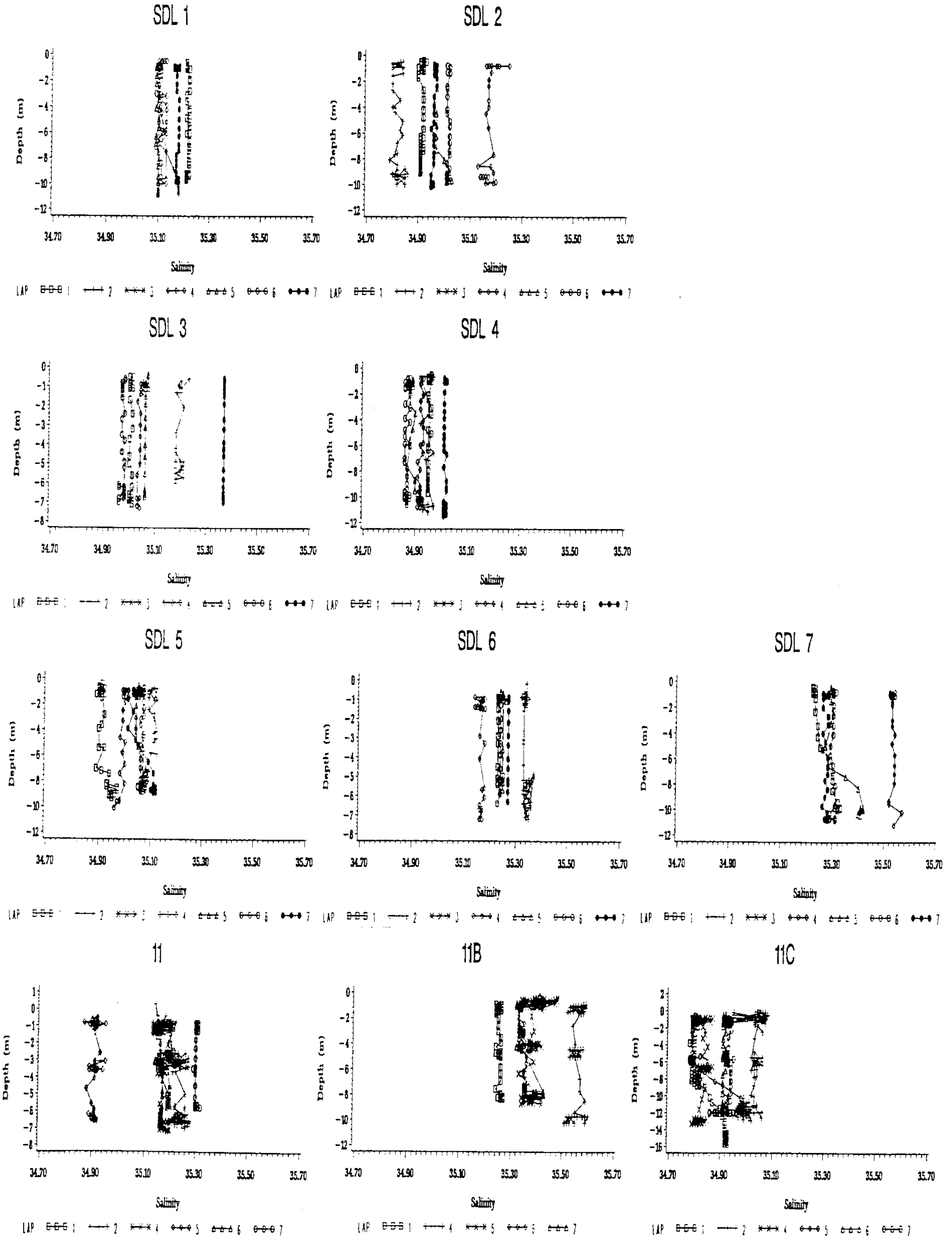

SDL 1
SDL 2
SDL 3
SDL 4
SDL 5
SDL 6
SDL 7
11
11B
11C
Depth (m)
Salinity

Figure 25

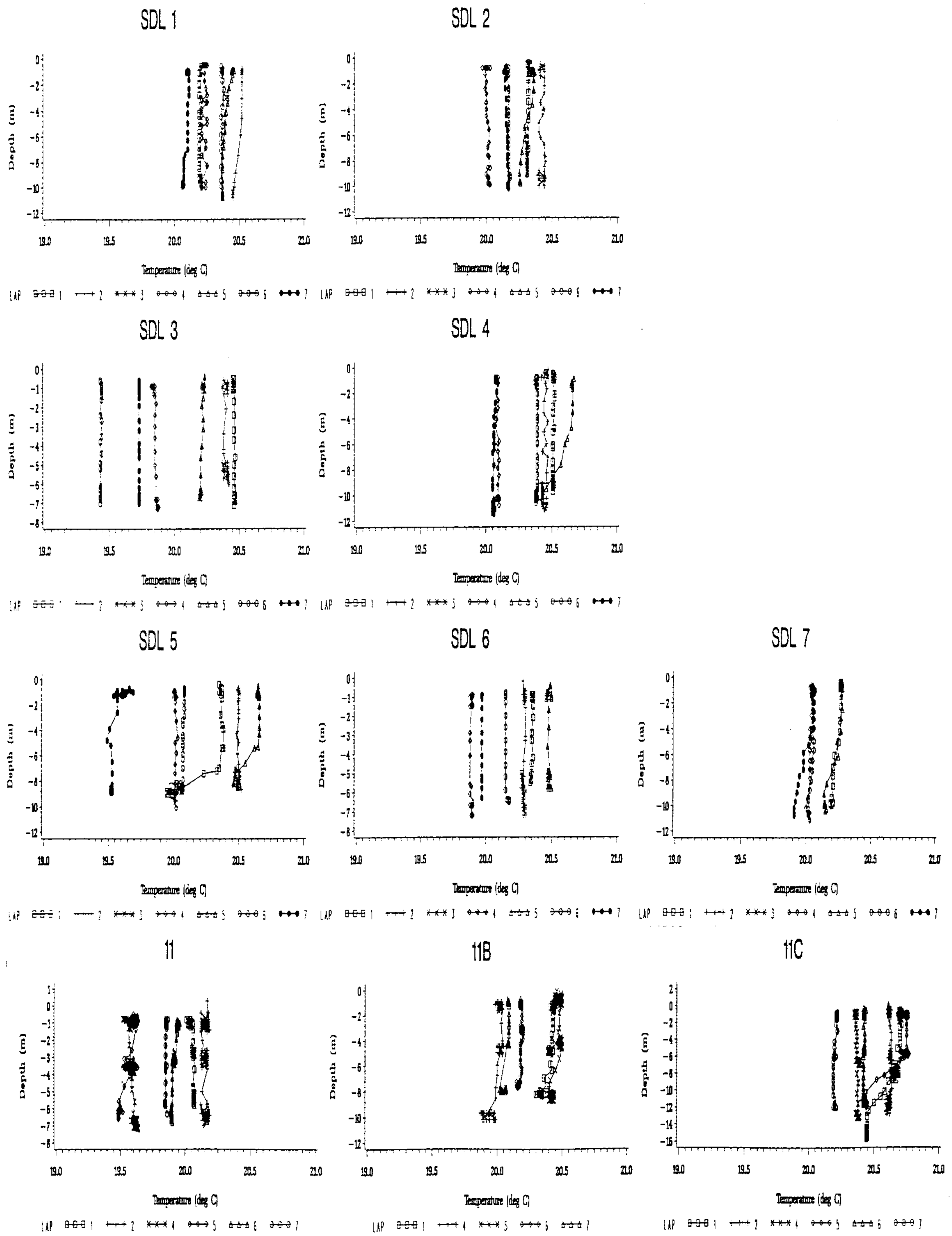

SDL 1
SDL 2
SDL 3
SDL 4
SDL 5
SDL 6
SDL 7
11
11B
11C
Depth (m)
Temperature (deg C)

Figure 26

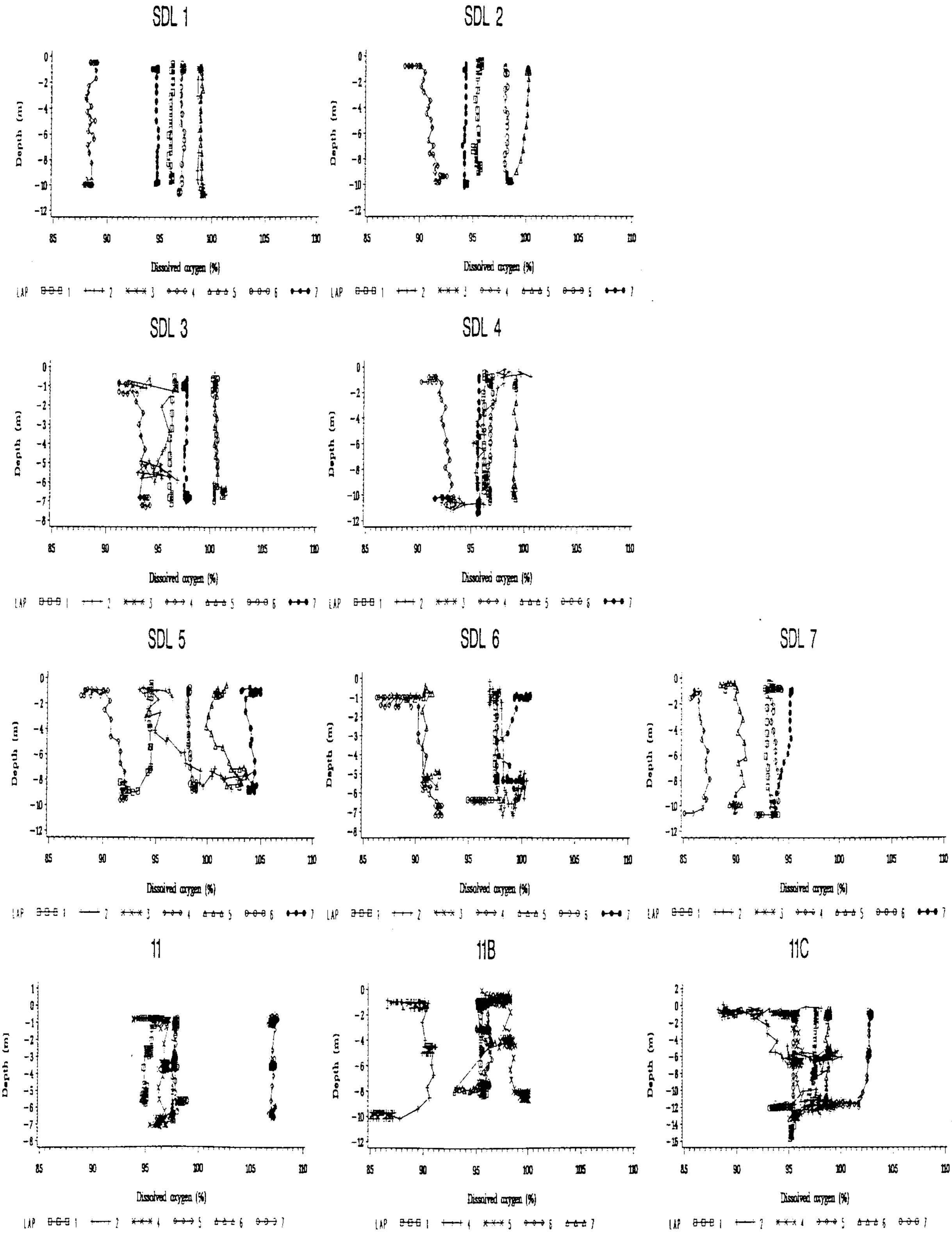

SDL 1
SDL 2
SDL 3
SDL 4
SDL 5
SDL 6
SDL 7
11
11B
11C
Depth (m)
Dissolved oxygen (%)
LAP

Figure 27

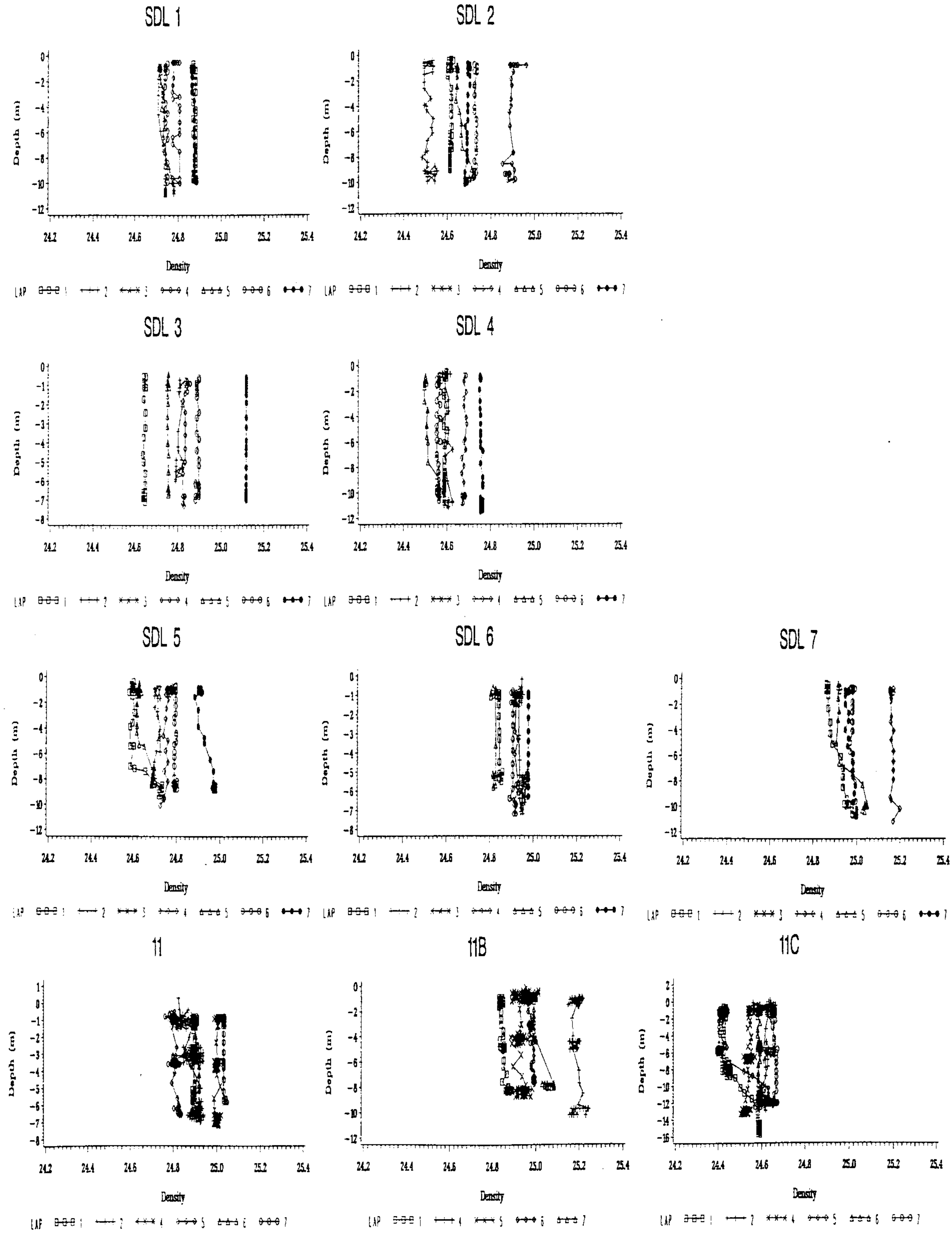

SDL 1
SDL 2
SDL 3
SDL 4
SDL 5
SDL 6
SDL 7
11
11B
11C
Depth (m)
Density
LAP

Figure 28

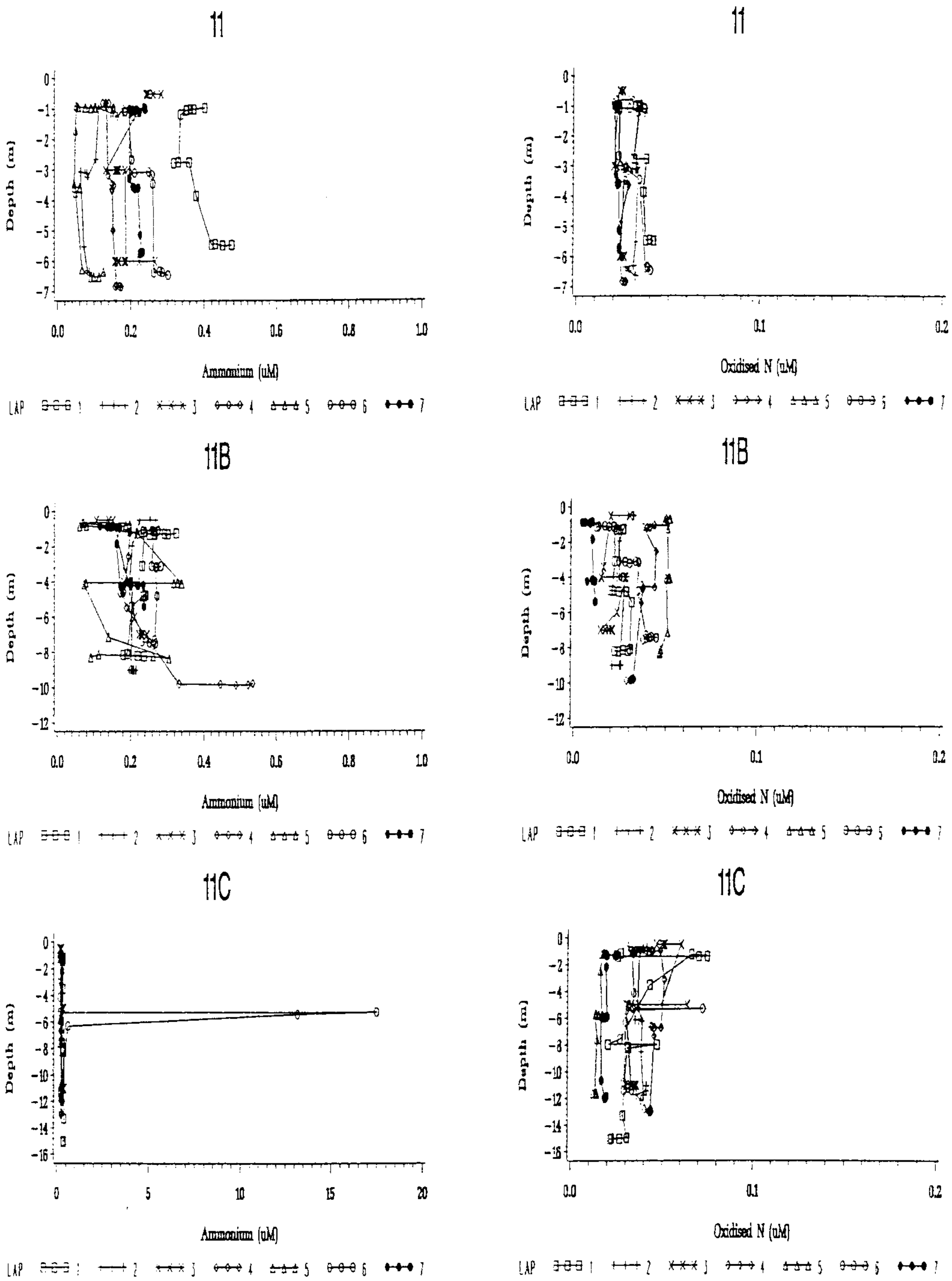

11
Depth (m)
Ammonium (uM)
11
Depth (m)
Oxidised N (uM)
11B
Depth (m)
Ammonium (uM)
11B
Depth (m)
Oxidised N (uM)
11C
Depth (m)
Ammonium (uM)
11C
Depth (m)
Oxidised N (uM)

Figure 29

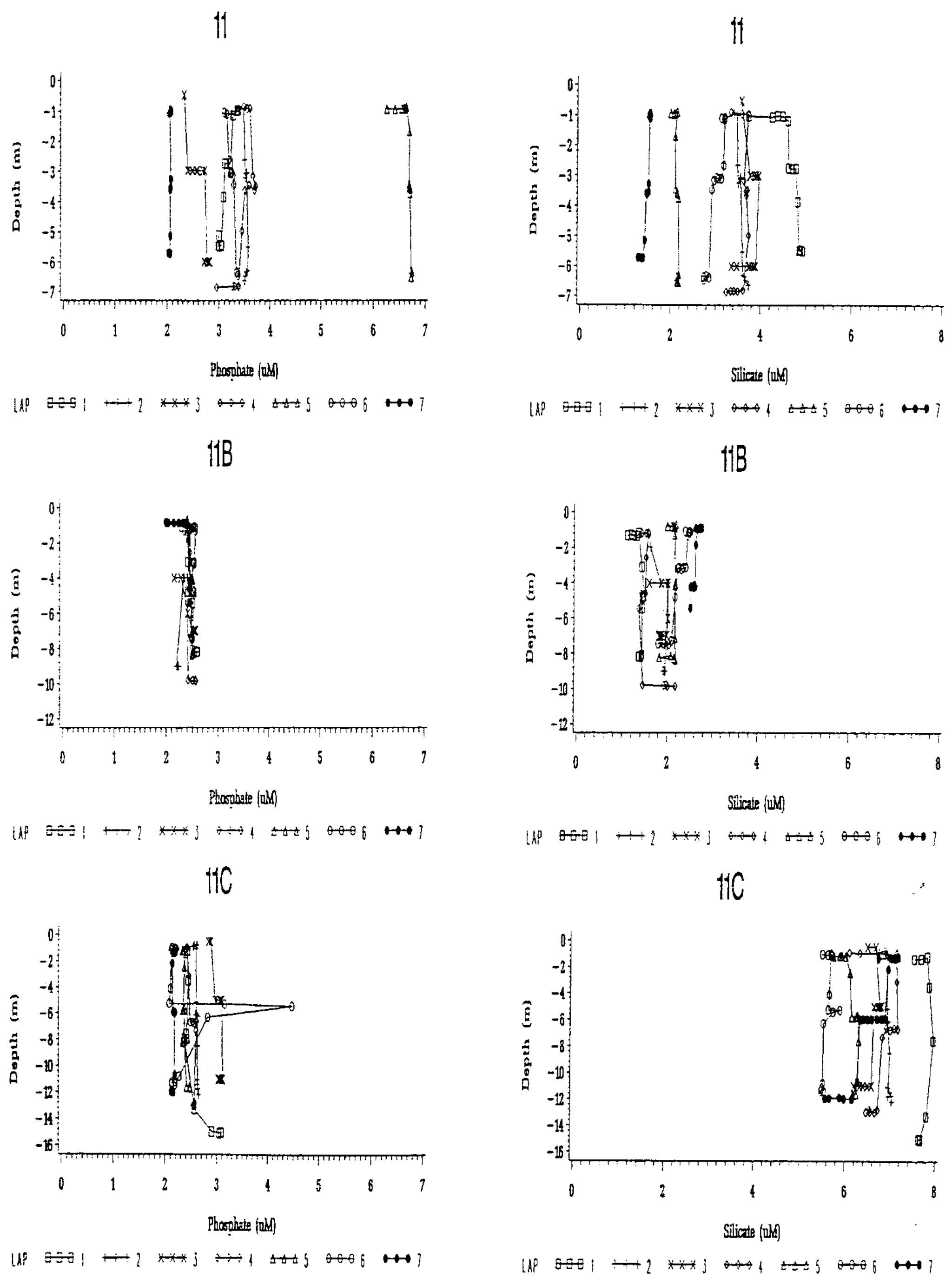

11
Depth (m)
Phosphate (uM)
LAP 1 2 3 4 5 6 7
11
Depth (m)
Silicate (uM)
LAP 1 2 3 4 5 6 7
11B
Depth (m)
Phosphate (uM)
LAP 1 2 3 4 5 6 7
11B
Depth (m)
Silicate (uM)
LAP 1 2 3 4 5 6 7
11C
Depth (m)
Phosphate (uM)
LAP 1 2 3 4 5 6 7
11C
Depth (m)
Silicate (uM)
LAP 1 2 3 4 5 6 7

Figure 30

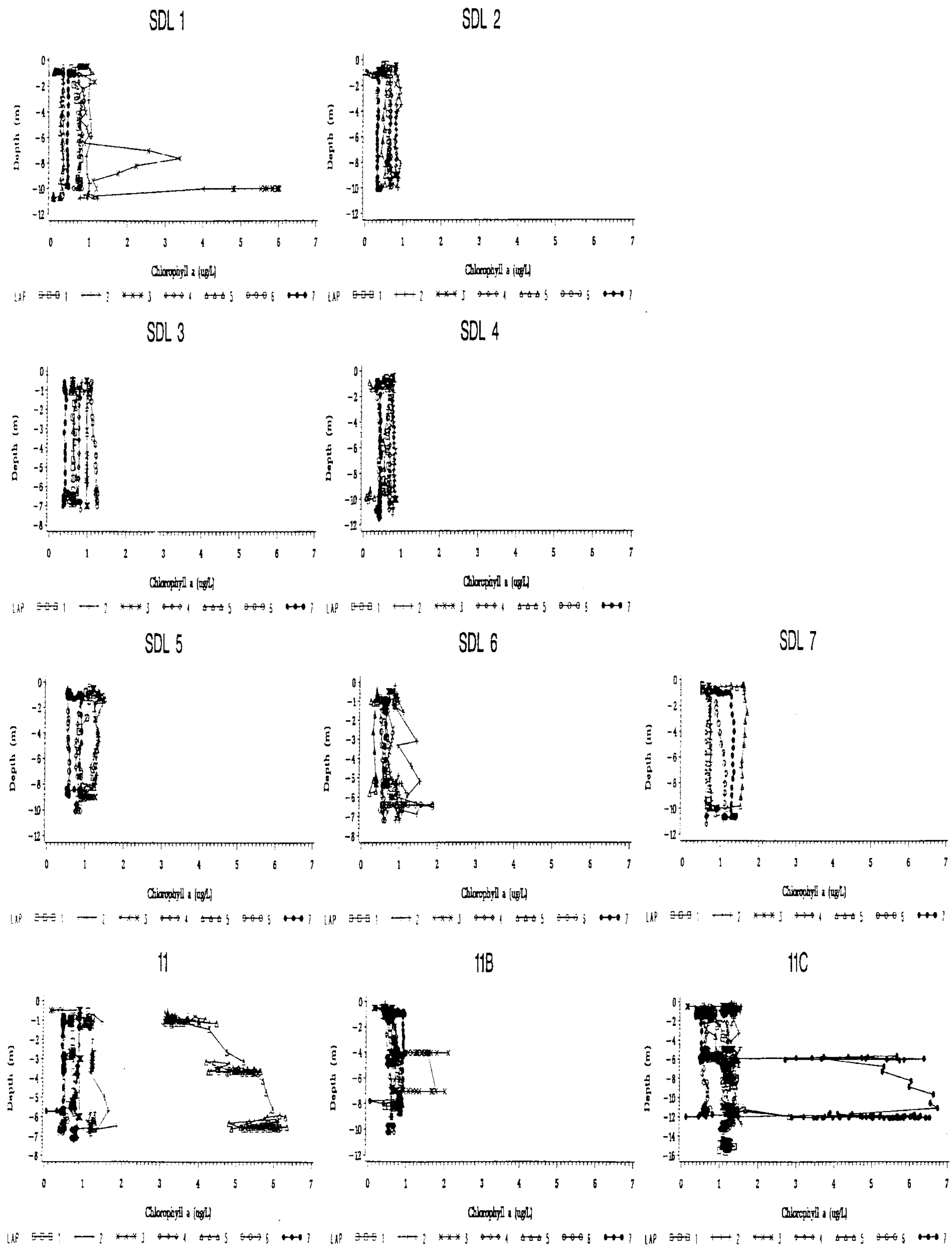
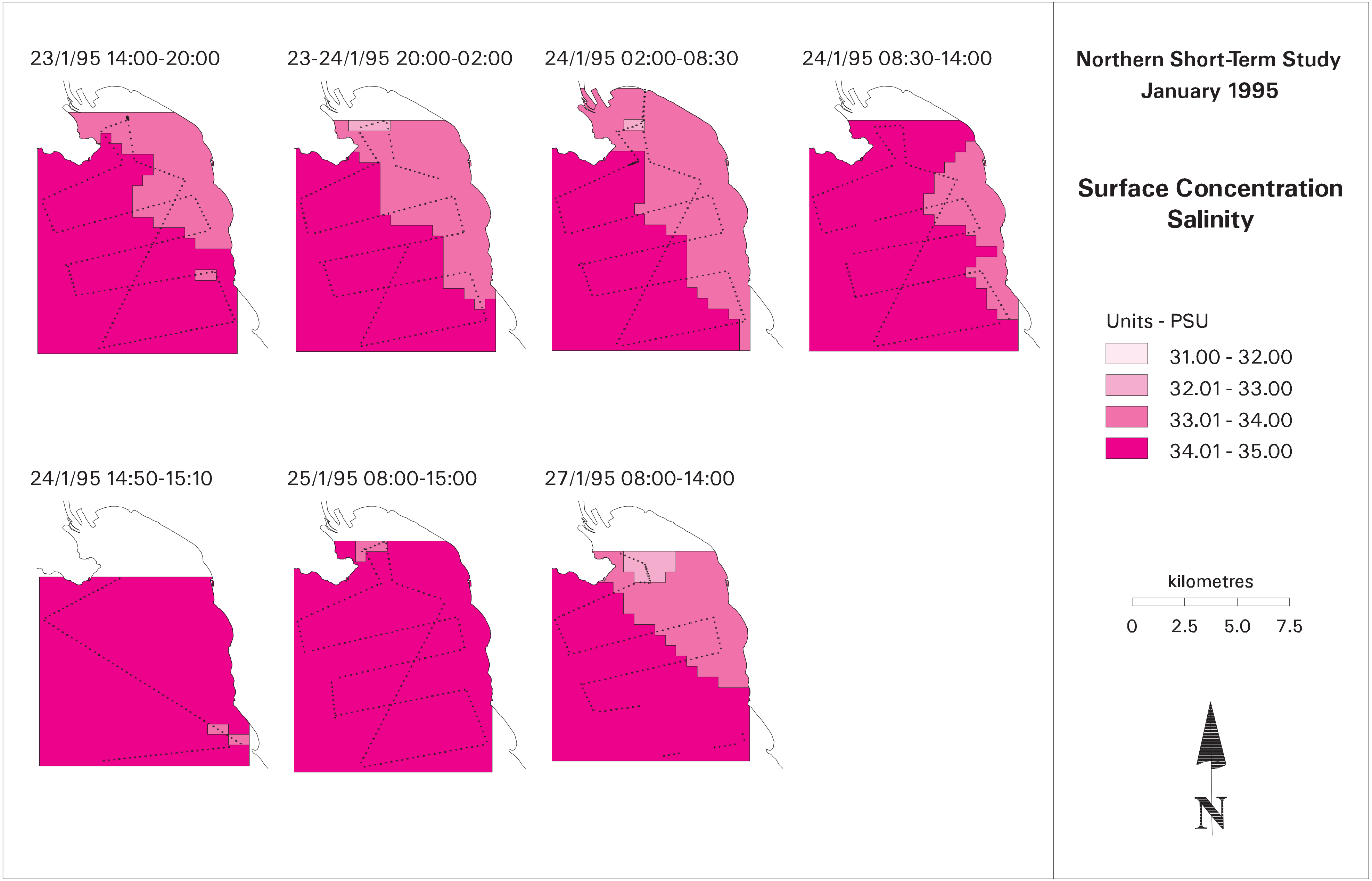

SDL 1
SDL 2
SDL 3
SDL 4
SDL 5
SDL 6
SDL 7
11
11B
11C
Depth (m)
Chlorophyll a (ug/L)

Figure 31


Northern Short-Term Study
January 1995
Surface Concentration
Salinity
23/1/95 14:00-20:00
23-24/1/95 20:00-02:00
24/1/95 02:00-08:30
24/1/95 08:30-14:00
24/1/95 14:50-15:10
25/1/95 08:00-15:00
27/1/95 08:00-14:00
Units - PSU
31.00 - 32.00
32.01 - 33.00
33.01 - 34.00
34.01 - 35.00
kilometres
0
2.5
5.0
7.5
N

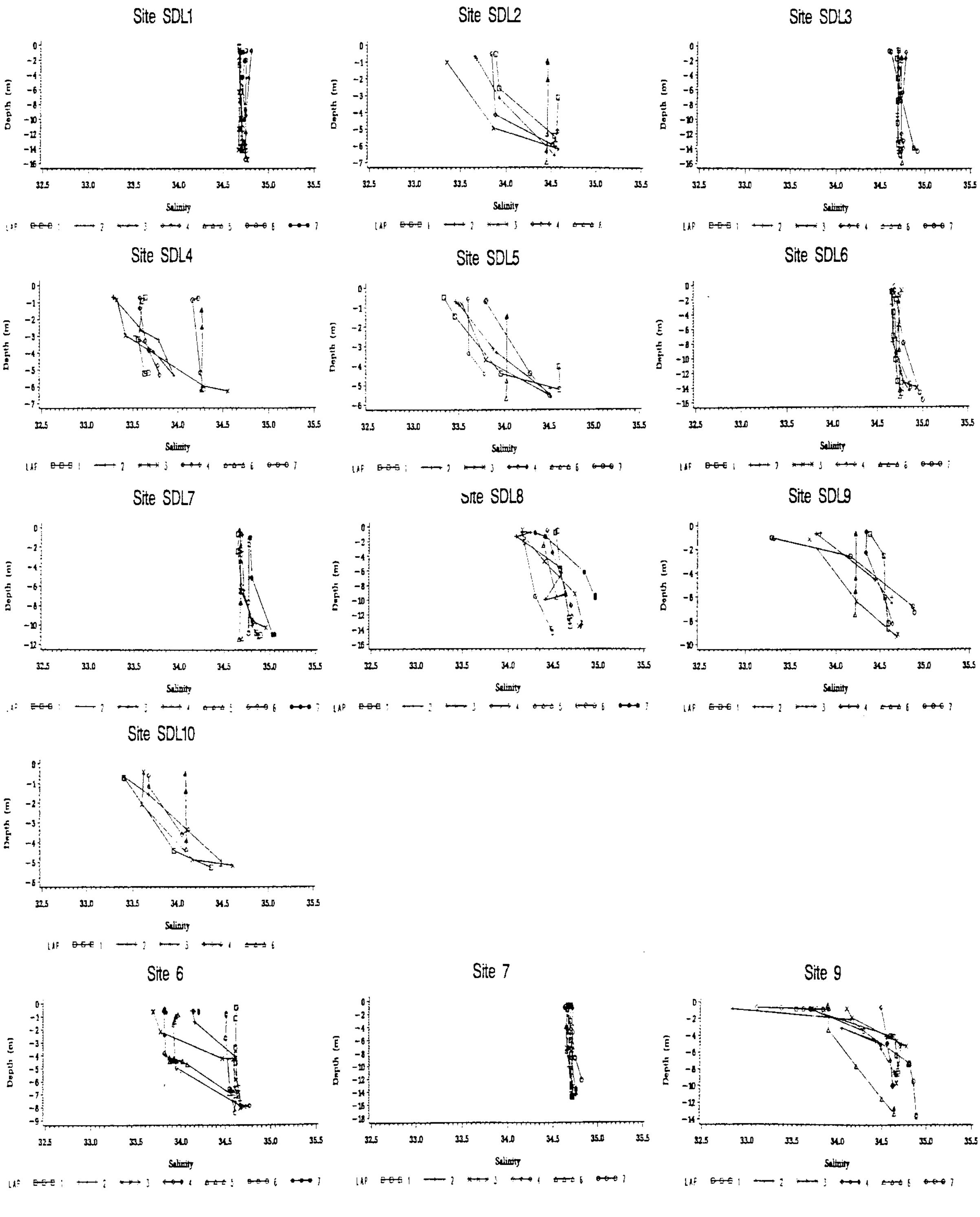
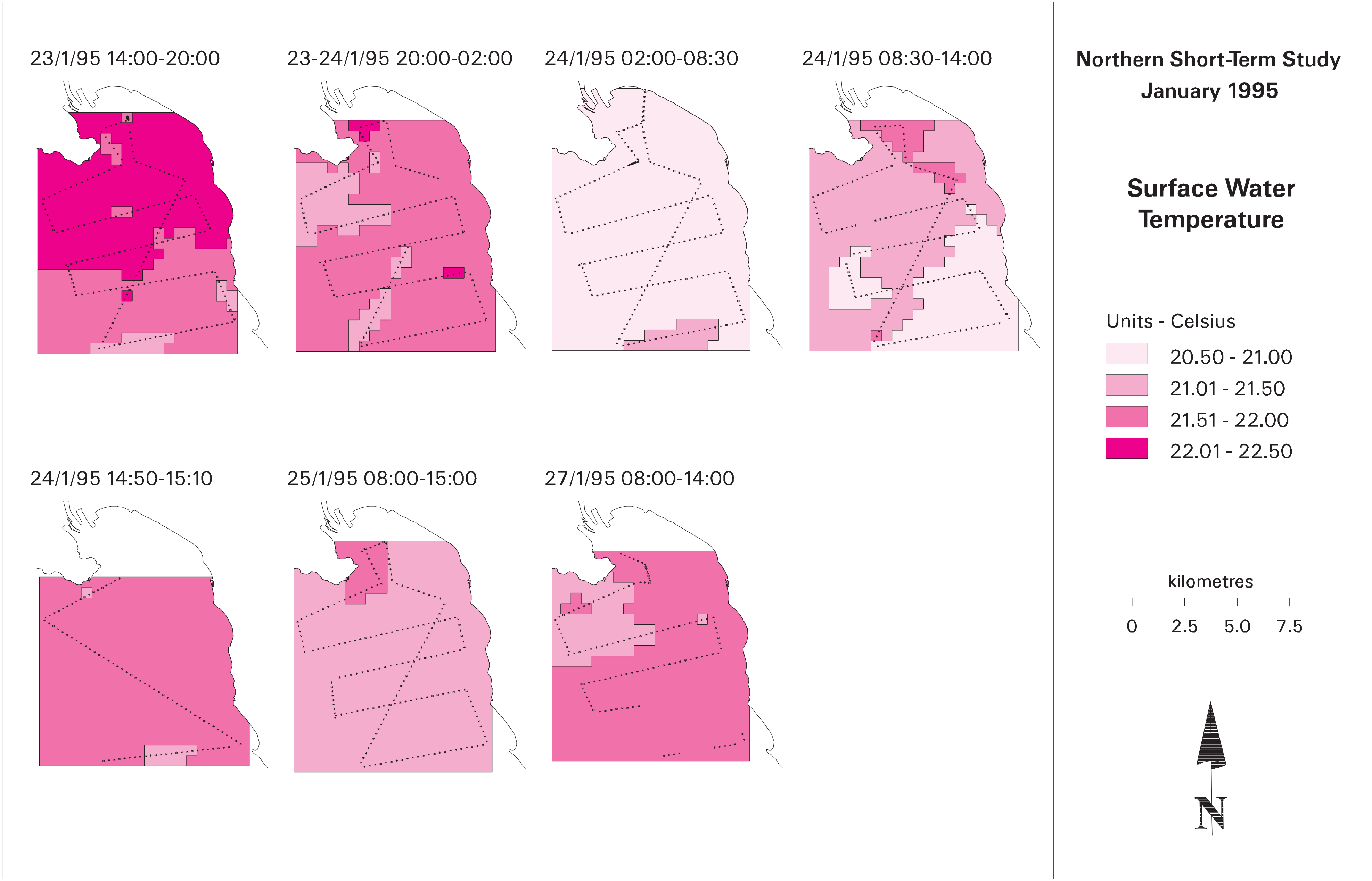


Figure 34: Vertical salinity structure, Northern Port Phillip Bay, January 1995.


23/1/95 14:00-20:00
23-24/1/95 20:00-02:00
24/1/95 02:00-08:30
24/1/95 08:30-14:00
24/1/95 14:50-15:10
25/1/95 08:00-15:00
27/1/95 08:00-14:00
Northern Short-Term Study
January 1995
Surface Water Temperature
Units - Celsius
20.50 - 21.00
21.01 - 21.50
21.51 - 22.00
22.01 - 22.50
kilometres
0
2.5
5.0
7.5
N

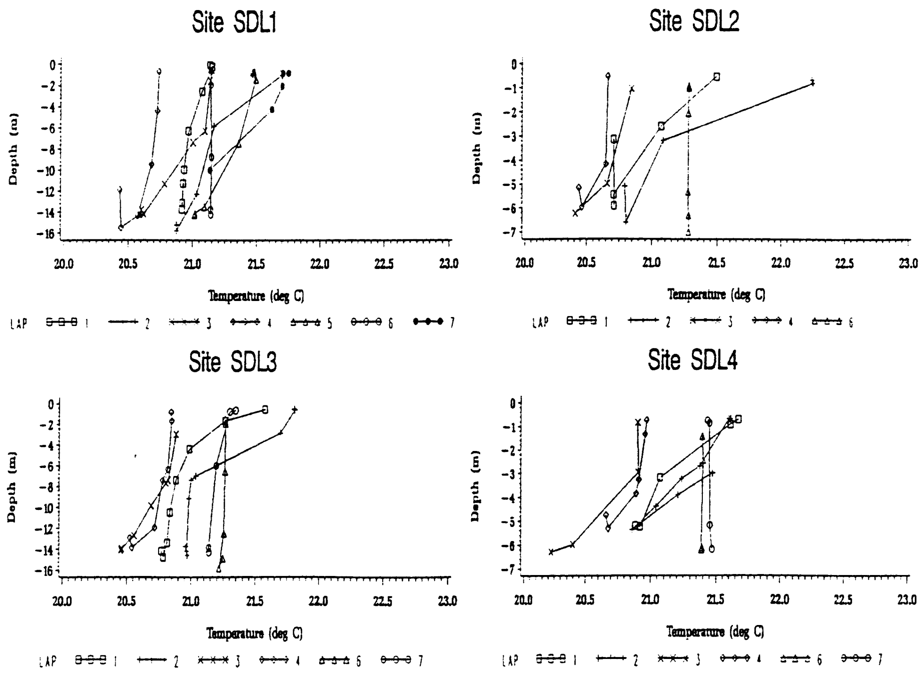


Figure 36 --- (continued next page...)

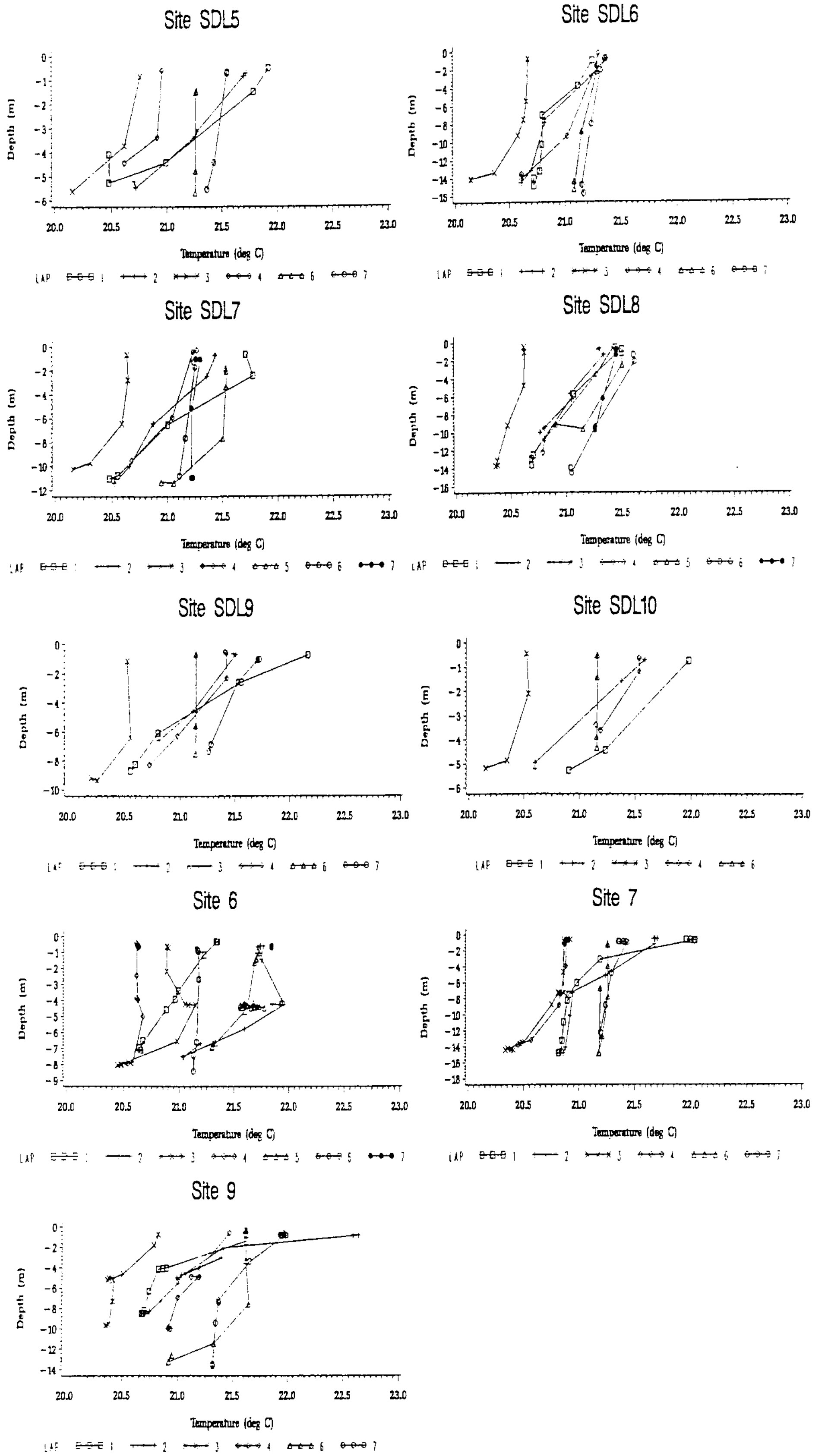


Figure 36 continued

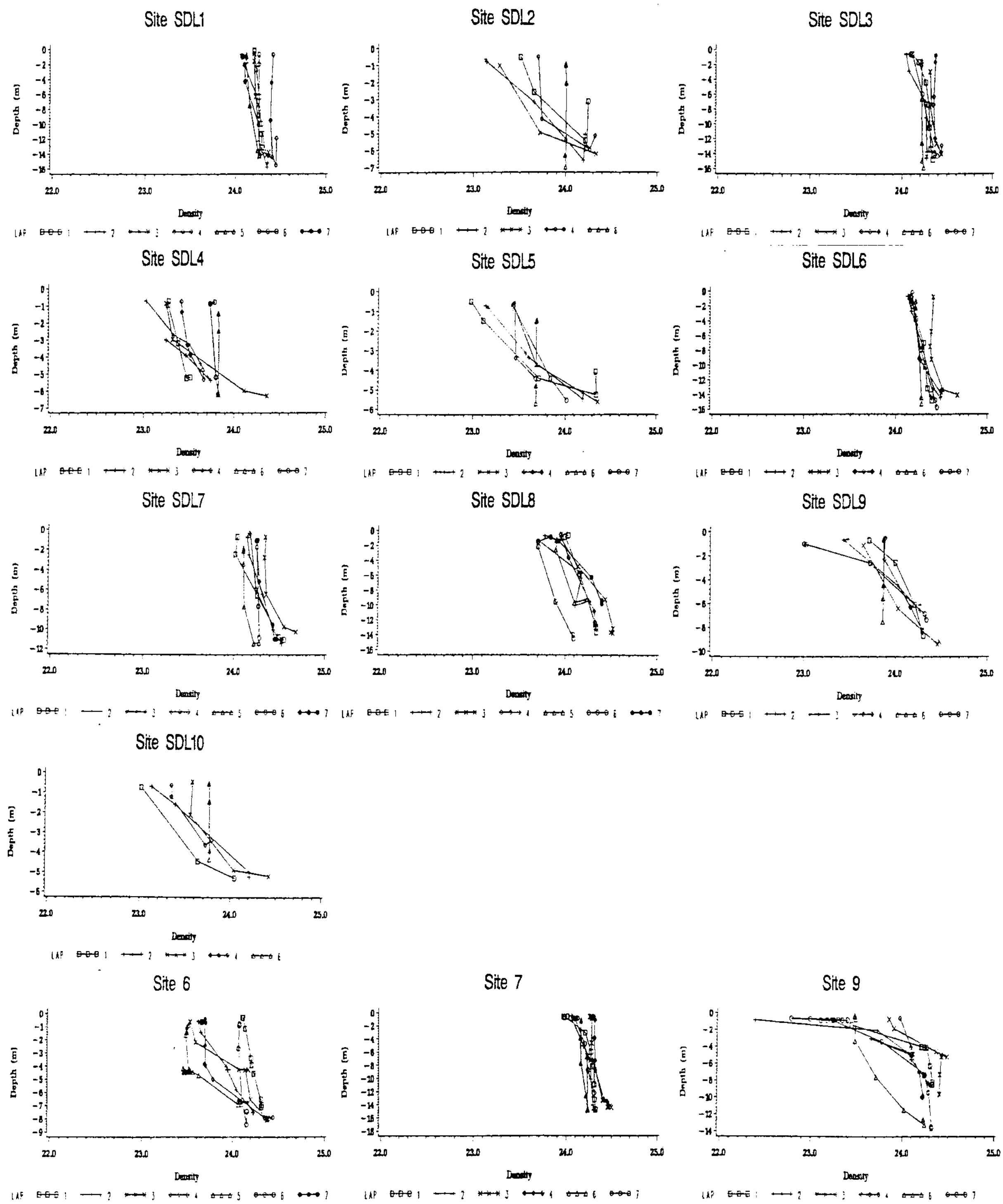
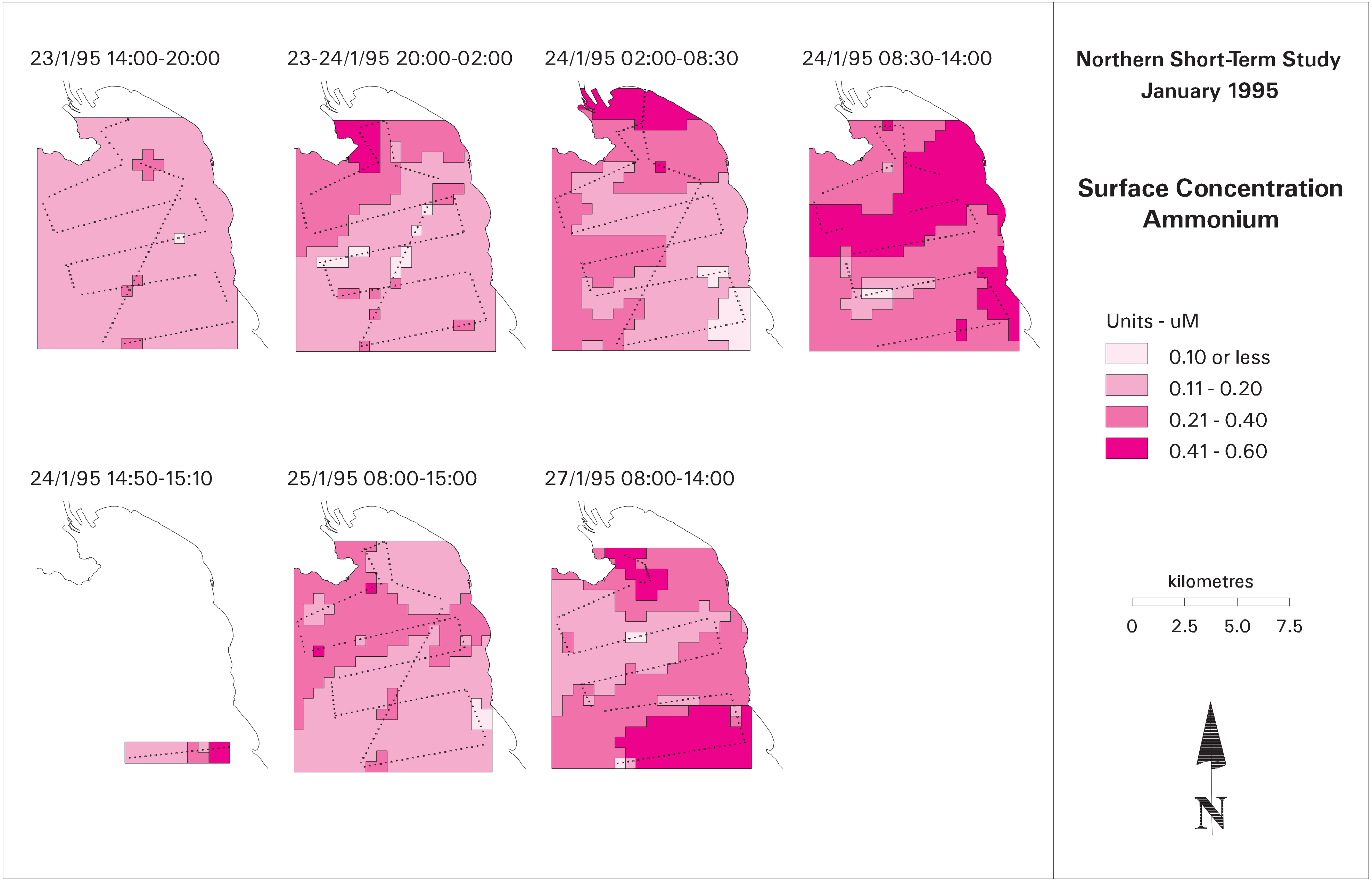
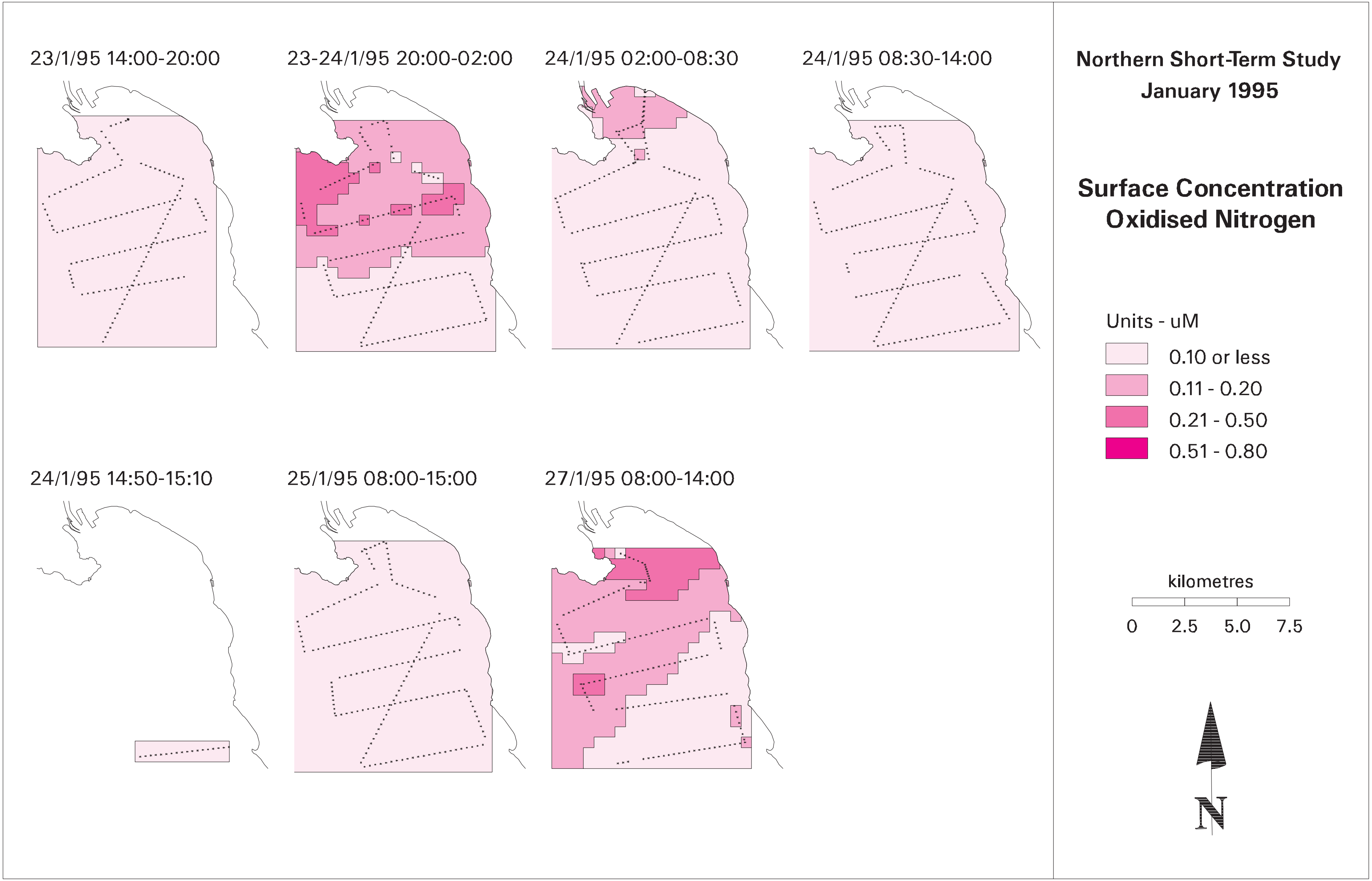

Site SDL1
Site SDL2
Site SDL3
Site SDL4
Site SDL5
Site SDL6
Site SDL7
Site SDL8
Site SDL9
Site SDL10
Site 6
Site 7
Site 9
Depth (m)
Density

Figure 37



Northern Short-Term Study
January 1995
Surface Concentration
Ammonium
23/1/95 14:00-20:00
23-24/1/95 20:00-02:00
24/1/95 02:00-08:30
24/1/95 08:30-14:00
24/1/95 14:50-15:10
25/1/95 08:00-15:00
27/1/95 08:00-14:00
Units - uM
0.10 or less
0.11 - 0.20
0.21 - 0.40
0.41 - 0.60
kilometres
0
2.5
5.0
7.5
N


Northern Short-Term Study
January 1995
Surface Concentration
Oxidised Nitrogen
23/1/95 14:00-20:00
23-24/1/95 20:00-02:00
24/1/95 02:00-08:30
24/1/95 08:30-14:00
24/1/95 14:50-15:10
25/1/95 08:00-15:00
27/1/95 08:00-14:00
Units - uM
0.10 or less
0.11 - 0.20
0.21 - 0.50
0.51 - 0.80
kilometres
0
2.5
5.0
7.5
N

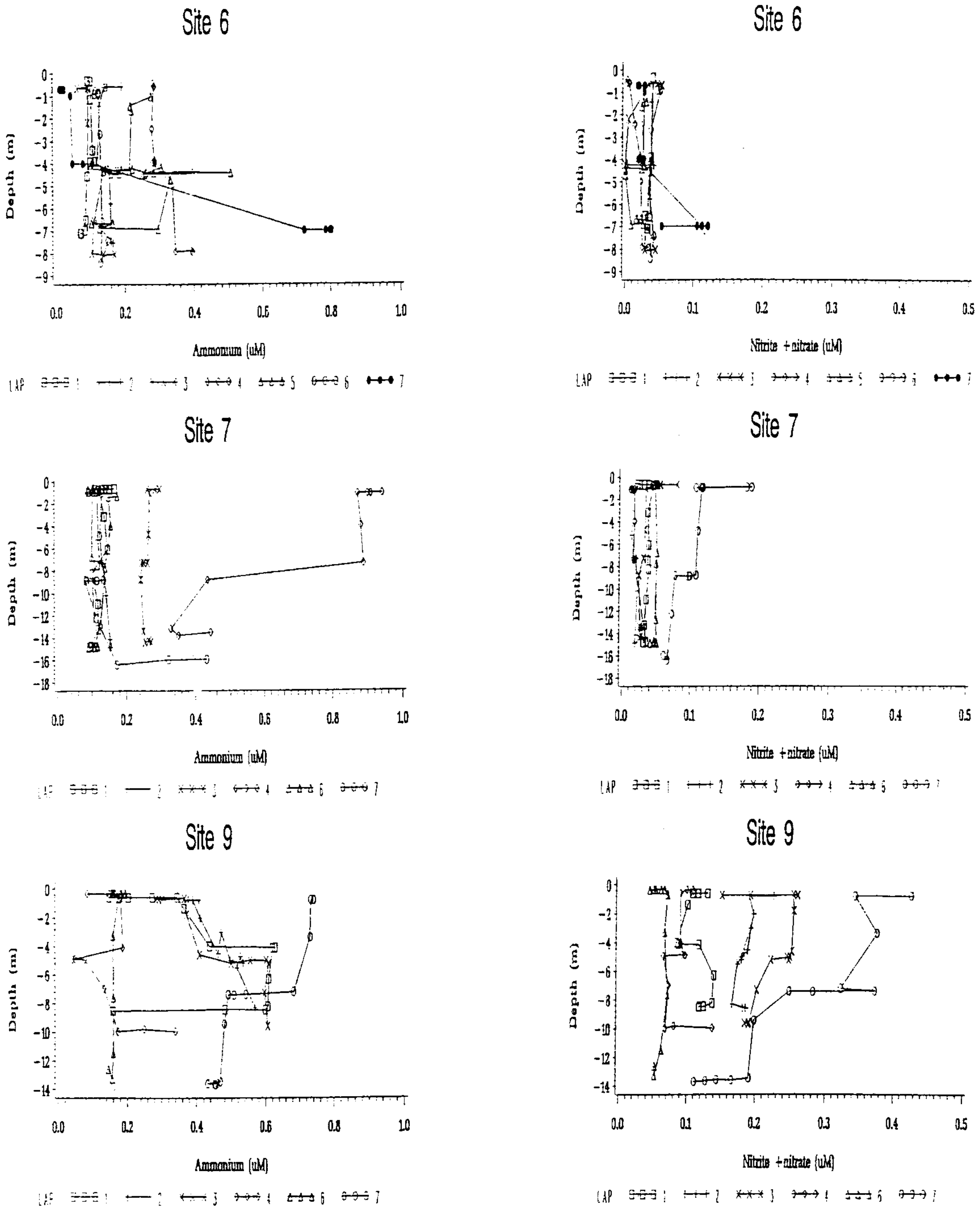
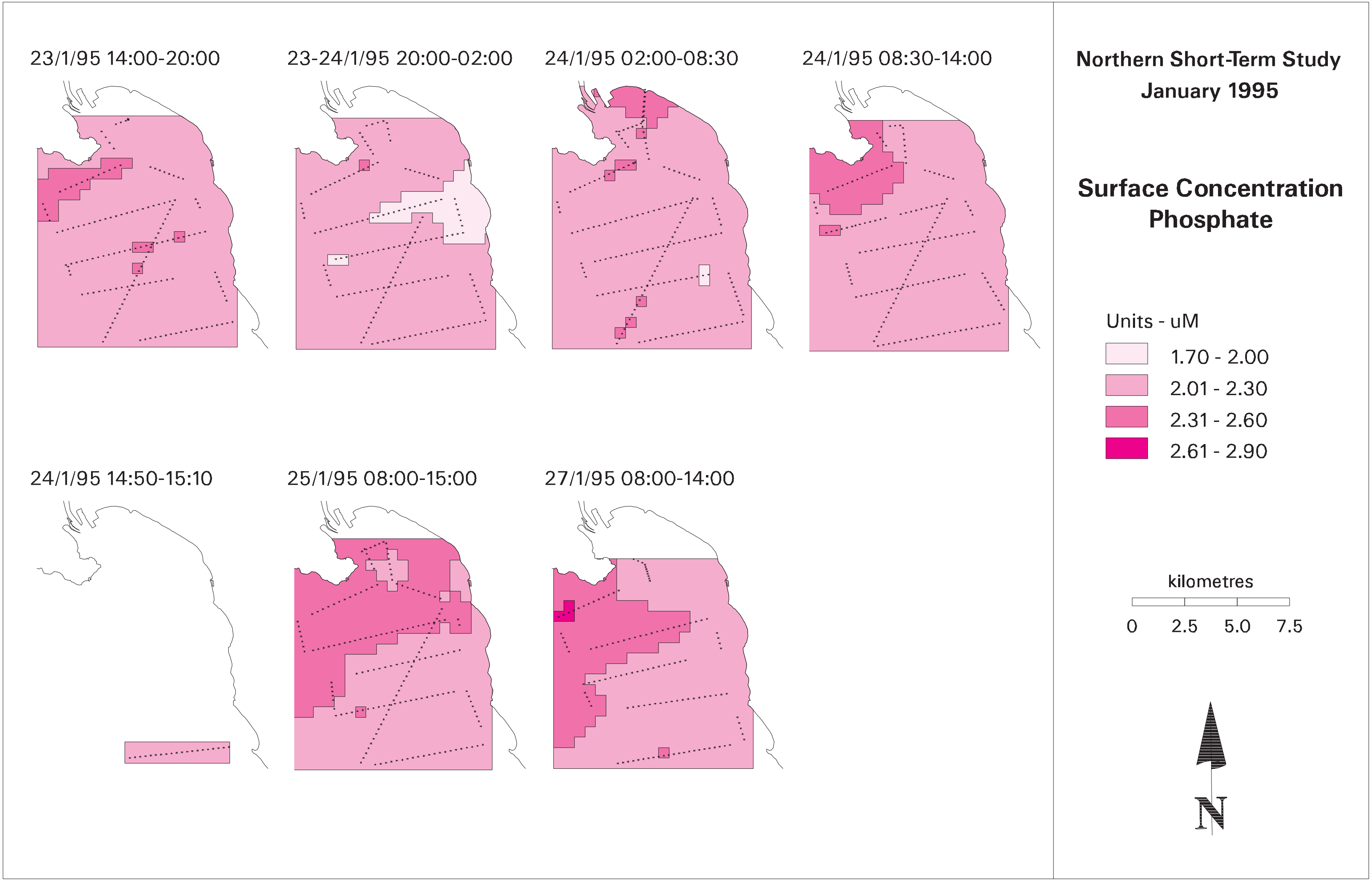
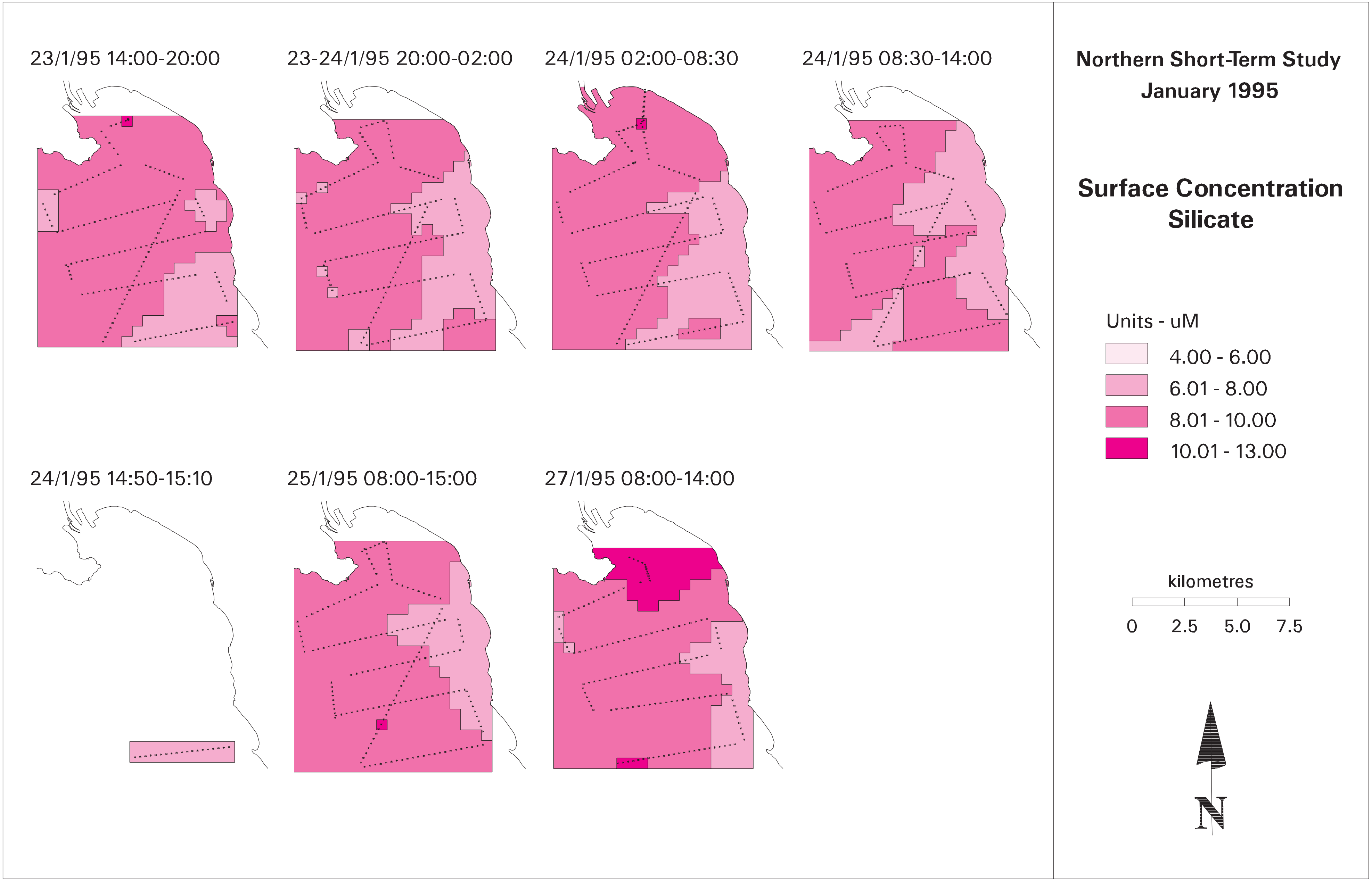

Site 6
Depth (m)
Ammonium (uM)
Site 6
Depth (m)
Nitrite + nitrate (uM)
Site 7
Depth (m)
Ammonium (uM)
Site 7
Depth (m)
Nitrite + nitrate (uM)
Site 9
Depth (m)
Ammonium (uM)
Site 9
Depth (m)
Nitrite + nitrate (uM)

Figure 40



Northern Short-Term Study
January 1995
Surface Concentration
Phosphate
23/1/95 14:00-20:00
23-24/1/95 20:00-02:00
24/1/95 02:00-08:30
24/1/95 08:30-14:00
24/1/95 14:50-15:10
25/1/95 08:00-15:00
27/1/95 08:00-14:00
Units - uM
1.70 - 2.00
2.01 - 2.30
2.31 - 2.60
2.61 - 2.90
kilometres
0
2.5
5.0
7.5
N



23/1/95 14:00-20:00
23-24/1/95 20:00-02:00
24/1/95 02:00-08:30
24/1/95 08:30-14:00
24/1/95 14:50-15:10
25/1/95 08:00-15:00
27/1/95 08:00-14:00
Northern Short-Term Study
January 1995
Surface Concentration
Silicate
Units - uM
4.00 - 6.00
6.01 - 8.00
8.01 - 10.00
10.01 - 13.00
kilometres
0
2.5
5.0
7.5
N

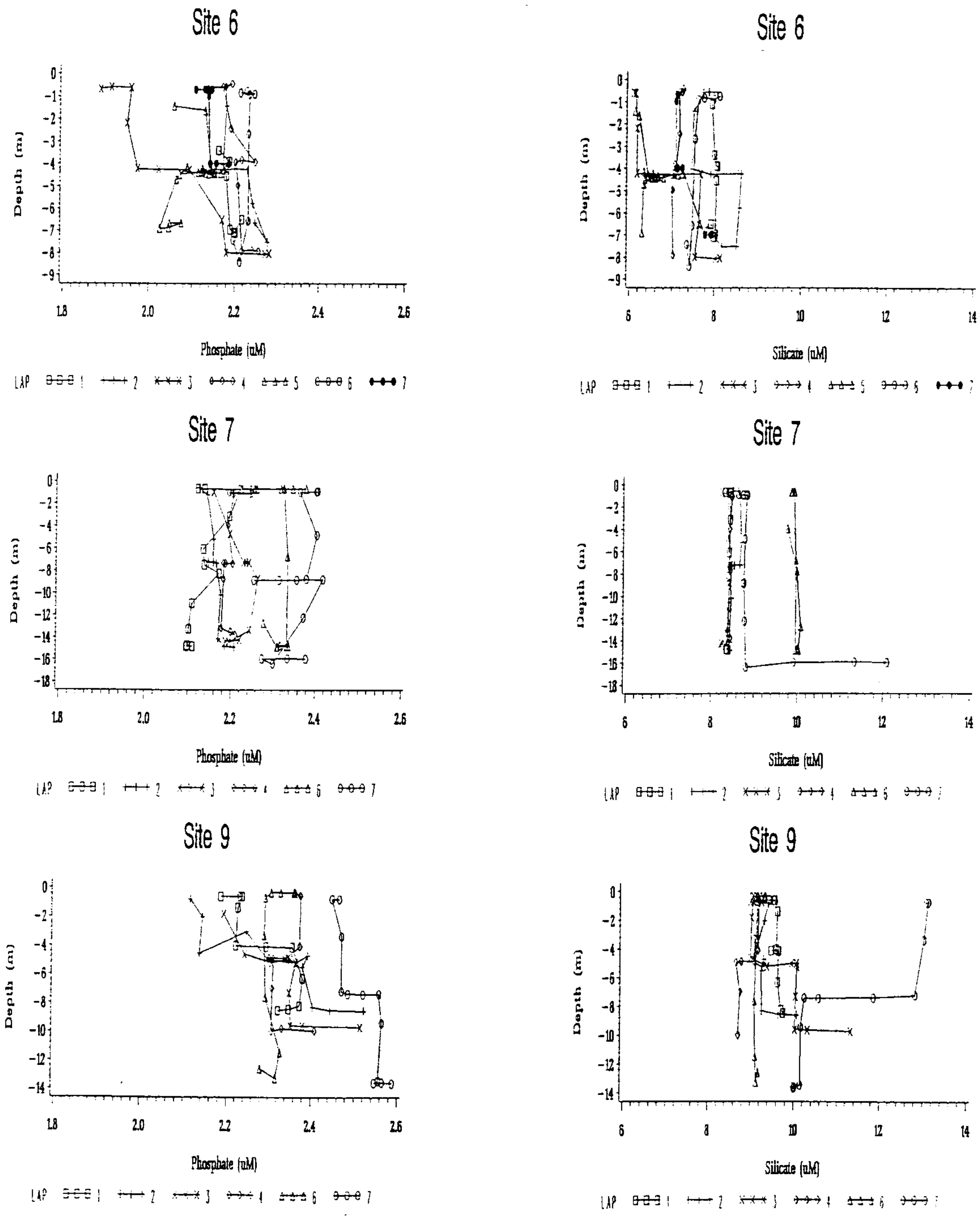
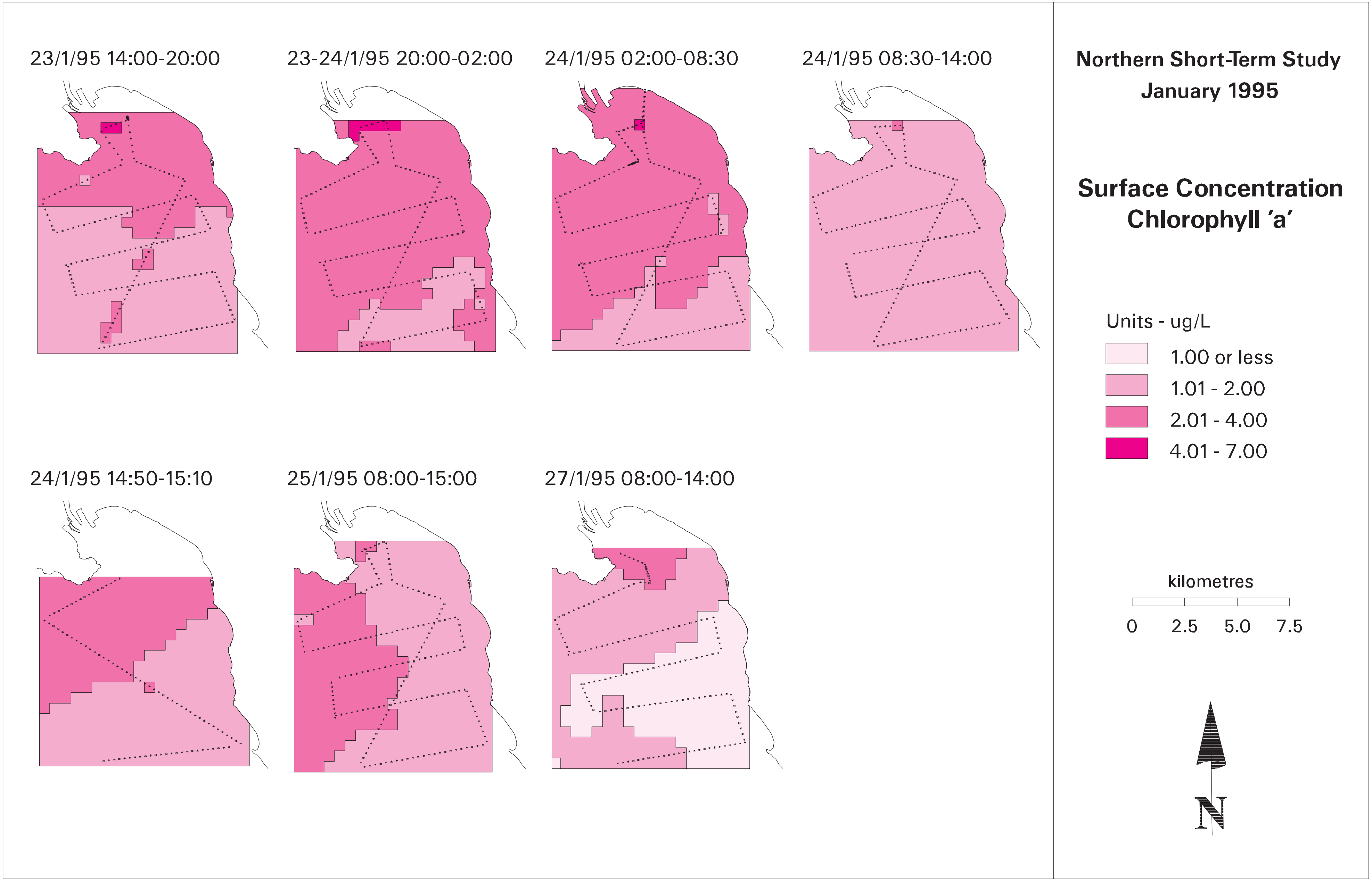
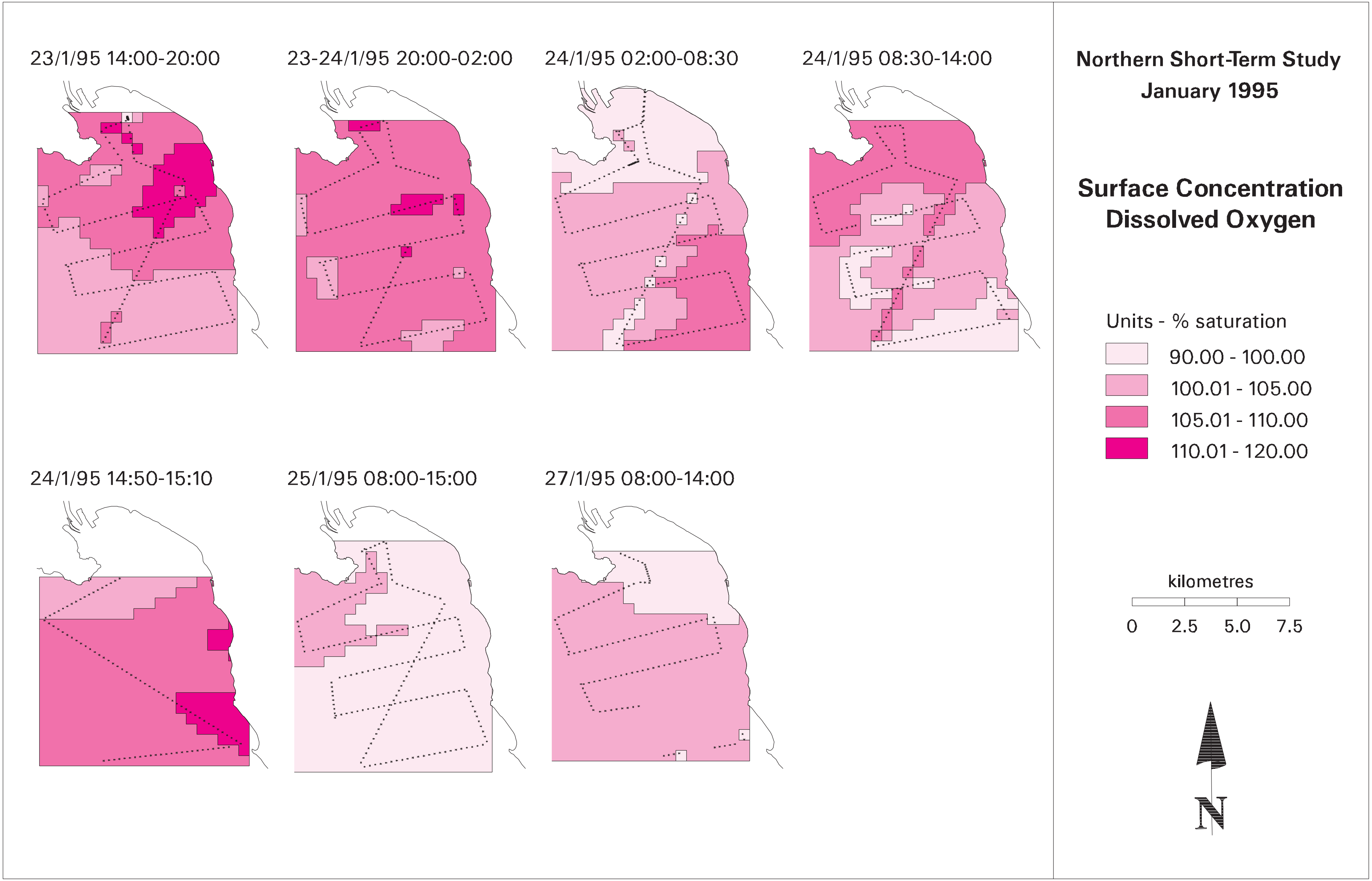

Site 6
Depth (m)
Phosphate (uM)
LAP 1 2 3 4 5 6 7
Site 6
Depth (m)
Silicate (uM)
LAP 1 2 3 4 5 6 7
Site 7
Depth (m)
Phosphate (uM)
LAP 1 2 3 4 6 7
Site 7
Depth (m)
Silicate (uM)
LAP 1 2 3 4 6 7
Site 9
Depth (m)
Phosphate (uM)
LAP 1 2 3 4 6 7
Site 9
Depth (m)
Silicate (uM)
LAP 1 2 3 4 6 7

Figure 43



Northern Short-Term Study
January 1995
Surface Concentration
Chlorophyll 'a'
23/1/95 14:00-20:00
23-24/1/95 20:00-02:00
24/1/95 02:00-08:30
24/1/95 08:30-14:00
24/1/95 14:50-15:10
25/1/95 08:00-15:00
27/1/95 08:00-14:00
Units - ug/L
1.00 or less
1.01 - 2.00
2.01 - 4.00
4.01 - 7.00
kilometres
0
2.5
5.0
7.5
N


23/1/95 14:00-20:00
23-24/1/95 20:00-02:00
24/1/95 02:00-08:30
24/1/95 08:30-14:00
24/1/95 14:50-15:10
25/1/95 08:00-15:00
27/1/95 08:00-14:00
Northern Short-Term Study
January 1995
Surface Concentration
Dissolved Oxygen
Units - % saturation
90.00 - 100.00
100.01 - 105.00
105.01 - 110.00
110.01 - 120.00
kilometres
0
2.5
5.0
7.5
N

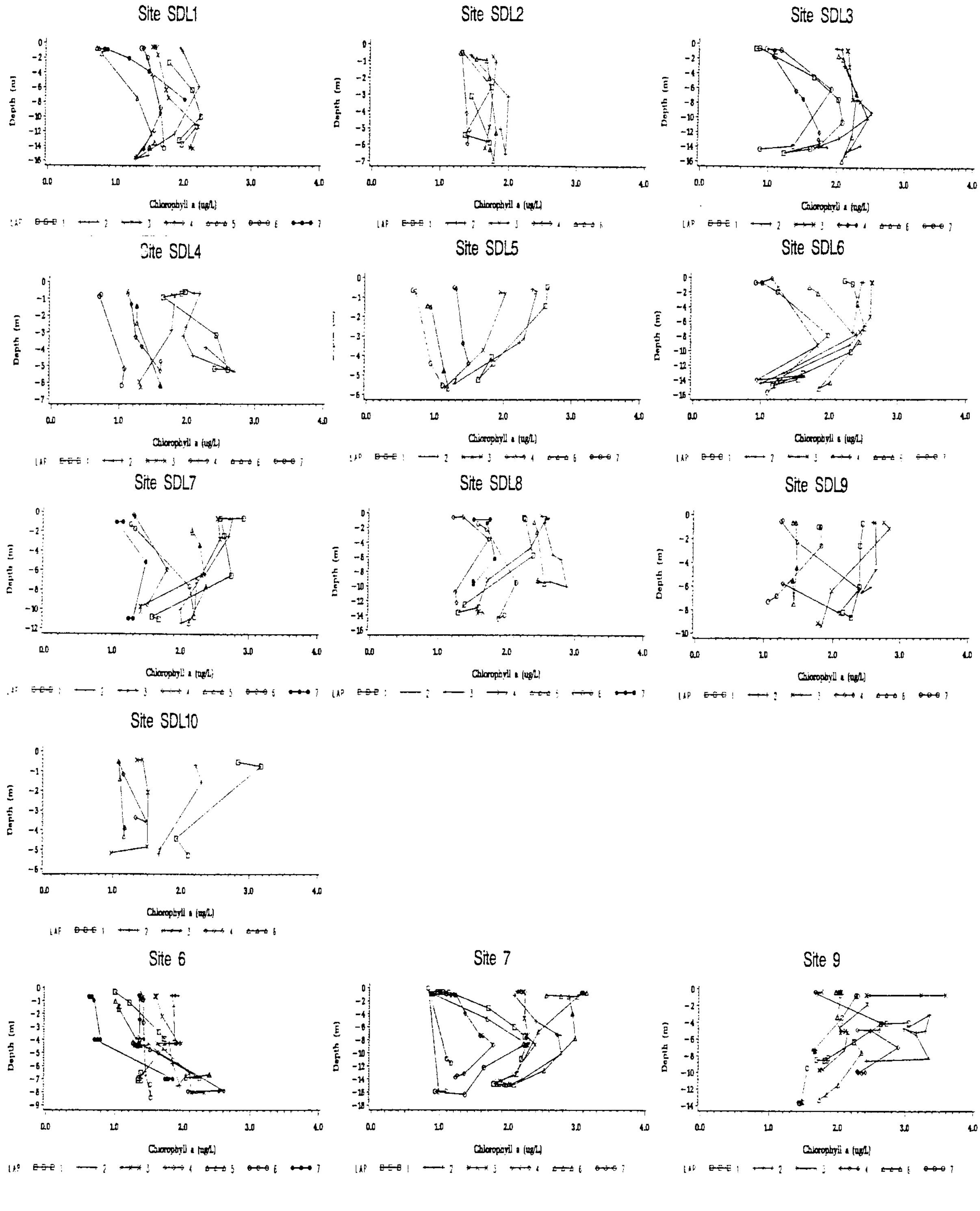

Site SDL1
Site SDL2
Site SDL3
Site SDL4
Site SDL5
Site SDL6
Site SDL7
Site SDL8
Site SDL9
Site SDL10
Site 6
Site 7
Site 9
Depth (m)
Chlorophyll a (ug/L)
0.0
1.0
2.0
3.0
4.0

Figure 46

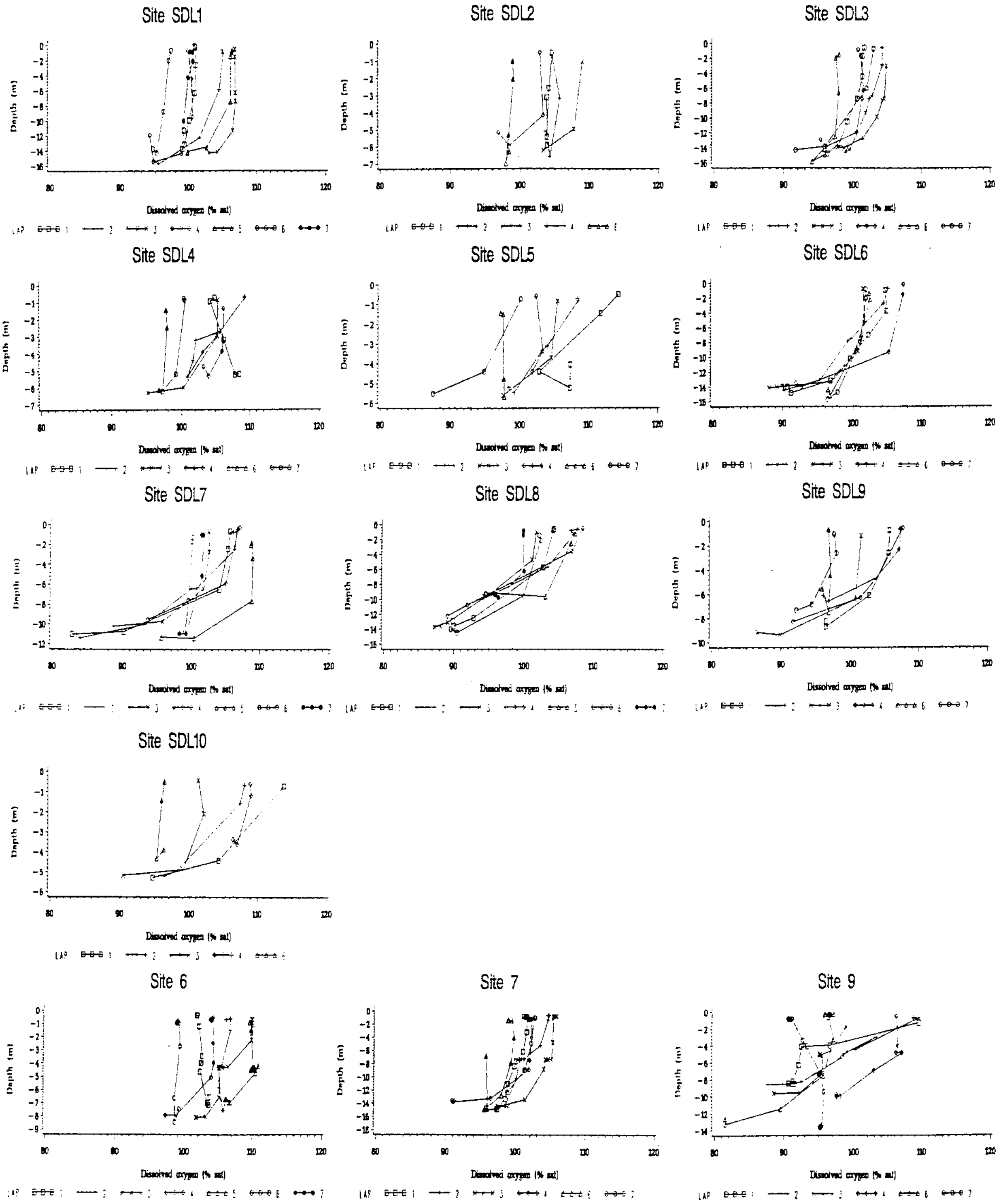

Site SDL1
Site SDL2
Site SDL3
Site SDL4
Site SDL5
Site SDL6
Site SDL7
Site SDL8
Site SDL9
Site SDL10
Site 6
Site 7
Site 9
Depth (m)
Dissolved oxygen (% sat)

Figure 47

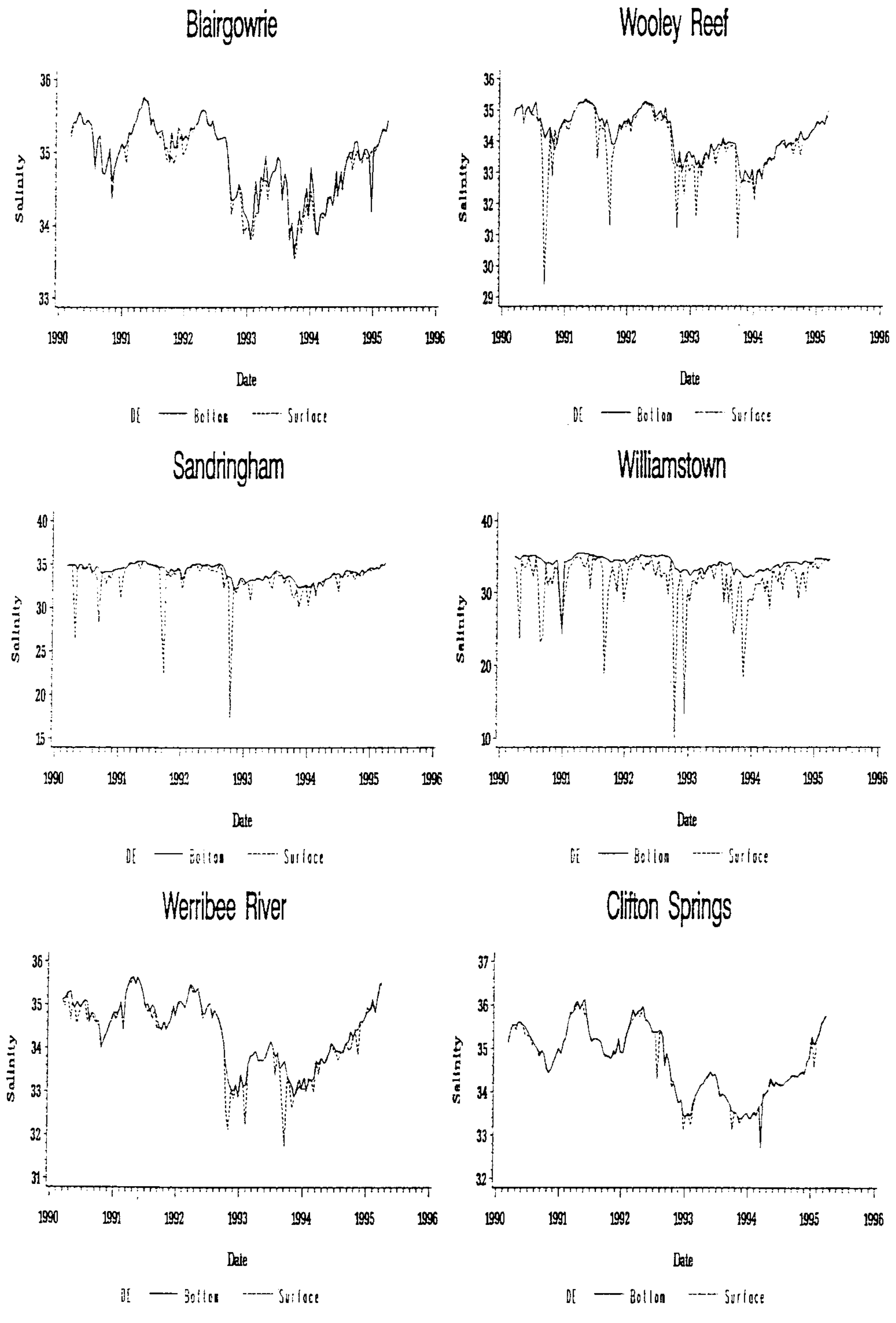


Figure 48: Surface and bottom salinity at six sites, 1990-95.

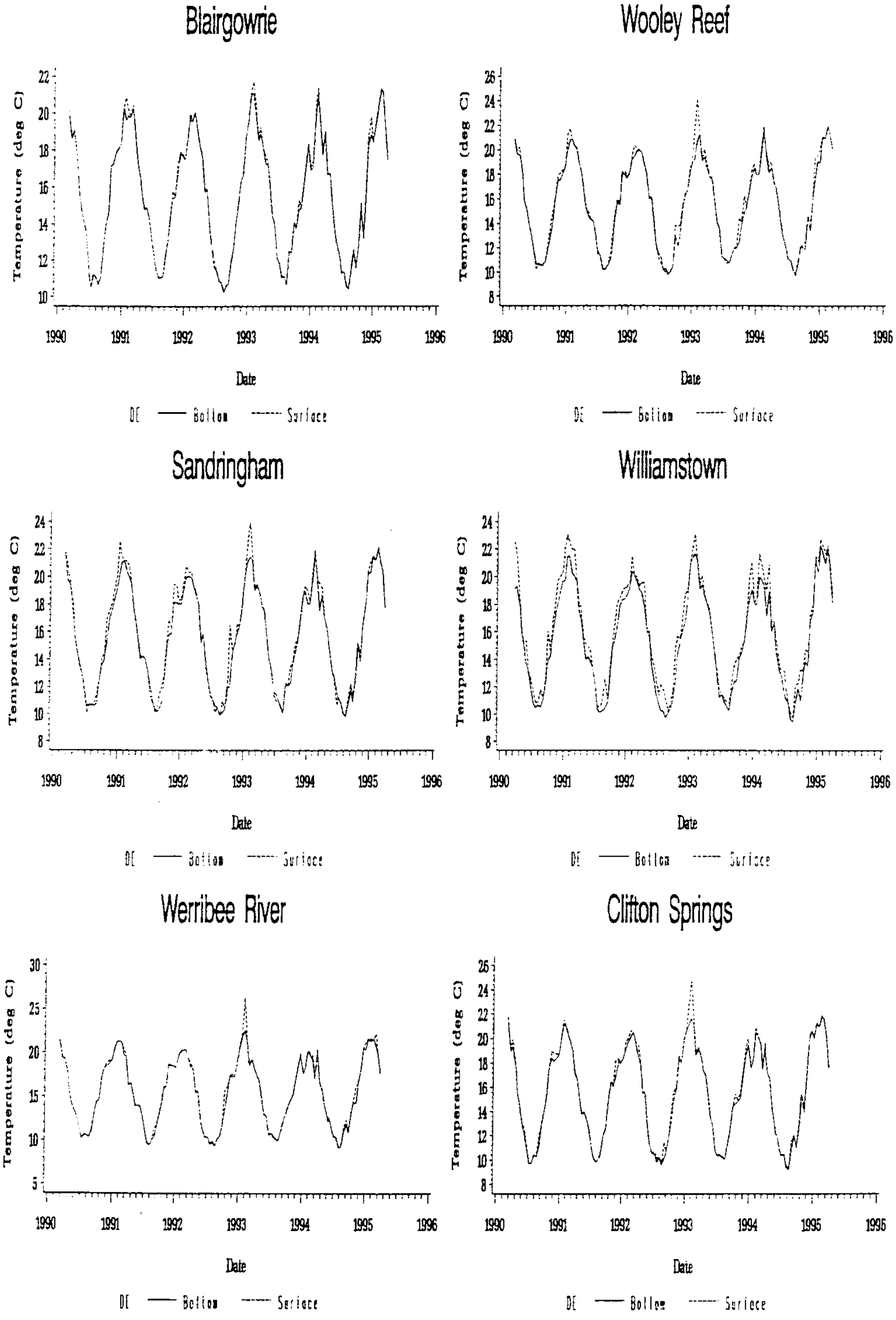


Figure 49: Surface and bottom temperatures at six sites, 1990-95.

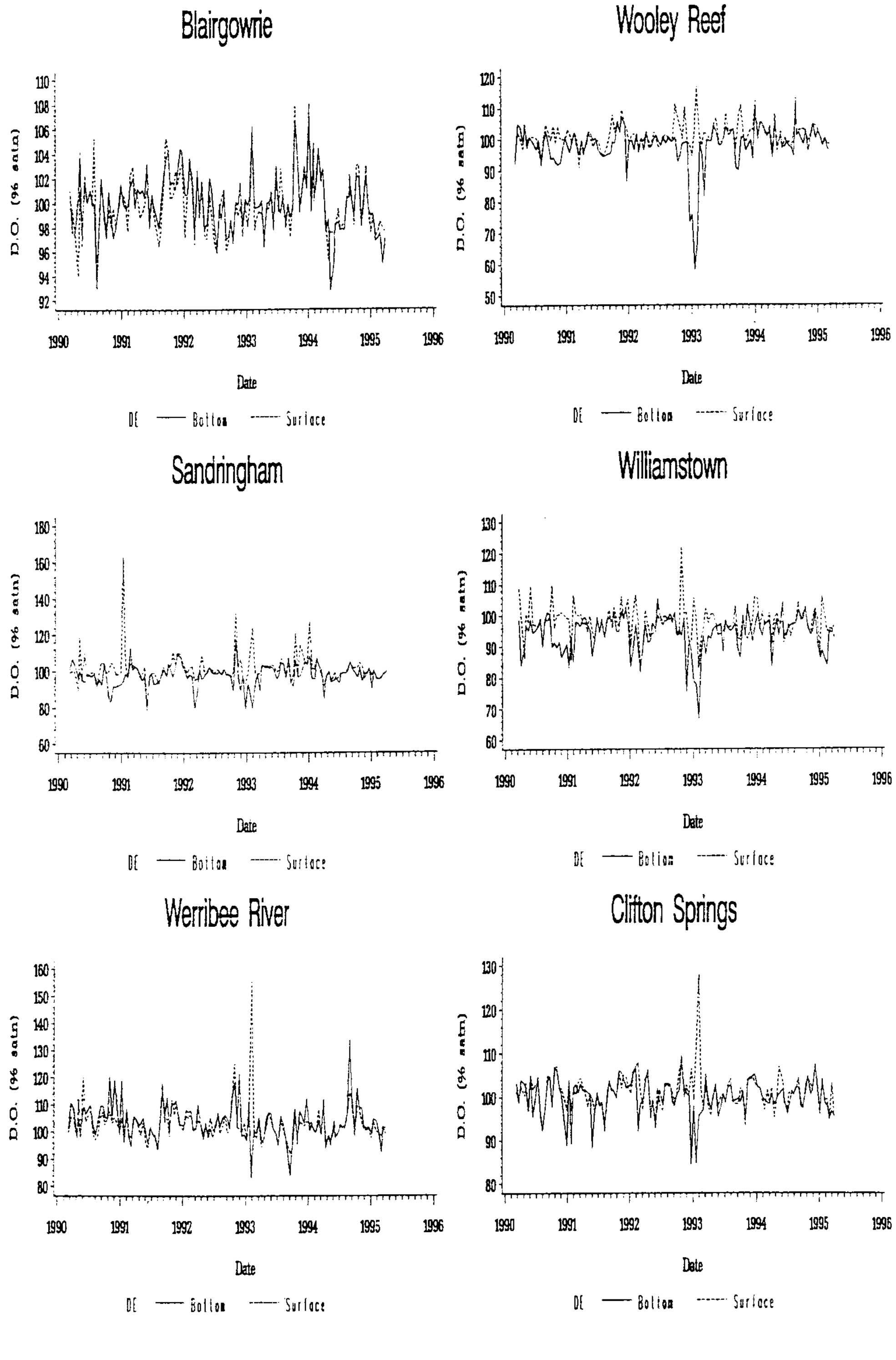


Figure 50: Surface and bottom dissolved oxygen concentration at six sites, 1990-95.

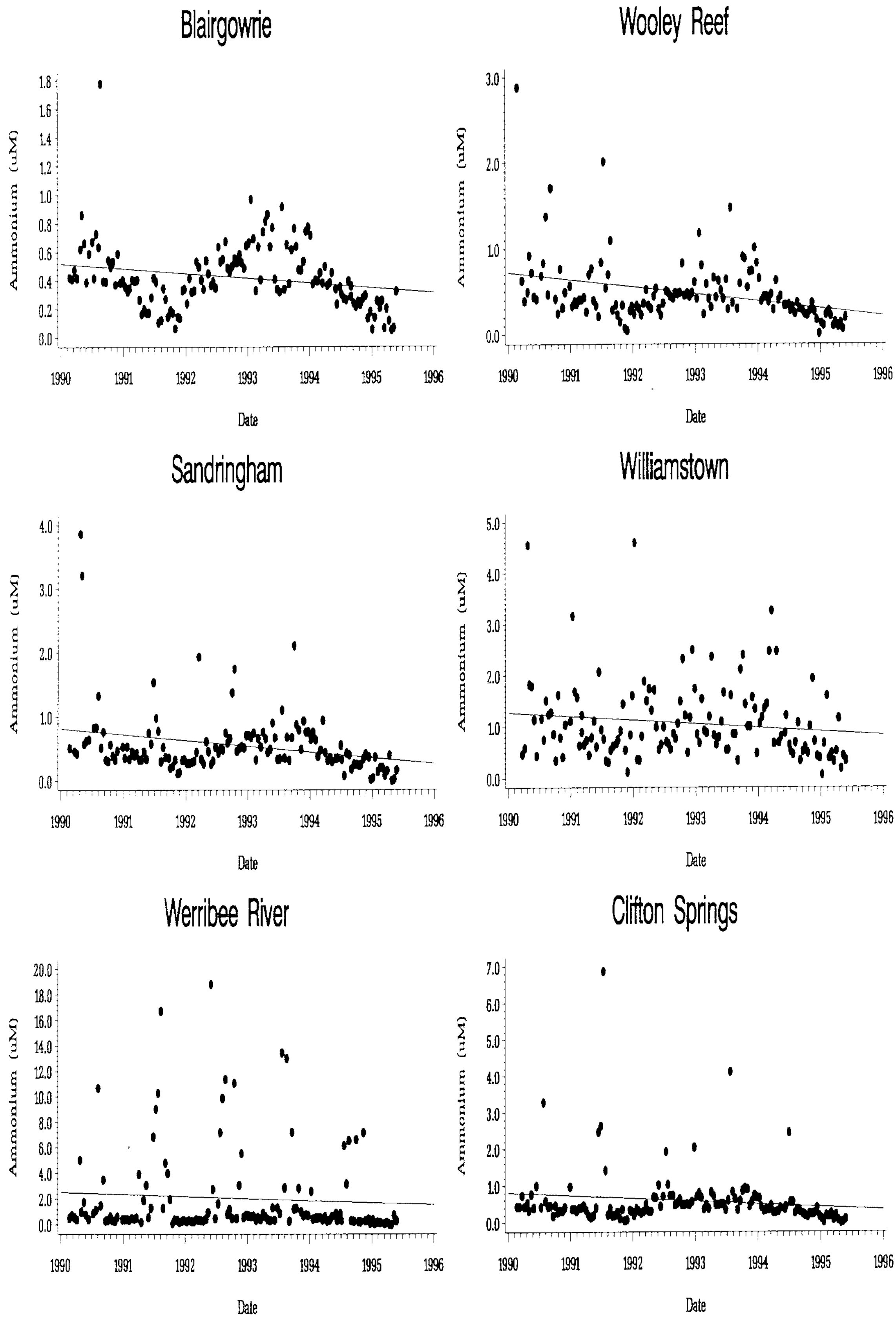


Figure 51: Variation of ammonium concentration by site, 1990-95.

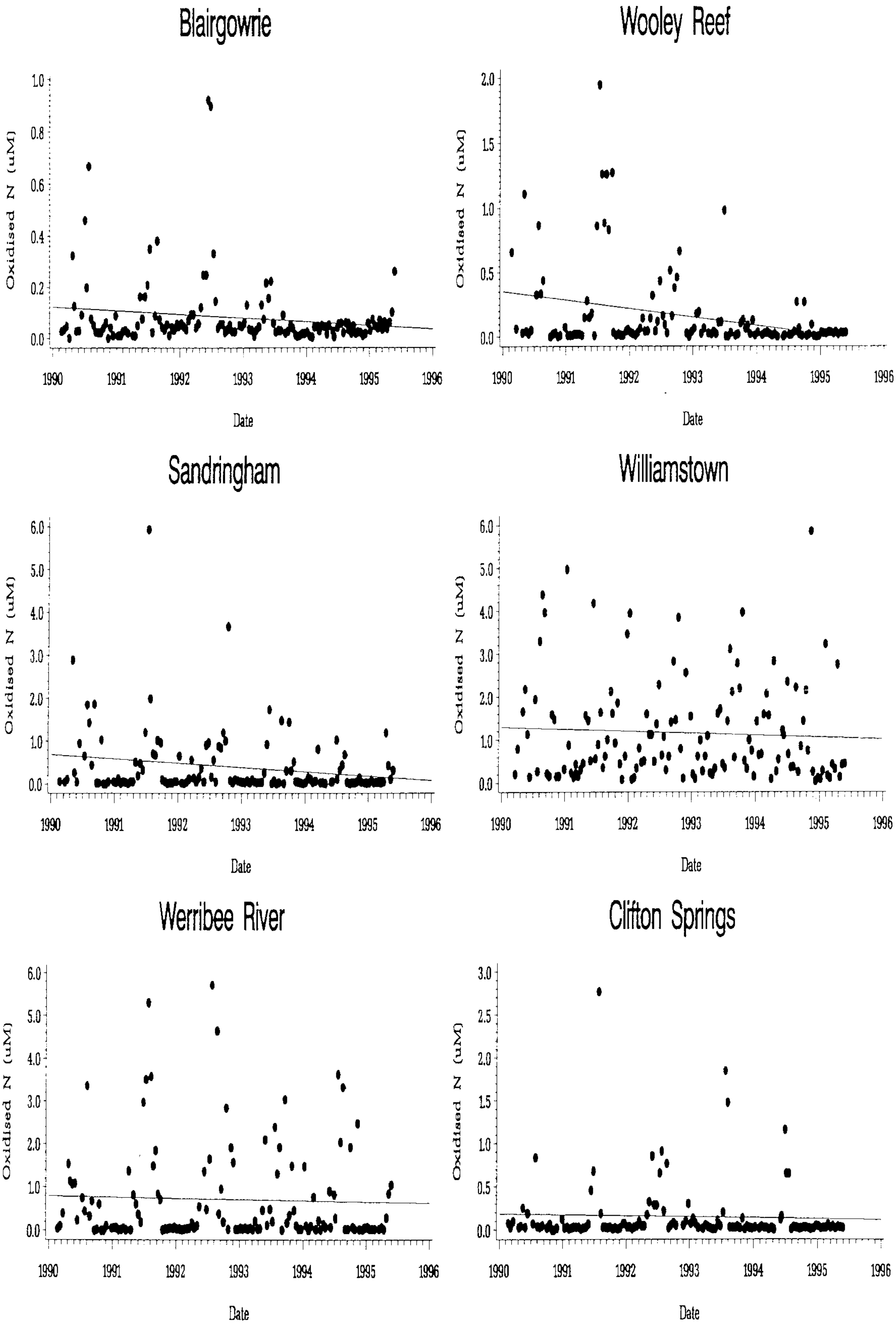


Figure 52: Variation of oxidised nitrogen concentration by site, 1990-95.

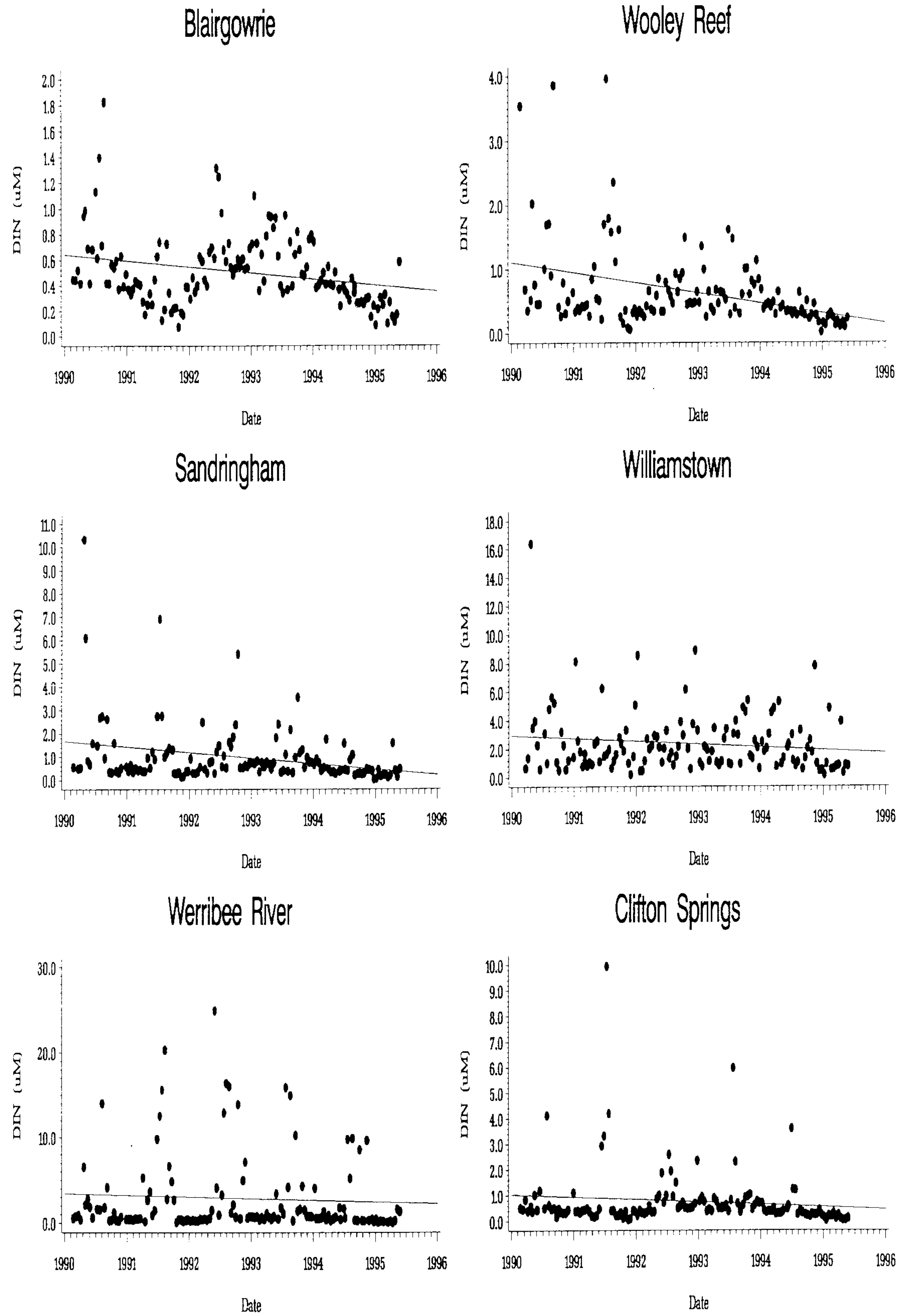


Figure 53: Variation of dissolved inorganic nitrogen concentration by site, 1990-95.

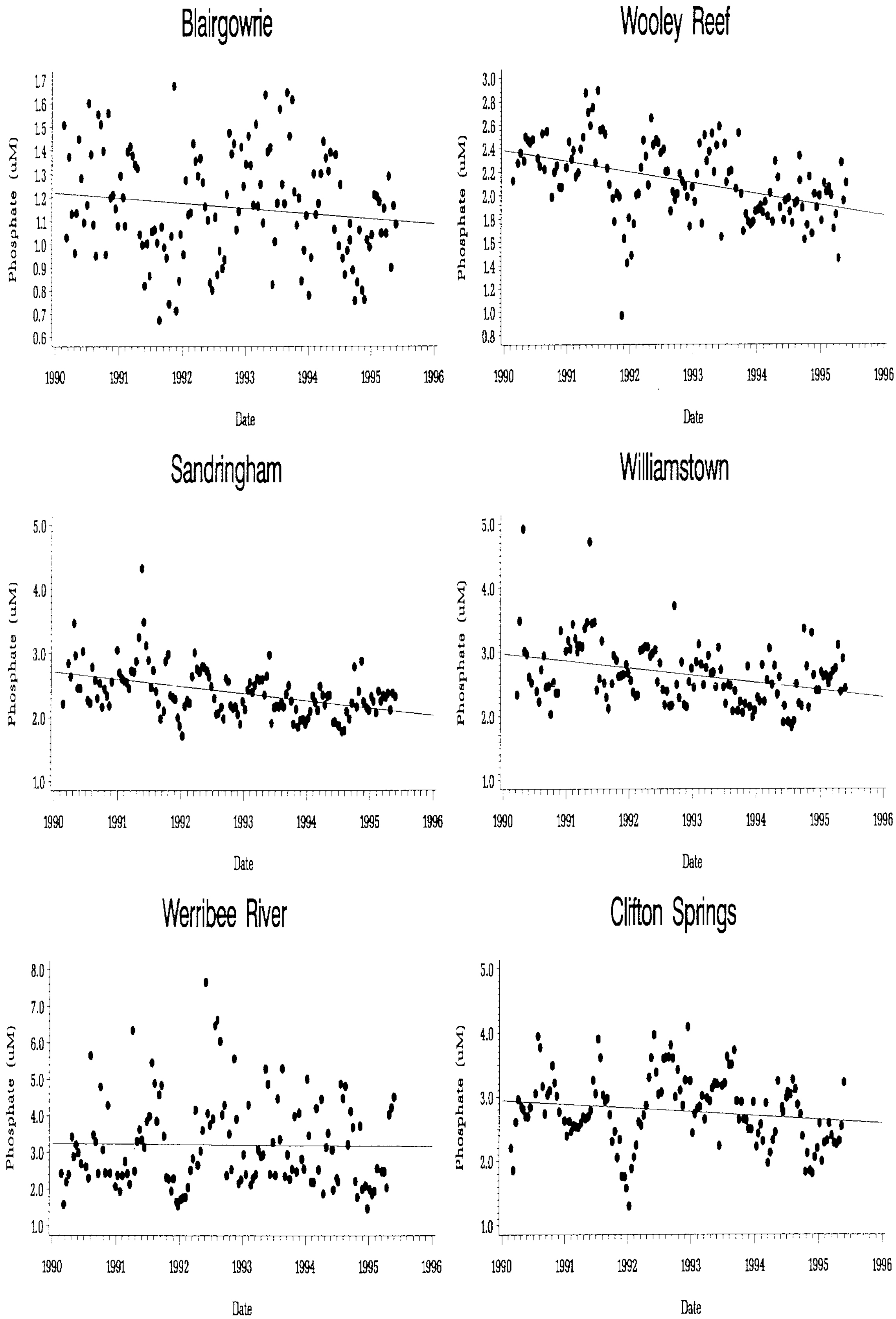


Figure 54: Variation of phosphate concentration by site, 1990-95.

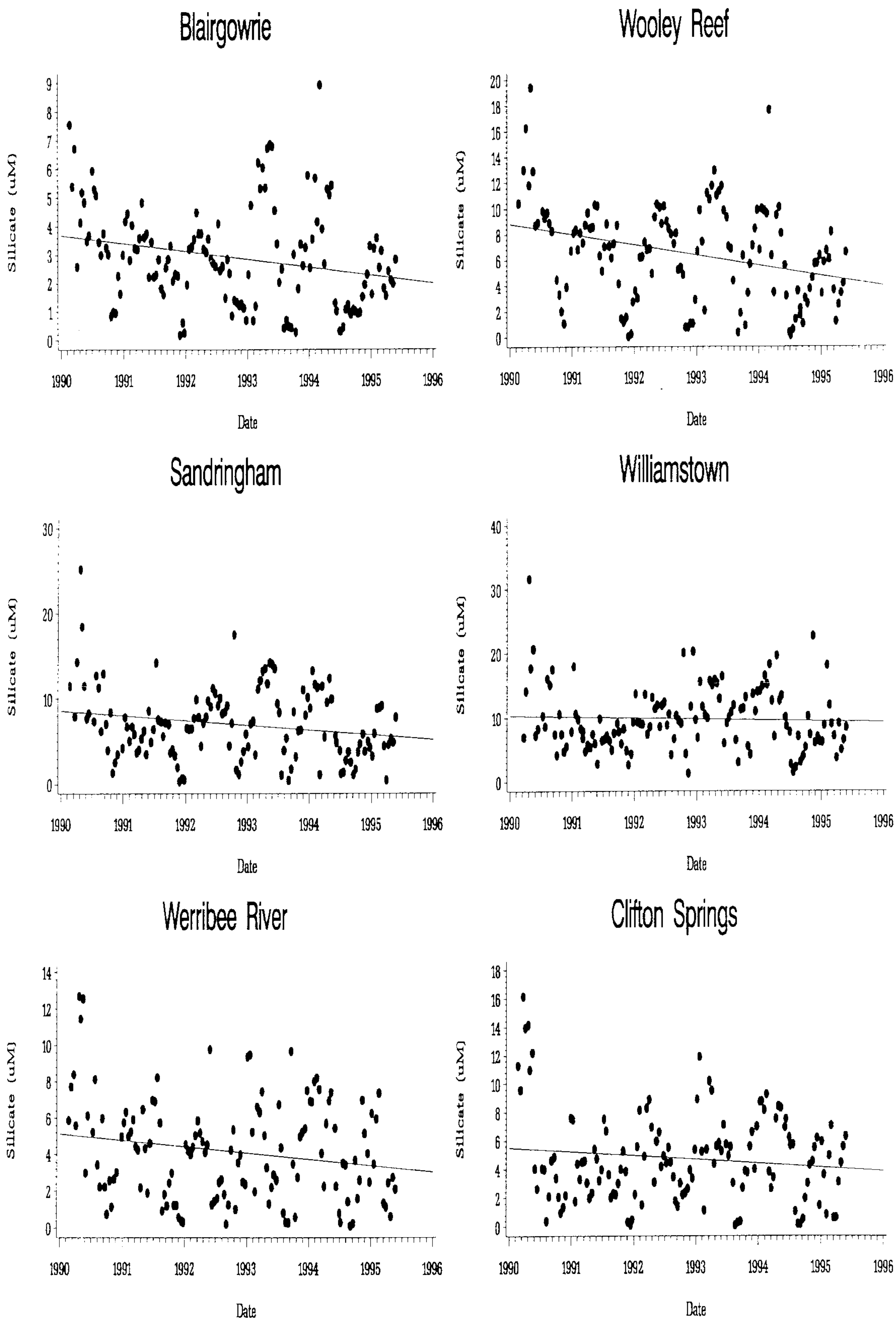


Figure 55: Variation of silicate concentration by site, 1990-95.

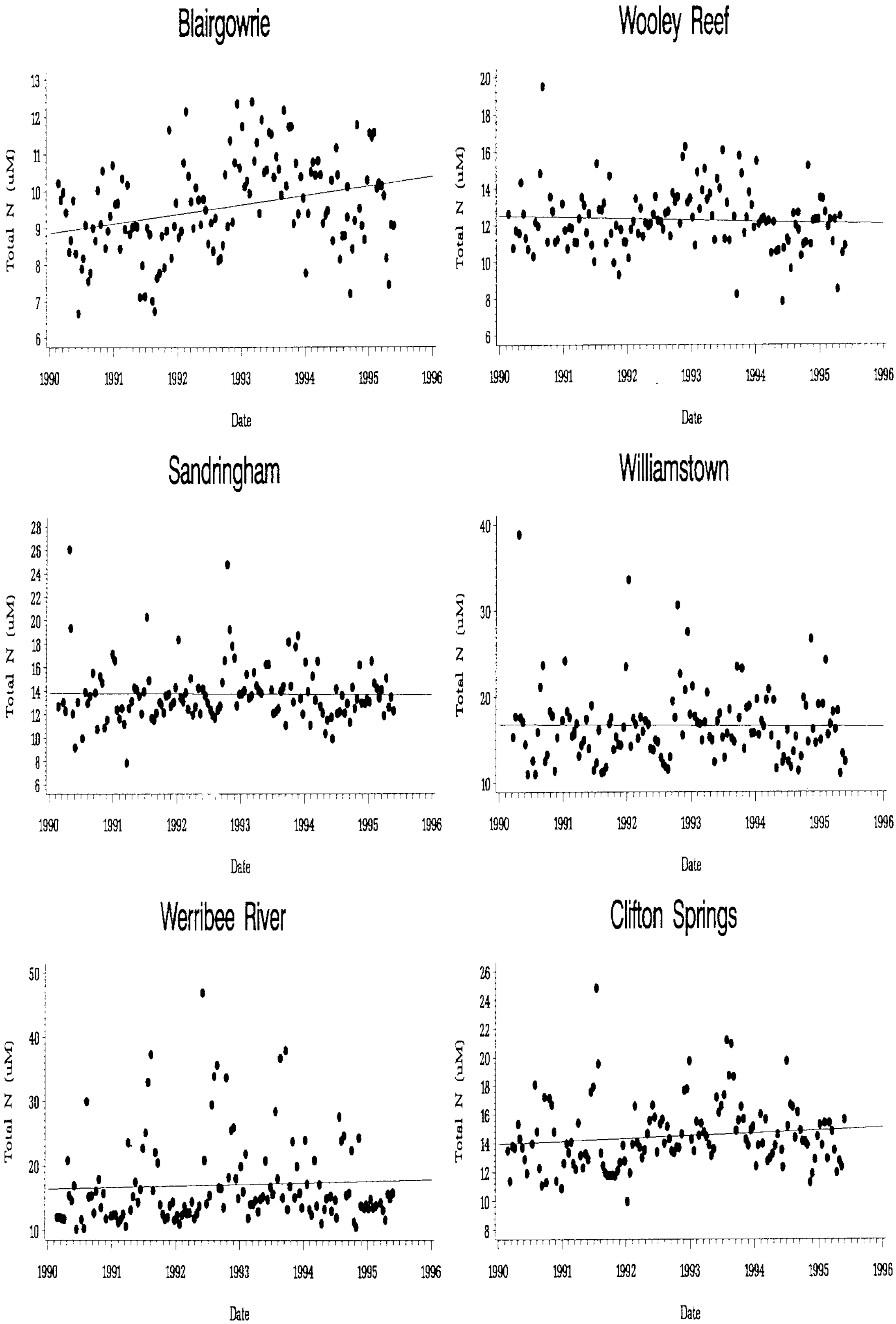


Figure 56: Variation of total nitrogen concentration by site, 1990-95.

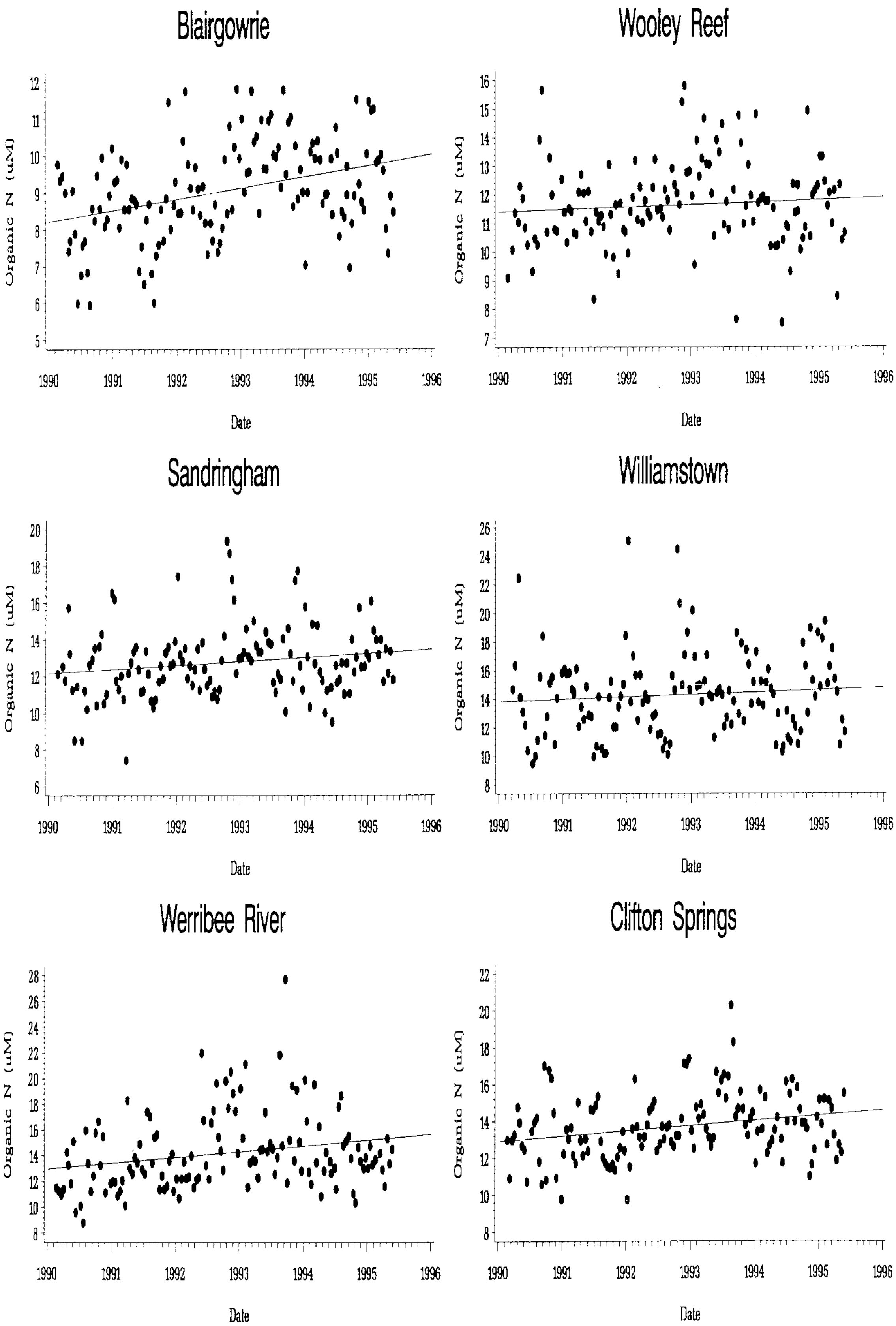


Figure 57: Variation of organic nitrogen concentration by site, 1990-95.

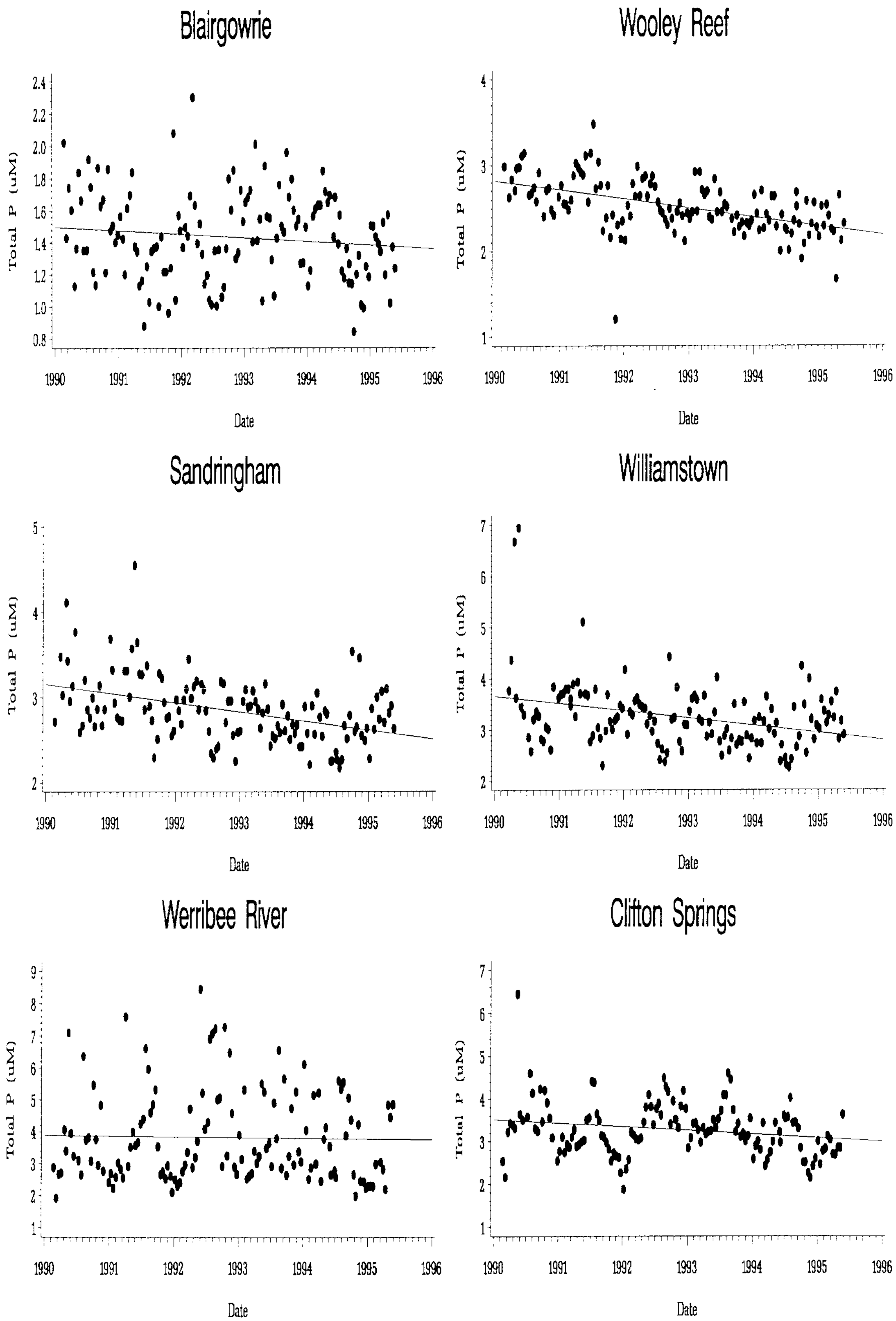


Figure 58: Variation of total phosphorus concentration by site, 1990-95.

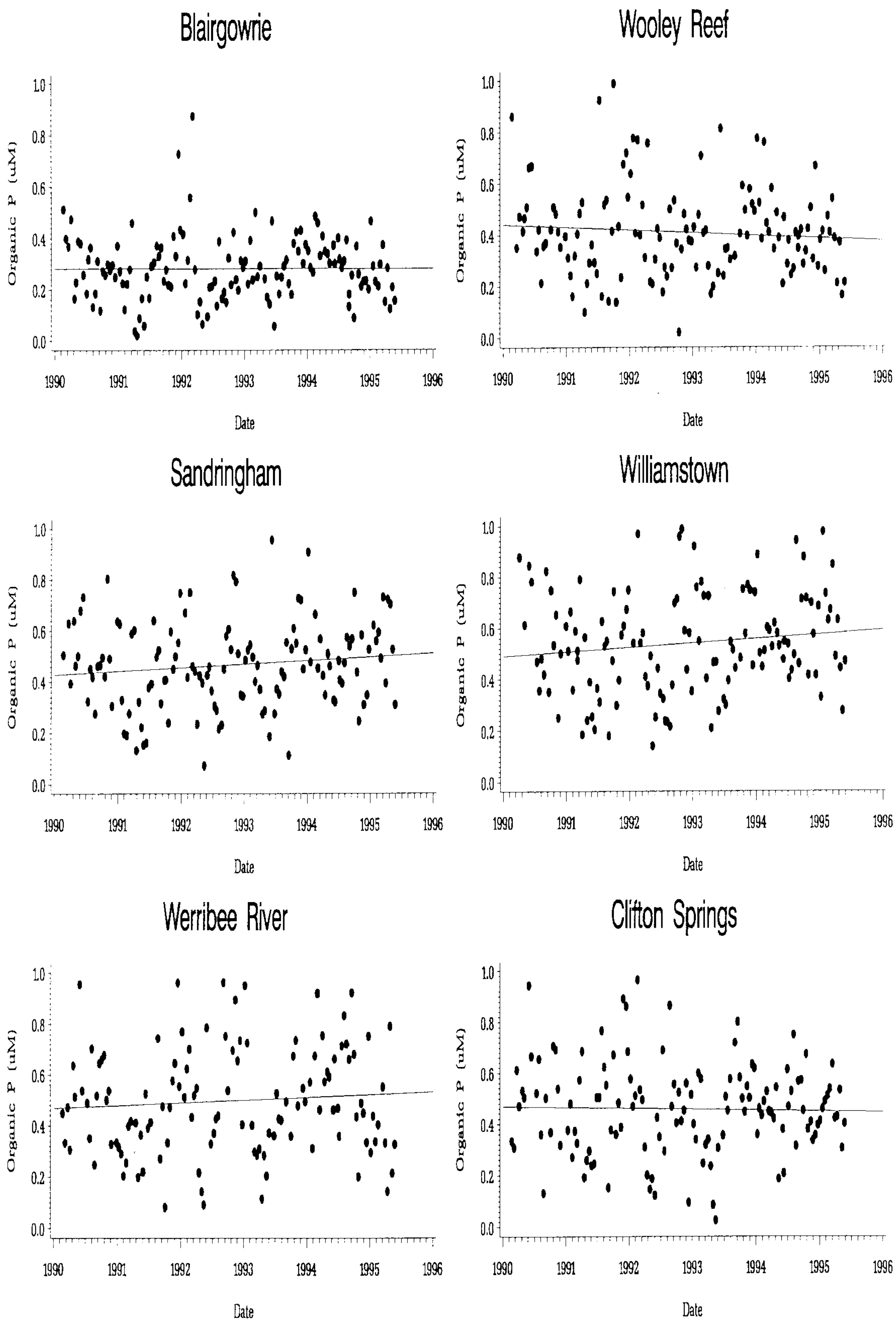


Figure 59: Variation of organic phosphorus concentration by site, 1990-95.

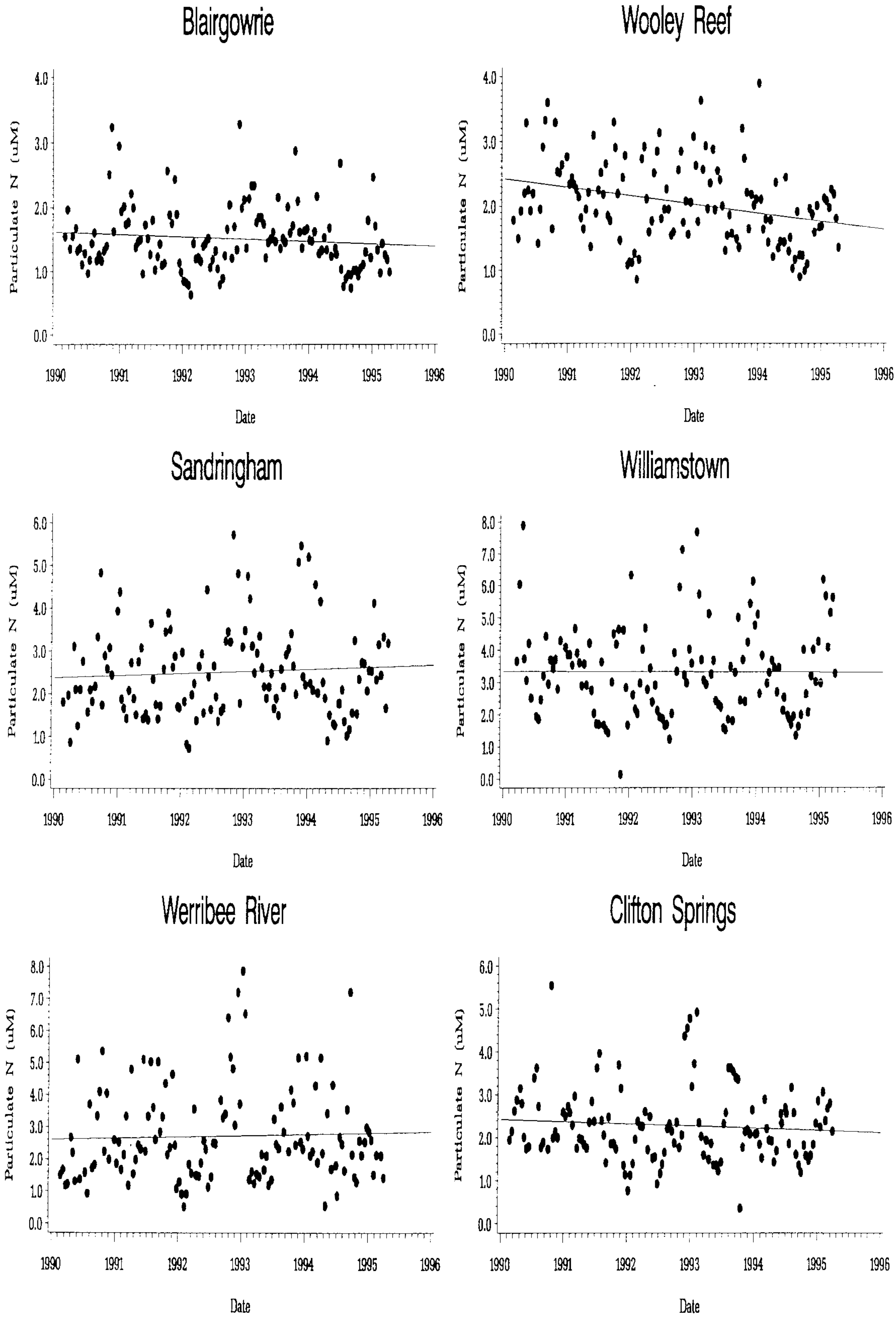


Figure 60: Variation of particulate nitrogen concentration by site, 1990-95.

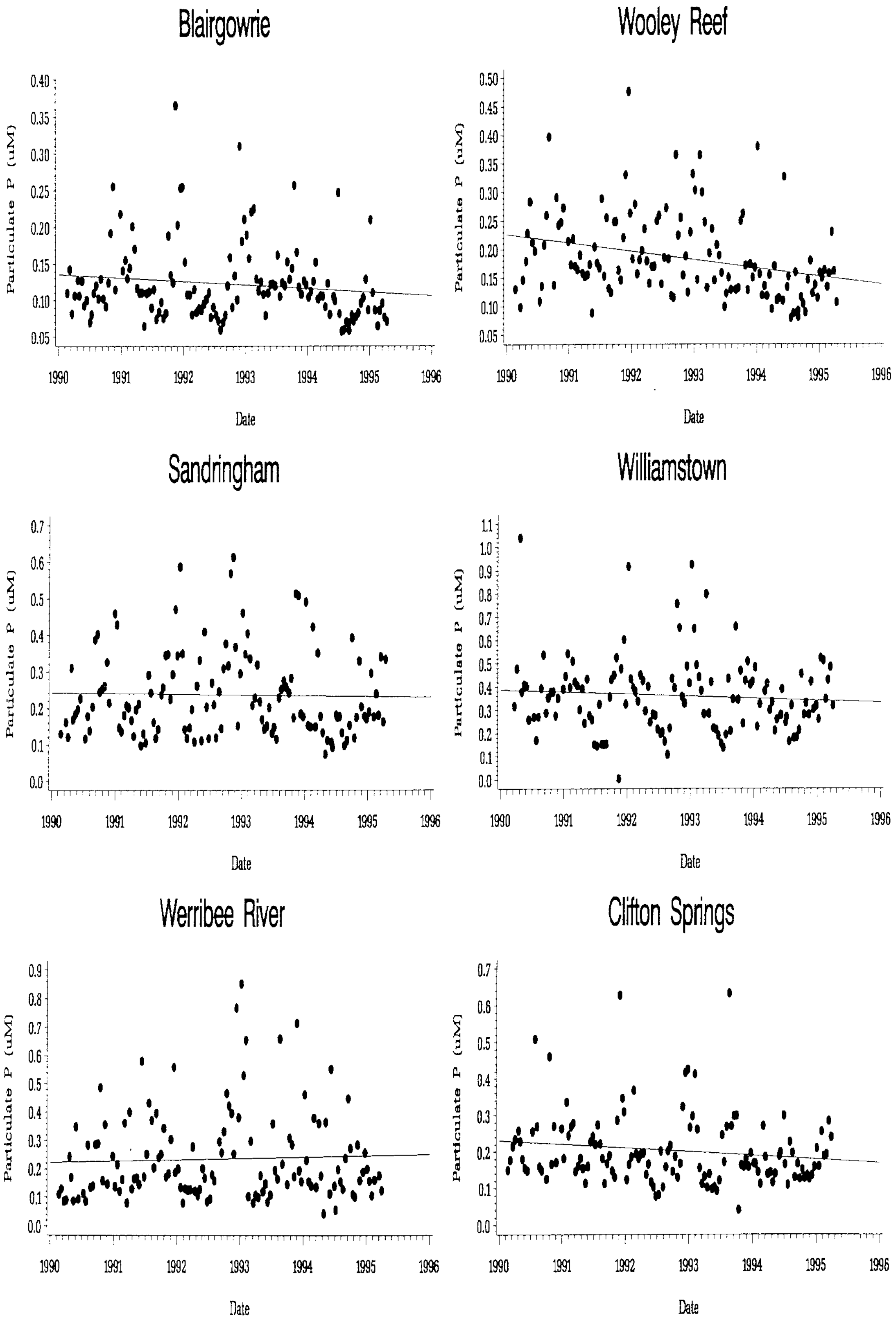


Figure 61: Variation of particulate phosphorus concentration by site, 1990-95.

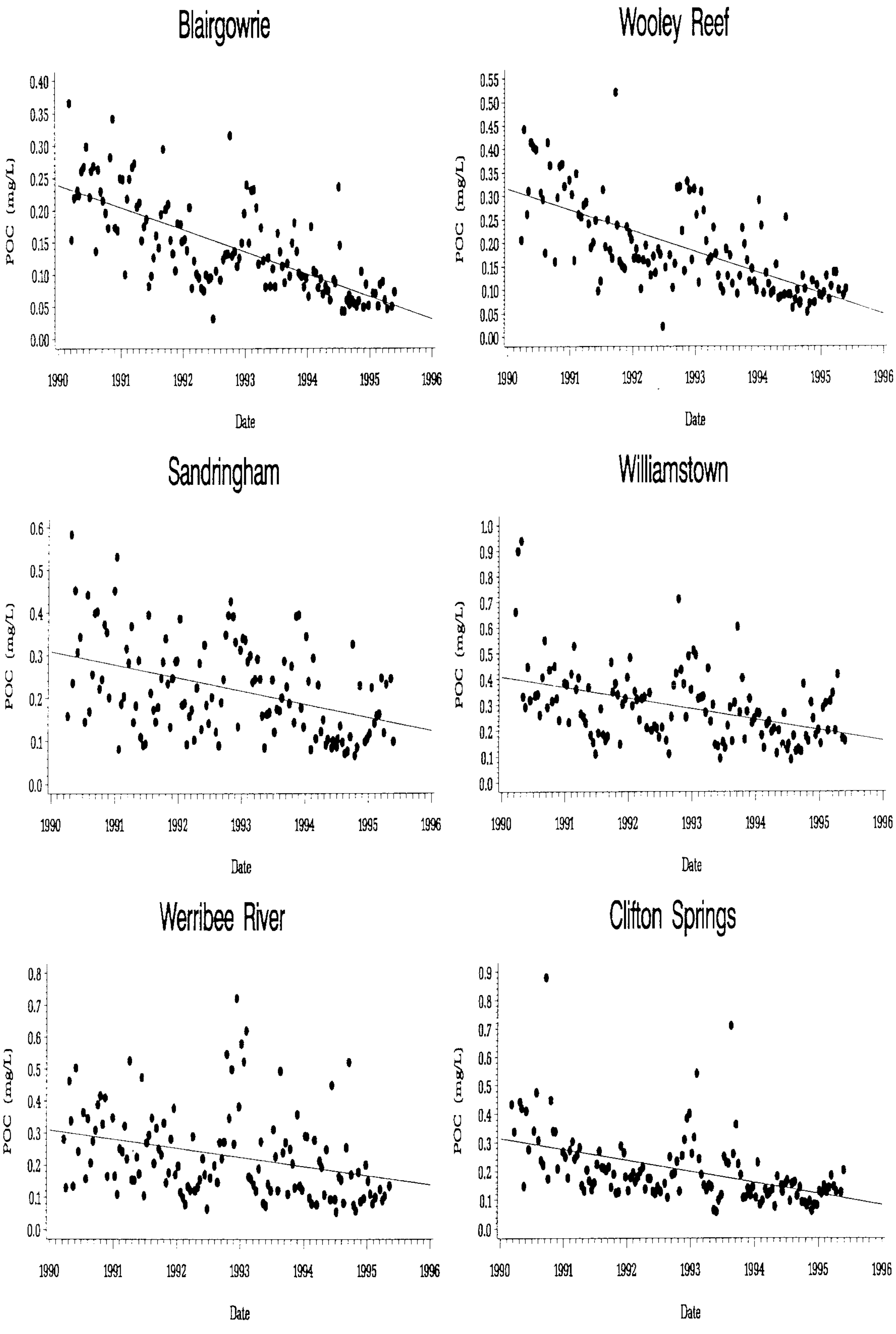


Figure 62: Variation of particulate organic carbon concentration by site, 1990-95.

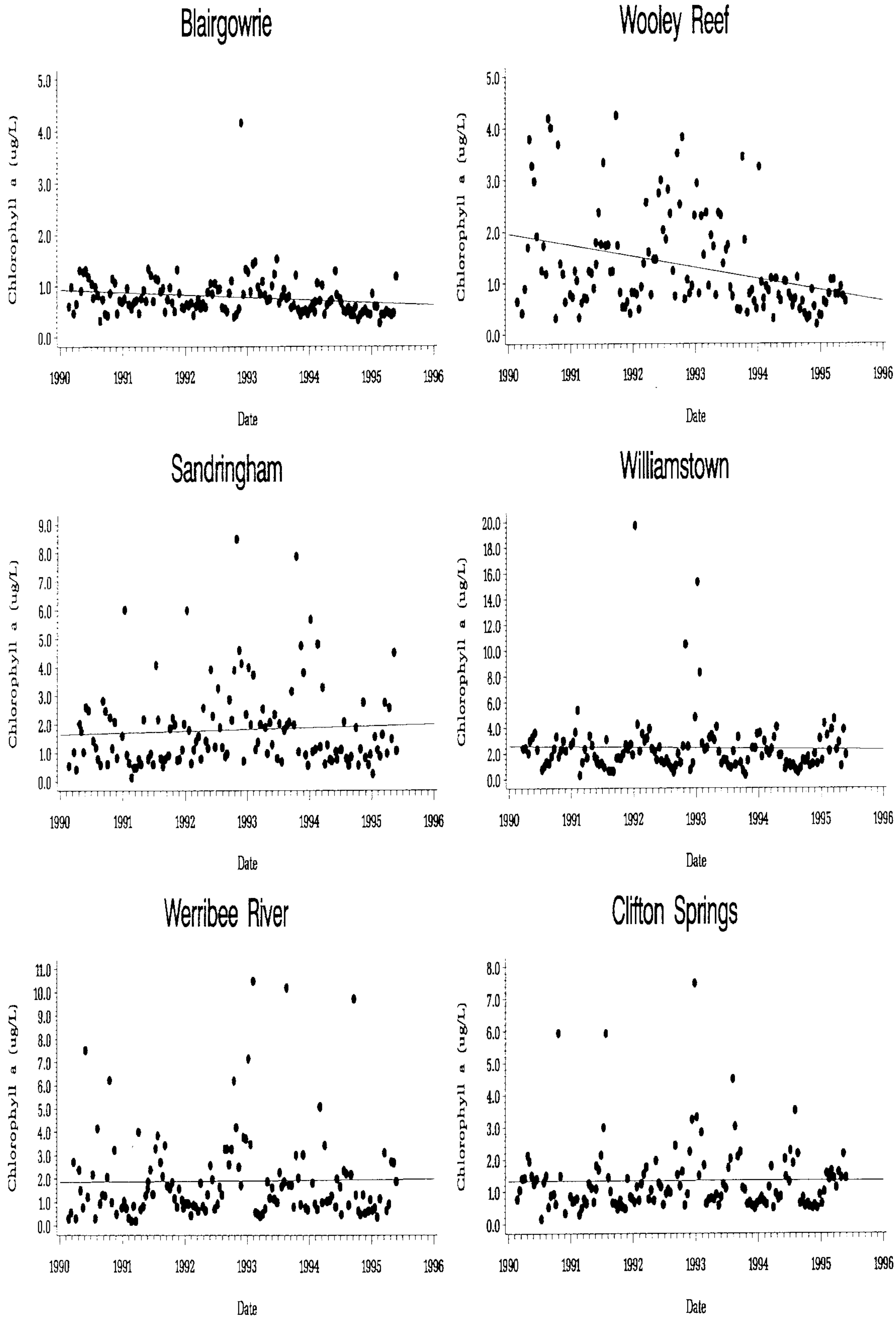


Figure 63: Variation of chlorophyll a concentration by site, 1990-95.

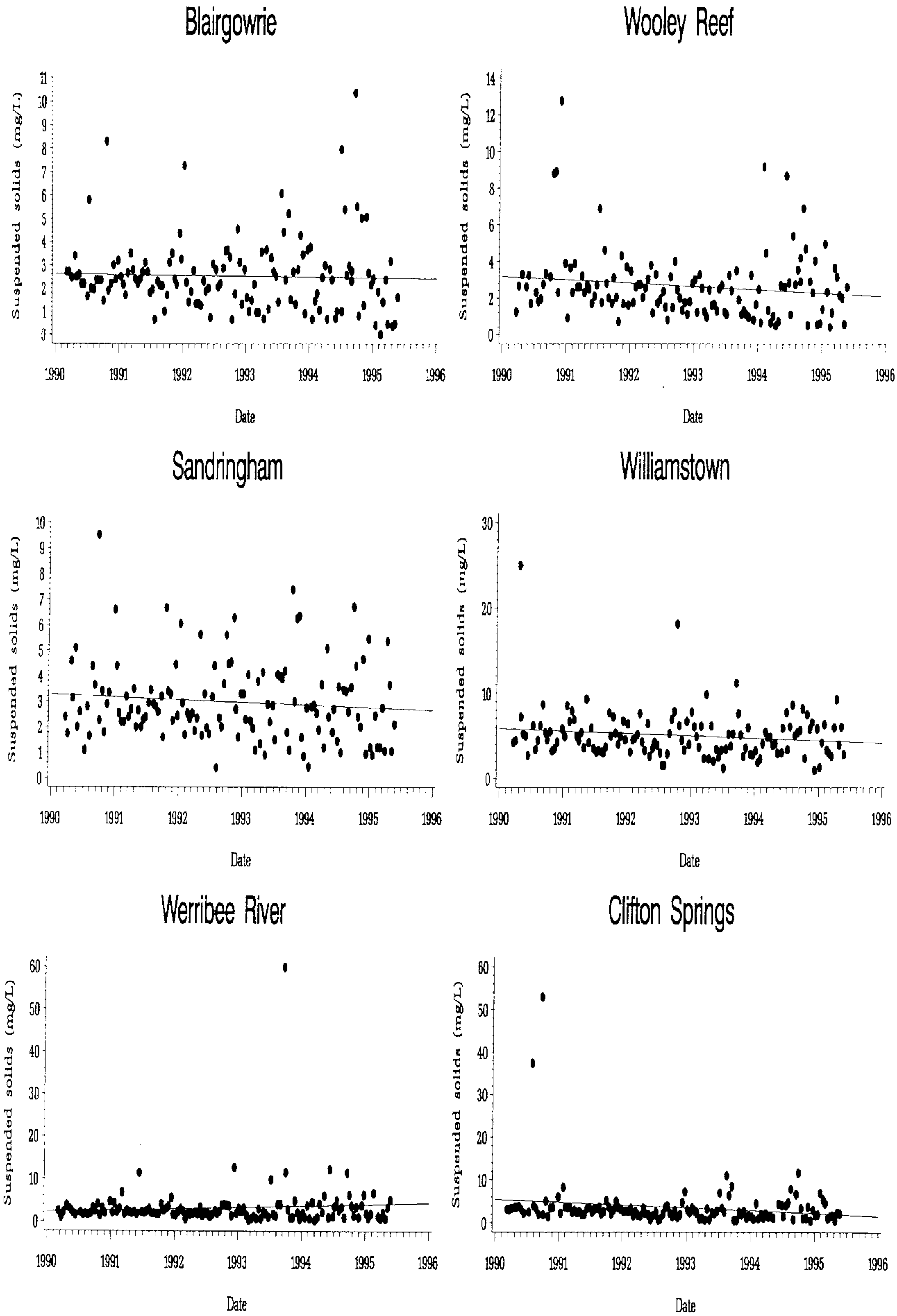


Figure 64: Variation of suspended solid (NFR) concentration by site, 1990-95.

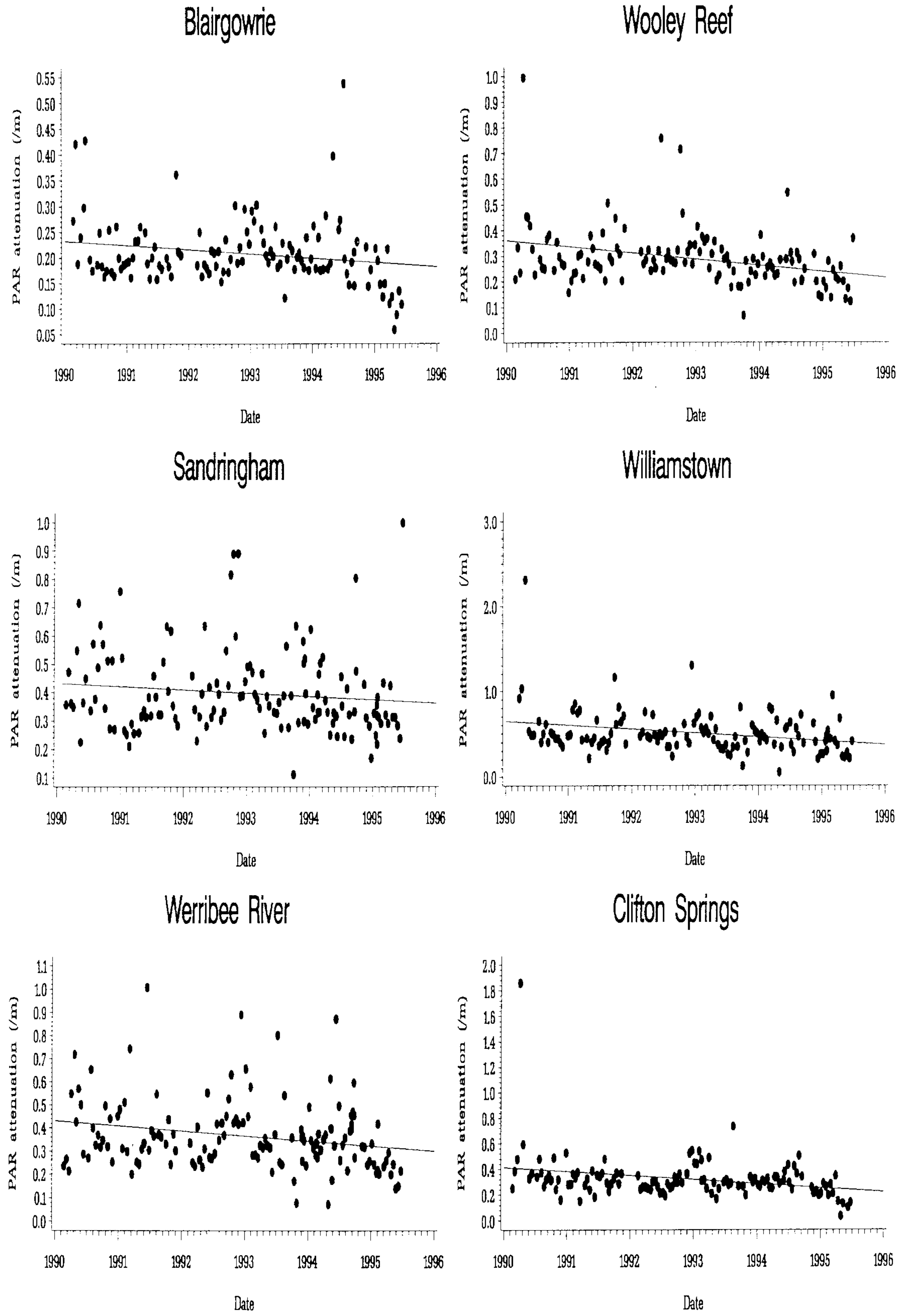


Figure 65: Variation of PAR attenuation coefficient by site, 1990-95.

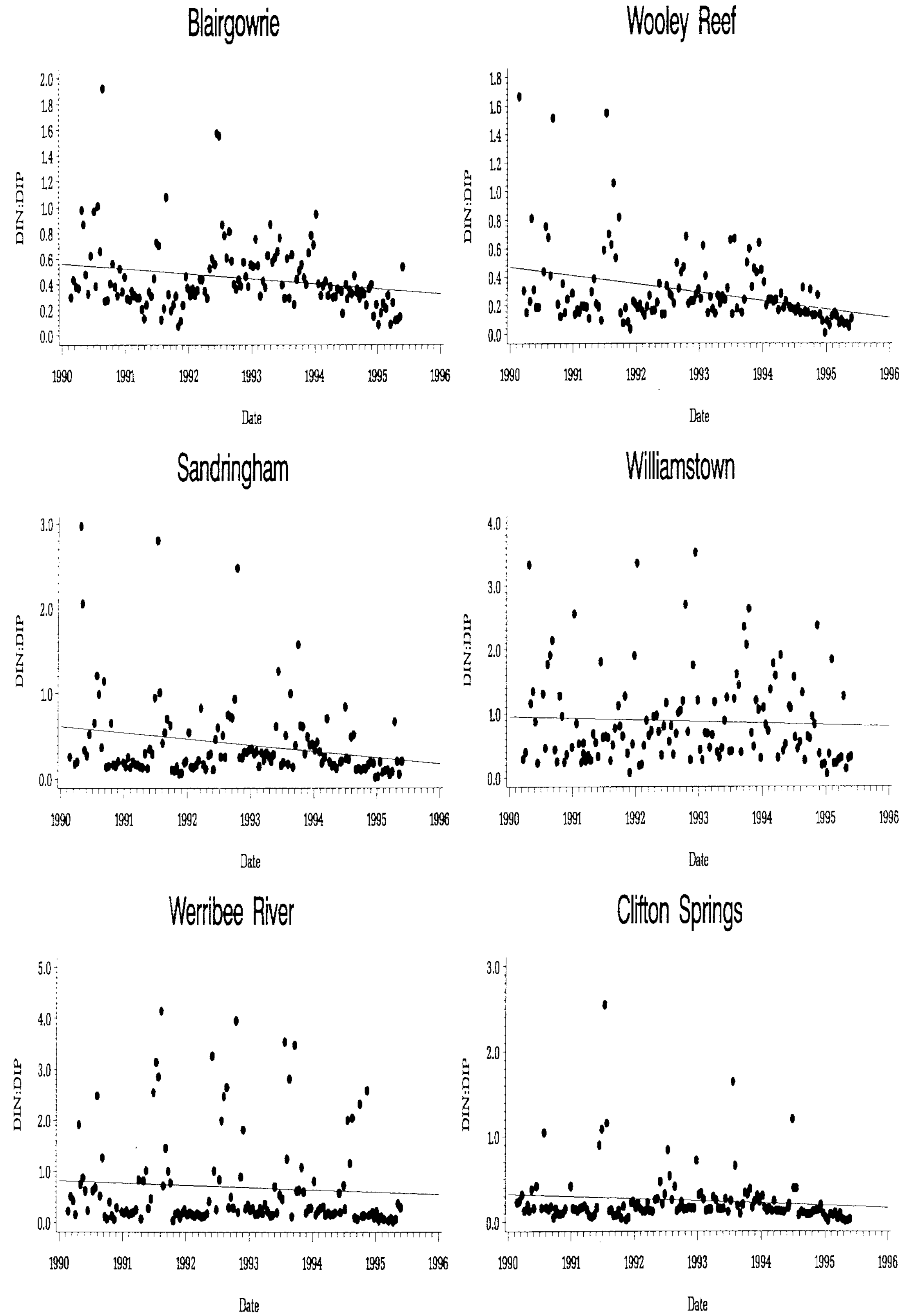


Figure 66: Variation of the ratio DIN:DIP by site, 1990-95.

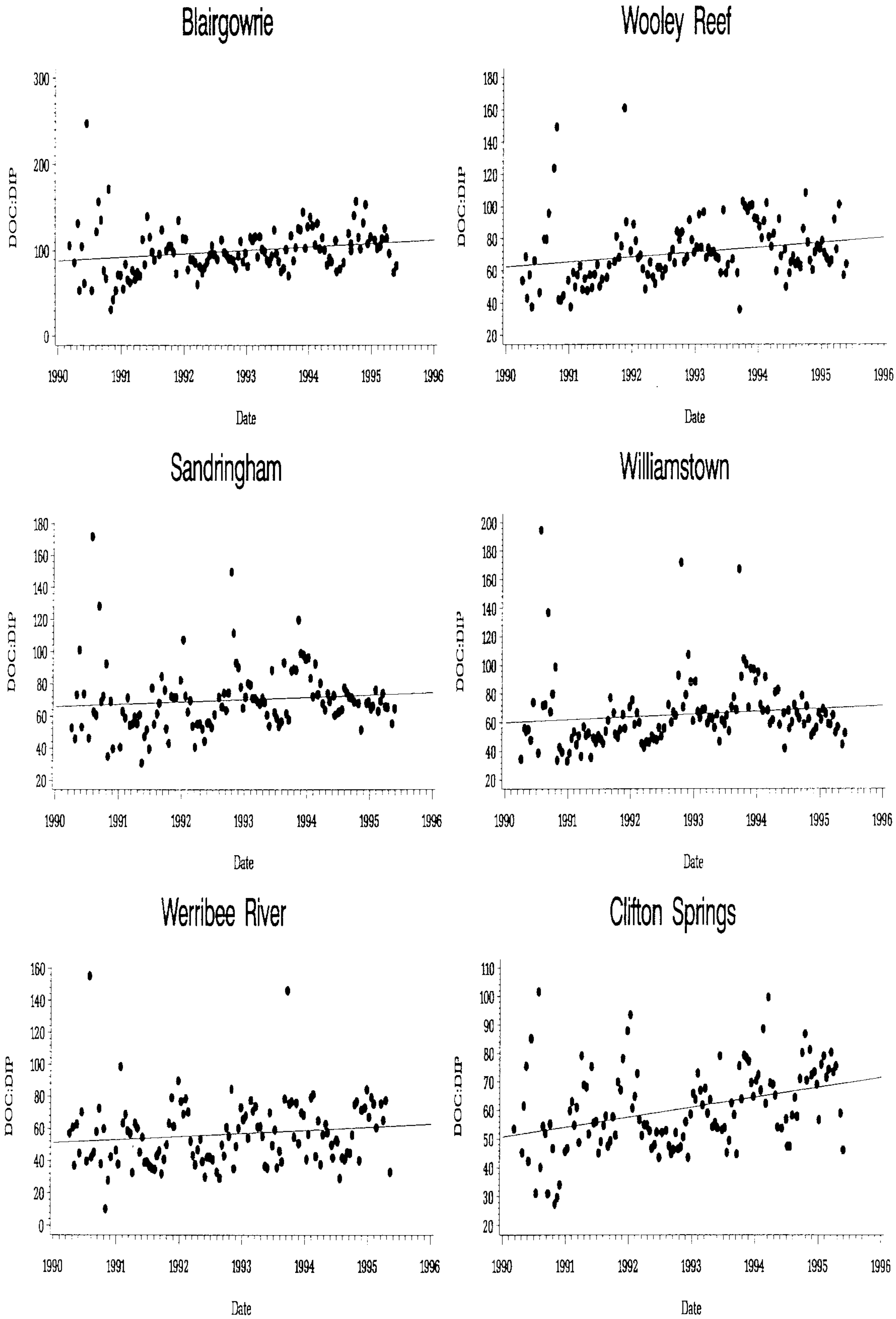
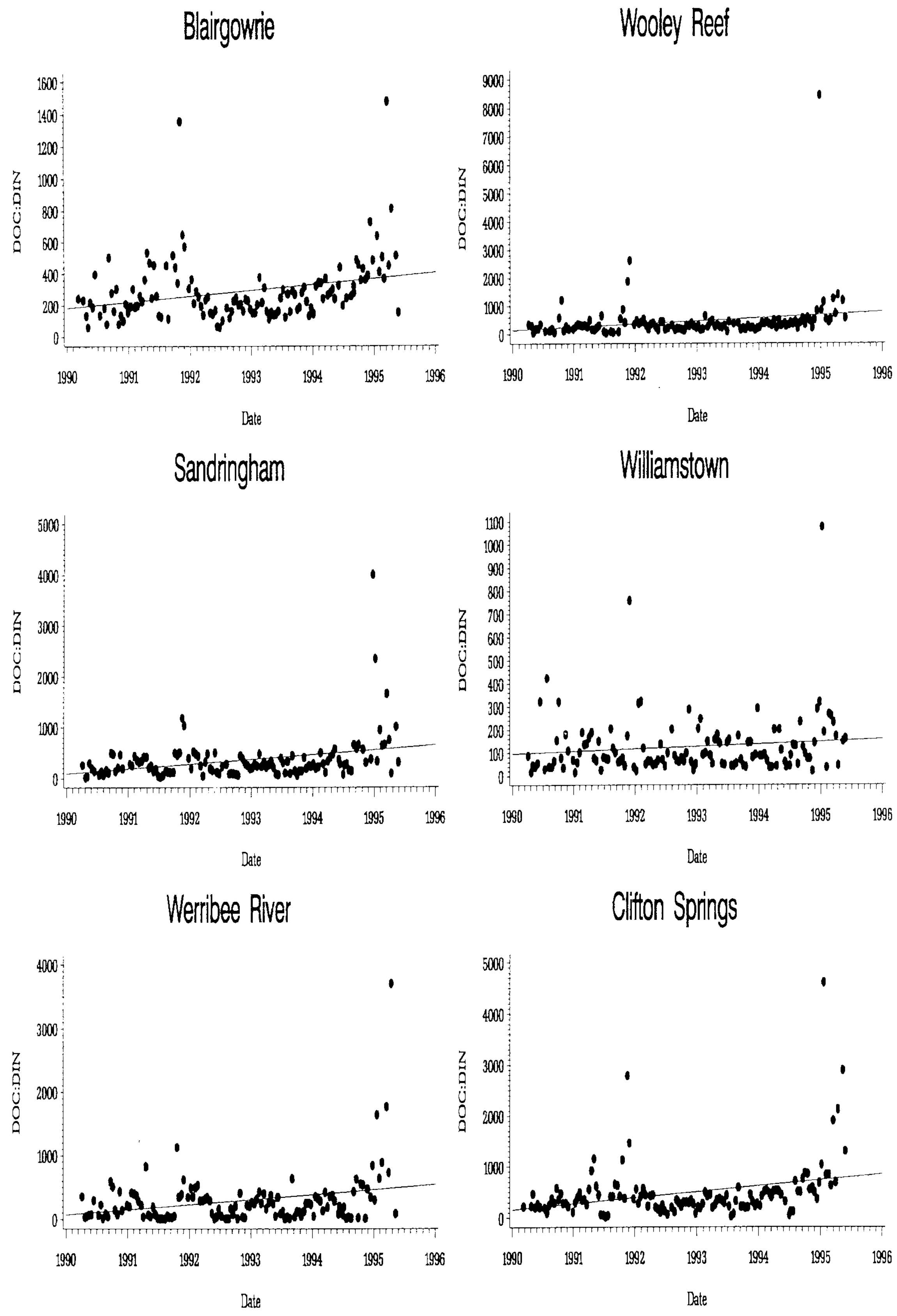


Figure 67: Variation of the ratio DOC:DIP by site, 1990-95.

Figure 68: Variation of the ratio DOC:DIN by site, 1990-95.



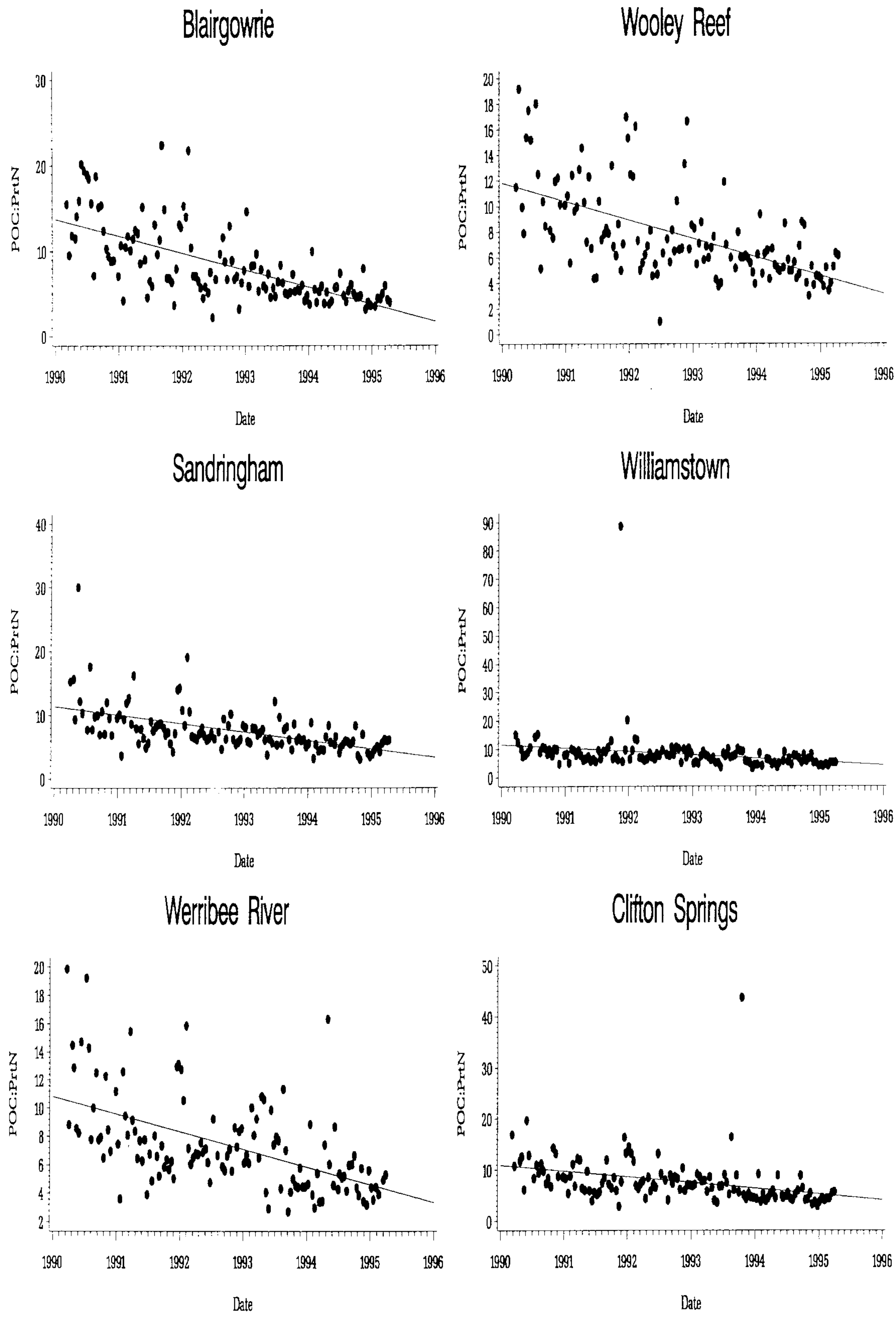


Figure 69: Variation of the ratio POC:PrtN by site, 1990-95.

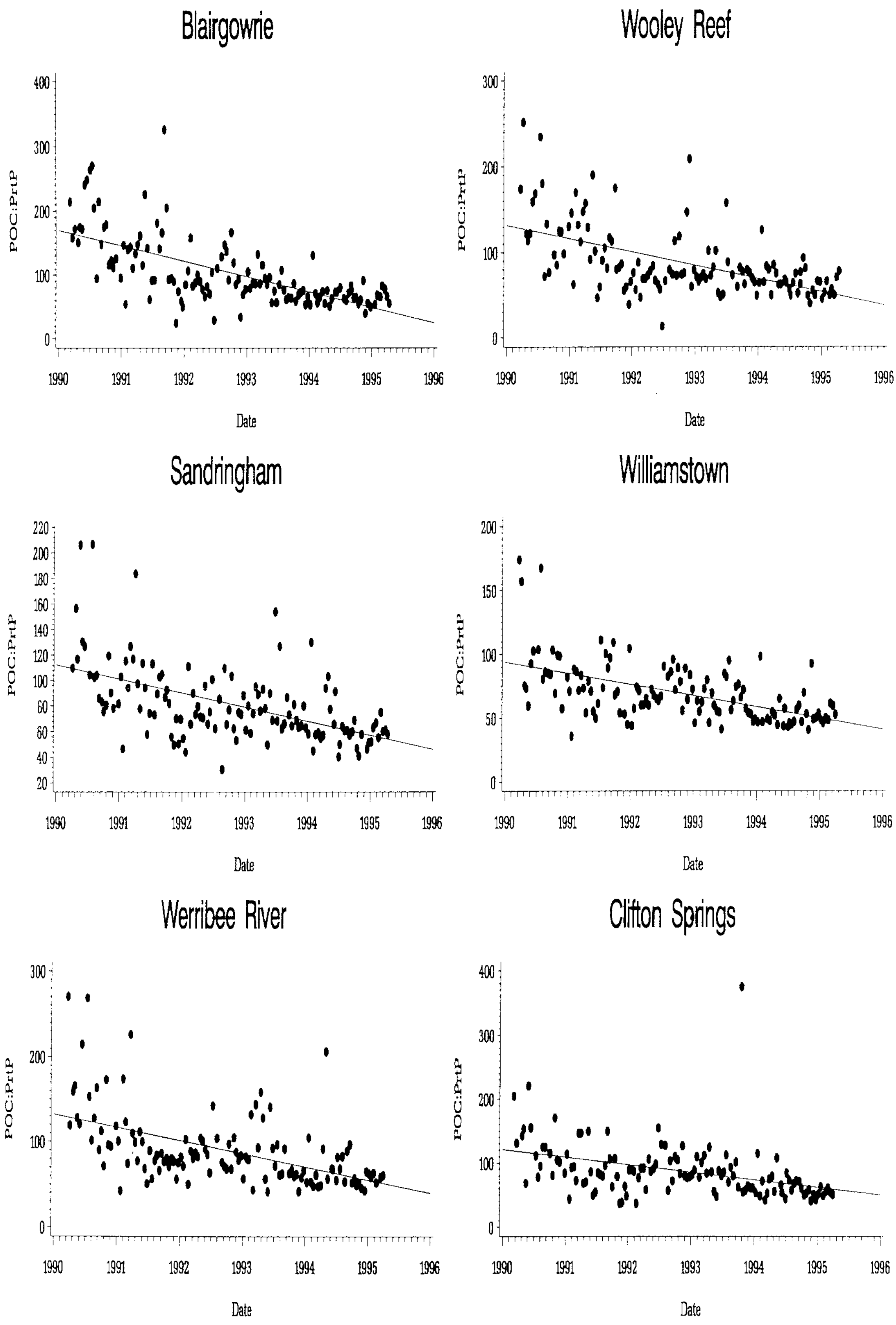


Figure 70: Variation of the ratio POC:PrtP by site, 1990-95.

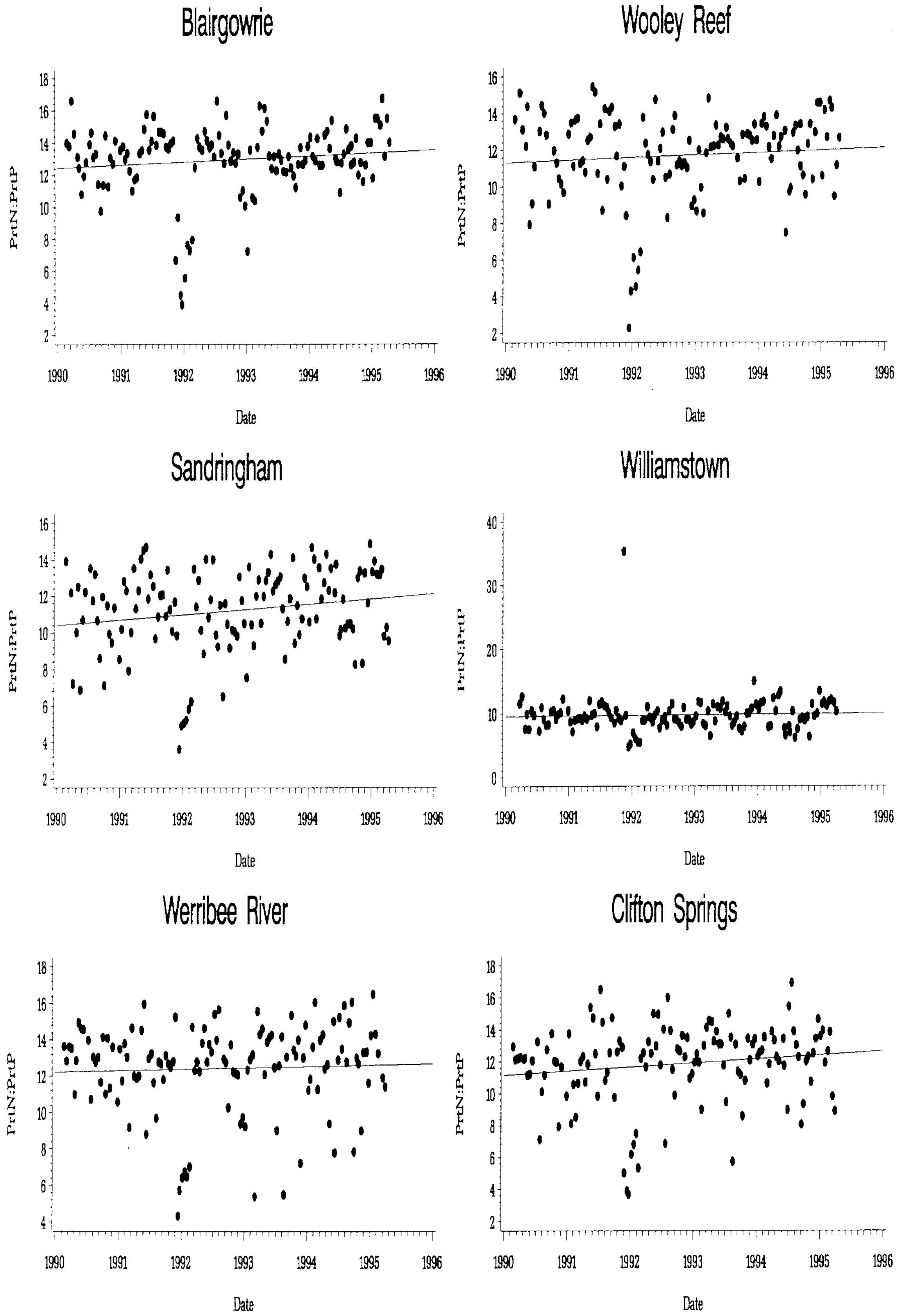


Figure 71: Variation of the ratio PrtN:PrtP by site, 1990-95.

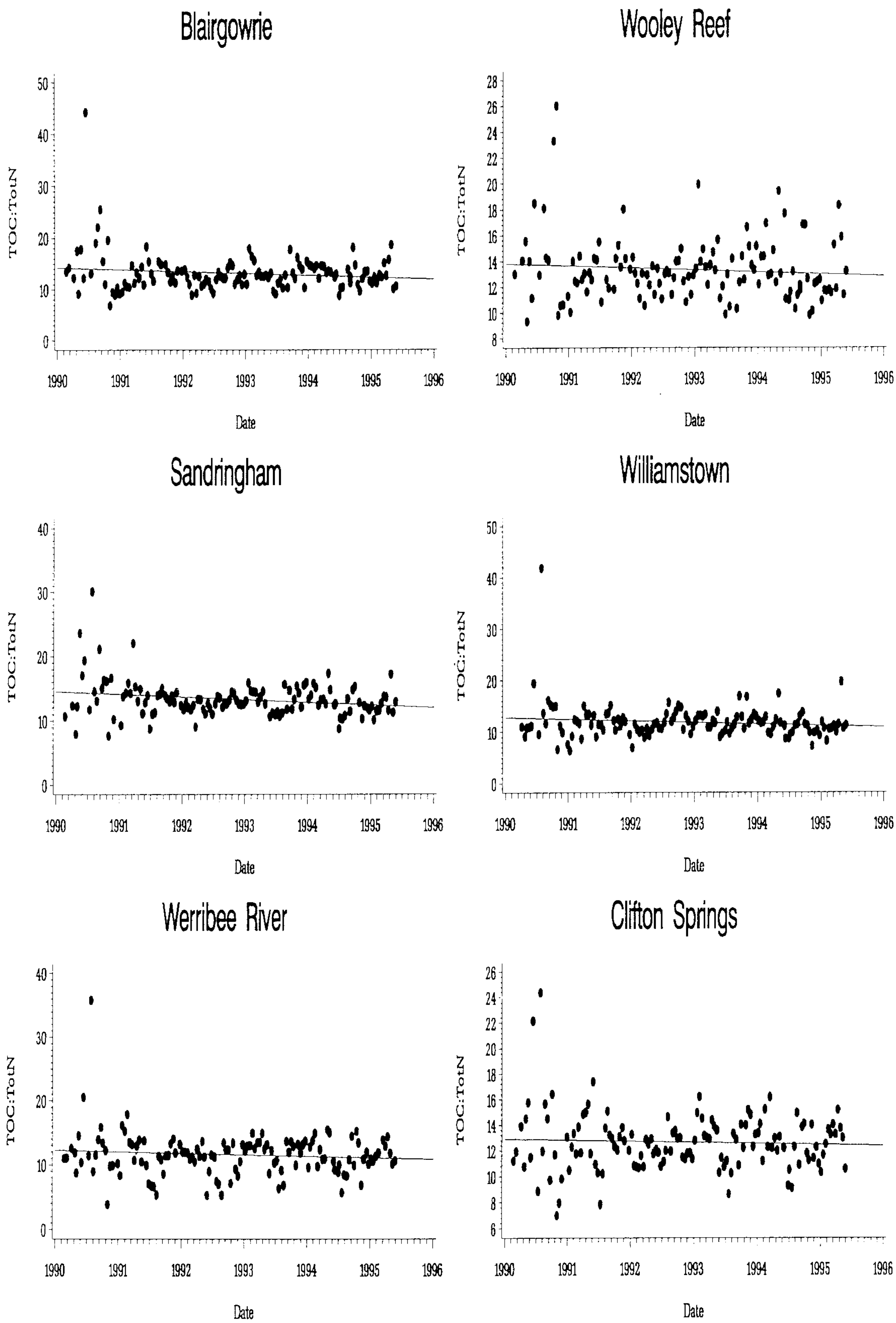


Figure 72: Variation of the ratio TOC:TotN by site, 1990-95.

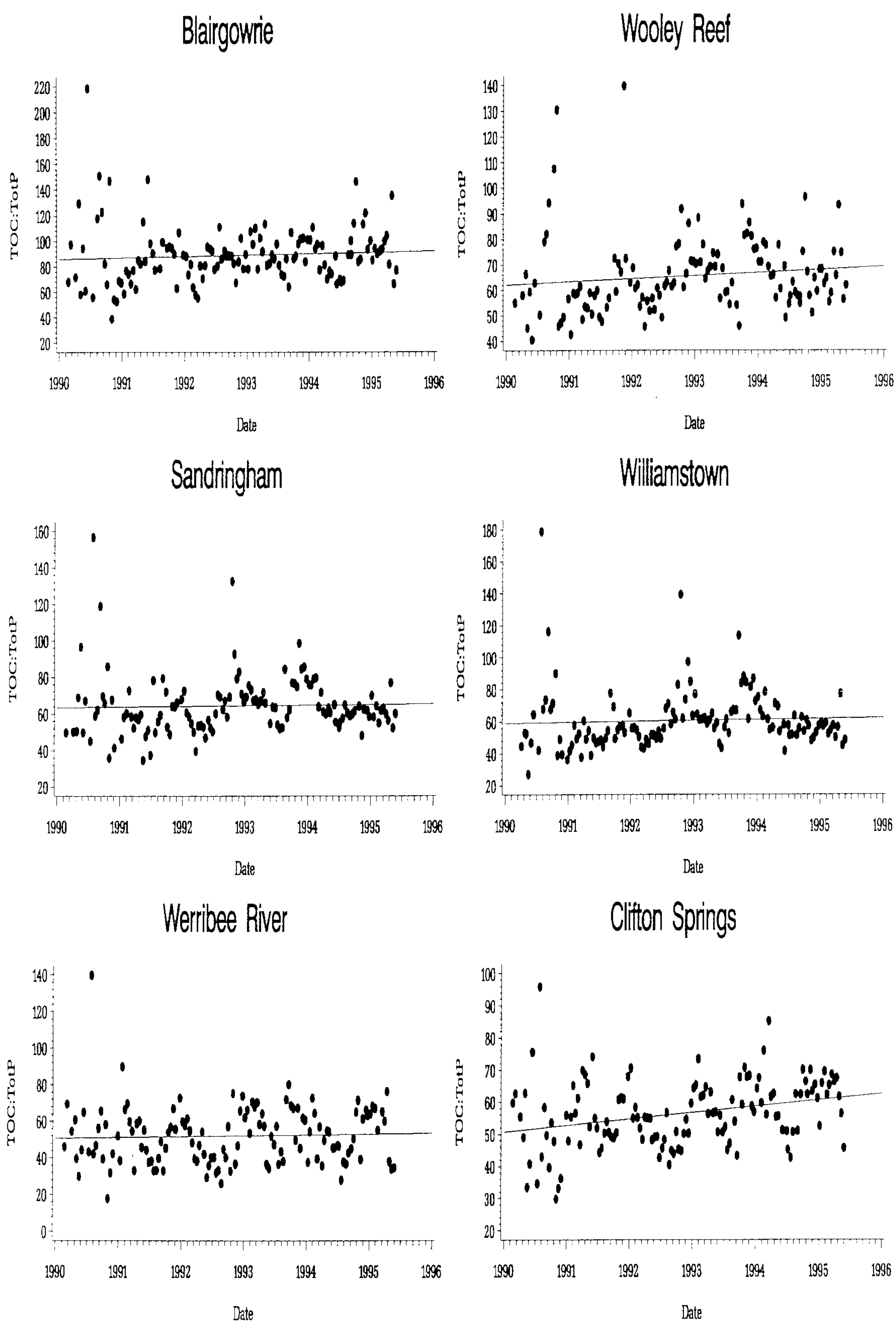


Figure 73: Variation of the ratio TOC:TotP by site, 1990-95.

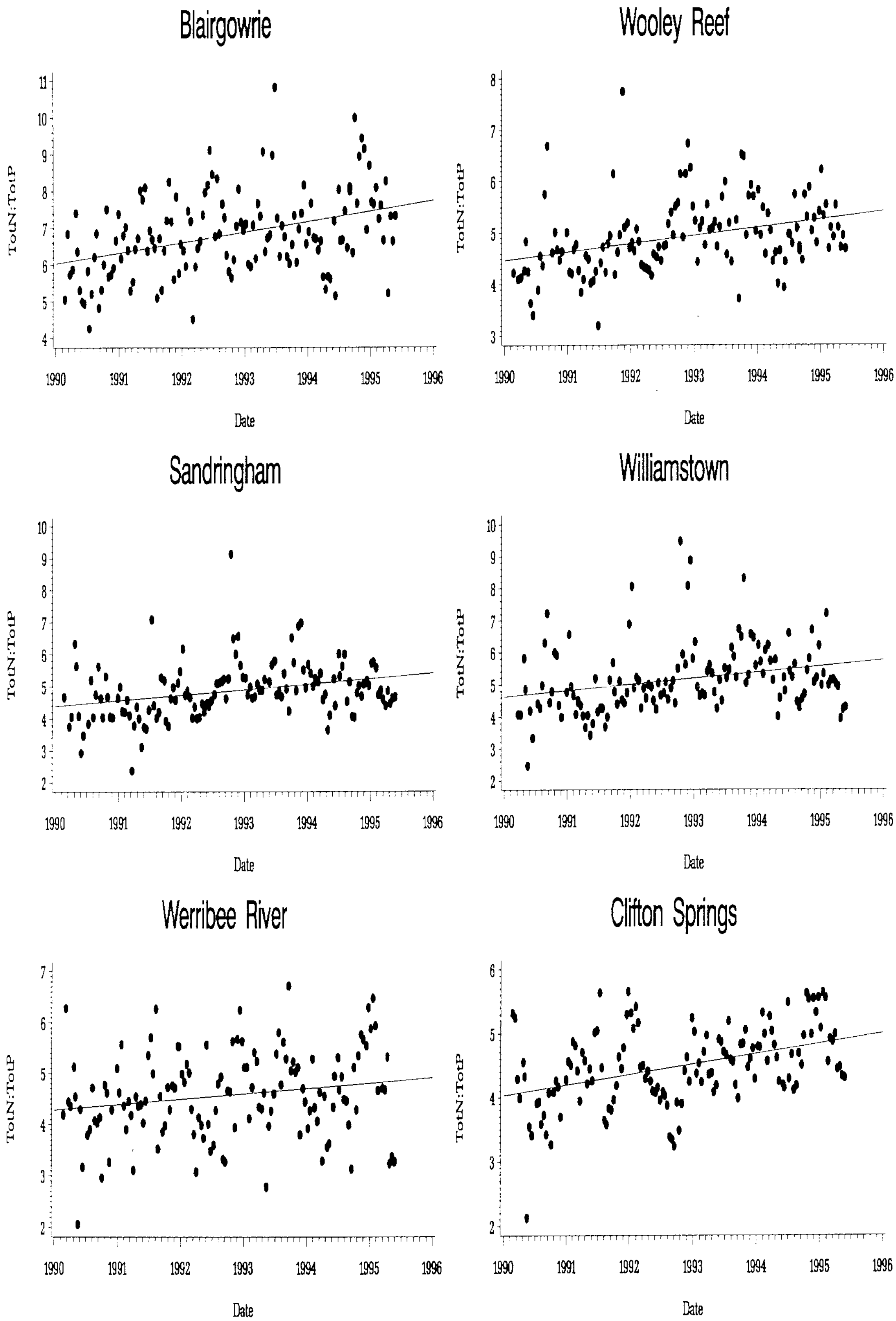


Figure 74: Variation of the ratio TotN:TotP by site, 1990-95.

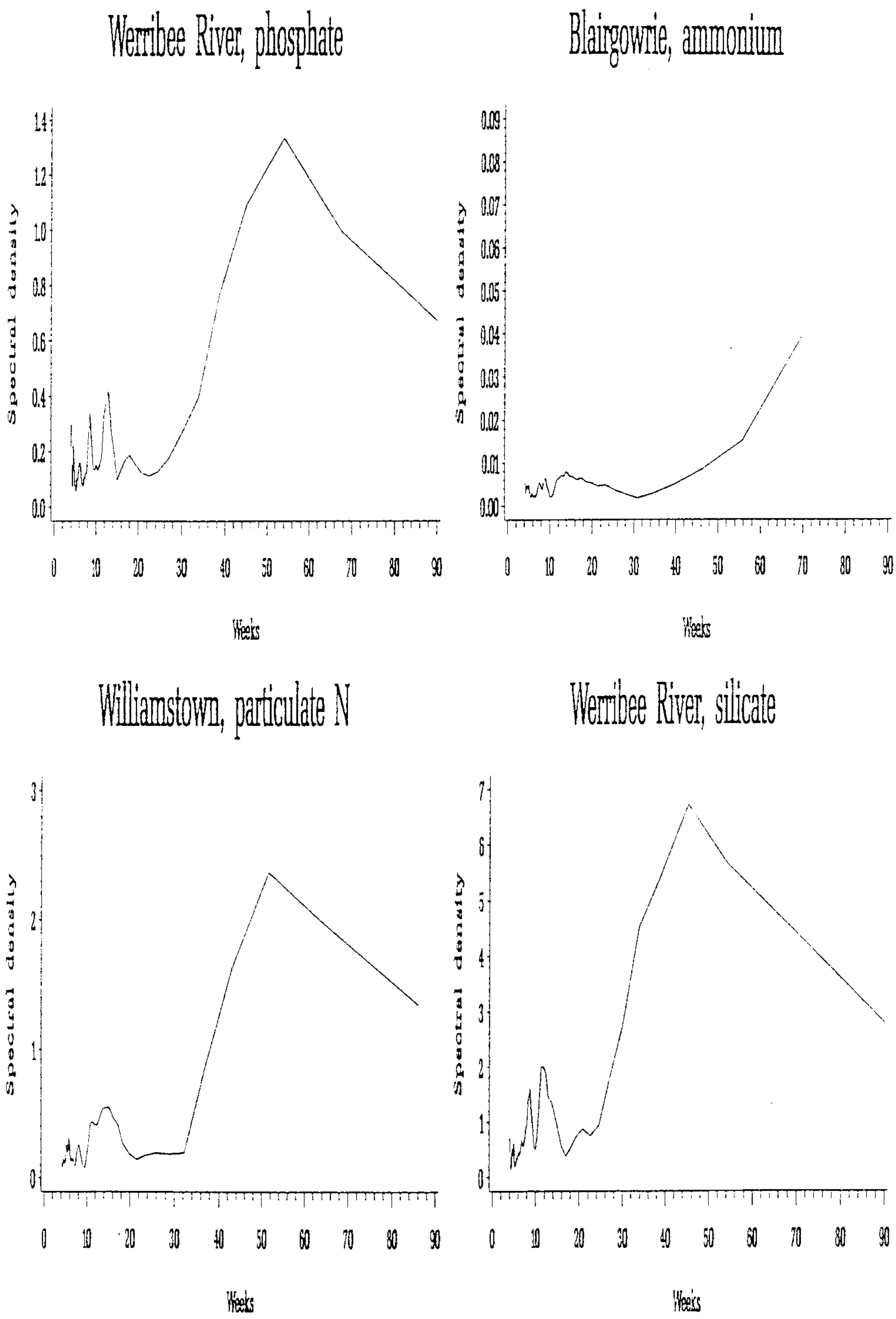
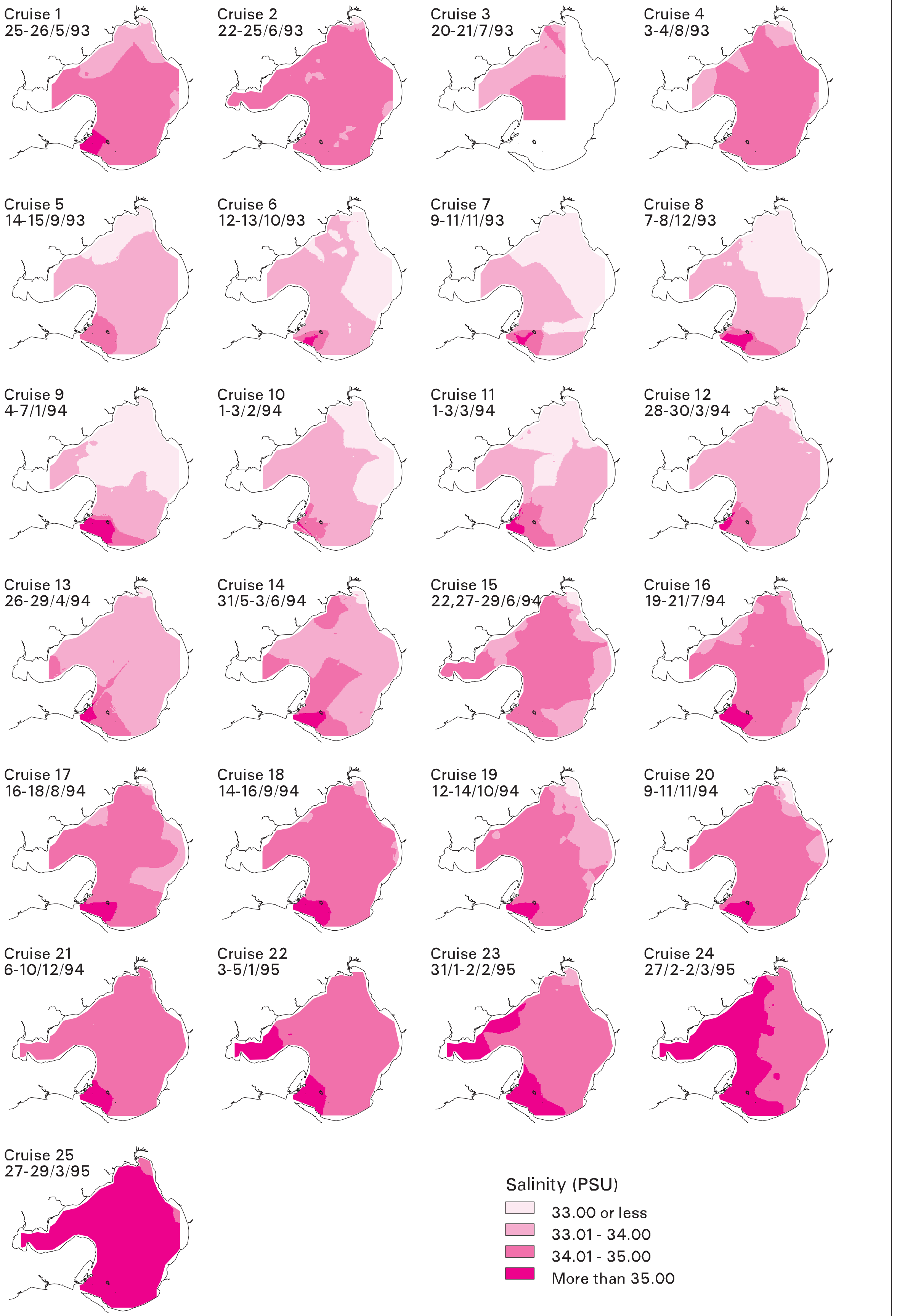
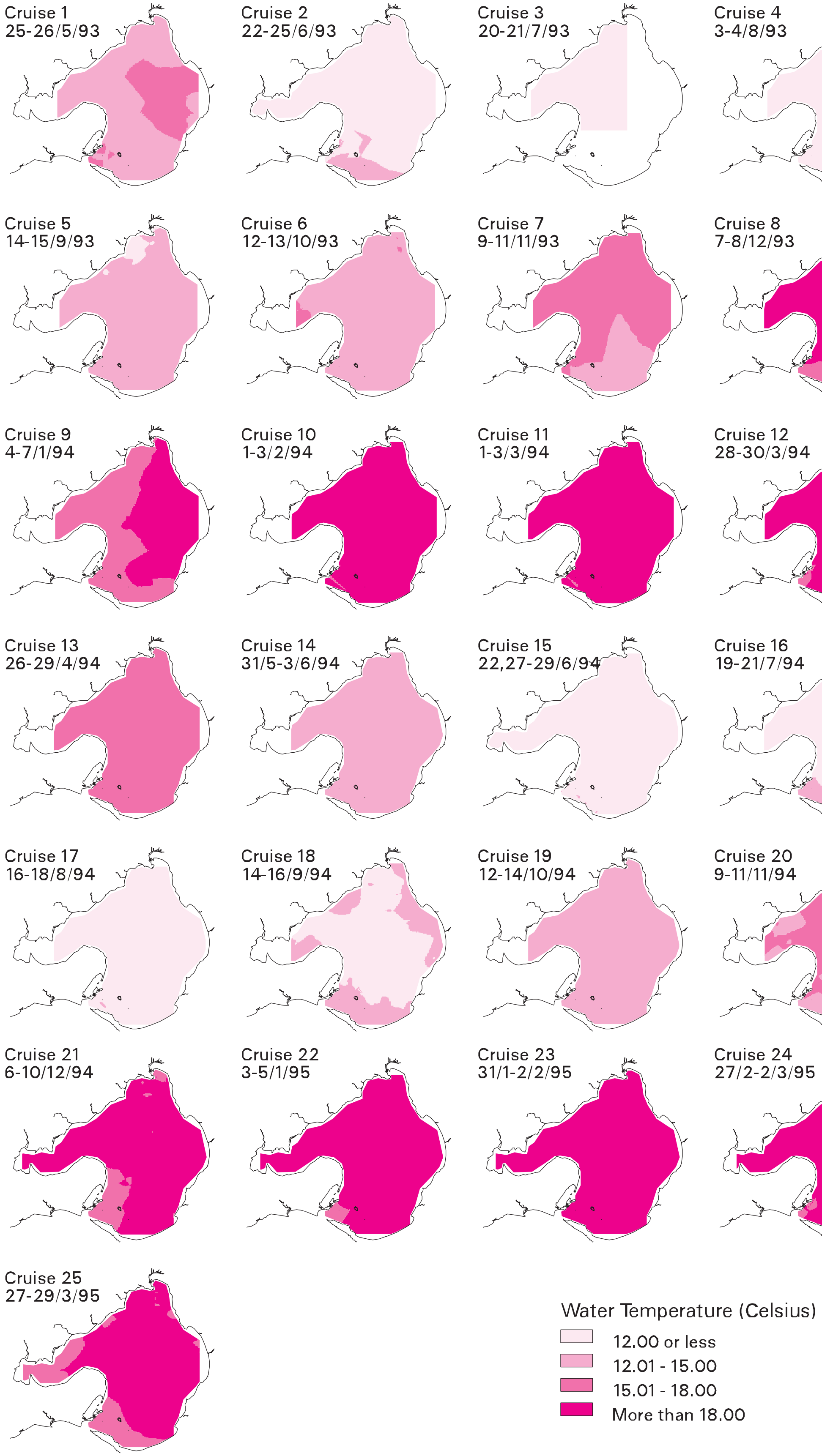


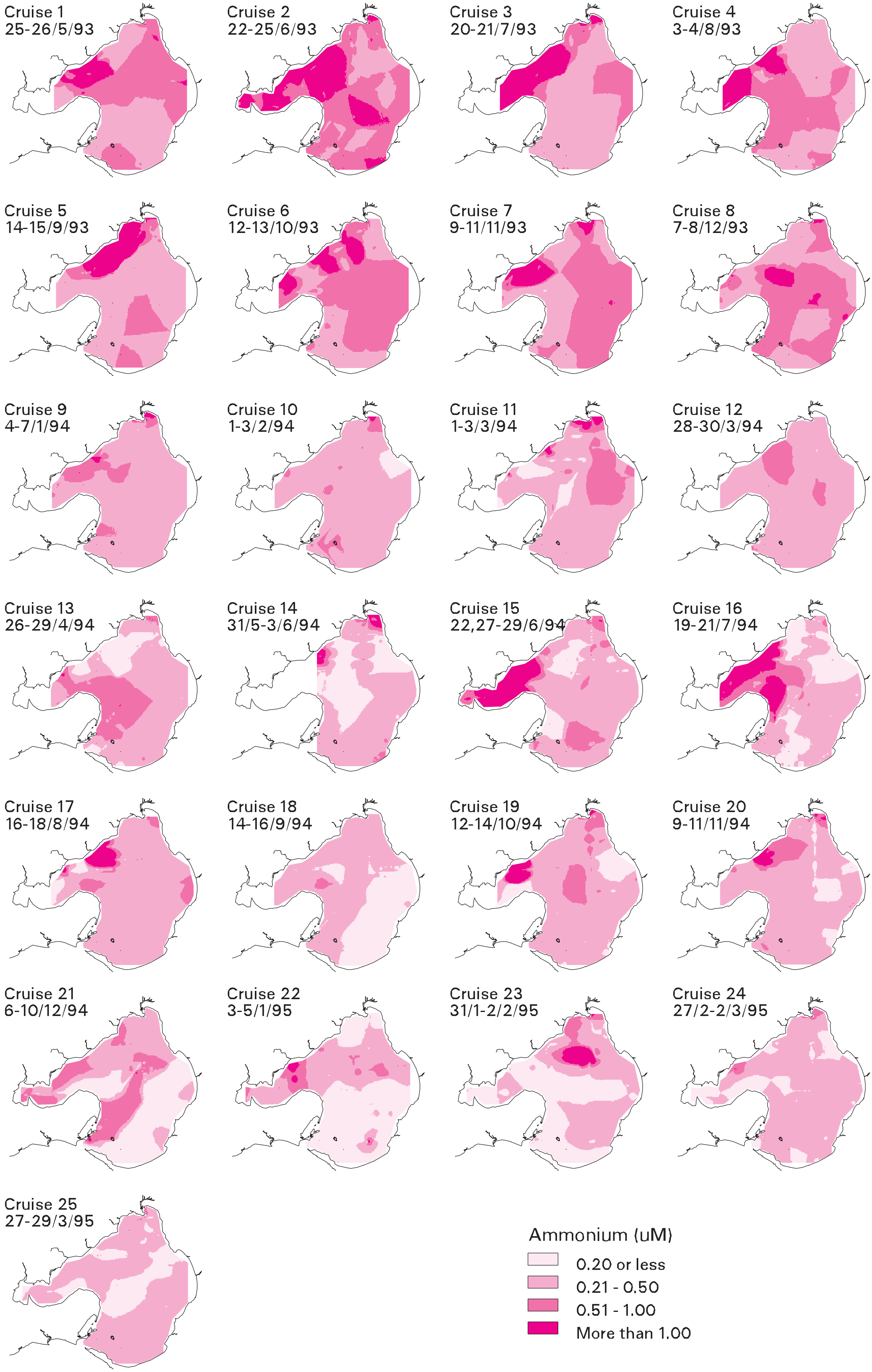
Figure 75: Examples of spectral analysis of data collected from 1990 to 1995.

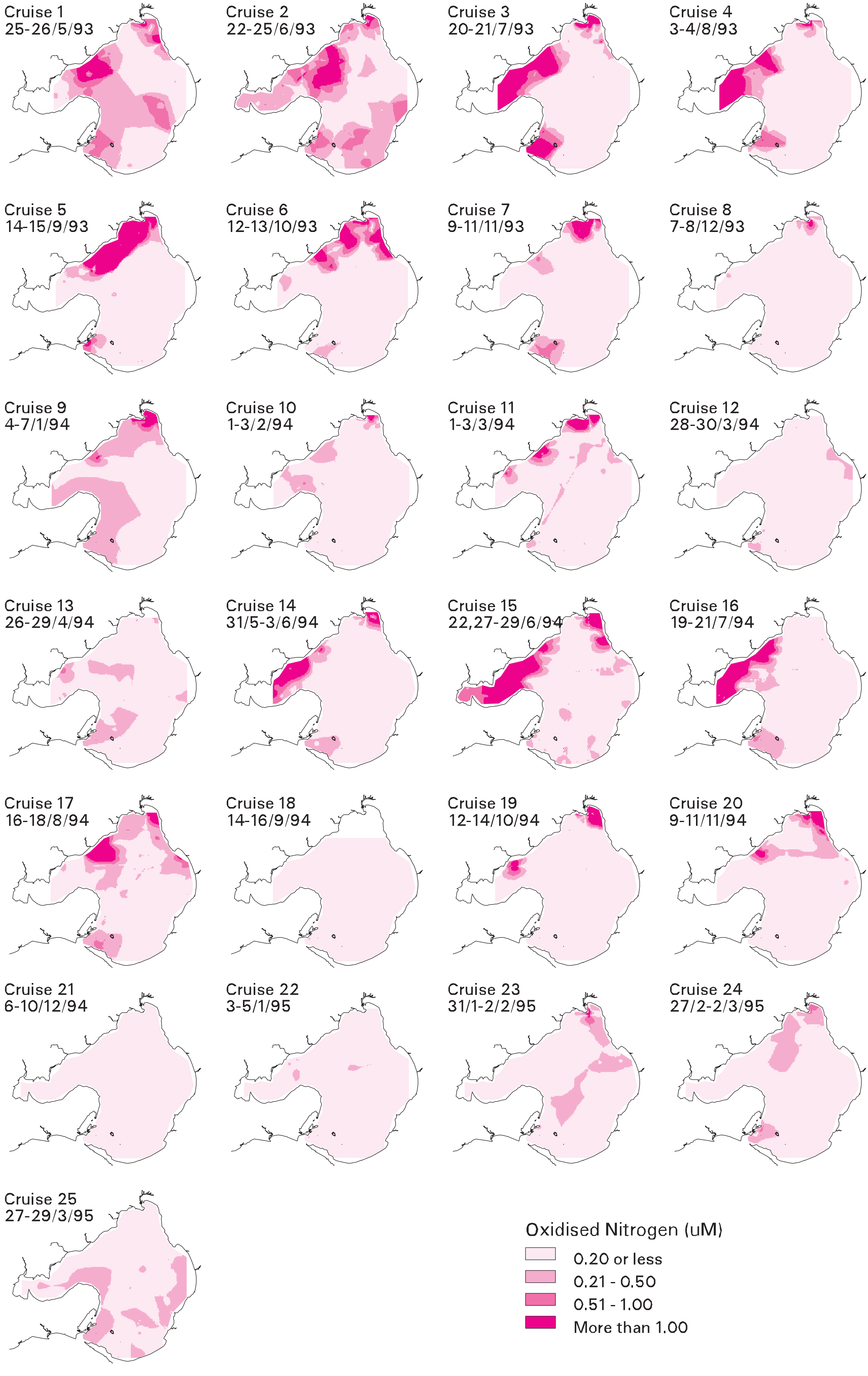
Figure 75: Examples of spectral analysis of data collected from 1990 to 1995.



Cruise 1
25-26/5/93
Cruise 2
22-25/6/93
Cruise 3
20-21/7/93
Cruise 4
3-4/8/93
Cruise 5
14-15/9/93
Cruise 6
12-13/10/93
Cruise 7
9-11/11/93
Cruise 8
7-8/12/93
Cruise 9
4-7/1/94
Cruise 10
1-3/2/94
Cruise 11
1-3/3/94
Cruise 12
28-30/3/94
Cruise 13
26-29/4/94
Cruise 14
31/5-3/6/94
Cruise 15
22,27-29/6/94
Cruise 16
19-21/7/94
Cruise 17
16-18/8/94
Cruise 18
14-16/9/94
Cruise 19
12-14/10/94
Cruise 20
9-11/11/94
Cruise 21
6-10/12/94
Cruise 22
3-5/1/95
Cruise 23
31/1-2/2/95
Cruise 24
27/2-2/3/95
Cruise 25
27-29/3/95
Salinity (PSU)
33.00 or less
33.01 - 34.00
34.01 - 35.00
More than 35.00


Cruise 1
25-26/5/93
Cruise 2
22-25/6/93
Cruise 3
20-21/7/93
Cruise 4
3-4/8/93
Cruise 5
14-15/9/93
Cruise 6
12-13/10/93
Cruise 7
9-11/11/93
Cruise 8
7-8/12/93
Cruise 9
4-7/1/94
Cruise 10
1-3/2/94
Cruise 11
1-3/3/94
Cruise 12
28-30/3/94
Cruise 13
26-29/4/94
Cruise 14
31/5-3/6/94
Cruise 15
22,27-29/6/94
Cruise 16
19-21/7/94
Cruise 17
16-18/8/94
Cruise 18
14-16/9/94
Cruise 19
12-14/10/94
Cruise 20
9-11/11/94
Cruise 21
6-10/12/94
Cruise 22
3-5/1/95
Cruise 23
31/1-2/2/95
Cruise 24
27/2-2/3/95
Cruise 25
27-29/3/95
Water Temperature (Celsius)
12.00 or less
12.01 - 15.00
15.01 - 18.00
More than 18.00


Cruise 1
25-26/5/93
Cruise 2
22-25/6/93
Cruise 3
20-21/7/93
Cruise 4
3-4/8/93
Cruise 5
14-15/9/93
Cruise 6
12-13/10/93
Cruise 7
9-11/11/93
Cruise 8
7-8/12/93
Cruise 9
4-7/1/94
Cruise 10
1-3/2/94
Cruise 11
1-3/3/94
Cruise 12
28-30/3/94
Cruise 13
26-29/4/94
Cruise 14
31/5-3/6/94
Cruise 15
22,27-29/6/94
Cruise 16
19-21/7/94
Cruise 17
16-18/8/94
Cruise 18
14-16/9/94
Cruise 19
12-14/10/94
Cruise 20
9-11/11/94
Cruise 21
6-10/12/94
Cruise 22
3-5/1/95
Cruise 23
31/1-2/2/95
Cruise 24
27/2-2/3/95
Cruise 25
27-29/3/95
Ammonium (uM)
0.20 or less
0.21 - 0.50
0.51 - 1.00
More than 1.00


Cruise 1
25-26/5/93
Cruise 2
22-25/6/93
Cruise 3
20-21/7/93
Cruise 4
3-4/8/93
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14-15/9/93
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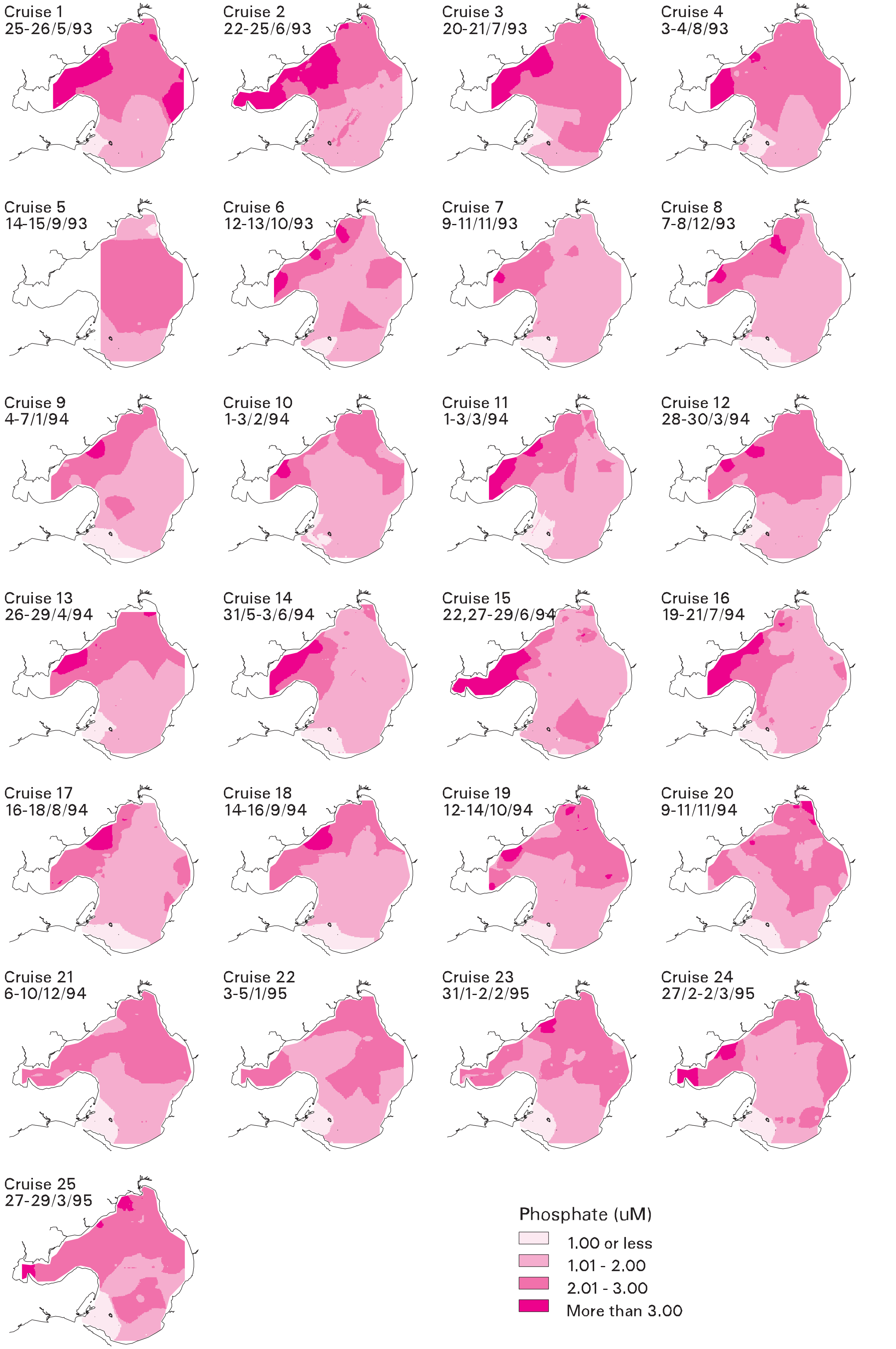
12-13/10/93
Cruise 7
9-11/11/93
Cruise 8
7-8/12/93
Cruise 9
4-7/1/94
Cruise 10
1-3/2/94
Cruise 11
1-3/3/94
Cruise 12
28-30/3/94
Cruise 13
26-29/4/94
Cruise 14
31/5-3/6/94
Cruise 15
22,27-29/6/94
Cruise 16
19-21/7/94
Cruise 17
16-18/8/94
Cruise 18
14-16/9/94
Cruise 19
12-14/10/94
Cruise 20
9-11/11/94
Cruise 21
6-10/12/94
Cruise 22
3-5/1/95
Cruise 23
31/1-2/2/95
Cruise 24
27/2-2/3/95
Cruise 25
27-29/3/95
Oxidised Nitrogen (uM)
0.20 or less
0.21 - 0.50
0.51 - 1.00
More than 1.00


Cruise 1
25-26/5/93
Cruise 2
22-25/6/93
Cruise 3
20-21/7/93
Cruise 4
3-4/8/93
Cruise 5
14-15/9/93
Cruise 6
12-13/10/93
Cruise 7
9-11/11/93
Cruise 8
7-8/12/93
Cruise 9
4-7/1/94
Cruise 10
1-3/2/94
Cruise 11
1-3/3/94
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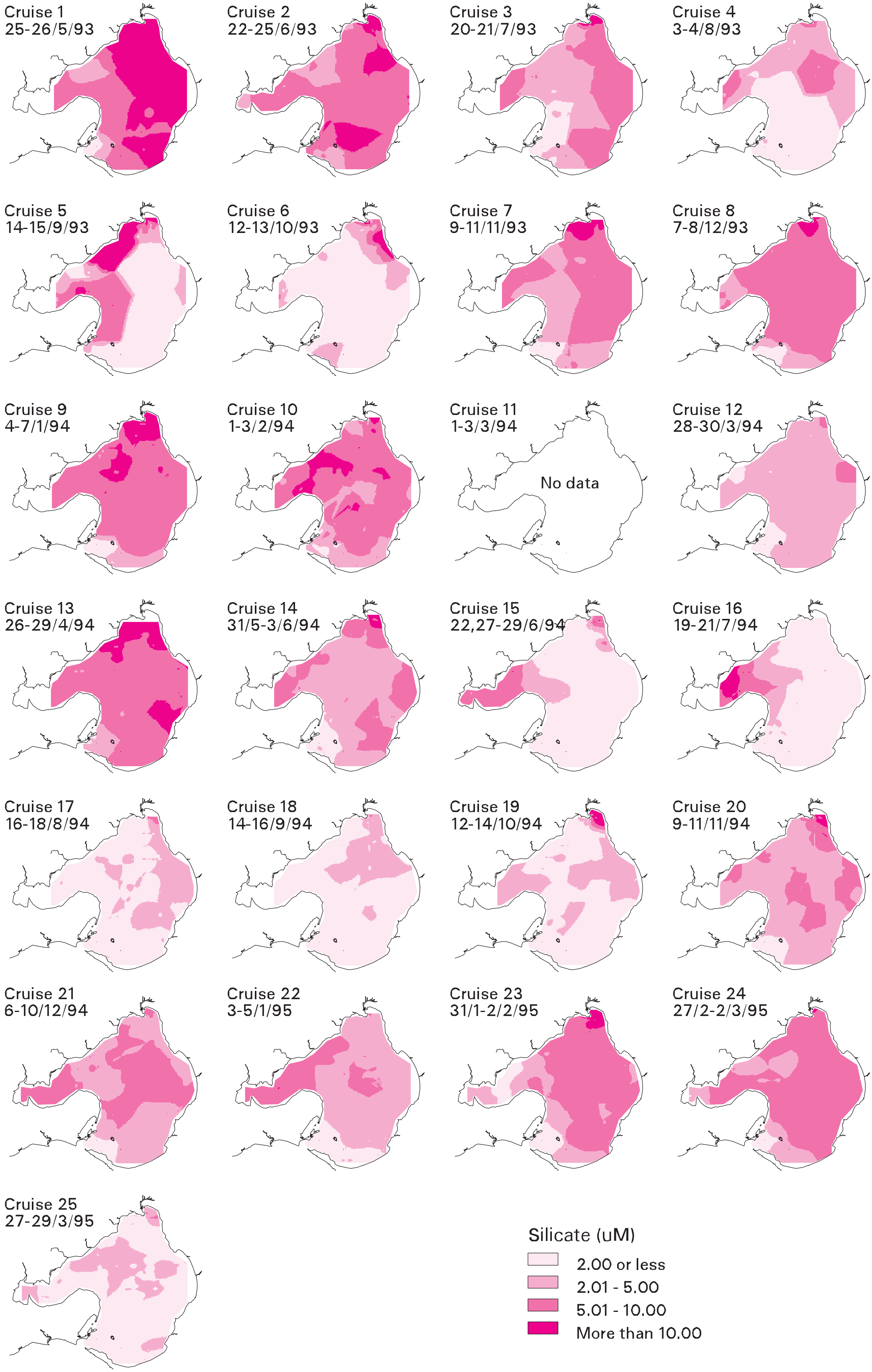
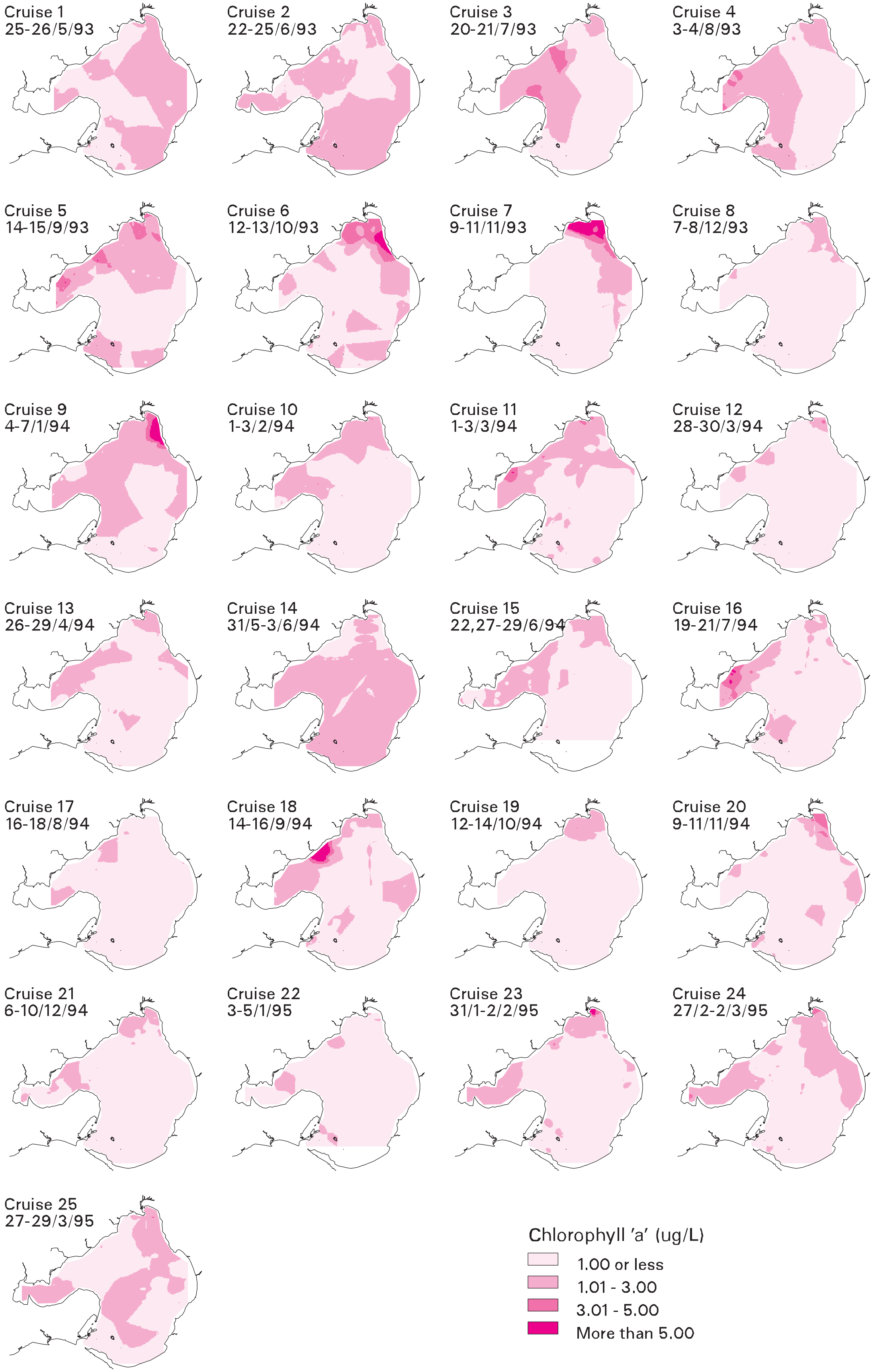
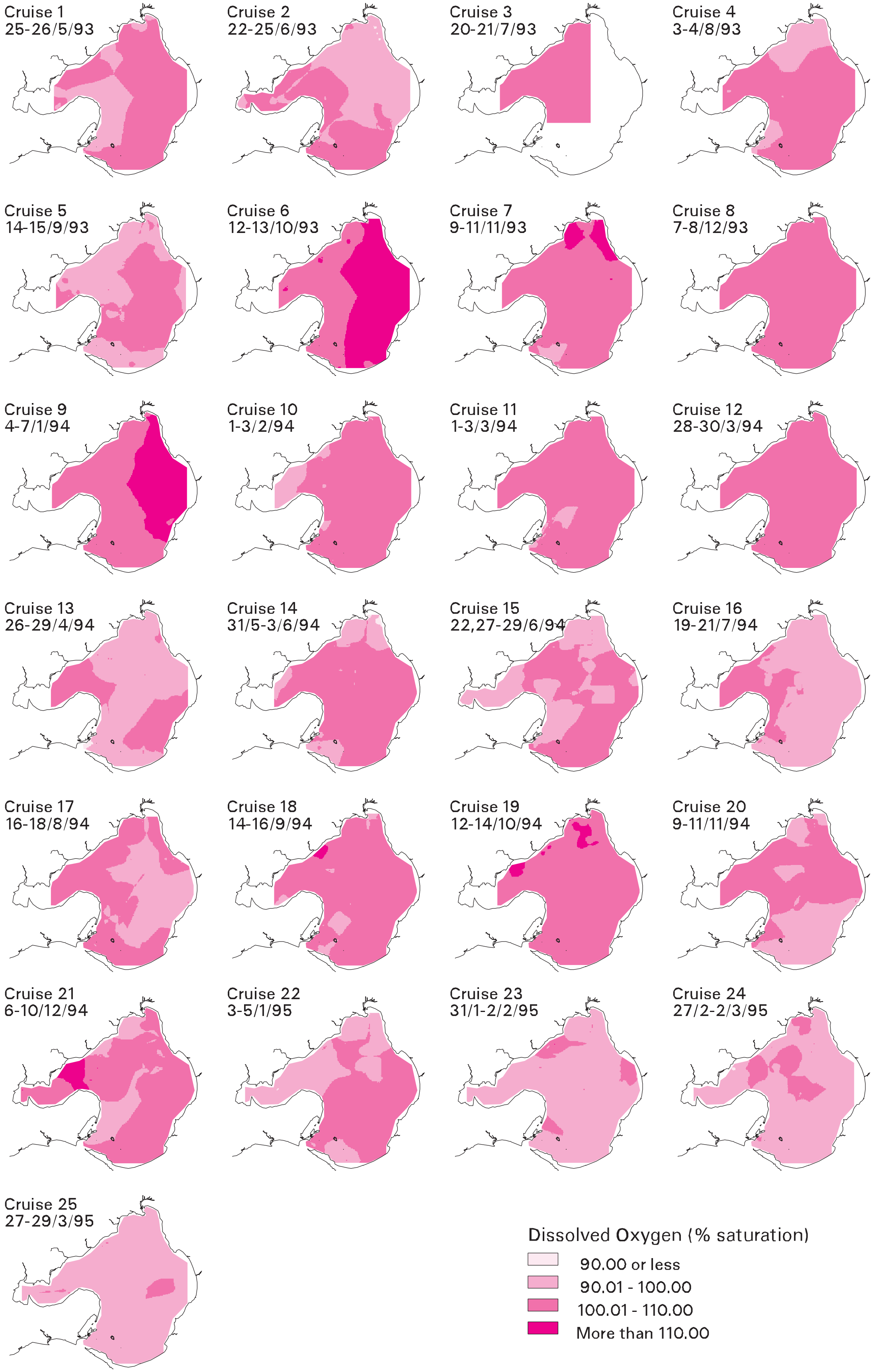
28-30/3/94
Cruise 13
26-29/4/94
Cruise 14
31/5-3/6/94
Cruise 15
22,27-29/6/94
Cruise 16
19-21/7/94
Cruise 17
16-18/8/94
Cruise 18
14-16/9/94
Cruise 19
12-14/10/94
Cruise 20
9-11/11/94
Cruise 21
6-10/12/94
Cruise 22
3-5/1/95
Cruise 23
31/1-2/2/95
Cruise 24
27/2-2/3/95
Cruise 25
27-29/3/95
Phosphate (uM)
1.00 or less
1.01 - 2.00
2.01 - 3.00
More than 3.00


Cruise 1
25-26/5/93
Cruise 2
22-25/6/93
Cruise 3
20-21/7/93
Cruise 4
3-4/8/93
Cruise 5
14-15/9/93
Cruise 6
12-13/10/93
Cruise 7
9-11/11/93
Cruise 8
7-8/12/93
Cruise 9
4-7/1/94
Cruise 10
1-3/2/94
Cruise 11
1-3/3/94
No data
Cruise 12
28-30/3/94
Cruise 13
26-29/4/94
Cruise 14
31/5-3/6/94
Cruise 15
22,27-29/6/94
Cruise 16
19-21/7/94
Cruise 17
16-18/8/94
Cruise 18
14-16/9/94
Cruise 19
12-14/10/94
Cruise 20
9-11/11/94
Cruise 21
6-10/12/94
Cruise 22
3-5/1/95
Cruise 23
31/1-2/2/95
Cruise 24
27/2-2/3/95
Cruise 25
27-29/3/95
Silicate (uM)
2.00 or less
2.01 - 5.00
5.01 - 10.00
More than 10.00


Cruise 1
25-26/5/93
Cruise 2
22-25/6/93
Cruise 3
20-21/7/93
Cruise 4
3-4/8/93
Cruise 5
14-15/9/93
Cruise 6
12-13/10/93
Cruise 7
9-11/11/93
Cruise 8
7-8/12/93
Cruise 9
4-7/1/94
Cruise 10
1-3/2/94
Cruise 11
1-3/3/94
Cruise 12
28-30/3/94
Cruise 13
26-29/4/94
Cruise 14
31/5-3/6/94
Cruise 15
22,27-29/6/94
Cruise 16
19-21/7/94
Cruise 17
16-18/8/94
Cruise 18
14-16/9/94
Cruise 19
12-14/10/94
Cruise 20
9-11/11/94
Cruise 21
6-10/12/94
Cruise 22
3-5/1/95
Cruise 23
31/1-2/2/95
Cruise 24
27/2-2/3/95
Cruise 25
27-29/3/95
Chlorophyll 'a' (ug/L)
1.00 or less
1.01 - 3.00
3.01 - 5.00
More than 5.00


Cruise 1
25-26/5/93
Cruise 2
22-25/6/93
Cruise 3
20-21/7/93
Cruise 4
3-4/8/93
Cruise 5
14-15/9/93
Cruise 6
12-13/10/93
Cruise 7
9-11/11/93
Cruise 8
7-8/12/93
Cruise 9
4-7/1/94
Cruise 10
1-3/2/94
Cruise 11
1-3/3/94
Cruise 12
28-30/3/94
Cruise 13
26-29/4/94
Cruise 14
31/5-3/6/94
Cruise 15
22,27-29/6/94
Cruise 16
19-21/7/94
Cruise 17
16-18/8/94
Cruise 18
14-16/9/94
Cruise 19
12-14/10/94
Cruise 20
9-11/11/94
Cruise 21
6-10/12/94
Cruise 22
3-5/1/95
Cruise 23
31/1-2/2/95
Cruise 24
27/2-2/3/95
Cruise 25
27-29/3/95
Dissolved Oxygen (% saturation)
90.00 or less
90.01 - 100.00
100.01 - 110.00
More than 110.00

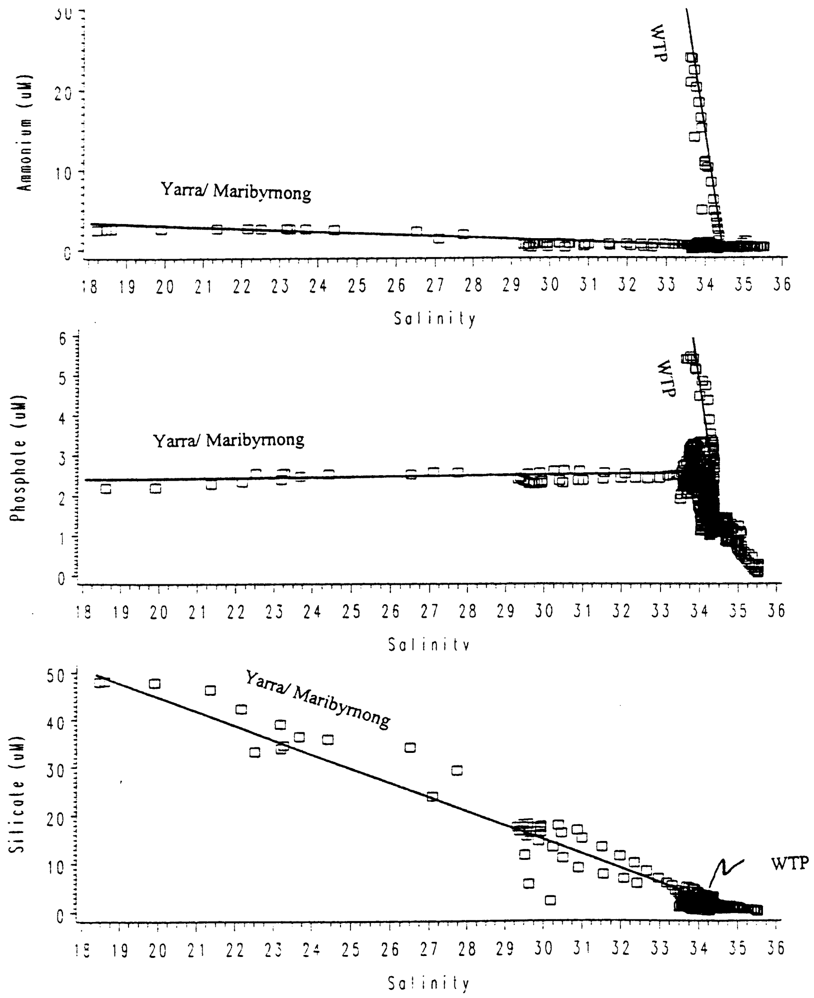


Figure 84: Identification of multiple nutrient sources from property/property plots (October 1994).

Table 14. Variation of mean values with depth: site 1 (Blairgowrie, southern PPB). S= 0-6 m; M= 6-12 m; B= 12-18 m.

Date	Ammonium (µM)			Nitrite (µM)			Nitrite + nitrate (µM)			Phosphate (µM)			Silicate (µM)			Chlorophyll a (µg L⁻¹)			Salinity			Temperature (°C)			Dissolved oxygen (% satn)		
	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B
May-93	0.59	0.59	0.58	0.02	0.02	0.02	0.22	0.23	0.21	1.55	1.55	1.49	6.64	6.65	6.65	1.05	1.02	1.00	34.73	34.72	34.71	14.44	14.44	14.43	101.0	100.8	100.8
Jun-93	0.93	0.85	0.81	0.01	0.01	0.01	0.02	0.05	0.03	1.26	1.25	1.26	3.66	3.69	3.60	1.65	1.71	1.72	34.93	34.93	34.93	12.19	12.18	12.16	102.8	102.4	102.4
Jul-93	0.64	0.35	0.19	0.02	0.02	0.02	0.16	0.11	0.10	1.60	1.56	1.59	2.62	2.66	2.60	0.72	0.73	0.67	34.33	34.33	34.35	11.46	11.44	11.42	100.6	102.1	99.2
Aug-93	0.37	0.44	---	0.05	0.05	---	0.05	0.05	---	1.13	1.16	---	0.37	0.50	---	1.08	1.41	---	34.71	34.72	---	11.49	11.53	---	100.3	100.8	---
Sep-93	0.55	0.54	0.56	0.04	0.04	0.04	0.04	0.04	0.04	1.50	1.52	1.55	0.46	0.40	0.39	0.96	1.13	1.08	34.02	34.02	34.02	12.44	12.42	12.43	97.2	98.5	98.6
Oct-93	0.25	0.27	0.27	0.06	0.05	0.04	0.06	0.05	0.04	1.32	1.29	1.28	2.64	2.52	1.38	1.45	1.70	1.64	33.68	33.76	33.84	13.79	13.75	13.72	107.8	105.7	107.0
Nov-93	0.36	0.39	0.45	0.02	0.02	0.02	0.14	0.12	0.12	1.20	1.14	1.13	3.75	3.63	3.64	0.71	0.78	0.76	33.88	34.00	34.00	14.58	14.56	14.54	99.0	99.1	99.1
Dec-93	0.40	0.38	0.38	0.02	0.02	0.01	0.12	0.09	0.08	0.99	0.83	0.75	3.11	3.06	2.82	0.68	0.70	0.72	34.30	34.45	34.50	17.07	16.94	16.88	102.2	102.3	102.6
Jan-94	0.37	0.37	0.35	0.05	0.06	0.07	0.15	0.13	0.13	0.81	0.82	0.78	4.81	4.22	2.90	0.86	0.95	0.98	34.45	34.51	34.69	17.08	17.01	16.91	106.4	107.5	107.6
Feb-94	0.40	0.37	0.37	0.03	0.04	0.04	0.07	0.07	0.06	1.27	1.29	1.30	5.38	5.32	4.74	0.54	0.76	0.76	33.91	33.91	33.92	19.59	19.53	19.52	103.9	104.3	104.7
Mar-94	0.45	0.57	---	0.04	0.04	---	0.07	0.08	---	1.24	1.31	---	---	---	---	0.85	1.03	---	---	---	---	---	---	---	---	---	---
Mar-94-2	0.40	0.37	0.35	0.02	0.02	0.02	0.04	0.08	0.12	1.46	1.51	1.47	2.63	2.60	2.55	0.54	0.52	0.53	34.11	34.11	34.12	19.00	18.99	18.96	102.7	102.8	102.9
Apr-94	0.36	0.24	0.19	0.02	0.03	0.04	0.08	0.06	0.05	1.26	1.28	1.28	5.27	5.72	6.20	0.77	0.82	0.80	34.39	34.38	34.38	16.69	16.74	16.74	91.7	96.3	96.7
May-94	0.34	0.35	0.34	0.02	0.01	0.01	0.03	0.04	0.04	1.07	1.06	0.98	2.30	2.16	2.13	1.24	1.25	1.25	34.59	34.64	34.73	12.94	13.03	13.16	97.9	96.6	96.4
Jun-94	0.36	0.38	0.28	0.07	0.08	0.06	0.13	0.24	0.19	1.06	1.05	0.93	1.25	0.48	0.46	---	---	---	34.78	34.75	34.76	12.03	12.05	12.07	99.0	98.4	98.4
Jul-94	0.27	0.24	0.19	0.03	0.02	0.02	0.09	0.12	0.12	0.87	0.90	0.97	0.50	0.48	0.48	0.67	0.68	0.60	34.77	34.77	34.79	11.39	11.37	11.37	97.8	97.7	97.7
Aug-94	0.35	0.37	0.35	0.00	0.00	0.00	0.12	0.17	0.17	0.93	1.04	0.96	1.35	1.07	1.25	0.64	0.60	0.58	34.96	34.95	34.97	10.37	10.36	10.37	100.6	100.5	100.5
Sep-94	0.24	0.15	0.06	0.01	0.01	0.02	0.01	0.01	0.02	0.97	0.87	0.73	1.04	1.15	2.04	0.46	0.63	0.65	34.90	34.97	35.05	12.41	12.50	12.57	100.8	100.0	99.8
Oct-94	0.30	0.26	0.18	0.01	0.01	0.01	0.04	0.03	0.03	1.11	1.21	1.16	0.35	0.84	0.95	0.39	0.53	0.57	34.87	34.87	34.90	12.82	12.81	12.83	102.8	102.5	102.3
Nov-94	0.29	0.28	0.24	0.05	0.02	0.02	0.06	0.06	0.05	0.93	0.87	0.80	2.09	1.95	1.96	0.65	0.83	0.91	35.01	35.02	35.04	13.18	13.17	13.15	98.1	98.3	97.8
Dec-94	0.14	0.17	0.10	0.01	0.01	0.01	0.03	0.04	0.05	1.09	1.13	1.14	2.10	2.18	2.38	0.43	0.64	0.68	34.92	34.93	34.93	18.43	18.24	18.19	102.5	102.1	100.7
Jan-95	0.11	0.10	0.10	0.01	0.01	0.00	0.03	0.03	0.02	1.01	1.10	1.03	1.18	1.59	1.63	---	---	---	34.97	35.03	35.07	18.41	18.43	18.44	97.7	98.7	99.0
Feb-95	0.11	0.13	0.14	0.02	0.02	0.02	0.03	0.04	0.06	1.17	1.14	1.11	3.63	3.59	3.53	0.82	0.82	0.81	35.09	35.11	35.12	20.29	20.16	20.11	97.1	96.8	97.0
Mar-95	0.22	0.21	0.25	0.02	0.02	0.03	0.07	0.09	0.10	1.04	1.03	1.05	3.21	3.18	3.19	0.71	0.72	0.62	35.31	35.32	35.33	21.19	21.17	21.14	98.4	98.2	97.2
Mar-95-2	0.27	0.27	0.30	0.03	0.02	0.02	0.10	0.13	0.14	1.08	1.07	1.05	1.60	1.47	1.45	0.58	0.52	0.48	35.43	35.44	35.43	17.53	17.48	17.48	97.6	97.1	97.0
Min	0.11	0.10	0.06	0.00	0.00	0.00	0.01	0.01	0.02	0.81	0.82	0.73	0.35	0.40	0.39	0.39	0.52	0.48	33.68	33.76	33.84	10.37	10.36	10.37	91.7	96.3	96.4
Max	0.93	0.85	0.81	0.07	0.08	0.07	0.22	0.24	0.21	1.60	1.56	1.59	6.64	6.65	6.65	1.65	1.71	1.72	35.43	35.44	35.43	21.19	21.17	21.14	107.8	107.5	107.6
Mean	0.36	0.35	0.31	0.03	0.03	0.02	0.08	0.09	0.09	1.16	1.16	1.12	2.58	2.55	2.56	0.80	0.89	0.85	34.63	34.65	34.68	15.03	15.01	15.16	100.2	100.4	100.2

Percentage of differences between depths exceeding the estimated analytical error.

	Ammonium	Nitrite	Nitrite + nitrate	Phosphate	Silicate	Chlorophyll a	Salinity	Temperature	Dissolved oxygen
Estimated accuracy	±0.08	±0.03	±0.05	±0.10	±0.20	±0.10	±0.05	±0.03	±1.0
No difference	64	100	88	88	52	56	72	36	60
Surface max	24	0	4	4	28	0	0	48	16
Mid max	8	0	4	8	0	20	0	4	4
Bottom max	4	0	4	0	20	24	28	16	20

Table 14: Variation of mean values with depth: site 1 (Blairgowrie).

Table 15. Variation of mean value with depth: site 4 (Wooley Reef, eastern PPB). S= 0-5 m; M=5-10 m; B=10-14 m.

Date	Ammonium (µM)			Nitrite (µM)			Nitrite + nitrate (µM)			Phosphate (µM)			Silicate (µM)			Chlorophyll a (µg L⁻¹)			Salinity			Temperature (°C)			Dissolved oxygen (% satn)		
	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B
May-93	0.84	0.68	0.62	0.02	0.02	0.01	0.10	0.13	0.08	------	------	------	10.68	11.04	11.47	1.78	1.79	1.65	33.28	33.67	33.75	13.91	14.23	14.28	105.9	103.9	102.5
Jun-93	0.99	0.86	------	0.11	0.11	0.11	0.98	0.96	0.93	------	------	------	10.08	9.73	------	1.72	1.95	1.92	33.83	33.86	34.10	11.27	11.29	11.45	98.6	98.0	97.6
Jul-93	0.62	1.04	0.94	0.01	0.01	0.02	0.14	0.17	0.20	2.29	2.64	2.41	6.79	6.69	7.11	0.69	0.97	0.97	33.63	33.69	33.87	11.07	11.12	11.33	108.3	108.0	104.4
Aug-93	0.53	0.40	0.38	0.05	0.06	0.06	0.06	0.06	0.06	2.20	2.26	2.23	4.04	4.29	4.52	0.76	0.94	0.85	33.84	33.89	33.97	11.14	11.12	11.11	102.2	101.4	99.90
Sep-93	0.44	0.46	0.46	0.03	0.03	0.02	0.03	0.03	0.01	2.09	2.13	2.13	1.82	1.90	3.43	0.72	1.18	3.34	33.76	33.79	33.95	12.07	12.03	11.91	97.3	97.7	91.2
Oct-93	0.34	0.35	0.38	0.10	0.07	0.08	0.16	0.07	0.09	1.74	1.81	1.91	0.93	1.03	2.95	1.47	2.71	3.27	32.62	32.74	32.86	14.11	13.86	13.91	111.5	110.1	102.6
Nov-93	0.72	0.72	0.75	0.05	0.04	0.04	0.13	0.11	0.11	1.78	1.75	1.72	7.42	7.40	7.40	0.60	0.63	0.51	32.74	33.05	33.07	15.04	15.00	15.01	98.9	96.9	96.4
Dec-93	0.24	0.21	0.20	0.02	0.01	0.02	0.05	0.03	0.04	1.83	1.77	1.78	7.83	7.77	8.71	0.64	1.34	1.47	32.71	32.66	32.75	17.92	17.46	17.33	102.7	102.4	99.8
Jan-94	0.31	0.35	------	0.02	0.02	------	0.13	0.13	------	1.82	1.81	------	7.22	7.05	------	2.69	3.39	------	32.13	32.27	------	18.23	18.04	------	111.5	111.7	------
Feb-94	0.23	0.24	0.25	0.02	0.00	0.00	0.02	0.01	0.01	1.93	1.92	1.97	9.11	8.89	7.61	0.58	1.15	1.16	33.06	33.15	33.16	19.90	19.41	19.41	105.9	105.5	105.7
Mar-94	0.30	0.31	0.35	0.05	0.06	0.09	0.13	0.11	0.11	1.79	1.79	1.82	------	------	------	0.83	1.25	1.28	33.31	33.31	33.30	20.11	19.51	19.46	102.3	102.3	102.6
Mar-94-2	0.32	0.30	0.26	0.04	0.04	0.05	0.05	0.06	0.06	1.87	1.93	1.86	3.59	3.75	4.57	0.34	0.49	0.96	33.48	33.47	33.51	18.82	18.49	18.42	104.4	104.2	102.8
Apr-94	0.33	0.34	0.31	0.02	0.03	0.02	0.10	0.09	0.10	1.91	1.96	1.90	10.41	10.29	10.65	0.57	0.77	0.80	33.46	33.48	33.48	16.78	16.77	16.76	105.0	106.2	105.7
May-94	0.27	0.31	0.29	0.04	0.03	0.04	0.04	0.05	0.04	1.96	1.76	1.83	4.99	5.04	5.72	1.21	1.28	1.30	33.91	33.93	33.94	13.17	12.92	12.92	102.6	101.5	101.4
Jun-94	0.33	0.33	0.35	------	------	------	0.15	0.07	0.06	1.98	1.92	1.89	0.68	0.69	1.00	------	------	------	33.93	33.97	34.10	11.60	11.62	11.78	100.6	100.2	97.7
Jul-94	0.33	0.30	0.32	0.01	0.01	0.01	0.05	0.05	0.05	2.03	2.06	2.05	0.62	0.57	0.61	0.73	0.85	0.76	33.93	33.93	33.93	10.99	10.98	10.96	99.2	99.0	97.7
Aug-94	0.36	0.31	0.44	0.11	0.07	0.04	0.18	0.16	0.14	1.96	1.94	1.96	2.75	2.45	2.51	0.79	1.11	1.76	33.64	33.71	33.91	9.82	9.66	9.61	101.5	100.1	93.9
Sep-94	0.32	0.28	0.26	0.00	0.00	0.01	0.06	0.06	0.05	1.57	1.50	1.40	0.87	1.02	1.05	1.43	1.25	1.12	34.04	34.04	34.06	11.99	12.03	12.07	102.9	102.7	102.6
Oct-94	0.25	0.27	0.27	0.01	0.01	0.01	0.04	0.04	0.04	1.23	1.55	1.62	2.49	2.52	2.29	0.32	0.41	0.77	34.02	34.02	34.14	12.57	12.40	11.89	103.5	103.0	98.6
Nov-94	0.31	0.36	0.42	0.03	0.02	0.03	0.09	0.08	0.08	2.03	2.03	1.97	6.03	5.89	4.67	0.71	1.49	1.40	34.17	34.17	34.10	14.29	14.08	13.35	99.5	99.1	95.8
Dec-94	0.19	0.26	0.23	0.01	0.01	0.01	0.03	0.03	0.02	1.90	1.96	1.94	5.24	5.54	5.81	0.20	0.40	0.84	34.36	34.38	34.39	19.37	17.96	17.41	106.1	104.8	104.8
Jan-95	0.06	0.09	0.11	0	0.01	0.01	0.04	0.04	------	1.84	1.98	1.93	3.55	3.08	3.23	------	------	------	34.65	------	34.69	19.90	------	18.95	102.8	------	102.2
Feb-95	0.27	0.21	0.22	0.01	0.01	0.03	0.05	0.04	0.04	1.89	1.93	1.96	6.30	6.89	6.98	0.36	0.62	0.75	34.69	34.69	34.69	21.07	21.04	20.99	97.9	98.0	97.8
Mar-95	0.25	0.20	0.22	0.01	0.02	0.02	0.08	0.06	0.07	2.25	1.90	2.13	8.15	7.70	8.03	1.29	1.31	1.31	34.86	34.86	34.86	1.37	21.39	21.36	98.2	97.9	97.0
Mar-95-2	0.19	0.24	0.24	0.03	0.03	0.03	0.33	0.38	0.35	1.78	1.83	1.84	1.42	1.25	1.02	0.65	0.83	1.02	------	------	------	------	------	------	------	------	------
Min	0.06	0.09	0.11	0.00	0.00	0.00	0.02	0.01	0.01	1.23	1.50	1.40	0.62	0.57	0.61	0.20	0.40	0.51	32.13	32.27	32.75	1.37	9.66	9.61	97.3	96.9	91.2
Max	0.99	1.04	0.94	0.11	0.11	0.11	0.98	0.96	0.93	2.29	2.64	2.41	10.68	11.04	11.47	2.69	3.39	3.34	34.86	34.86	34.86	21.07	21.39	21.36	111.5	111.7	105.7
Mean	0.37	0.38	0.36	0.03	0.03	0.03	0.13	0.12	0.12	1.90	1.92	1.92	5.13	5.10	5.06	0.92	1.22	1.33	33.67	33.68	33.85	14.44	14.89	14.86	102.8	102.4	100.0

Percentage of differences between depths exceeding the estimated analytical error.

	Ammonium	Nitrite	Nitrite + nitrate	Phosphate	Silicate	Chlorophyll a	Salinity	Temperature	Dissolved oxygen
Estimated accuracy	±0.08	±0.03	±0.05	±0.10	±0.20	±0.10	±0.05	±0.03	±1.0
No difference	76	96	88	72	16	16	48	28	40
Surface max	12	4	8	12	32	4	4	56	48
Mid max	8	0	0	8	4	28	0	0	12
Bottom max	4	0	4	8	48	52	48	16	0

Table 15: Variation of mean values with depth: site 4 (Wooley Reef).

Table 16. Variation of mean value with depth: site 6 (Sandringham, north-eastern PPB). S= 0-3 m; M=3-6 m; B= 6-8 m.																														
Date	Ammonium			Nitrite			Nitrite + nitrate			Phosphate			Silicate			Chlorophyll a			Salinity			Temperature			Dissolved oxygen		
		(μM)			(μM)			(μM)			(μM)			(μM)			(μg L⁻¹)						(°C)			(% satn)	
	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B
May-93	1.01	0.94	0.82	0.02	----	0.03	0.05	----	1.00	----	----	2.87	----	----	13.27	1.48	1.64	1.63	32.89	33.30	33.41	14.05	14.12	14.10	103.5	102.5	102.2
Jun-93	1.27	0.65	0.71	0.02	0.01	0.01	0.08	0.08	0.08	2.34	2.35	2.33	9.40	9.64	9.60	0.81	0.92	0.97	34.23	34.24	34.24	11.61	11.59	11.57	99.0	96.6	95.6
Jul-93	0.24	0.23	0.23	0.02	0.02	0.02	0.09	0.31	0.11	2.19	2.15	2.16	8.52	7.45	7.07	0.85	0.83	0.73	33.57	33.85	34.03	11.41	11.29	11.40	106.7	106.9	105.5
Aug-93	0.29	0.26	0.24	0.03	0.04	0.04	0.05	0.04	0.05	2.28	2.32	2.32	3.70	3.91	3.96	1.79	1.76	1.83	33.75	33.74	33.78	11.03	11.03	11.02	103.7	103.6	103.50
Sep-93	0.53	0.52	0.48	0.04	0.04	0.04	0.38	0.36	0.18	2.28	2.26	2.14	2.57	2.53	1.65	3.04	3.12	2.78	33.11	33.36	33.68	12.05	12.04	12.02	93.8	93.9	93.6
Oct-93	0.37	0.35	0.30	0.12	0.05	0.05	0.85	0.10	0.11	1.43	1.90	1.88	9.78	3.20	3.05	6.38	2.05	2.43	31.60	33.18	33.17	13.84	13.77	13.71	117.4	107.5	106.2
Nov-93	0.23	0.27	0.60	0.01	0.01	0.02	0.04	0.04	0.17	1.56	1.65	1.92	8.73	6.31	5.74	5.16	3.90	2.64	30.06	31.75	32.27	15.30	14.98	15.03	114.6	107.6	97.5
Dec-93	0.45	1.07	1.74	0.04	0.03	0.02	0.05	0.03	0.02	1.64	1.83	1.84	8.06	8.16	8.17	1.19	1.68	1.79	32.45	32.49	32.47	18.31	18.33	18.36	104.3	104.2	104.5
Jan-94	0.23	0.24	0.27	0.05	0.03	0.04	0.20	0.20	0.22	1.86	2.06	2.09	8.68	7.73	8.32	6.35	4.27	3.34	30.64	31.95	32.31	18.59	17.98	18.04	127.3	115.2	109.0
Feb-94	0.49	0.61	0.65	0.05	0.05	0.05	0.10	0.09	0.06	2.28	2.34	2.43	12.59	11.27	10.74	1.17	1.66	0.82	32.83	32.83	32.96	20.23	20.20	19.71	100.8	101.0	95.6
Mar-94	0.43	0.48	0.52	0.04	0.04	0.07	0.29	0.30	0.30	2.11	2.16	2.16	----	----	----	1.05	2.20	2.97	32.94	32.92	32.89	19.81	19.61	19.57	102.3	102.1	101.8
Mar-94-2	----	----	----	0.01	0.01	0.02	0.17	0.17	0.18	2.24	2.29	2.34	4.37	4.50	7.01	0.62	0.71	1.13	32.99	33.01	33.42	19.14	19.12	18.68	98.0	97.9	90.4
Apr-94	0.26	0.22	0.23	0.03	0.02	0.03	0.04	0.03	0.03	2.36	2.39	2.35	12.64	12.64	12.92	0.90	0.94	0.94	33.35	33.33	33.34	16.21	16.19	16.18	99.5	99.4	99.4
May-94	0.19	0.20	0.25	0.05	0.06	0.04	0.06	0.05	0.07	1.88	1.92	1.98	6.24	5.73	5.58	0.97	0.98	0.94	33.92	33.92	34.07	12.78	12.70	12.95	99.5	99.6	94.9
Jun-94	0.65	0.53	0.39	0.12	0.08	0.06	2.67	1.39	0.30	1.82	1.77	2.00	7.06	2.53	1.27	1.00	1.17	1.64	32.16	33.81	34.17	10.62	11.19	11.54	96.9	97.2	94.1
Jul-94	0.15	0.33	0.23	0.06	0.06	0.08	0.31	0.45	0.40	1.81	1.83	1.68	1.26	1.44	1.66	2.23	2.37	2.63	33.41	33.37	33.49	10.90	10.90	10.88	99.0	98.7	99.1
Aug-94	0.38	0.38	0.33	0.09	0.08	0.04	1.13	1.25	0.73	1.89	1.97	1.87	3.76	3.72	2.50	0.53	0.69	0.53	33.60	33.68	34.25	9.87	9.78	9.79	100.8	100.6	99.7
Sep-94	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	0.59	1.07	1.06	33.95	33.97	34.12	12.22	12.11	11.83	101.0	100.8	100.3
Oct-94	0.24	0.30	0.37	0.03	0.02	0.01	0.15	0.14	0.15	2.29	2.38	2.34	4.15	4.10	3.73	0.51	0.60	0.58	33.98	34.01	34.06	12.73	12.46	12.43	101.5	100.4	99.1
Nov-94	0.33	0.43	0.57	0.09	0.08	0.05	0.25	0.28	0.25	2.78	3.36	3.03	7.04	5.50	5.35	2.77	3.90	1.60	33.58	34.14	34.39	14.56	13.85	13.77	103.2	97.5	93.8
Dec-94	0.37	0.38	0.37	0.02	0.01	0.01	0.04	0.03	0.03	2.12	2.15	2.14	4.02	4.12	4.32	0.54	0.65	0.72	34.24	34.26	34.27	18.24	18.17	18.14	99.0	98.5	98.7
Jan-95	0.10	0.10	0.08	0.02	0.02	0.02	0.06	0.03	0.04	2.19	2.29	2.32	2.72	3.24	4.25	----	----	----	34.22	34.47	34.68	21.12	21.00	20.31	97.7	96.8	90.8
Feb-95	0.13	0.16	0.25	0.02	0.03	0.04	0.23	0.12	0.45	2.05	2.07	2.07	8.92	8.82	8.82	0.88	1.08	1.09	34.64	34.64	34.63	21.21	21.19	21.18	95.5	95.4	95.2
Mar-95	0.14	0.17	0.21	0.03	0.03	0.03	0.05	0.09	0.09	2.34	2.36	2.36	8.72	8.92	9.00	1.59	1.54	1.61	34.99	34.98	34.96	21.14	21.10	21.05	96.4	98.1	95.7
Mar-95-2	0.19	0.18	0.20	0.02	0.01	0.01	0.09	0.04	0.04	2.36	2.26	2.17	0.64	0.49	0.24	0.95	1.33	1.34	35.17	35.19	35.19	17.82	17.80	17.75	99.6	99.1	98.9
Min	0.10	0.10	0.08	0.01	0.01	0.01	0.04	0.03	0.02	1.43	1.65	1.68	0.64	0.49	0.24	0.51	0.60	0.53	30.06	31.75	32.27	9.87	9.78	9.79	93.8	93.9	90.4
Max	1.27	1.07	1.74	0.12	0.08	0.08	2.67	1.39	1.00	2.78	3.36	3.03	12.64	12.64	13.27	6.38	4.27	3.34	35.17	35.19	35.19	21.21	21.19	21.18	127.3	115.2	109.0
Mean	0.38	0.39	0.44	0.04	0.04	0.03	0.31	0.24	0.21	2.09	2.18	2.20	6.53	5.73	6.01	1.81	1.71	1.57	33.29	33.62	33.77	15.39	15.30	15.24	102.4	100.8	98.6
Percentage of differences between depths exceeding the estimated analytical error.																											
Estimated accuracy		±0.08			±0.03			±0.05			±0.10			±0.20			±0.10			±0.05			±0.03			±1.0	
No difference		56			84			64			56			24			28			36			20			44	
Surface max		12			16			12			8			48			16			0			60			56	
Mid max		4			0			12			12			4			24			0			8			0	
Bottom max		28			0			12			24			24			32			64			12			0	

Table 16: Variation of mean values with depth: site 6 (Sandringham).

Table 17. Variation of mean value with depth: site 9 (Williamstown, northern PPB). S= 0-4 m; M=4-7 m; B= 7-12 m.																														
Date	Ammonium			Nitrite			Nitrite + nitrate			Phosphate			Silicate			Chlorophyll a			Salinity			Temperature			Dissolved oxygen		
		(μM)			(μM)			(μM)			(μM)			(μM)			(μg L⁻¹)						(°C)			(% satn)	
	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B
May-93	1.58	1.20	0.42	0.24	0.09	----	5.65	2.10	0.35	4.18	3.38	2.33	19.95	14.34	11.54	1.17	1.19	1.14	32.31	33.82	33.91	14.52	14.46	14.50	93.3	95.1	96.3
Jun-93	0.70	0.66	1.06	0.04	0.05	0.06	0.53	0.44	0.36	2.55	2.52	2.48	10.32	9.96	9.12	1.44	1.50	1.13	34.02	34.20	34.26	11.89	11.62	11.33	93.9	89.7	88.4
Jul-93	1.82	0.78	0.52	0.14	0.07	0.07	6.16	0.41	0.96	2.83	2.52	2.62	15.73	4.52	5.28	1.05	1.24	1.37	30.87	33.95	34.04	11.56	11.39	11.33	97.4	97.2	95.6
Aug-93	0.93	0.44	0.71	0.15	0.05	0.02	5.14	0.96	0.48	2.59	2.48	2.41	11.34	4.86	4.45	2.86	2.48	2.08	32.94	33.59	33.72	11.25	11.10	10.97	96.3	96.1	94.9
Sep-93	2.30	1.14	0.74	0.49	0.26	0.22	8.48	3.11	1.72	2.84	2.48	2.51	29.66	9.48	3.45	2.36	2.11	3.92	25.78	31.47	32.31	12.96	12.57	12.42	92.6	93.1	67.1
Oct-93	2.41	0.28	0.35	0.26	0.01	0.01	9.14	0.46	0.28	2.00	2.07	2.05	56.80	2.26	2.51	3.64	5.09	4.70	30.23	33.08	33.12	14.34	14.45	14.23	102.4	107.1	101.5
Nov-93	1.84	1.30	0.86	0.08	0.01	0.01	1.86	0.35	0.18	2.20	2.22	2.32	18.31	4.36	3.85	2.49	1.93	2.33	28.35	32.13	32.24	15.03	15.11	15.14	98.0	100.6	102.2
Dec-93	1.25	0.85	1.54	0.20	0.08	0.08	4.51	0.92	0.34	2.37	2.16	2.31	21.62	11.25	10.91	2.13	1.52	1.19	28.31	31.53	32.05	19.36	18.40	18.05	98.2	97.9	91.7
Jan-94	0.78	0.57	0.66	0.08	0.04	0.02	1.53	1.03	0.41	2.31	2.32	2.49	14.99	10.07	9.69	3.07	3.13	2.94	29.74	32.08	32.16	18.04	18.02	17.95	104.8	102.6	100.7
Feb-94	1.56	1.93	1.75	0.08	0.04	0.03	1.86	0.76	0.48	2.59	2.67	2.94	18.32	15.09	14.78	2.50	1.60	1.23	31.08	31.94	32.92	21.55	21.20	20.04	100.3	96.8	93.1
Mar-94	2.92	1.11	0.85	0.28	0.12	0.13	4.87	0.74	0.58	2.74	2.41	2.31	----	----	----	2.09	2.03	2.01	27.27	32.84	32.97	19.59	19.54	19.34	98.4	97.0	97.3
Mar-94-2	----	----	----	0.03	0.02	0.03	0.19	0.10	0.13	2.71	2.69	2.71	8.29	7.54	7.51	2.86	2.18	1.28	32.36	33.28	33.38	20.09	19.12	18.81	89.4	97.8	84.2
Apr-94	0.86	0.93	0.77	0.04	0.03	0.07	0.22	0.43	0.32	2.51	2.65	2.32	12.02	13.25	13.61	1.65	1.12	1.17	33.12	33.42	33.46	16.71	16.61	16.61	99.1	99.2	99.1
May-94	1.67	0.88	0.66	0.21	0.10	0.05	1.74	1.16	0.21	2.24	2.21	2.12	17.40	9.87	5.98	0.96	0.79	0.81	31.63	33.97	34.01	13.32	12.93	12.89	98.9	103.1	104.2
Jun-94	1.63	0.49	0.46	0.14	0.04	0.04	7.54	1.48	0.12	2.04	2.10	2.06	18.71	1.49	0.97	1.51	1.46	1.61	30.81	34.05	34.08	12.14	11.51	11.46	94.0	94.6	94.8
Jul-94	0.84	0.52	----	0.09	0.10	0.09	----	----	----	2.01	1.86	----	----	----	----	1.22	1.09	1.03	33.15	34.06	34.10	11.12	10.94	10.92	92.8	93.1	96.0
Aug-94	1.79	0.64	0.80	0.22	0.02	0.02	9.79	2.22	0.42	2.52	2.76	2.80	22.87	1.80	0.93	0.92	0.59	0.56	32.18	34.21	34.21	9.70	9.43	9.42	98.7	97.6	96.7
Sep-94	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	1.68	2.31	2.51	32.88	34.20	34.22	12.20	11.95	11.91	97.5	98.8	99.2
Oct-94	0.57	0.26	0.30	0.08	0.05	0.04	3.10	0.78	0.03	2.41	2.78	2.96	14.10	4.20	2.57	1.66	1.41	1.47	32.52	33.75	33.84	13.06	12.97	12.96	102.2	102.6	103.1
Nov-94	2.65	1.41	1.14	0.46	0.31	0.23	10.09	3.67	1.10	3.16	3.47	3.32	38.26	9.71	6.22	2.19	4.44	4.05	30.28	34.22	34.42	14.67	13.51	13.47	93.9	93.1	93.6
Dec-94	0.40	0.33	0.32	0.01	0.01	0.02	0.10	0.06	0.03	2.50	2.45	2.44	7.34	6.62	7.01	1.91	1.90	2.06	34.09	34.10	34.22	18.06	18.04	17.75	102.8	104.0	99.9
Jan-95	0.04	0.02	0.28	0.03	0.01	0.03	0.08	0.04	0.09	2.42	2.30	2.61	6.36	5.43	6.73	----	----	----	34.42	34.72	34.82	20.88	20.33	20.26	87.5	87.1	86.6
Feb-95	2.68	0.32	0.25	0.36	0.02	0.03	6.11	1.01	0.66	2.63	2.55	2.49	24.78	11.95	10.76	3.60	2.64	1.98	----	----	----	----	----	----	----	----	----
Mar-95	0.53	0.46	0.26	0.04	0.04	0.03	0.14	0.13	0.06	2.62	2.67	2.65	9.22	9.20	9.01	3.71	4.30	4.34	34.60	34.63	34.64	22.36	22.24	22.20	95.0	97.2	97.8
Mar-95-2	0.69	0.24	0.20	0.10	0.06	0.04	0.46	0.27	0.07	2.70	2.66	2.63	6.31	3.07	2.17	2.11	1.57	1.21	34.54	34.50	34.64	18.58	18.03	18.06	92.8	97.4	97.0
Min	0.04	0.02	0.20	0.01	0.01	0.01	0.08	0.04	0.03	2.00	1.86	2.05	6.31	1.49	0.93	0.92	0.59	0.56	25.78	31.47	32.05	9.70	9.43	9.42	87.5	87.1	67.1
Max	2.92	1.93	1.75	0.49	0.31	0.23	10.09	3.67	1.72	4.18	3.47	3.32	56.80	15.09	14.78	3.71	5.09	4.70	34.60	34.72	34.82	22.36	22.24	22.20	104.8	107.1	104.2
Mean	1.41	0.73	0.68	0.16	0.07	0.06	3.88	0.98	0.41	2.57	2.52	2.52	18.30	7.74	6.78	2.12	2.07	2.01	31.56	33.49	33.66	15.54	15.23	15.08	96.7	97.5	95.0
Percentage of differences between depths exceeding the estimated analytical error.																											
Estimated accuracy		±0.08			±0.03			±0.05			±0.10			±0.20			±0.10			±0.05			±0.03			±1.0	
No difference		12			28			8			40			12			12			4			4			28	
Surface max		72			72			88			28			80			48			0			88			36	
Mid max		8			0			4			8			0			16			0			4			12	
Bottom max		8			0			0			24			8			24			96			4			24	

Table 17: Variation of mean values with depth: site 9 (Williamstown).

Table 18. Variation of mean value with depth: site 11 (Werribee River, westem PPB). S= 0-3 m; M=3-5 m; B= 5-7 m.

Date	Ammonium	(μM)		Nitrite	(μM)		Nitrite + nitrate	(μM)		Phosphate	(μM)		Silicate	(μM)		Chlorophyll a	(μg L⁻¹)		Salinity			Temperature	(°C)		Dissolved oxygen	(% satn)	
	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B
May-93	0.90	0.88	0.86	0.38	0.38	0.37	2.35	2.34	2.25	4.97	5.00	4.99	2.44	2.47	2.48	1.60	1.67	1.62	33.80	33.81	33.76	12.94	12.94	12.95	104.5	104.5	105.8
Jun-93	1.52	1.45	1.39	0.16	0.16	0.15	0.52	0.51	0.49	3.66	3.66	3.63	2.65	2.51	2.55	1.01	1.01	1.01	34.16	34.16	34.17	10.61	10.61	10.60	99.4	99.0	99.1
Jul-93	18.46	11.86	5.03	0.47	0.43	0.22	3.12	2.81	1.13	5.61	5.26	3.56	5.45	4.51	3.31	1.98	2.39	2.06	33.39	33.77	33.80	10.66	10.81	10.85	104.7	104.9	105.5
Aug-93	2.75	2.29	2.35	0.39	0.44	0.59	1.50	1.43	1.23	2.71	2.33	2.14	2.37	2.21	1.98	1.73	1.89	1.80	33.92	33.93	33.92	10.56	10.55	10.55	101.0	101.2	102.6
Sep-93	26.45	1.48	1.06	2.25	0.09	0.06	11.90	1.39	0.44	----	----	----	25.68	11.66	8.29	4.04	3.47	3.68	31.60	33.70	33.70	12.27	12.33	12.32	91.9	92.4	84.6
Oct-93	1.40	0.29	0.24	0.17	0.01	0.00	0.69	0.09	0.06	2.89	2.43	2.43	0.85	0.24	0.41	1.25	1.58	2.17	33.15	33.24	33.25	14.13	14.08	14.07	108.3	107.8	106.9
Nov-93	0.62	0.60	0.61	0.08	0.08	0.08	0.58	0.54	0.47	2.38	2.46	2.48	5.37	5.20	5.30	0.73	1.46	1.65	32.87	32.87	32.86	15.12	14.80	14.81	104.1	106.4	108.0
Dec-93	0.18	0.20	0.20	0.06	0.05	0.04	0.06	0.06	0.05	2.83	2.94	3.16	5.50	6.05	5.66	0.60	0.77	1.36	33.13	33.17	33.28	18.38	18.23	18.28	101.6	101.1	103.1
Jan-94	2.52	2.02	0.89	0.77	0.66	0.23	2.18	1.94	0.91	5.51	5.58	----	7.54	6.49	7.32	3.30	3.24	2.10	33.06	33.03	33.26	17.55	17.59	17.64	103.2	104.1	101.6
Feb-94	0.35	0.35	0.39	----	----	----	0.14	0.21	0.31	1.94	2.06	2.07	11.22	13.08	12.01	1.17	1.40	1.49	33.32	33.30	33.27	20.22	20.27	20.29	100.2	100.2	100.6
Mar-94	0.34	0.40	0.45	0.31	0.07	0.02	1.24	0.50	0.24	5.17	3.61	3.05	----	----	----	3.07	1.26	2.84	33.05	33.26	33.28	19.70	19.23	19.14	107.4	106.3	104.2
Mar-94-2	----	----	----	0.05	0.04	0.03	0.85	0.13	0.12	4.53	4.18	4.04	3.04	2.76	2.69	2.12	1.78	1.11	33.30	33.59	33.66	20.39	20.07	20.02	109.0	111.0	112.5
Apr-94	0.24	0.17	0.41	0.03	0.04	0.06	0.15	0.11	0.17	2.66	2.63	2.75	7.34	7.10	6.39	1.25	1.29	0.95	33.64	33.66	33.66	15.93	15.91	15.80	99.4	99.6	99.8
May-94	0.66	0.71	0.64	0.22	0.21	0.20	1.10	1.10	1.05	3.23	3.31	3.23	5.06	5.09	4.85	0.82	0.94	0.86	33.94	33.94	33.94	12.33	12.09	12.11	101.6	102.5	104.8
Jun-94	0.69	0.63	0.30	0.11	0.11	0.02	2.22	2.18	0.29	2.53	2.55	2.28	1.29	0.74	0.62	1.18	1.08	0.99	34.01	34.09	34.08	10.96	10.98	10.98	100.0	100.0	100.0
Jul-94	6.91	6.61	----	0.35	0.35	0.32	3.92	3.61	3.61	4.75	4.72	----	4.17	3.92	----	2.09	2.15	----	33.71	33.72	33.82	10.17	10.18	10.34	101.7	101.3	101.4
Aug-94	7.00	6.59	6.25	0.43	0.45	0.47	3.68	3.63	3.57	4.66	4.82	4.93	1.86	1.81	1.83	0.84	0.93	2.52	33.95	33.92	33.91	9.39	9.32	9.31	106.3	106.9	106.7
Sep-94	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	7.58	8.82	9.23	33.99	34.00	34.08	12.37	12.27	12.02	111.5	111.5	110.3
Oct-94	0.22	0.24	0.32	0.03	0.03	0.02	0.10	0.10	0.11	2.34	2.42	2.78	1.64	1.55	1.73	0.53	0.76	0.84	34.24	34.24	34.23	13.05	12.96	12.94	109.4	112.9	116.0
Nov-94	13.75	1.61	1.31	1.04	0.10	0.07	4.61	0.83	0.28	5.05	2.47	2.46	9.31	5.01	5.38	1.06	0.69	0.74	33.92	34.35	34.42	15.92	14.54	14.19	102.9	99.8	111.9
Dec-94	0.33	0.42	0.44	0.04	0.02	0.02	0.04	0.02	0.02	1.53	2.04	2.15	4.63	4.91	4.79	0.48	0.62	0.73	34.62	34.62	34.62	18.64	18.33	18.31	100.3	100.5	102.1
Jan-95	0.74	4.16	4.75	0.02	0.03	0.03	0.06	0.08	0.07	2.16	2.17	1.86	6.45	6.19	6.07	----	----	----	34.89	34.84	34.81	20.86	20.32	20.28	97.1	97.1	99.3
Feb-95	0.16	0.19	0.24	0.01	0.01	0.01	0.02	0.01	0.01	1.90	2.31	2.44	5.60	5.88	5.91	0.49	0.58	0.77	35.05	35.11	35.13	21.58	21.34	21.33	100.7	103.1	104.0
Mar-95	0.18	0.22	0.32	0.02	0.02	0.02	0.03	0.02	0.02	1.66	1.58	1.75	5.09	5.00	5.32	0.82	1.13	1.96	35.22	35.21	35.22	21.30	20.77	20.65	97.2	96.6	92.4
Mar-95-2	0.17	0.16	0.15	0.01	0.00	0.01	0.04	0.05	0.05	2.39	2.46	2.72	1.89	1.80	1.75	0.68	0.82	1.78		----	----	----	----	----	----	----	----
Min	0.16	0.16	0.15	0.01	0.00	0.00	0.02	0.01	0.01	1.53	1.58	1.75	0.85	0.24	0.41	0.48	0.58	0.73	31.60	32.87	32.86	9.39	9.32	9.31	91.9	92.4	84.6
Max	26.45	11.86	6.25	2.25	0.66	0.59	11.90	3.63	3.61	5.61	5.58	4.99	25.68	13.08	12.01	7.58	8.82	9.23	35.22	35.21	35.22	21.58	21.34	21.33	111.5	112.9	116.0
Mean	3.76	1.89	1.30	0.32	0.16	0.13	1.71	0.99	0.71	3.35	3.17	2.90	5.50	4.62	4.39	1.68	1.74	1.92	33.75	33.90	33.92	15.21	15.02	14.99	102.6	102.9	103.6

Percentage of differences between depths exceeding the estimated analytical error.

	Ammonium	Nitrite	Nitrite + nitrate	Phosphate	Silicate	Chlorophyll a	Salinity	Temperature	Dissolved oxygen
Estimated accuracy	±0.08	±0.03	±0.05	±0.10	±0.20	±0.10	±0.05	±0.03	±1.0
No difference	40	64	50	32	36	16	52	20	36
Surface max	40	28	42	28	44	24	0	60	12
Mid max	0	0	0	4	16	16	0	4	4
Bottom max	20	8	8	36	4	44	48	16	48

Table 18: Variation of mean values with depth: site 11 (Werribee River).

Table 19. Variation of mean value with depth: site 13 (Clifton Springs, south-western PPB). S= 0-3 m; M= 3-7 m; B= 7-10 m.

Date	Ammonium	(μM)		Nitrite	(μM)		Nitrite + nitrate	(μM)		Phosphate	(μM)		Silicate	(μM)		Chlorophyll a	(μg L⁻¹)		Salinity			Temperature	(°C)		Dissolved oxygen	(% satn)	
	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B
May-93	0.27	0.26	0.28	0.02	0.01	0.00	0.14	0.13	0.13	3.23	3.21	3.22	5.06	4.90	4.77	0.80	1.24	1.27	34.47	34.47	34.47	13.68	13.67	13.57	97.3	97.8	95.8
Jun-93	----	----	----	0.05	0.02	0.02	0.07	0.09	0.11	3.33	3.37	3.36	5.86	5.62	5.55	1.10	1.07	1.05	34.42	34.41	34.42	10.78	10.78	10.77	101.0	100.6	100.5
Jul-93	4.04	3.65	3.61	0.32	0.33	0.31	1.92	1.87	1.80	3.94	3.60	3.60	5.82	5.47	5.37	1.89	2.37	2.16	33.89	33.90	33.90	10.82	10.80	10.77	102.7	102.7	102.5
Aug-93	0.70	0.80	0.90	0.50	0.51	0.54	1.56	1.67	1.92	3.32	3.40	3.49	3.50	3.61	3.69	4.20	4.55	4.05	33.96	33.95	33.95	10.76	10.68	10.62	104.2	103.6	102.7
Sep-93	0.34	0.35	0.41	0.02	0.01	0.01	0.07	0.05	0.05	----	----	----	3.70	6.32	5.43	1.47	1.88	3.01	33.72	33.71	33.71	12.79	12.72	12.55	98.5	99.3	99.5
Oct-93	0.34	0.30	0.27	0.01	0.01	0.01	0.04	0.04	0.04	2.61	2.68	2.70	3.85	3.79	4.61	1.01	1.41	1.60	33.55	33.52	33.53	15.18	14.70	14.66	100.4	100.5	101.0
Nov-93	0.16	0.26	0.21	0.03	0.02	0.02	0.03	0.02	0.03	2.56	2.65	2.66	6.11	5.68	5.63	0.70	0.99	1.16	33.36	33.28	33.27	15.42	15.02	14.83	103.7	103.4	103.9
Dec-93	0.43	0.38	0.37	0.01	0.01	0.01	0.03	0.03	0.03	2.50	2.60	2.62	5.09	5.01	4.97	0.48	0.68	0.90	33.46	33.43	33.46	18.97	18.51	18.18	104.1	104.0	104.5
Jan-94	0.16	0.18	0.23	0.03	0.03	0.03	0.16	0.17	0.19	2.23	2.25	2.25	8.69	8.65	8.55	1.02	1.19	1.24	33.36	33.36	33.37	17.59	17.58	17.56	102.1	102.2	102.0
Feb-94	0.25	0.26	----	0.11	0.10	0.10	0.11	0.11	0.19	2.36	2.39	2.40	9.03	7.25	7.22	0.67	1.03	1.14	33.51	33.54	33.55	20.88	20.64	20.54	99.0	99.2	99.6
Mar-94	0.20	0.19	0.19	0.02	0.00	0.03	0.05	0.09	0.09	3.43	3.43	3.44	----	----	----	1.58	1.90	2.02	33.68	33.69	33.68	19.61	19.54	19.51	101.6	101.0	100.0
Mar-94-2	0.22	0.23	0.24	0.01	0.01	0.01	0.03	0.03	0.05	1.93	2.03	2.41	2.86	2.97	4.40	0.50	0.75	0.94	33.85	33.88	33.95	19.58	19.28	19.10	102.3	102.0	100.6
Apr-94	0.36	0.42	0.44	0.06	0.05	0.05	0.07	0.06	0.07	2.44	2.48	2.43	8.95	8.88	8.99	0.66	0.78	0.81	34.04	34.04	34.03	16.66	16.69	16.71	99.7	99.5	99.5
May-94	----	----	----	0.07	0.07	0.06	0.09	0.08	0.06	2.97	2.95	2.95	5.67	5.53	5.72	1.92	2.18	2.11	34.11	34.12	34.12	12.07	12.01	11.99	102.8	102.1	101.7
Jun-94	2.09	2.04	2.33	0.14	0.15	0.18	1.21	1.26	1.15	3.23	3.39	2.82	6.97	6.32	5.41	1.09	1.07	1.37	34.20	34.20	34.20	10.57	10.58	10.60	97.3	96.7	96.1
Jul-94	0.85	0.84	0.70	0.18	0.15	0.12	0.79	0.71	0.62	3.45	3.53	3.51	7.96	7.84	8.70	1.77	1.82	1.48	34.15	34.16	34.17	10.47	10.46	10.41	101.4	101.1	101.0
Aug-94	0.23	0.27	0.35	0.03	0.01	0.01	0.09	0.07	0.07	2.99	2.98	3.00	1.14	1.07	0.87	1.51	2.61	4.58	34.26	34.26	34.26	9.41	9.29	9.17	102.2	102.7	102.4
Sep-94	0.30	0.32	0.34	0.04	0.04	0.03	0.05	0.04	0.04	2.62	2.64	2.64	0.66	0.72	0.77	0.98	1.48	1.63	34.37	34.38	34.37	12.07	12.07	12.06	97.9	97.7	97.5
Oct-94	0.16	0.16	0.13	0.03	0.02	0.01	0.10	0.08	0.08	1.67	1.85	1.79	3.41	3.31	3.21	0.47	0.66	0.88	34.34	34.35	34.35	13.11	12.69	12.59	103.4	102.3	102.2
Nov-94	0.35	0.42	0.65	0.02	0.02	0.01	0.02	0.03	0.04	----	1.84	1.91	4.32	4.53	4.60	0.39	0.81	1.68	34.47	34.47	34.48	14.54	14.14	13.90	102.8	101.4	100.2
Dec-94	0.40	0.46	0.46	0.02	0.01	0.01	0.02	0.02	0.03	1.97	2.00	2.01	6.26	6.22	6.06	0.57	0.50	0.53	34.70	34.68	34.68	20.09	20.14	20.18	107.5	107.4	107.4
Jan-95	0.17	0.11	0.13	0.05	0.04	0.05	0.05	0.05	0.05	2.52	2.60	2.67	6.12	5.94	5.89	----	----	----	35.28	35.29	35.29	20.04	19.99	19.98	96.7	96.5	96.0
Feb-95	0.12	0.15	0.23	0.01	0.01	0.02	0.08	0.05	0.05	2.30	2.34	2.36	1.12	1.31	1.39	1.57	1.84	1.89	35.20	35.20	35.22	20.99	20.99	21.00	99.2	99.3	98.7
Mar-95	0.29	0.27	0.30	0.02	0.02	0.01	0.07	0.11	0.26	2.55	2.59	2.61	7.15	7.15	7.06	1.91	1.84	1.72	35.56	35.58	35.57	21.57	21.57	21.58	96.0	94.8	94.5
Mar-95-2	0.21	0.25	0.31	0.04	0.03	0.03	0.05	0.05	0.06	2.28	2.28	2.16	1.15	1.16	1.18	1.59	1.93	1.79	35.76	35.77	35.77	17.63	17.61	17.58	96.7	95.9	95.5
Min	0.12	0.11	0.13	0.01	0.00	0.00	0.02	0.02	0.03	1.67	1.84	1.79	0.66	0.72	0.77	0.39	0.50	0.53	33.36	33.28	33.27	9.41	9.29	9.17	96.0	94.8	94.5
Max	4.04	3.65	3.61	0.50	0.51	0.54	1.92	1.87	1.92	3.94	3.60	3.60	9.03	8.88	8.99	4.20	4.55	4.58	35.76	35.77	35.77	21.57	21.57	21.58	107.5	107.4	107.4
Mean	0.55	0.55	0.59	0.07	0.07	0.07	0.28	0.28	0.29	2.71	2.71	2.71	5.02	4.97	5.00	1.24	1.52	1.71	34.23	34.23	34.23	15.41	15.29	15.22	100.7	100.5	100.2

Percentage of differences between depths exceeding the estimated analytical error.

	Ammonium	Nitrite	Nitrite + nitrate	Phosphate	Silicate	Chlorophyll a	Salinity	Temperature	Dissolved oxygen
Estimated accuracy	±0.08	±0.03	±0.05	±0.10	±0.20	±0.10	±0.05	±0.03	±1.0
No difference	68	92	76	68	44	12	92	24	72
Surface max	12	4	8	8	32	4	4	68	24
Mid max	0	0	4	8	4	20	0	0	4
Bottom max	20	4	12	16	20	64	4	8	0

Table 19: Variation of mean values with depth: site 13 (Clifton Springs).

Table 20. Variation of mean value with depth: site MW1 (southern central PPB). S= 0-6 m; M=6-14 m; B= 14-22 m.																											
Date	Ammonium (µM)			Nitrite (µM)			Nitrite + nitrate (µM)			Phosphate (µM)			Silicate (µM)			Chlorophyll a (µg L⁻¹)			Salinity			Temperature (°C)			Dissolved oxygen (% satn)		
	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B
May-93	0.29	0.26	0.32	0.01	0.01	0.01	0.03	0.03	0.11	2.04	2.00	1.82	10.40	10.36	10.35	1.04	1.31	1.42	34.25	34.30	35.54	14.57	14.56	14.59	1[illegible]2.8	102.4	101.2
Jun-93	0.59	0.59	0.42	0.02	0.01	0.02	0.18	0.17	0.28	1.65	1.83	1.58	8.89	8.81	8.42	1.61	1.81	1.75	34.18	34.23	34.35	11.85	11.87	11.95	104.0	103.5	102.8
Jul-93	0.61	0.41	0.28	0.01	0.01	0.01	0.08	0.06	0.03	2.49	2.20	2.01	5.93	6.14	6.47	0.58	0.88	1.46	34.02	34.23	34.27	11.31	11.48	11.50	104.7	100.9	95.3
Aug-93	0.65	0.57	0.44	0.02	0.04	0.05	0.02	0.04	0.05	1.96	1.98	1.87	1.05	1.04	0.71	0.76	1.04	1.57	34.14	34.16	34.42	11.22	11.22	11.41	100.9	100.9	97.1
Sep-93	0.50	0.48	0.46	0.05	0.06	0.06	0.05	0.06	0.06	2.01	2.04	2.05	0.74	0.79	0.76	0.77	1.06	1.09	33.81	33.81	33.81	12.21	12.18	12.17	98.6	99.7	99.9
Oct-93	0.34	0.36	0.41	0.02	0.02	0.03	0.04	0.05	0.10	1.80	1.95	1.82	0.55	1.12	2.55	2.10	2.68	2.53	33.00	33.10	33.51	13.66	13.70	13.84	110.5	104.7	99.1
Nov-93	0.62	0.59	0.59	0.01	0.01	0.01	0.03	0.03	0.03	1.70	1.71	1.70	4.62	4.65	5.03	0.75	0.89	0.87	33.24	33.34	33.35	14.80	14.79	14.79	100.9	100.6	100.3
Dec-93	0.33	0.32	0.34	0.02	0.02	0.02	0.08	0.06	0.06	1.59	1.52	1.34	5.90	5.79	4.94	0.36	0.73	0.88	33.33	33.46	33.81	17.10	16.92	17.18	102.2	101.7	101.8
Jan-94	0.33	0.32	0.33	0.06	0.07	0.07	0.09	0.09	0.10	1.43	1.42	1.42	6.92	6.83	6.72	0.90	1.12	1.14	33.48	33.49	33.59	17.98	17.93	17.87	109.4	109.7	109.6
Feb-94	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Mar-94	0.50	0.54	1.04	0.05	0.06	0.08	0.17	0.19	0.29	1.56	1.62	1.54	----	----	----	0.63	1.03	1.02	33.57	33.57	33.85	19.69	19.48	19.54	102.5	102.5	99.0
Mar-94-2	0.33	0.33	0.33	0.02	0.02	0.03	0.05	0.04	0.04	1.90	1.90	1.71	2.72	3.01	3.30	0.28	0.56	0.52	33.59	33.61	33.86	18.49	18.73	19.69	104.7	104.4	103.6
Apr-94	0.27	0.26	0.13	0.05	0.04	0.04	0.08	0.08	0.08	1.85	1.87	1.55	8.88	8.78	7.70	0.46	0.60	0.68	33.72	33.75	34.12	16.98	16.99	16.92	99.8	102.6	101.8
May-94	0.32	0.32	0.35	0.03	0.03	0.03	0.02	0.02	0.02	1.81	1.80	1.79	6.18	5.76	4.04	1.87	1.86	1.90	33.92	34.00	34.35	12.68	12.75	13.00	102.0	101.5	100.3
Jun-94	0.25	0.27	0.27	0.02	0.01	0.01	0.18	0.14	0.13	2.15	2.18	1.84	0.51	0.38	0.53	----	----	----	33.94	34.00	34.39	11.58	11.62	11.94	100.0	99.3	98.4
Jul-94	0.08	0.08	0.10	0.02	0.02	0.03	0.04	0.03	0.03	1.78	1.77	1.58	0.53	0.48	0.53	0.47	0.76	0.81	34.11	34.21	34.50	11.05	11.09	11.29	99.2	99.0	97.6
Aug-94	0.37	0.36	0.33	0.00	0.00	0.00	0.09	0.08	0.07	1.62	1.60	1.38	1.65	1.47	1.10	0.42	0.66	0.72	34.21	34.30	34.56	9.93	9.87	10.05	100.9	100.8	100.1
Sep-94	0.15	0.16	0.17	0.01	0.01	0.01	0.04	0.04	0.04	1.40	1.35	1.28	0.75	0.79	0.67	0.31	0.44	0.46	34.61	34.64	34.63	12.06	12.03	12.01	101.8	101.3	100.8
Oct-94	0.18	0.22	0.30	0.01	0.01	0.01	0.03	0.03	0.02	1.40	1.55	1.55	2.40	2.06	2.28	0.20	0.31	0.59	34.28	34.28	34.36	12.55	12.11	11.92	102.7	101.7	98.6
Nov-94	0.23	0.22	0.26	0.02	0.03	0.02	0.12	0.12	0.10	1.47	1.45	1.43	3.09	3.18	3.21	0.38	0.65	0.81	34.52	34.55	34.56	13.99	13.78	13.68	98.6	98.0	97.8
Dec-94	----	----	----	0.01	0.01	0.01	0.01	0.01	0.01	1.76	1.68	1.39	4.61	3.89	3.37	0.21	0.43	0.63	34.42	34.77	34.78	18.73	17.86	17.80	104.7	104.2	104.0
Jan-95	0.09	0.09	0.09	0.01	0.01	0.01	0.03	0.04	0.04	1.37	1.50	1.40	2.41	2.40	2.38	----	----	----	34.85	34.84	34.88	19.08	18.84	18.76	101.7	101.4	101.6
Feb-95	0.20	0.21	0.26	0.01	0.01	0.01	0.02	0.03	0.05	1.84	1.88	1.90	6.61	6.59	6.51	0.78	1.07	1.17	34.83	34.82	34.82	20.61	20.58	20.57	96.0	96.1	96.1
Mar-95	0.23	0.22	0.21	0.01	0.01	0.01	0.04	0.02	0.01	1.87	1.97	1.93	5.96	6.11	6.04	0.67	0.72	0.80	34.98	34.99	35.00	21.35	21.34	20.61	98.1	96.7	96.0
Mar-95-2	0.18	0.19	0.22	0.01	.01.	0.01	0.27	0.28	0.95	1.85	1.87	1.92	2.04	2.16	2.11	1.05	1.30	1.26	35.23	35.24	35.24	18.69	18.69	18.69	97.2	97.1	96.9
Min	0.08	0.08	0.09	0.00	0.00	0.00	0.01	0.01	0.01	1.37	1.35	1.28	0.51	0.38	0.53	0.20	0.31	0.46	33.00	33.10	33.35	9.93	9.87	10.05	96.0	96.1	95.3
Max	0.65	0.59	1.04	0.06	0.07	0.08	0.27	0.28	0.95	2.49	2.20	2.05	10.40	10.36	10.35	2.10	2.68	2.53	35.23	35.24	35.54	21.35	21.34	20.61	110.5	109.7	109.6
Mean	0.33	0.32	0.33	0.02	0.02	0.02	0.07	0.07	0.11	1.76	1.78	1.66	4.06	4.03	3.90	0.75	1.00	1.09	34.09	34.15	34.36	15.09	15.02	15.07	101.8	101.3	100.0
Percentage of differences between depths exceeding the estimated analytical error.																											
Estimated accuracy		±0.08			±0.03			±0.05			±0.10			±0.20			±0.10			±0.05			±0.03			±1.0	
No difference		80			100			80			44			48			16			32			16			44	
Surface max		16			0			0			32			32			0			0			40			52	
Mid max		0			0			0			20			0			20			0			4			4	
Bottom max		4			0			20			4			20			64			68			40			0	

Table 20: Variation of mean values with depth: site MW1 (Southern Central Bay).

Table 21. Variation of mean value with depth: site MW2 (northern central PPB). S= 0-6 m; M=6-14 m; B= 14-22 m.																											
Date	Ammonium (µM)			Nitrite (µM)			Nitrite + nitrate (µM)			Phosphate (µM)			Silicate (µM)			Chlorophyll a (µg L⁻¹)			Salinity			Temperature (°C)			Dissolved oxygen (% satn)		
	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B
May-93	0.57	0.69	0.71	0.02	0.03	0.02	0.15	0.14	0.13	2.37	2.55	2.66	12.16	11.54	11.32	1.50	1.54	1.41	34.17	34.18	34.19	15.01	14.97	14.96	103.4	101.6	99.9
Jun-93	0.50	0.51	0.55	0.10	0.05	0.03	0.13	0.10	0.10	2.14	2.03	1.95	9.76	9.30	9.08	0.87	0.88	0.94	34.32	34.33	34.33	11.84	11.83	11.81	96.9	97.3	96.9
Jul-93	0.55	0.61	0.65	0.02	0.02	0.06	0.30	0.23	0.31	2.37	2.63	2.36	4.67	4.36	4.69	0.91	1.03	0.94	34.20	34.19	34.20	11.32	11.26	11.24	103.7	103.8	99.6
Aug-93	0.44	0.42	0.29	0.02	0.02	0.02	0.04	0.04	0.03	2.27	2.38	2.36	1.71	5.17	5.49	0.92	0.58	0.68	34.16	34.16	----	11.16	11.14	----	101.4	101.3	----
Sep-93	0.40	0.41	0.44	0.02	0.02	0.02	0.03	0.03	0.05	2.23	2.28	2.27	1.23	1.41	1.71	1.09	1.27	0.92	33.60	33.61	33.80	12.09	12.09	12.08	100.2	101.3	99.2
Oct-93	0.59	0.44	0.38	0.09	0.08	0.09	0.10	0.11	0.13	1.83	1.97	2.00	0.37	0.53	1.44	1.13	1.93	1.63	32.83	33.03	33.06	14.43	13.72	13.54	112.4	110.2	102.2
Nov-93	----	0.61	0.73	0.01	0.01	0.01	0.06	0.06	0.06	1.79	1.84	1.87	5.48	5.51	5.57	0.76	1.11	1.03	32.98	32.98	32.95	15.09	15.05	15.01	101.5	101.1	100.7
Dec-93	0.38	0.39	0.38	0.01	0.01	0.01	0.05	0.04	0.05	1.67	1.75	1.73	6.71	6.60	6.09	0.57	1.16	1.87	32.67	32.82	32.99	18.07	17.44	17.03	104.0	103.1	102.5
Jan-94	0.29	0.30	0.28	0.02	0.04	0.04	0.19	0.16	0.16	1.82	1.83	1.82	9.19	9.44	9.70	0.90	1.51	1.44	32.72	32.79	32.80	18.98	18.09	18.08	110.8	110.6	110.2
Feb-94	----	----	----	0.01	0.00	0.00	0.01	0.03	0.05	1.87	1.92	1.92	9.18	9.03	9.65	0.71	1.15	1.20	33.09	33.31	33.34	20.60	19.37	19.17	107.3	106.9	105.1
Mar-94	0.79	0.66	0.70	0.08	0.03	0.02	0.11	0.09	0.20	2.00	1.99	1.94	----	----	----	0.80	1.18	0.91	33.10	33.13	33.13	20.37	19.79	19.70	102.1	101.9	101.2
Mar-94-2	----	----	----	0.03	0.02	0.04	0.21	0.12	0.32	2.07	2.14	2.02	6.19	3.87	12.04	0.38	0.64	0.34	33.35	33.37	33.90	19.61	18.62	18.03	100.2	98.9	93.0
Apr-94	0.33	0.37	0.43	0.06	0.03	0.03	0.09	0.04	0.03	1.74	1.79	1.87	7.26	7.27	7.29	0.87	0.83	0.83	33.94	33.93	33.93	16.72	16.72	16.72	94.5	95.0	99.8
May-94	0.14	0.18	0.19	0.02	0.01	0.01	0.02	0.02	0.02	1.94	1.95	1.87	2.88	2.70	3.17	0.78	0.82	1.04	33.98	34.00	34.05	12.91	12.72	12.79	101.7	100.0	96.4
Jun-94	0.26	0.22	0.24	0.06	0.06	0.06	0.13	0.10	0.05	1.60	1.72	1.74	0.50	0.57	0.43	0.79	0.94	1.10	34.16	34.16	34.16	11.51	11.43	11.42	97.8	97.3	97.1
Jul-94	0.13	0.18	0.24	0.09	0.09	0.07	0.09	0.08	0.07	1.82	1.85	1.87	1.25	0.60	0.39	0.46	0.45	0.42	34.12	34.12	34.11	10.89	10.89	10.89	98.2	97.9	97.7
Aug-94	0.31	0.27	0.27	0.02	0.02	0.02	0.21	0.24	0.23	1.58	1.64	1.62	2.01	2.13	2.08	0.52	0.50	0.47	34.38	34.37	34.38	10.03	10.02	9.99	100.3	100.0	99.6
Sep-94	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	0.33	0.35	0.42	34.26	34.25	34.25	11.77	11.48	11.42	100.7	100.4	100.0
Oct-94	----	----	----	0.05	0.05	0.05	0.07	0.12	0.14	2.11	2.03	1.94	4.84	3.54	3.07	0.64	0.39	0.51	33.87	34.28	34.30	13.12	12.12	11.99	102.8	100.2	99.5
Nov-94	0.24	0.25	0.26	0.03	0.03	0.03	0.15	0.15	0.14	1.92	1.94	1.89	3.71	3.72	3.82	0.16	0.41	0.64	34.27	34.28	34.29	15.34	14.00	13.86	99.9	98.0	98.0
Dec-94	0.37	0.44	0.49	0.03	0.03	0.03	0.04	0.03	0.03	2.05	2.03	2.26	5.69	5.92	5.78	0.30	0.46	0.76	34.41	34.41	34.43	18.27	17.70	17.66	99.8	98.9	98.4
Jan-95	0.23	0.23	0.22	0.03	0.04	0.03	0.06	0.05	0.03	1.98	1.97	2.11	4.54	4.70	4.87	----	----	----	34.68	34.72	34.72	20.45	20.11	19.77	97.0	96.7	96.3
Feb-95	0.28	0.28	0.30	0.04	0.04	0.04	0.27	0.28	0.26	1.85	1.87	1.89	5.56	5.64	5.68	0.49	0.63	0.84	34.71	34.71	34.71	21.32	21.16	21.05	97.8	97.3	95.4
Mar-95	0.22	0.27	0.29	0.01	0.03	0.01	0.08	0.04	0.02	1.88	1.94	1.90	7.45	7.67	7.60	0.84	1.23	1.26	34.96	34.95	34.95	21.15	21.11	21.11	97.0	97.0	96.8
Mar-95-2	0.15	0.23	----	0.02	0.02	0.01	0.69	0.34	0.36	2.01	2.25	2.32	1.82	2.27	2.63	1.27	1.31	0.90	35.21	35.21	35.19	18.64	18.56	18.47	97.0	96.1	94.7
Min	0.13	0.18	0.19	0.01	0.00	0.00	0.01	0.02	0.02	1.58	1.64	1.62	0.37	0.53	0.39	0.16	0.35	0.34	32.67	32.79	32.80	10.03	10.02	9.99	94.5	95.0	93.0
Max	0.79	0.69	0.73	0.10	0.09	0.09	0.69	0.34	0.36	2.37	2.63	2.66	12.16	11.54	12.04	1.50	1.93	1.87	35.21	35.21	35.19	21.32	21.16	21.11	112.4	110.6	110.2
Mean	0.36	0.38	0.40	0.04	0.03	0.03	0.14	0.11	0.12	1.95	2.01	2.01	4.96	4.93	5.37	0.75	0.93	0.94	33.93	33.97	34.01	15.63	15.26	15.32	101.1	100.5	99.2
Percentage of differences between depths exceeding the estimated analytical error.																											
Estimated accuracy		±0.08			±0.03			±0.05			±0.10			±0.20			±0.10			±0.05			±0.03			±1.0	
No difference		55			85			72			52			40			24			68			20			40	
Surface max		15			5			12			8			20			8			0			80			48	
Mid max		0			5			0			12			0			36			0			0			8	
Bottom max		30			5			16			28			40			32			32			0			4	

Table 21: Variation of mean values with depth: site MW2 (Northern Central Bay).

Table 22. Variation of mean value with depth: site N1(The Rip). S= 0-4 m; M=4-10 m; B= 10-14 m.																											
Date	Ammonium (µM)			Nitrite (µM)			Nitrite + nitrate (µM)			Phosphate (µM)			Silicate (µM)			Chlorophyll a (µg L⁻¹)			Salinity			Temperature (°C)			Dissolved oxygen (% satn)		
	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B
May-93	----	0.30	0.26	0.04	0.04	0.04	0.39	0.36	0.36	0.59	0.77	0.77	0.94	1.01	1.08	0.77	0.77	0.72	35.44	35.42	35.44	14.99	14.95	14.99	100.0	99.5	99.3
Jun-93	0.97	0.97	0.95	0.02	0.02	0.02	0.16	0.21	0.25	2.26	2.16	2.03	7.56	7.43	6.98	0.94	0.97	1.22	34.40	34.48	34.52	11.71	11.86	11.95	100.5	100.5	97.8
Jul-93	0.52	0.53	0.52	0.16	0.18	0.18	1.60	1.60	1.57	0.21	0.21	0.15	0.84	0.73	0.56	0.44	0.43	0.44	----	----	----	----	----	----	----	----	----
Aug-93	0.45	0.45	0.48	0.03	0.05	0.08	0.07	0.07	0.08	1.60	1.57	1.73	0.67	0.73	0.94	4.54	1.67	1.62	34.45	34.38	34.26	11.09	11.02	10.84	97.7	97.8	97.30
Sep-93	0.44	0.49	0.47	0.34	0.30	0.28	1.70	1.56	1.54	----	----	----	3.77	4.00	2.50	1.06	1.12	1.07	34.80	34.84	34.80	12.80	12.80	12.79	96.9	97.9	98.1
Oct-93	0.50	0.41	----	0.02	0.01	----	0.05	0.08	----	1.22	1.21	----	1.05	0.88	----	1.67	2.02	----	34.13	34.23	----	14.27	14.22	----	105.4	105.3	----
Nov-93	0.28	0.31	0.43	0.03	0.03	0.02	0.03	0.13	0.16	0.82	0.75	0.71	2.26	1.78	1.68	0.74	0.83	0.78	34.18	34.44	34.49	15.66	15.19	15.18	104.2	102.9	102.6
Dec-93	0.46	0.48	0.48	0.03	0.03	0.02	0.11	0.11	0.10	0.30	0.33	0.43	1.12	0.74	0.68	0.19	0.21	0.21	35.64	35.60	35.59	15.46	15.51	15.55	104.2	104.0	103.7
Min	0.28	0.30	0.26	0.02	0.01	0.02	0.03	0.07	0.08	0.21	0.21	0.15	0.84	0.73	0.56	0.19	0.21	0.21	34.13	34.23	34.26	11.09	11.02	10.84	96.9	97.8	97.3
Max	0.97	0.97	0.95	0.34	0.30	0.28	1.70	1.60	1.57	2.26	2.16	2.03	7.56	7.43	6.98	4.54	2.02	1.62	35.64	35.60	35.59	15.66	15.51	15.55	105.4	105.3	103.7
Mean	0.52	0.49	0.51	0.08	0.08	0.09	0.51	0.52	0.58	1.00	1.00	0.97	2.30	2.16	2.06	1.29	1.00	0.87	34.72	34.77	34.85	13.71	13.65	13.55	101.3	101.1	99.8
Percentage of differences between depths exceeding the estimated analytical error.																											
Estimated accuracy		±0.08			±0.03			±0.05			±0.10			±0.20			±0.10			±0.05			±0.03			±1.0	
No difference		76			76			64			52			28			64			40			40			64	
Surface max		12			12			12			12			48			12			24			36			24	
Mid max		0			0			0			0			12			12			12			0			0	
Bottom max		12			12			24			36			12			12			24			24			12	

Table 22: Variation of mean values with depth: site N1 (The Rip).

Table 23. Variation of mean value with depth: site N1E (The Rip, ebb tide). S= 0-4 m; M=4-10 m; B= 10-14 m.

Date	Ammonium (µM)			Nitrite (µM)			Nitrite + nitrate (µM)			Phosphate (µM)			Silicate (µM)			Chlorophyll a (µg L^{-1})			Salinity			Temperature (°C)			Dissolved oxygen (% satn)		
	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B
Feb-94	0.64	0.61	0.63	0.00	0.01	0.02	0.16	0.19	0.26	1.32	1.39	1.24	5.59	5.61	5.55	0.66	0.99	0.92	33.83	34.05	34.30	20.00	19.61	19.21	100.5	100.6	100.5
Mar-94	0.63	0.60	0.53	0.09	0.10	0.10	0.45	0.48	0.48	0.41	0.41	0.32	----	----	----	0.76	0.74	0.74	33.38	33.37	33.37	17.98	17.98	17.97	97.2	97.8	97.8
Mar-94-2	0.35	0.34	0.38	0.03	0.02	0.02	0.19	0.22	0.25	0.87	0.84	0.77	0.63	0.38	0.45	0.52	0.47	0.45	35.08	35.18	35.23	18.20	18.03	17.89	101.9	101.9	101.9
Apr-94	0.47	0.49	0.51	0.13	0.13	0.12	0.46	0.46	0.47	0.22	0.27	0.24	1.81	1.51	1.38	0.46	0.53	0.51	35.46	35.46	35.47	16.83	16.82	16.81	98.2	97.9	97.9
May-94	0.35	0.35	0.37	0.12	0.14	0.16	0.36	0.42	0.46	0.76	0.67	0.58	1.69	1.40	1.29	1.23	1.21	1.19	35.06	35.18	35.19	13.75	14.00	14.07	89.9	87.4	87.8
Jun-94	0.35	0.34	0.30	0.11	0.12	0.13	0.39	0.37	0.36	0.99	1.03	1.29	0.45	0.49	0.58	----	----	----	35.05	35.03	34.86	12.57	12.53	12.17	97.2	97.6	97.5
Jul-94	----	0.41	0.43	0.15	0.17	0.18	0.20	0.38	0.42	0.27	0.26	0.25	0.82	0.80	0.45	0.47	0.44	0.42	35.56	35.56	35.57	13.18	13.18	13.18	100.0	99.8	99.5
Aug-94	0.42	0.41	0.42	0.19	0.20	0.22	0.36	0.44	0.59	0.70	0.68	0.54	1.24	0.99	0.91	0.66	0.61	0.53	35.20	35.31	35.41	11.55	11.80	12.02	100.1	99.8	99.1
Sep-94	0.33	0.32	0.31	0.08	0.08	0.08	0.38	0.31	0.32	0.76	0.77	0.84	0.90	0.96	0.94	0.60	0.70	0.60	35.63	35.63	35.63	12.89	12.89	12.90	100.0	99.7	99.4
Oct-94	0.28	0.31	0.35	0.02	0.02	0.03	0.07	0.03	0.04	----	0.99	1.04	1.31	1.49	1.46	0.48	0.57	0.61	34.66	34.69	34.82	13.33	13.18	13.19	106.4	106.0	105.2
Nov-94	0.26	0.27	0.31	0.02	0.01	0.01	0.11	0.07	0.07	----	0.91	1.15	----	1.82	1.91	0.98	1.22	1.16	34.73	34.82	34.89	14.89	14.81	14.75	100.6	100.3	99.8
Dec-94	0.08	0.14	0.13	0.01	0.01	0.01	0.11	0.10	0.11	0.25	0.24	0.20	0.63	0.83	0.79	0.34	0.33	0.74	35.45	35.45	35.45	15.22	15.21	15.21	101.8	101.7	101.6
Jan-95	0.12	0.07	0.03	0.01	0.01	0.01	0.14	0.14	0.13	0.20	0.14	0.14	0.30	0.36	0.28	----	----	----	35.46	35.46	35.46	17.18	17.19	17.17	99.2	99.1	99.1
Feb-95	0.11	0.07	0.07	0.05	0.05	0.04	0.08	0.13	0.11	0.22	0.11	0.12	0.47	0.30	0.49	0.58	0.59	0.55	35.47	35.47	35.47	18.44	18.51	18.55	98.9	99.0	98.7
Mar-95	0.16	0.14	0.17	0.05	0.09	0.15	0.17	0.18	0.25	0.42	0.43	0.29	0.52	0.77	0.83	0.33	0.59	0.69	35.48	35.42	35.42	18.50	17.06	17.06	103.3	97.1	98.2
Mar-95-2	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
Min	0.08	0.07	0.03	0.00	0.01	0.01	0.07	0.03	0.04	0.20	0.11	0.12	0.30	0.30	0.28	0.33	0.33	0.42	33.38	33.37	33.37	11.55	11.80	12.02	89.9	87.4	87.8
Max	0.64	0.61	0.63	0.19	0.20	0.22	0.46	0.48	0.59	1.32	1.39	1.29	5.59	5.61	5.55	1.23	1.22	1.19	35.63	35.63	35.63	20.00	19.61	19.21	106.4	106.0	105.2
Mean	0.33	0.32	0.33	0.07	0.08	0.09	0.24	0.26	0.29	0.57	0.61	0.60	1.26	1.27	1.24	0.62	0.69	0.70	35.03	35.07	35.10	15.63	15.52	15.48	99.7	99.0	98.9

Percentage of differences between depths exceeding the estimated analytical error.

	Ammonium	Nitrite	Nitrite + nitrate	Phosphate	Silicate	Chlorophyll a	Salinity	Temperature	Dissolved oxygen
Estimated accuracy	±0.08	±0.03	±0.05	±0.10	±0.20	±0.10	±0.05	±0.03	±1.0
No difference	86	86	58	58	58	58	51	37	79
Surface max	14	0	0	21	35	7	7	42	21
Mid max	0	0	0	7	0	14	0	0	0
Bottom max	0	14	42	14	7	21	42	21	0

Table 23: Variation of mean values with depth: site N1E (The Rip, ebb tide).

Table 24. Variation of mean value with depth: site N1F (The Rip, flood tide). S= 0-4 m; M=4-10 m; B= 10-14 m.

Date	Ammonium (µM)			Nitrite (µM)			Nitrite + nitrate (µM)			Phosphate (µM)			Silicate (µM)			Chlorophyll a (µg L^{-1})			Salinity			Temperature (°C)			Dissolved oxygen (% satn)		
	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B
Feb-94	0.62	0.59	0.56	0.02	0.01	0.00	0.19	0.19	0.20	0.18	0.18	0.20	0.73	0.50	0.51	0.32	0.32	0.33	35.40	35.41	35.40	17.82	17.80	17.75	103.1	103.3	103.5
Mar-94	0.51	----	----	0.06	----	----	0.12	----	----	0.91	----	----	----	----	----	1.03	----	----	----	----	----	----	----	----	----	----	----
Mar-94-2	0.26	0.33	0.38	0.02	0.02	0.02	0.19	0.20	0.20	0.10	0.15	0.15	0.24	0.29	0.33	0.29	0.35	0.39	35.38	35.39	35.39	17.38	17.40	17.41	100.2	100.1	100.2
Apr-94	0.44	0.32	0.23	0.13	0.10	0.10	0.25	0.25	0.19	0.24	0.28	0.14	0.70	0.59	0.60	0.38	0.39	0.43	35.42	35.42	35.42	16.83	16.84	16.85	97.8	97.4	97.7
May-94	0.36	0.35	0.33	0.24	0.24	0.24	0.36	0.37	0.37	0.31	0.22	0.20	1.35	1.30	1.26	1.21	1.21	1.21	35.44	35.45	35.46	14.68	14.66	14.65	96.8	96.2	97.1
Jun-94	0.33	0.28	0.25	0.26	0.22	0.22	0.34	0.24	0.17	0.49	0.32	0.13	2.32	2.77	2.91	0.42	0.49	0.58	35.46	35.47	35.46	13.61	13.61	13.62	100.0	99.5	99.5
Jul-94	0.24	0.17	0.26	0.19	0.21	0.21	0.36	0.34	0.30	0.12	0.13	0.10	0.60	0.63	0.63	0.41	0.40	0.38	35.53	35.53	35.54	13.09	13.08	13.08	97.7	97.3	97.4
Aug-94	0.34	0.38	0.40	0.22	0.25	0.25	0.57	0.54	0.52	0.39	0.28	0.28	1.09	1.06	0.92	0.58	0.56	0.56	35.56	35.57	35.56	12.21	12.22	12.22	99.8	99.9	99.8
Sep-94	0.29	0.30	0.28	0.07	0.06	0.06	0.07	0.06	0.06	0.23	0.20	0.16	0.99	0.98	0.93	0.43	0.38	0.37	35.63	35.64	35.63	12.86	12.87	12.87	100.0	100.0	99.8
Oct-94	0.22	0.21	0.26	0.01	0.01	0.01	0.04	0.04	0.04	0.37	0.31	0.26	0.35	0.26	0.37	0.52	0.55	0.55	35.53	35.53	35.54	12.75	12.75	12.75	101.2	100.5	100.4
Nov-94	0.41	0.40	0.38	0.03	0.02	0.02	0.03	0.04	0.03	0.27	0.29	0.25	0.57	0.25	1.18	0.57	0.83	0.81	35.43	35.43	35.45	13.56	13.57	13.57	97.1	97.2	97.4
Dec-94	0.44	0.46	0.48	0.06	0.04	0.04	0.06	0.05	0.06	0.09	0.19	0.32	0.93	1.13	1.49	----	----	----	35.44	35.44	35.43	16.33	16.33	16.34	100.9	100.6	101.3
Jan-95	0.16	0.17	0.18	0.07	0.07	0.07	0.22	0.20	0.19	0.23	0.38	0.42	0.27	0.39	0.40	----	----	----	35.43	35.43	35.43	17.46	17.51	17.53	101.5	101.4	101.4
Feb-95	0.15	0.12	0.14	0.07	0.07	0.07	0.17	0.23	0.25	0.09	0.15	0.18	0.47	0.57	0.65	0.66	0.85	0.90	35.44	35.43	35.43	18.37	18.34	18.32	102.8	100.8	99.4
Mar-95	0.22	0.24	0.18	0.84	0.82	0.82	1.39	1.47	1.48	0.30	0.32	0.31	1.08	1.06	1.07	0.38	0.40	0.46	35.44	35.44	35.44	15.58	15.59	15.62	86.1	86.2	86.3
Mar-95-2	0.26	0.28	0.32	0.05	0.05	0.05	0.12	0.29	0.40	0.20	0.20	0.20	0.57	0.60	0.66	0.34	0.34	0.34	35.48	35.48	35.49	17.65	17.66	17.67	97.1	96.8	96.6
Min	0.15	0.12	0.14	0.01	0.01	0.00	0.03	0.04	0.03	0.09	0.13	0.10	0.24	0.25	0.33	0.29	0.32	0.33	35.38	35.39	35.39	12.21	12.22	12.22	86.1	86.2	86.3
Max	0.62	0.59	0.56	0.84	0.82	0.82	1.39	1.47	1.48	0.91	0.38	0.42	2.32	2.77	2.91	1.21	1.21	1.21	35.63	35.64	35.63	18.37	18.34	18.32	103.1	103.3	103.5
Mean	0.33	0.31	0.31	0.15	0.15	0.15	0.28	0.30	0.30	0.28	0.24	0.22	0.82	0.83	0.93	0.54	0.54	0.56	35.47	35.47	35.47	15.35	15.35	15.35	98.8	98.5	98.5

Percentage of differences between depths exceeding the estimated analytical error.

	Ammonium	Nitrite	Nitrite + nitrate	Phosphate	Silicate	Chlorophyll a	Salinity	Temperature	Dissolved oxygen
Estimated accuracy	±0.08	±0.03	±0.05	±0.10	±0.20	±0.10	±0.05	±0.03	±1.0
No difference	82	94	70	58	76	82	100	76	94
Surface max	6	6	18	24	6	0	0	12	6
Mid max	0	0	0	6	0	6	0	0	0
Bottom max	12	0	12	12	18	12	0	12	0

Table 24: Variation of mean values with depth: site N1F (The Rip, flood tide).

Table 25. Variation of mean value with depth: site N2 (Point Wilson, south-western PPB). S= 0-4 m; M=4-7 m; B= 7-10 m.																											
Date	Ammonium (µM)			Nitrite (µM)			Nitrite + nitrate (µM)			Phosphate (µM)			Silicate (µM)			Chlorophyll a (µg L⁻¹)			Salinity			Temperature (°C)			Dissolved oxygen (% satn)		
	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B
May-93	0.43	0.42	0.39	0.06	0.05	0.03	0.26	0.26	0.25	3.59	3.61	3.62	5.70	5.67	5.33	1.10	1.04	1.00	34.51	34.52	34.53	13.18	13.12	13.08	97.1	97.3	97.5
Jun-93	1.10	1.14	1.17	0.07	0.13	0.11	0.28	0.31	0.29	3.44	3.48	3.54	5.41	5.45	5.36	0.89	0.92	0.89	34.40	34.40	34.43	10.63	10.61	10.48	100.4	100.2	99.8
Jul-93	7.81	7.56	7.40	0.35	0.36	0.36	2.64	2.62	2.60	4.89	4.63	4.53	6.28	6.23	6.36	2.38	2.66	2.39	33.86	33.86	33.86	10.74	10.72	10.71	101.0	101.3	101.1
Aug-93	6.46	5.62	4.06	0.96	0.87	0.69	4.24	3.92	3.07	5.17	5.08	4.79	4.51	4.04	2.77	3.55	4.17	4.35	33.80	33.82	33.87	10.41	10.37	10.35	101.7	101.8	101.4
Sep-93	0.31	0.38	0.41	0.02	0.04	0.02	0.08	0.05	0.06	----	----	----	3.39	3.23	3.41	2.06	3.49	4.49	33.70	33.70	33.69	12.76	12.65	12.53	98.7	99.3	99.2
Oct-93	0.28	0.28	0.33	0.02	0.02	0.02	0.06	0.11	0.12	3.11	3.10	3.10	5.16	4.57	4.85	1.11	1.40	1.30	33.58	33.57	33.56	15.06	14.77	14.77	101.1	102.4	103.1
Nov-93	0.24	0.22	0.23	0.03	0.02	0.03	0.03	0.02	0.03	3.02	3.07	3.14	6.51	6.61	6.60	0.83	1.47	1.47	33.36	33.32	33.32	15.43	15.03	15.01	104.0	104.6	105.1
Dec-93	0.34	0.44	0.48	0.01	0.01	0.01	0.09	0.08	0.08	2.89	2.84	2.89	5.14	5.13	5.21	0.52	0.74	3.20	33.55	33.55	33.55	18.88	18.60	18.52	102.7	102.2	105.2
Min	0.24	0.22	0.23	0.01	0.01	0.01	0.03	0.02	0.03	2.89	2.84	2.89	3.39	3.23	2.77	0.52	0.74	0.89	33.36	33.32	33.32	10.41	10.37	10.35	97.1	97.3	97.5
Max	7.81	7.56	7.40	0.96	0.87	0.69	4.24	3.92	3.07	5.17	5.08	4.79	6.51	6.61	6.60	3.55	4.17	4.49	34.51	34.52	34.53	18.88	18.60	18.52	104.0	104.6	105.2
Mean	2.12	2.01	1.81	0.19	0.19	0.16	0.96	0.92	0.81	3.73	3.69	3.66	5.26	5.12	4.99	1.56	1.99	2.39	33.85	33.84	33.85	13.39	13.23	13.18	100.8	101.1	101.6
Percentage of differences between depths exceeding the estimated analytical error.																											
Estimated accuracy		±0.08			±0.03			±0.05			±0.10			±0.20			±0.10			±0.05			±0.03			±1.0	
No difference		50			64			76			63			64			25			88			12			64	
Surface max		25			12			12			25			36			25			0			88			0	
Mid max		0			12			0			0			0			0			0			0			0	
Bottom max		25			12			12			12			0			50			12			0			36	

Table 25: Variation of mean values with depth: site N2 (Point Wilson).

Table 26. Variation of mean value with depth: site N3 (western central PPB). S= 0-6 m; M=6-14 m; B= 14-22 m.																											
Date	Ammonium (µM)			Nitrite (µM)			Nitrite + nitrate (µM)			Phosphate (µM)			Silicate (µM)			Chlorophyll a (µg L⁻¹)			Salinity			Temperature (°C)			Dissolved oxygen (% satn)		
	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B	S	M	B
Jan-94	0.21	----	----	0.13	----	----	0.28	----	----	1.94	----	----	7.62	----	----	1.20	1.22	----	33.16	33.18	----	17.90	17.87	----	102.2	102.2	----
Feb-94	0.27	0.28	0.36	0.04	0.01	0.02	0.05	0.03	0.03	1.62	1.65	1.63	9.75	8.73	8.19	0.59	1.03	0.95	33.43	33.43	33.63	19.66	19.59	19.31	100.3	100.6	98.7
Mar-94	0.21	0.21	0.26	0.03	0.02	0.03	0.06	0.04	0.08	1.83	1.85	1.88	----	----	----	0.72	0.85	1.11	33.46	33.45	33.59	19.59	19.60	19.48	103.0	104.2	103.4
Mar-94-2	0.38	0.38	0.52	0.05	0.02	0.02	0.11	0.11	0.11	2.03	2.03	1.89	2.22	2.43	5.16	0.34	0.35	0.95	33.49	33.49	33.98	18.71	18.67	18.20	96.4	96.4	91.6
Apr-94	----	----	----	0.06	0.07	0.08	0.18	0.17	0.18	1.97	1.88	1.75	7.29	7.57	7.67	0.51	0.66	0.66	33.86	33.86	33.85	16.95	16.95	16.95	98.2	98.1	98.1
May-94	0.12	0.12	0.15	0.05	0.04	0.04	0.05	0.04	0.04	1.69	1.62	1.58	2.91	2.78	2.78	1.27	1.31	1.84	34.15	34.17	34.30	12.80	12.81	12.94	100.7	100.1	98.2
Jun-94	0.39	0.41	0.42	0.08	0.07	0.07	0.12	0.12	0.12	1.55	1.61	1.63	0.87	0.76	0.65	0.78	0.97	1.00	34.24	34.24	34.25	11.55	11.48	11.47	98.6	98.1	97.3
Jul-94	0.12	0.23	0.21	0.01	0.01	0.05	0.06	0.04	0.06	1.68	1.75	1.66	1.54	1.67	0.85	0.64	0.75	0.76	34.23	34.23	34.23	11.10	11.09	11.09	98.3	98.3	98.2
Aug-94	0.36	0.39	0.43	0.00	0.00	0.00	0.18	0.17	0.17	1.94	1.91	1.76	1.86	1.79	1.90	0.39	0.53	0.54	34.14	34.14	34.38	9.70	9.70	9.90	99.7	99.3	98.0
Sep-94	0.20	0.22	0.26	0.02	0.02	0.02	0.03	0.03	0.02	1.56	1.62	1.63	1.79	1.46	1.49	0.04	0.20	0.34	34.49	34.48	34.48	11.67	11.63	11.61	100.0	99.8	99.4
Oct-94	0.36	0.41	0.46	0.03	0.03	0.02	0.03	0.03	0.01	1.91	1.89	1.76	2.86	2.73	2.33	0.24	0.34	0.46	34.13	34.18	34.36	12.36	12.33	11.89	103.1	103.0	101.8
Nov-94	0.33	0.35	0.36	0.02	0.03	0.02	0.06	0.05	0.05	2.03	2.02	2.12	4.36	4.21	4.99	0.54	0.67	0.91	34.14	34.16	34.15	15.00	14.33	14.04	99.4	98.3	94.9
Dec-94	0.51	0.63	0.54	0.04	0.04	0.04	0.06	0.04	0.05	1.71	1.69	1.77	5.04	5.67	5.57	0.39	0.44	0.62	34.45	34.46	34.59	18.22	17.49	17.24	100.6	99.6	99.5
Jan-95	0.07	0.09	0.08	0.04	0.05	0.05	0.06	0.05	0.05	----	2.01	2.00	4.51	4.47	4.40	----	----	----	34.62	34.68	34.68	20,41	19.70	19.61	101.3	100.8	100.2
Feb-95	0.16	0.18	0.20	0.03	0.02	0.02	0.24	0.25	0.21	1.80	1.86	1.88	5.42	5.59	5.66	0.44	0.65	0.93	34.84	34.82	34.83	21.24	21.02	20.87	98.3	97.2	94.6
Mar-95	0.14	0.13	0.14	0.01	0.01	0.01	0.10	0.08	0.08	1.77	1.82	1.80	6.10	6.21	6.22	0.66	0.94	1.03	35.01	35.02	35.02	20.99	20,97	20,96	98.1	98.2	97.7
Mar-95-2	0.12	0.11	0.09	0.01	0.02	0.02	0.04	0.06	0.05	1.59	1.71	1.80	1.25	1.37	1.08	1.42	1.96	1.86	35.24	35.25	35.26	18.65	18.57	18.56	98.1	97.3	96.6
Min	0.07	0.09	0.08	0.00	0.00	0.00	0.03	0.03	0.01	1.55	1.61	1.58	0.87	0.76	0.65	0.04	0.20	0.34	33.16	33.18	33.59	9.70	9.70	9.90	96.4	96.4	91.6
Max	0.51	0.63	0.54	0.13	0.07	0.08	0.28	0.25	0.21	2.03	2.03	2.12	9.75	8.73	8.19	1.42	1.96	1.86	35.24	35.25	35.26	21.24	21.02	20.87	103.1	104.2	103.4
Mean	0.25	0.28	0.30	0.04	0.03	0.03	0.10	0.08	0.08	1.79	1.81	1.78	4.09	3.83	3.93	0.64	0.80	0.93	34.18	34.19	34.35	16.01	15.80	15.54	99.8	99.5	98.0
Percentage of differences between depths exceeding the estimated analytical error.																											
Estimated accuracy		±0.08			±0.03			±0.05			±0.10			±0.20			±0.10			±0.05			±0.03			±1.0	
No difference		70			100			100			64			34			12			52			22			34	
Surface max		0			0			0			30			24			0			0			60			54	
Mid max		6			0			0			0			18			12			0			6			12	
Bottom max		24			0			0			6			24			76			48			12			0	

Table 26: Variation of mean values with depth: site N3 (Western Central Bay).