Technical Report

Investigations and Monitoring Group

Akaroa Harbour nutrient status

April 1989 – June 2004

Report No. U05/11

Environment Canterbury

Your regional council

Akaroa Harbour nutrient status

April 1989 – June 2004

Report No. U05/11

Lesley Bolton-Ritchie

March 2005

Environment Canterbury
Your regional council

Report U05/11

58 Kilmore Street
PO Box 345
Christchurch
Phone (03) 365 3828
Fax (03) 365 3194

75 Church Street
PO Box 550
Timaru
Phone (03) 688 9069
Fax (03) 688 9067

Website: www.ecan.govt.nz
Customer Services Phone 0800 324 636

Executive Summary

Water quality monitoring was carried out at 6 sites in Akaroa Harbour. At all sites the surface water was sampled while at four of the sites samples were also collected from at least one other water depth. Sampling was carried out approximately monthly over five, year-long periods between April 1989 and June 2004.

Significant differences occurred in the surface water concentration of the nutrients between sites. For ammonia nitrogen there was no obvious pattern with respect to the difference in concentration between sites; for the other nutrients there was a clear pattern to the differences. For total organic nitrogen, total nitrogen, dissolved reactive phosphorus and total phosphorus the pattern consisted of generally higher concentrations at inner harbour (Robinsons Bay, French Farm, Takamatua Bay and Childrens Bay) than at mid (between the Kaik and Cape Three Points) and outer (between the heads) harbour sites. For nitrate-nitrite, the pattern consisted of higher concentrations between the heads than at inner harbour and mid harbour sites.

The pattern of differences in nutrient concentrations with respect to location in the harbour indicates:

- The water between the heads is dominated by offshore oceanic water
- The water in the inner harbour is predominantly from offshore with localised nutrient inputs and natural processes relating to water depth affecting nutrient concentrations

The results indicate that there is a greater likelihood of enhanced phytoplankton growth at the heads than at other sites. The current nutrient concentrations of the inner harbour may contribute to the maintenance of the ecologically important seagrass beds of the intertidal flats in the inner harbour.

It is likely that higher nutrients concentrations at 3.5 m than in the surface water at the inner harbour sites results from the nutrients associated with the seafloor sediments being remixed into the overlying water column by waves and currents. At the mid and outer harbour sites the differences in nutrient concentrations with depth were temporally variable and likely result from stratification. Differences over time would occur because climatic factors, such as temperature, duration and strength of the wind etc., influence the presence of distinct layers in the water column.

Dissolved reactive phosphorus concentrations at all sites were significantly higher, and total phosphorus concentrations at some of the sites were significantly higher over 1989-1990 than over the other sampling periods. These results do not indicate a trend of a decrease in the concentration of these nutrients over time but rather that the concentrations were elevated during 1989-1990. Surface water ammonia nitrogen concentrations were significantly lower over 2003-2004 than over one or more of the other sampling periods. The ammonia nitrogen concentrations, at all sites except French farm, were lower between 1989 and 2004 than in 1976. These results suggest that the concentrations of ammonia nitrogen in surface water have decreased over time.

The seasonal pattern in the concentrations of nitrate-nitrite and dissolved reactive phosphorus reflects the uptake of these nutrients by the phytoplankton in the spring and the release of nutrients back into the water column in mid-late autumn.

The nutrient concentrations recorded in Akaroa Harbour are generally lower than those in Lyttelton Harbour. The Akaroa Harbour N based nutrient concentrations are lower than, while the P based nutrient concentrations are comparable to, those of Pegasus Bay. Overall the nutrient concentrations in the water of Akaroa Harbour are, to date, not a cause for concern. However, with the increase in the human population and the increasing burden of sewage disposal and likely stormwater runoff there is a need to maintain long-term monitoring of the nutrient status of this nationally and internationally important harbour. The minimum desirable frequency for the continued monitoring of the nutrient status of greater Akaroa Harbour is every 5 years. In future it would be advisable to measure the chlorophyll-a concentration and suspended sediment levels at all sites and water depths in addition to the concentration of the nutrients.

Table of Contents

List of Figures

List of Tables

1 Introduction

1.1 Akaroa Harbour

Akaroa Harbour is a long narrow inlet formed by the collapse of the seaward margin of the southern most crater of the volcanic complex that forms Banks Peninsula. The harbour is some 17 km long with the width ranging from 1.5 – 3.6 km. The outer harbour, orientated SSE is 1.8 km wide at its heads. Some 5 km inland, its orientation changes to N-S and the harbour widens variously with several large embayments (Figure 1.1).

Typically the shoreline of the harbour grades from the gently sloping mudflats between steep rocky headlands in the inner half of the harbour, through to rocky shores that increase in steepness to seaward with rugged shores and high cliffs at the heads. Water depths range from 30 m just beyond the heads to 15 m at the curve and thence steadily to intertidal mudflats in the inner embayments.

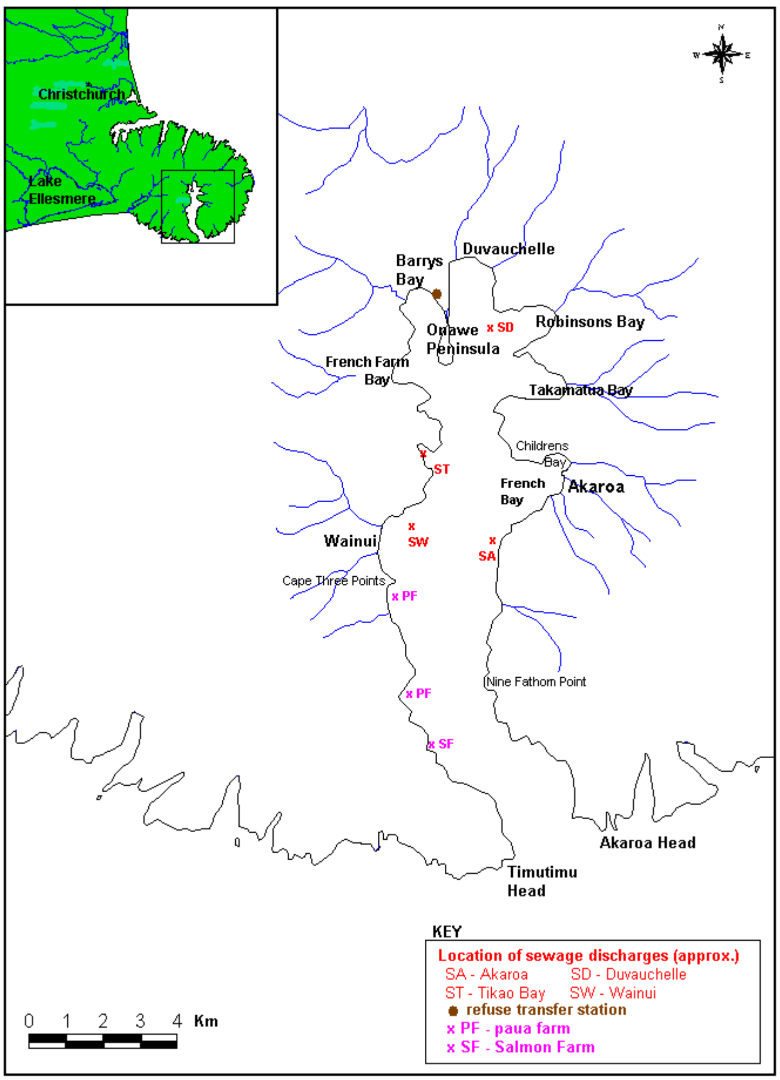


Figure 1.1 Akaroa Harbour: location, bays, streams, sewage discharges and marine farms

The harbour possesses considerable natural values and is important for a number of reasons. The Department of Conservation (1990) has ranked Akaroa Harbour as nationally important on the grounds that it:

- is important for Hector's dolphin
- is important for the yellow-eyed penguin
- has very high recreational use
- is a tourist attraction

They have also ranked the harbour as internationally important on the grounds that it is part of the Marine Mammal Sanctuary. This scenic harbour is a popular area for recreational boating, water skiing, fishing, kayaking and diving and commercial operations such as kayaking, swimming with the dolphins and dolphin watching. Aquaculture for paua, paua pearls and of salmon also takes place in the outer part of the harbour (Figure 1.1).

Maori communities have occupied sites around the harbour in the past and the harbour remains a valued area today for historical reasons. European occupation of the area began around the 1850s with the village of Akaroa being the focal point of the earliest settlers. Over time settlements have developed on the harbour fringes at not only Akaroa village but at Duvauchelle, Takamatua and Wainui. More recently there has been an increase in the number of lifestyle blocks and holiday homes in these settlements and in many of the other embayments within the inner harbour. Residents now total some 600 people, but with numerous holiday homes and tourist accommodation the effective population inhabiting the area is considerably larger and highly variable. Over time the Akaroa area has seen seal hunting, whaling, timber felling, ship-building, cocksfoot harvesting, fishing, dairying and dairy factories prosper and decline. Nowadays the permanent community consists of a farming community along with vintners, lifestylers, craftspeople, retirees and the infrastructure supporting the tourist industry and permanent residents.

Hand in hand with the increase in the human population of the area has been the increasing burden of sewage disposal. Reticulated sewage systems are in place in Takamatua/Akaroa village, Duvauchelle, Wainui and Tikao Bay. From the reticulated systems the sewage is discharged into the harbour through outfalls off Akaroa village (Green Point), Duvauchelle, Wainui and Tikao Bay (Figure 1.1). Of note is that the sewage from Tikao Bay will not be discharged into the harbour as of the middle of 2005. Sewage is a source of nitrogen and phosphorus compounds i.e. nutrients (Harris *et al.*, 1996).

With the increase in housing and roading in the embayments in the harbour there has been an increase in impervious surface area and hence stormwater runoff. Some of the stormwater in the region is discharged into the small streams which then flow into the harbour; however, stormwater is discharged directly into the sea via stormwater outlets in some areas, for example Akaroa main beach. Stormwater flow can result in inputs of rubbish, sediments, pathogens, organic matter, chemical contaminants such as heavy metals and organic compounds, and nitrogen and phosphorus compounds into harbour water (Morrisey, 1997; Vincent and Thomas, 1997; Bolton-Ritchie, 2003). During rainfall events there is also known runoff into the sea from the Akaroa refuse transfer station in Barrys Bay (Figure 1.1).

With large areas of the hillside surrounding the harbour used for grazing, artificial fertilisers are periodically applied (often by plane) to the hillside pastures. In addition the numerous commercial and lifestyle horticultural activities undertaken in the harbour surrounds likely use artificial fertilisers. Fertiliser and animal wastes run off from the land and into streams which then flow into the harbour contributing nutrients to the waters of the harbour. Marine farming within the harbour is another potential source of nutrients. Salmon farming, in particular results in appreciable nett additions of nutrients to the marine ecosystem.

With the increasing human presence and on-going land practices and water-based activities there is potential for the water quality of Akaroa Harbour to differ in different parts of the harbour and to change over time. As a result of the nutrient-rich discharges/runoff into the harbour water, the likelihood of eutrophication[1] in Akaroa Harbour needs to be assessed. Eutrophication can result in changes in the structure and functioning of marine ecosystems, reduced biodiversity, increase harmful algal blooms and impact on fisheries, aquaculture, recreation and

[1] Eutrophication - the enrichment of water by nutrients, especially compounds of nitrogen and/or phosphorus, causing an accelerated growth of aquatic plants (phytoplankton, cyanobacteria, algae and seagrasses) to produce an undesirable disturbance to the balance of organisms present in the water and to the quality of the water concerned (from Bock *et al,* 1997)

tourism (Rosenberg, 1985; EEA, 2001). Nutrient over–enrichment resulting in eutrophication is now evident in many coastal regions of Europe (Bonsdorff *et al*, 1977) and represents the greatest threat to coastal marine environments around the world (NRC, 2001). In the marine environment nitrogen is the critical limiting nutrient for phytoplankton (plant plankton) growth (NRC, 2001; Rosenberg, 1985; Valiela, 1995). Under optimal conditions phytoplankton will take up chemically available forms of nutrients in the ratio C:N:P of 106:16:1 (Redfield *et al,* 1963), i.e. when the nutrients are available in this ratio phytoplankton growth will not be limited. If the ratio of N:P is less than 16:1 then growth is nitrogen-limited and if it is greater than 16:1 growth is phosphorus limited (NRC, 2001).

1.2 Akaroa Harbour water quality

In 1989 the North Canterbury Catchment Board and Regional Water Board, the local body then responsible for the quality of the water in Akaroa Harbour, set up a programme to routinely sample the harbour water at a number of sites, and where relevant, a number of water depths at a site. The sites and depths sampled were the same as those sampled by Millhouse in 1976 (Millhouse, 1977). This monitoring programme, which continued after the Catchment Board amalgamated with other bodies to form the Canterbury Regional Council, was repeated over four other year-long (approximately) periods between March 1991 and June 2004. The considerable amount of Akaroa Harbour water quality data that now exists is the focus of this report.

1.3 Objectives of the analyses of these water quality data

To investigate if:

1. There was a significant difference in water quality between sites in Akaroa Harbour in each sampling period
2. There was a significant difference in water quality with water depth at each site in each sampling period
3. There was a significant difference in water quality at each site over time
4. The water quality in Akaroa Harbour is a cause for ecological concern, i.e.
    a. How do the nutrient concentrations in Akaroa Harbour water compare to trigger concentrations in the ANZECC (2000) guidelines?
    b. The N:P ratios in Akaroa Harbour compared to the 16:1 ratio considered optimal for aquatic plant growth

2 Methods

2.1 Sites and depths

Samples were collected from 6 sites in Akaroa Harbour (Figure 2.1). At each site the surface water was sampled and at four of the sites (A, D, E and F), samples were also collected at one or more depths below the surface. Details of the sites and depths sampled at each site are given in Appendix I.

2.2 Sampling regime

These sites were sampled in the following time periods:

- 1989-1990 (on 8 occasions between 12th April 1989 and 4th July 1990)
- 1991-1992 (on 9 occasions between 18th March 1991 and 15th of June 1992)
- 1996-1997 (on 9 occasions between 12th September 1996 and 26th May 1997)
- 1997-1998 (on 10 occasions between 30th September 1997 and 33rd June 1998)
- 2003-2004 (on 12 occasions between 24th July 2003 and 16thJune 2004)

2.3 Sample collection

The samples were collected by staff of the North Canterbury Catchment Board and staff from the Environmental Quality Section of the Canterbury Regional Council. Sampling was carried out from a boat with the surface water collected by leaning over the side of the boat and the water at depth collected using a modified 2L Van-Dorn sampler. All water collected was stored in specially prepared bottles provided by the laboratory undertaking the analyses, and kept cooled in chilli bins until delivery to the laboratory.

In the field the water temperature was measured using a field meter and general observations on the weather (cloud cover, wind direction, wind strength) were recorded at the time of sampling.

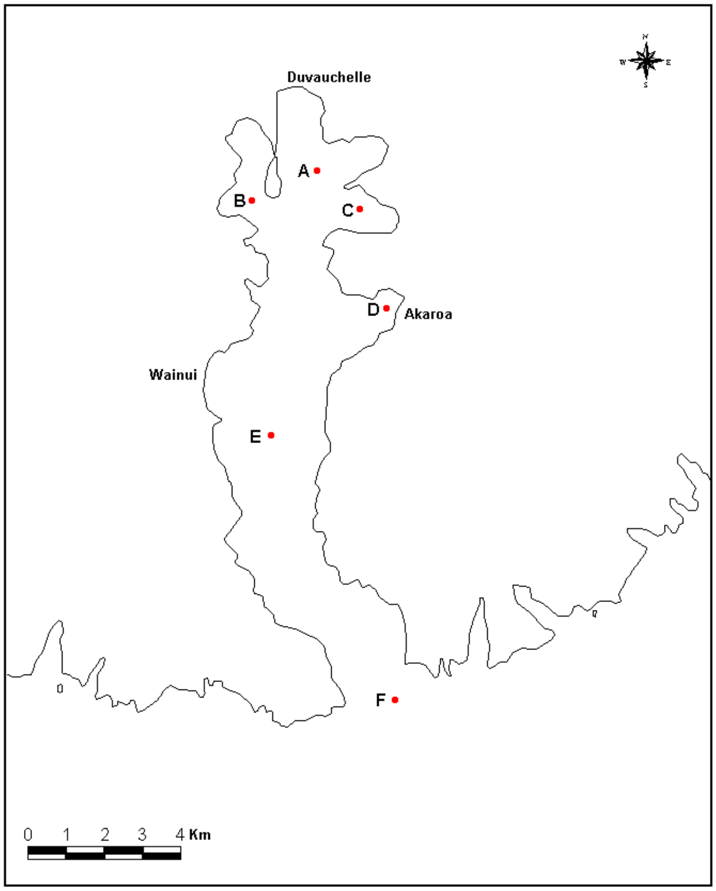


Figure 2.1 Water quality monitoring sites in Akaroa Harbour

A = between Robinsons Bay and Onawe Peninsula (referred to as Robinsons Bay in the text)
B = between French Farm and Onawe Peninsula (referred to as French Farm in the text)
C = Takamatua Bay
D = Childrens Bay
E = between the Kaik and Cape Three Points (referred to as Mid Harbour in the text)
F = between the heads (referred to as the heads in the text)
Note: Sites A, B, C and D are sometimes collectively referred to as the inner harbour sites

2.4 Sample analyses

The collected water samples were analysed for the range of chemical determinands listed in Table 2.1. Laboratory analyses of the 1989-1998 samples were carried out by the Cawthron Institute and analyses of the 2003-2004 samples were carried out by the Canterbury Regional Council. The details of the analytical methods are given in Appendix II.

Table 2.1 Chemical determinands (nutrients)

Nitrate and nitrite nitrogen (NNN)
Total ammonia nitrogen (NH3N)
Dissolved inorganic nitrogen (DIN) (=NNN+ NH3N)
Total nitrogen (TN)
Total organic nitrogen (TON) (=TN – DIN)
Dissolved reactive phosphorus (DRP)
Total phosphorus (TP)

2.5 Data analyses

Microsoft Excel 2000, Systat (version 9) (SPSS, 1999) and WQstat Plus (v1.5) (IDT, 1998) were used for the production of summary statistics, charts, box plots and all statistical analyses.

The Wilcoxon signed rank test (Systat V9) was used to determine if there was a significant difference in the concentration of each nutrient between sites in each sampling period. The data were separated into two sets, with the data sets consisting of surface water (six sites) and 3.5 m deep water (four sites).

To determine if there was a significant difference in the concentration of each nutrient with water depth, the Wilcoxon signed rank test was also used. Statistical analyses were performed on data from those sites where more than one water depth was sampled and were performed on the data from each sampling period.

To determine if there was a significant difference in the concentration of each nutrient at each site over time, Kruskal-Wallis ANOVA (Analysis of Variance) (Systat V9) and Tukey pairwise comparison (Systat V9) were used. Where the ANOVA analysis showed there was a statistically significant difference in nutrient concentration over time, the Tukey pairwise comparison was applied to determine between which sampling periods the difference/s occurred. At sites where more than one water depth was sampled, the data were separated into depth data sets. In addition the Kruskal-Wallis H statistic (WQstat Plus) for seasonality was performed on the data from each depth at each site.

The concentrations of DIN, TN, DRP and TP at each site were compared to the trigger levels' concentrations for both 'slightly disturbed marine water' and 'slightly disturbed estuarine water' as listed in the ANZECC (2000) guidelines to determine if the nutrient concentrations in Akaroa Harbour water are cause for ecological concern. The N:P ratio for each site was calculated using the DIN and DRP values.

Where concentrations of nutrients were less than the analytical limits of detection, the results were reported as 'less than' the detection limit. These non-detect data were converted to a value equal to half the detection limit for the purposes of data analyses.

3 Results

The results, for all samples collected at each depth at each site in Akaroa Harbour over the period April 1989 to June 2004, are summarised in Table 3.1.

3.1 Variation between sites

3.1.1 Surface water

The data for each nutrient for each sampling period are presented in box and whisker plots (Figures 3.1-3.6). The results of the Wilcoxon two-tailed sign test, used to determine if, over each sampling period, there was a significant difference in the concentration of each nutrient between sites, are presented in Appendix III.

Nitrate and nitrite nitrogen (NNN)

In general, NNN concentrations were significantly higher at the heads than at sites within the inner harbour i.e. Childrens Bay, French Farm, Takamatua Bay and Robinsons Bay. NNN concentrations at the heads were also significantly higher than those at the mid harbour site over 1996-1997 and 2003-2004. Over 1989-1990 NNN concentrations at the mid harbour site were significantly higher than in Takamatua Bay. There were no significant differences in NNN concentration between sites over 1997-1998.

Ammonia nitrogen (NH3N)

Significant differences in NH3N concentration occurred between some of the inner harbour sites over 1989-1990 and 1991-1992. There were no significant differences in NH3N concentration between sites over 1996-1997, 1997-1998 and 2003-2004.

Total nitrogen (TN)

The TN concentrations in Robinsons Bay were significantly higher than at the heads over all sampling periods except 2003-2004. Over 1991-1992 concentrations at French Farm and in 1997-1998 concentrations at Childrens Bay were also significantly higher than at the heads. Over 1989-1990 and 2003-2004 there were significant differences in TN concentrations between some of the inner harbour sites.

Total organic nitrogen (TON)

The significant differences in TON concentrations between sites mirrored those of TN, except over 1991-1992 when there was no significant difference in TON concentration between French

Farm and the site at the heads. In addition, over 1996-1997 TON concentrations in Takamatua Bay were significantly higher than at the heads and over 1997-1998 concentrations in Takamatua Bay and French Farm were significantly higher than at the heads.

Dissolved reactive phosphorus (DRP)
DRP concentrations in Robinsons Bay were significantly higher than at the mid harbour and the heads sites over 1989-1990, 1997-1998 and 2003-2004. In addition, over 2003-2004, DRP concentrations at French Farm and Takamatua Bay were significantly higher than at the mid harbour and at the heads. Over at least one of these sampling periods there were also significantly higher DRP concentrations at Takamatua Bay than at the heads and at Takamatua Bay and Childrens Bay than at the mid harbour site. Over some of the sampling period there were significant differences in DRP concentration between some of the inner harbour sites.

Total phosphorus (TP)
In general TP concentrations at the inner harbour sites were significantly higher than at the heads over 1996-1997, 1997-1998 and 2003-2004. Over 1991-1992 the concentrations at two of the inner harbour sites were significantly higher than at the heads. Over 1996-1997 and 2003-2004 the TP concentrations at the inner harbour sites were, in general, also significantly higher than at the mid harbour site. Over some of the sampling period there were significant differences in DRP concentration between some of the inner harbour sites.

3.1.2 3.5 metre deep water

Sampling at 3.5 m deep was undertaken at four sites: Robinsons Bay, Childrens Bay, the mid harbour and the heads. The data for each nutrient for each sampling period are presented in box and whisker plots (Figures 3.7-3.12). The results of the Wilcoxon two-tailed sign test are presented in Appendix IV.

Nitrate and nitrite nitrogen (NNN)
NNN concentrations were significantly higher at the heads than at the other three 3.5 m sites over all sampling periods except 1997-1998 when there were no significant differences in NNN concentration between sites.

Ammonia nitrogen (NH3N)
NH3N concentrations in Robinsons Bay were significantly higher than in Childrens Bay over 1989-1990 and higher than at the mid harbour site over 1989-1990 and 1991-1992. Concentrations in Childrens Bay were significantly higher than at two of the other sites over 1989-1990 and 1997-1998. There were no significant differences in NH3N concentration between sites over 1996-1997 and 2003-2004.

Total nitrogen (TN)
In general, TN concentrations at the inner harbour and mid harbour sites were significantly higher than at the heads. TN concentrations in Robinsons Bay were also significantly higher than in Childrens Bay over three sampling periods and higher than at the mid harbour site over 1989-1990.

Total organic nitrogen (TON)
The significant differences in TON concentration between sites were very similar to those for TN concentrations.

Dissolved reactive phosphorus (DRP)
DRP concentrations in Robinsons Bay and Childrens Bay were significantly higher than at the mid harbour site and/or at the heads over four of the sampling periods. Over 1997-1998 concentrations in Childrens Bay were significantly higher than those in Robinsons Bay. There was no significant difference in DRP concentrations between sites over 1991-1992.

Total phosphorus (TP)
TP concentrations in Robinsons Bay and Childrens Bay were significantly higher than at the heads over all sampling periods and significantly higher than at the mid harbour site over some of the sampling periods. TP concentrations at the mid harbour site were significantly higher than at the heads over three of the sampling periods. Over 1989-1990, 1991-1992 and 1996-1997 concentrations in Robinsons Bay were significantly higher than in Childrens Bay.

3.2 Variation within sites

3.2.1 Variation with water depth

Samples were collected at two or more water depths in Robinsons Bay (0 and 3.5 metres), Childrens Bay (0 and 3.5 metres), mid harbour (0, 3.5 and 6.5 metres) and the heads (0, 3.5, 6.5, 9.5 and 12.5 metres). The data for each nutrient at each water depth over each sampling period are presented in Figures 3.7-3.12. The Wilcoxon two-tailed sign test was used to determine if, over each sampling period, there was a significant difference in the concentration of each nutrient with water depth. The results of this are presented in Table 3.2.

Table 3.1 Summary of nutrient concentrations (mg/L) in the water at each depth at each site

n = number of samples A - F = sites 0, 3.5, 6.5, 9.5 and 12.5 = depth in metres

	A0	A3.5	B0	C0	D0	D3.5	E0	E3.5	E6.5	F0	F3.5	F6.5	F9.5	F12.5
NH3N														
Minimum	0.003	0.017	0.003	0.003	0.003	0.015	0.003	0.011	0.012	0.003	0.014	0.014	0.014	0.015
Mean	0.016	0.012	0.018	0.015	0.015	0.014	0.013	0.011	0.011	0.013	0.014	0.013	0.013	0.015
Median	0.012	0.003	0.013	0.011	0.012	0.003	0.010	0.003	0.003	0.013	0.003	0.003	0.003	0.003
Maximum	0.075	0.080	0.086	0.071	0.057	0.053	0.056	0.054	0.055	0.040	0.039	0.052	0.048	0.046
NNN														
Minimum	0.003	0.014	0.003	0.003	0.003	0.013	0.003	0.018	0.018	0.003	0.029	0.028	0.028	0.031
Mean	0.012	0.008	0.016	0.013	0.015	0.006	0.017	0.010	0.012	0.025	0.018	0.020	0.019	0.019
Median	0.006	0.003	0.008	0.006	0.007	0.003	0.009	0.003	0.003	0.016	0.003	0.003	0.003	0.003
Maximum	0.053	0.068	0.066	0.084	0.070	0.073	0.096	0.069	0.074	0.079	0.096	0.100	0.094	0.160
DIN														
Minimum	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
Mean	0.027	0.031	0.033	0.027	0.029	0.028	0.029	0.028	0.029	0.037	0.042	0.041	0.041	0.046
Median	0.023	0.022	0.027	0.020	0.023	0.023	0.022	0.023	0.025	0.029	0.035	0.038	0.039	0.037
Maximum	0.087	0.100	0.132	0.121	0.090	0.097	0.115	0.083	0.087	0.094	0.110	0.115	0.110	0.181
TN														
Minimum	0.100	0.193	0.070	0.040	0.025	0.176	0.040	0.164	0.159	0.040	0.133	0.141	0.144	0.142
Mean	0.185	0.180	0.174	0.165	0.169	0.160	0.160	0.160	0.150	0.139	0.130	0.140	0.140	0.140
Median	0.160	0.090	0.170	0.150	0.150	0.017	0.130	0.040	0.090	0.130	0.040	0.074	0.080	0.040
Maximum	0.620	0.350	0.330	0.650	0.520	0.610	0.650	0.340	0.270	0.340	0.240	0.230	0.250	0.230
TON														
Minimum	0.085	0.162	0.060	0.027	0.001	0.148	0.021	0.135	0.129	0.012	0.090	0.099	0.101	0.096
Mean	0.158	0.153	0.140	0.137	0.139	0.137	0.130	0.126	0.117	0.101	0.081	0.091	0.096	0.094
Median	0.132	0.066	0.128	0.128	0.133	0.007	0.117	0.020	0.069	0.099	0.005	0.045	0.021	0.009
Maximum	0.553	0.325	0.295	0.621	0.497	0.513	0.592	0.257	0.265	0.275	0.191	0.195	0.235	0.222
DRP														
Minimum	0.002	0.014	0.002	0.002	0.002	0.013	0.001	0.010	0.011	0.001	0.010	0.010	0.011	0.012
Mean	0.014	0.012	0.013	0.013	0.012	0.012	0.010	0.009	0.010	0.009	0.009	0.009	0.009	0.010
Median	0.012	0.002	0.013	0.013	0.012	0.004	0.008	0.001	0.001	0.009	0.002	0.002	0.002	0.002
Maximum	0.042	0.050	0.037	0.027	0.025	0.047	0.031	0.027	0.042	0.031	0.035	0.029	0.029	0.030
TP														
Minimum	0.018	0.037	0.012	0.019	0.020	0.038	0.011	0.029	0.029	0.011	0.024	0.024	0.024	0.026
Mean	0.035	0.035	0.034	0.037	0.031	0.034	0.026	0.027	0.029	0.023	0.022	0.023	0.023	0.022
Median	0.033	0.021	0.032	0.031	0.030	0.020	0.023	0.016	0.020	0.021	0.011	0.011	0.011	0.013
Maximum	0.100	0.063	0.077	0.260	0.052	0.210	0.077	0.051	0.051	0.042	0.039	0.039	0.043	0.053
n	48	48	48	48	47	47	48	48	48	47	47	47	47	47

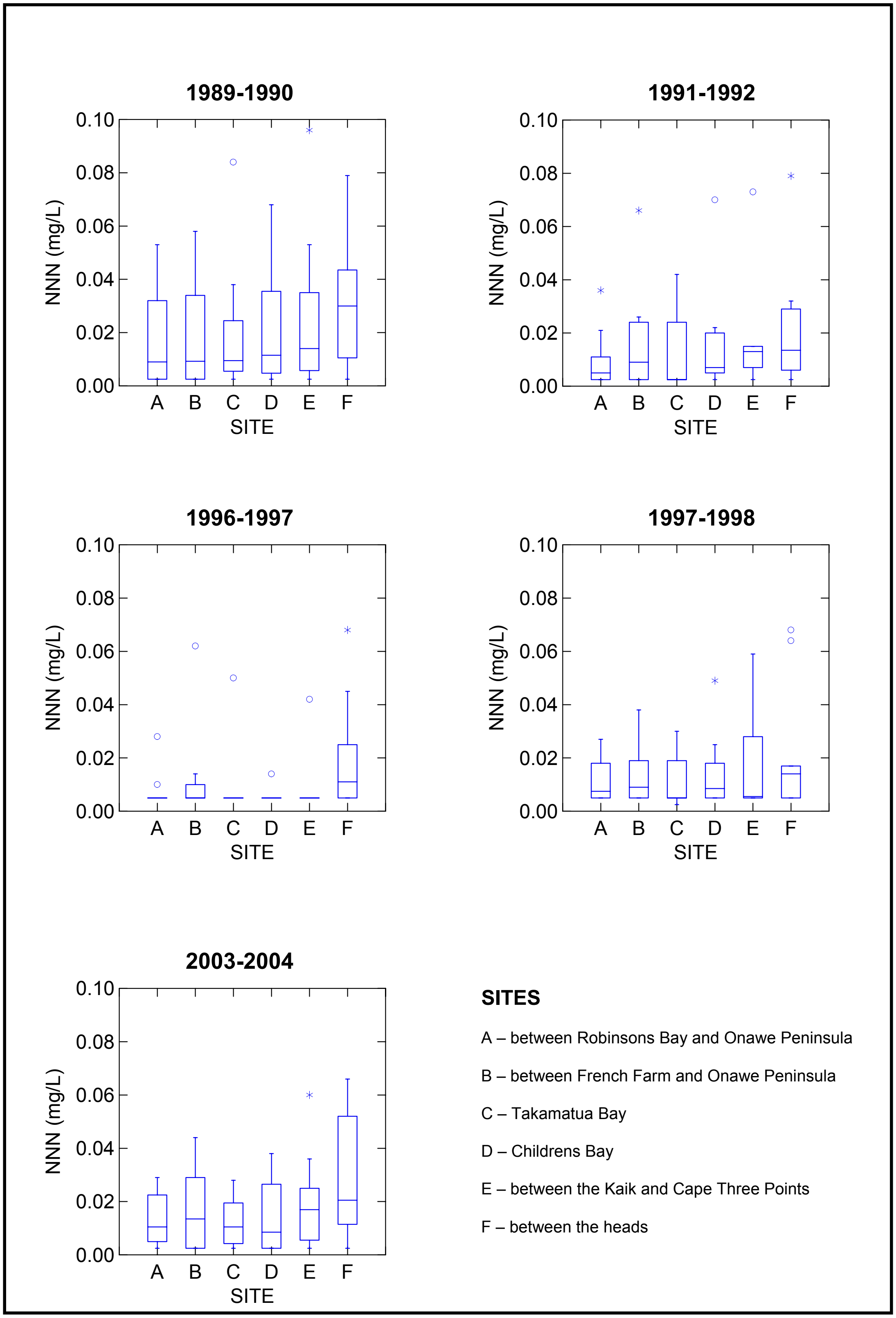


Figure 3.1 Nitrate-nitrite nitrogen (mg/L) in surface water at Akaroa Harbour sites, 1989-2004

NOTE: horizontal bar = median, box = interquartile range, whisker ends = 5% and 95%iles, * and o indicate outlier and extreme values respectively

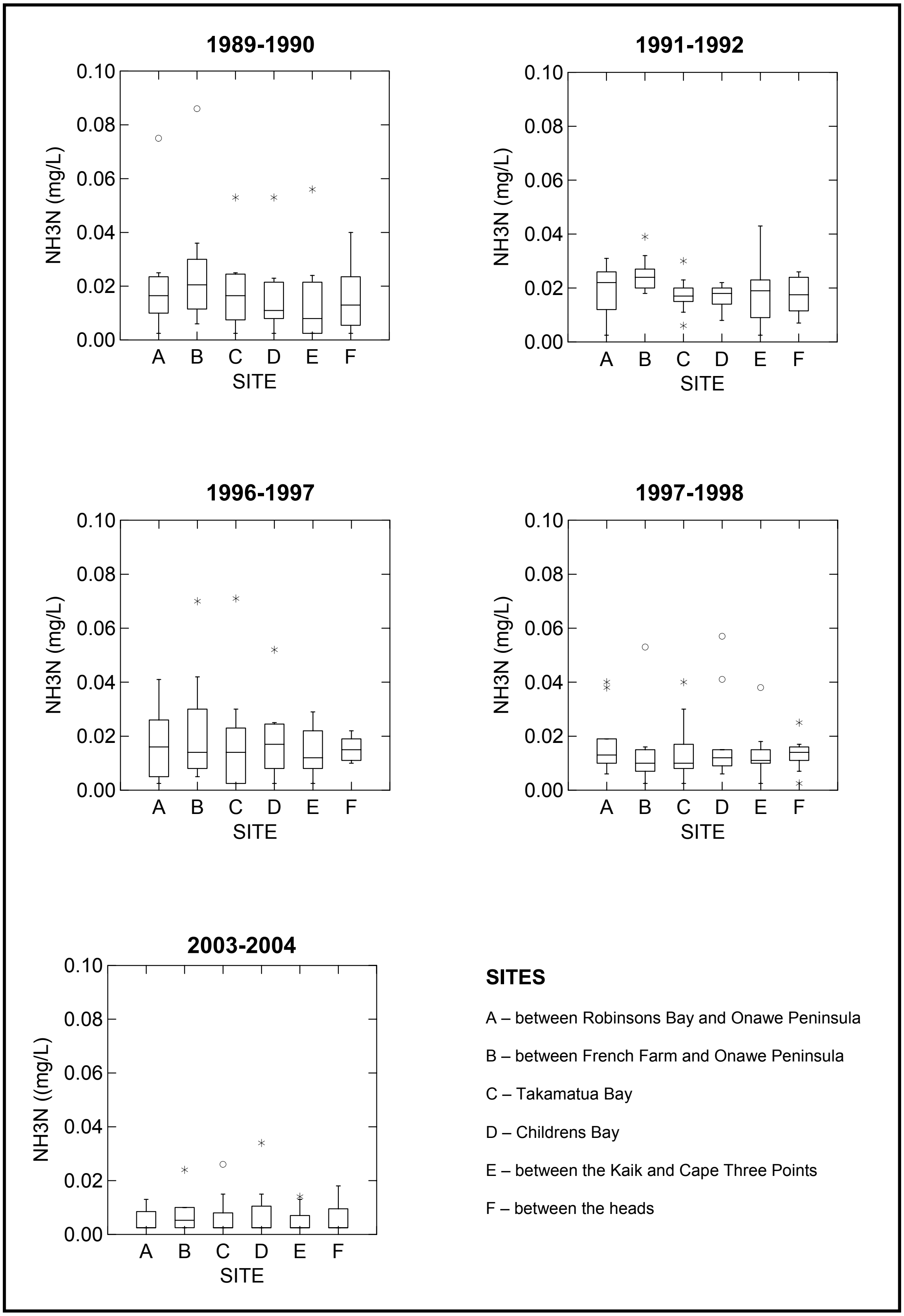


Figure 3.2 Ammonia nitrogen (mg/L) in surface water at Akaroa Harbour sites, 1989-2004

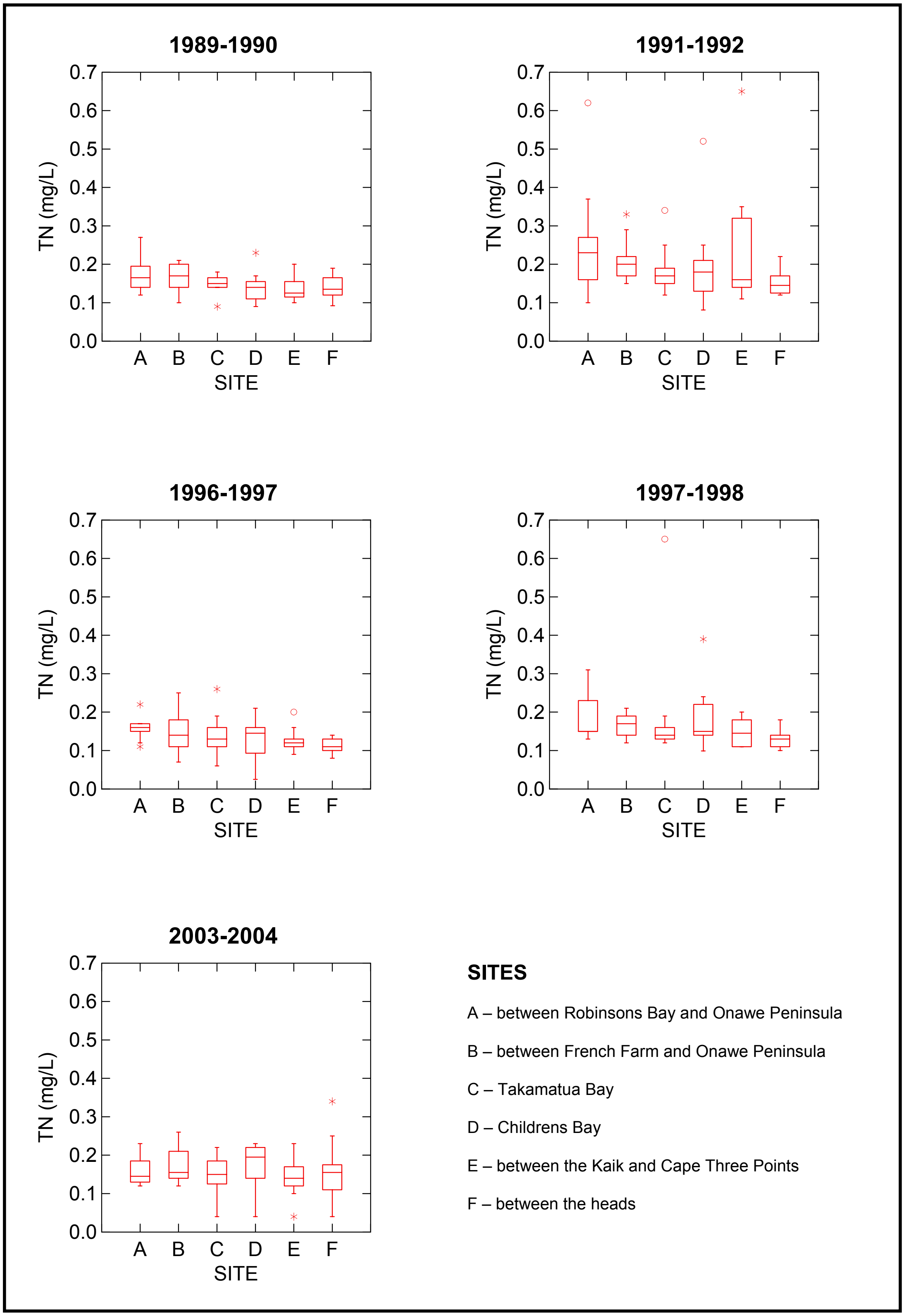


Figure 3.3 Total nitrogen (mg/L) in surface water at Akaroa Harbour sites, 1989-2004

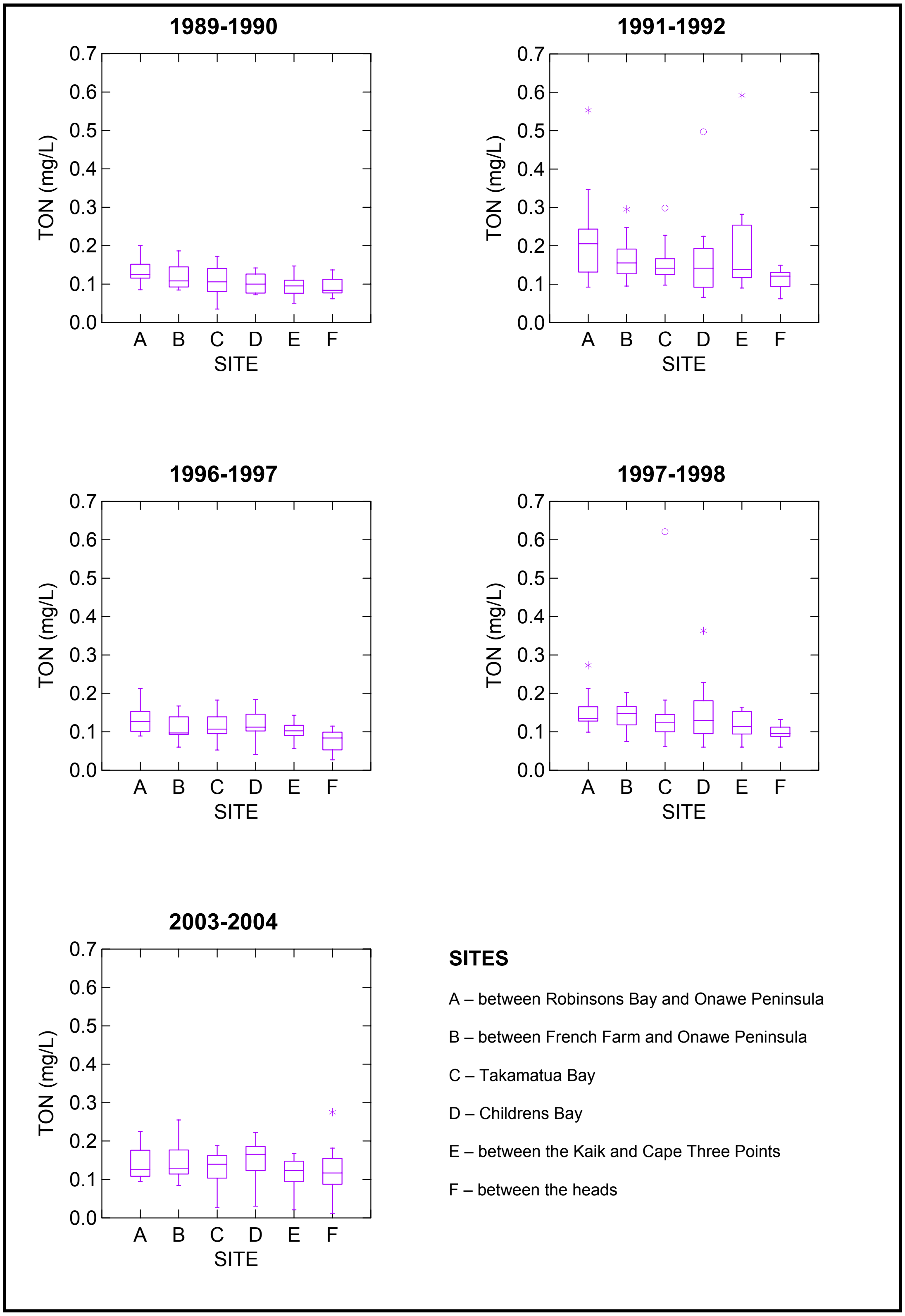


Figure 3.4 Total organic nitrogen (mg/L) in surface water at Akaroa Harbour sites, 1989-2004

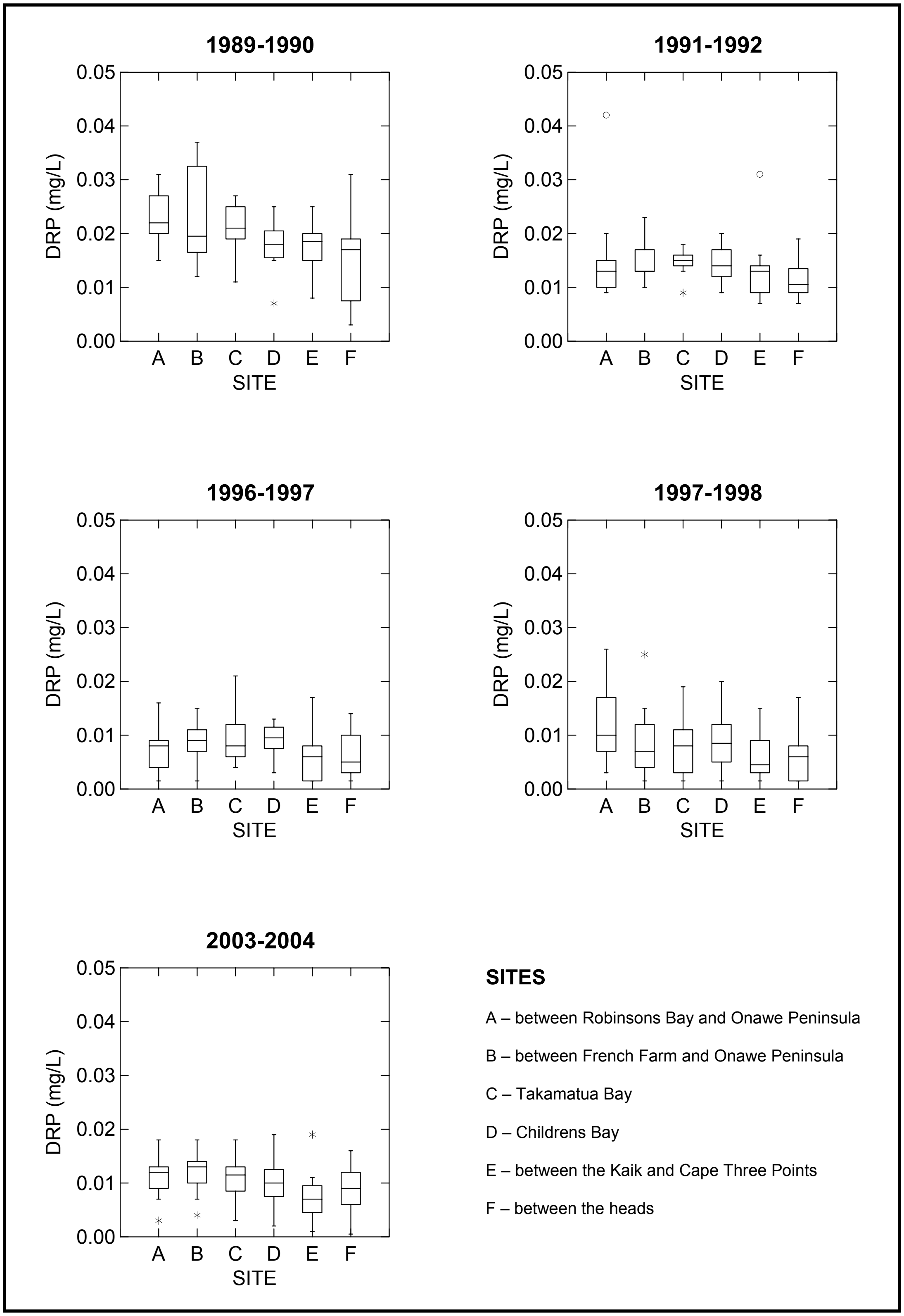


Figure 3.5 Dissolved reactive phosphorus (mg/L) in surface water at Akaroa Harbour sites, 1989-2004

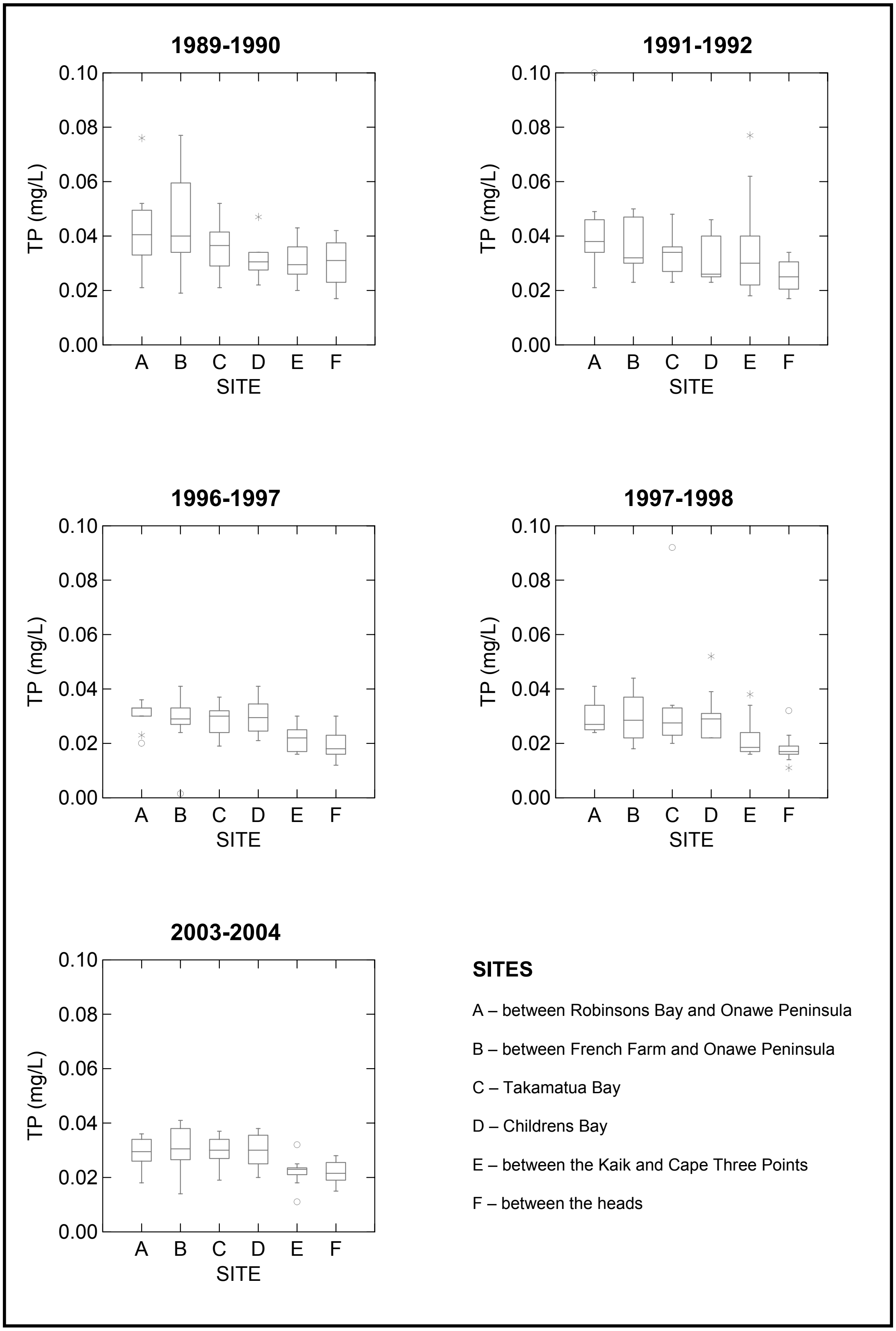


Figure 3.6 Total phosphorus (mg/L) in surface water at Akaroa Harbour sites, 1989-2004

At each site there was a significant difference in the concentration of at least two nutrients with water depth. The significant difference in concentration of a nutrient with water depth changed over time at each site. In general, the more depths that were sampled at a site, the more significant differences in nutrient concentrations between depths.

3.2.2 Variation over time

The results of the Kruskal-Wallis ANOVA, used to determine if there was a significant difference in the concentration of each nutrient at each site and each depth over time, are presented in Table 3.3 while the results of Tukey pairwise comparison test, used to determine between which sampling periods any differences occurred, are presented in Appendix V (The data are presented as figures in Appendix VI). NOTE: extreme values have precluded the application of the pairwise comparison test for some of the significant differences determined by the ANOVA. The results of the analysis for seasonality (Kruskal-Wallis H statistic) are presented in Table 3.4.

3.2.2.1 Surface water

Significant differences occurred in NH3N and DRP concentrations at all sites over time. For NH3N the differences consisted of significantly lower concentrations over 2003-2004 than over one or more of the other sampling periods. For DRP the differences consisted of significantly higher concentrations over 1989-1990 than over 1996-1997, 1997-1998 and 2003-2004. In addition DRP concentrations in Robinsons Bay and French farm were also significantly higher over 1989-1990 than over 1991-1992. Significant differences in TP concentration over time occurred at three sites. At the mid harbour and the heads sites the TP concentrations were significantly higher over 1989-1990 than over one or more of the other sampling periods.

3.2.2.2 3.5 m, 6.5 m, 9.5 m and 12.5 m deep water

At sites where there were significant differences in NH3N, DRP and TP concentrations over time, the differences between time periods were comparable to that in surface water. For TON there were significant differences in concentrations over time in 3.5 m and 6.5 m deep water at the mid harbour site and at the heads. The differences in TON concentrations at these sites and depths consisted of significantly higher concentrations over 1991-1992 and/or 2003-2004 than one or more of the other sampling periods.

In 6.5 m deep water at the heads the TN concentration was significantly higher over 2003-2004 than over 1997-1998. At the heads there were no significant differences in the concentration of the N-based nutrients and DRP in 12.5 m deep water over time.

3.2.2.3 Seasonality

Significant seasonal variation occurred in NNN and DRP concentrations at all sites and at all water depths. For both nutrients, concentrations were lowest during late spring-summer and highest in late autumn-winter (see Figures in Appendix VI). At the sites and depths where there were significant seasonal variations in TON, TN, and TP concentrations, the seasonal pattern was identical to those for NNN and DRP, i.e. concentrations were lowest during late spring-summer and highest in late autumn-winter. There was no significant seasonal variation in NH3N concentrations.

3.3 Are the nutrient concentrations in Akaroa Harbour water of ecological concern?

3.3.1 Comparison with guideline values

In the ANZECC (2000) Guidelines, trigger values in ‘slightly disturbed marine water’ and ‘slightly disturbed estuarine water’ are given for DIN (= NO_x (≡ NNN) + NH_4^+ (≡ NH3N)), TN, FRP (≡ DRP) and TP. The guideline trigger values are the concentrations below which there is a low risk that adverse biological effects will occur. While concentrations above the trigger values do not necessarily mean that adverse effects will occur, the potential is there for adverse effects such as eutrophication.

The range, mean and median concentrations of each nutrient at each water depth at each site, are presented in Table 3.1. At each depth at each site the trigger values for DIN (0.02 mg/L), TN (0.12 mg/L), DRP (0.01 mg/L) and TP (0.025 mg/L) in marine water were exceeded and at each depth at each inner harbour site the trigger values for DIN (0.03 mg/L), TN (0.3 mg/L), DRP (0.005 mg/L) and TP (0.03 mg/L) in estuarine water were exceeded.

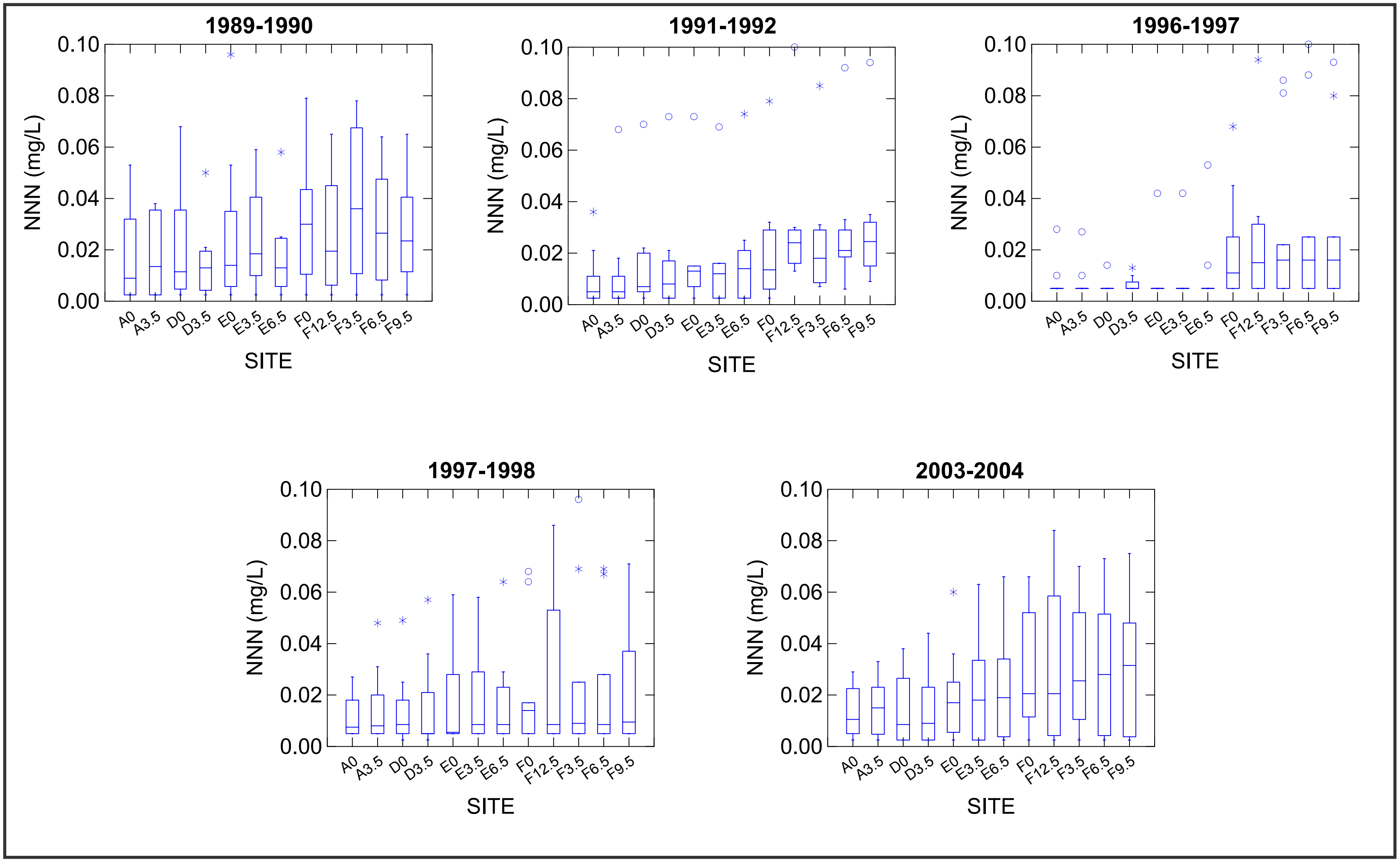


Figure 3.7 Nitrate-nitrite nitrogen (mg/L) at different depths at four Akaroa Harbour sites, 1989-2004
A – between Onawe Peninsula and Robinsons Bay B – Childrens Bay E – between the Kaik and Cape Three Points F – between the heads
0, 3.5, 6.5, 9.5, 12.5 – Depth in metres

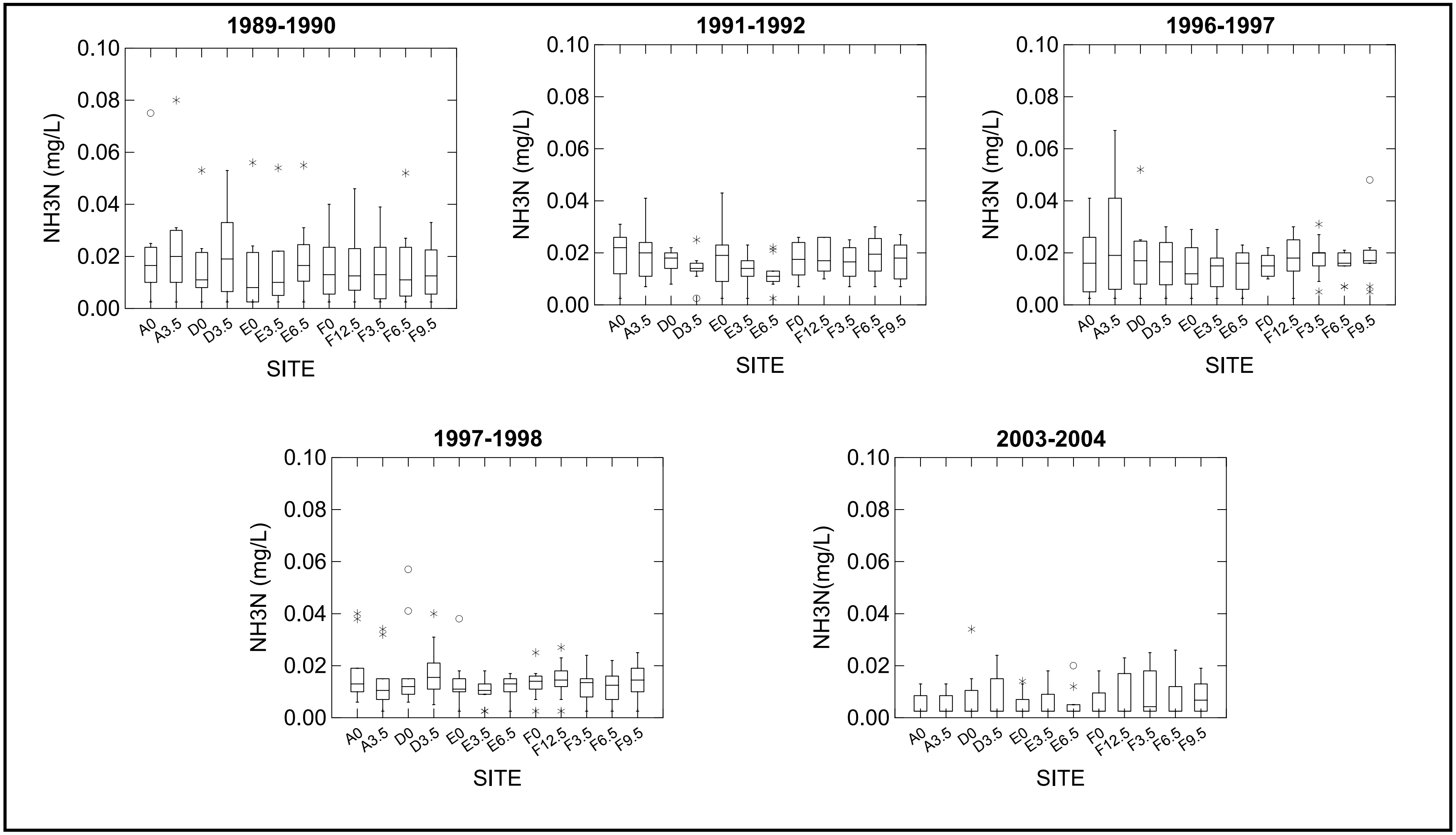


Figure 3.8 Ammonia nitrogen (mg/L) at different depths at four Akaroa Harbour Sites, 1989-2004

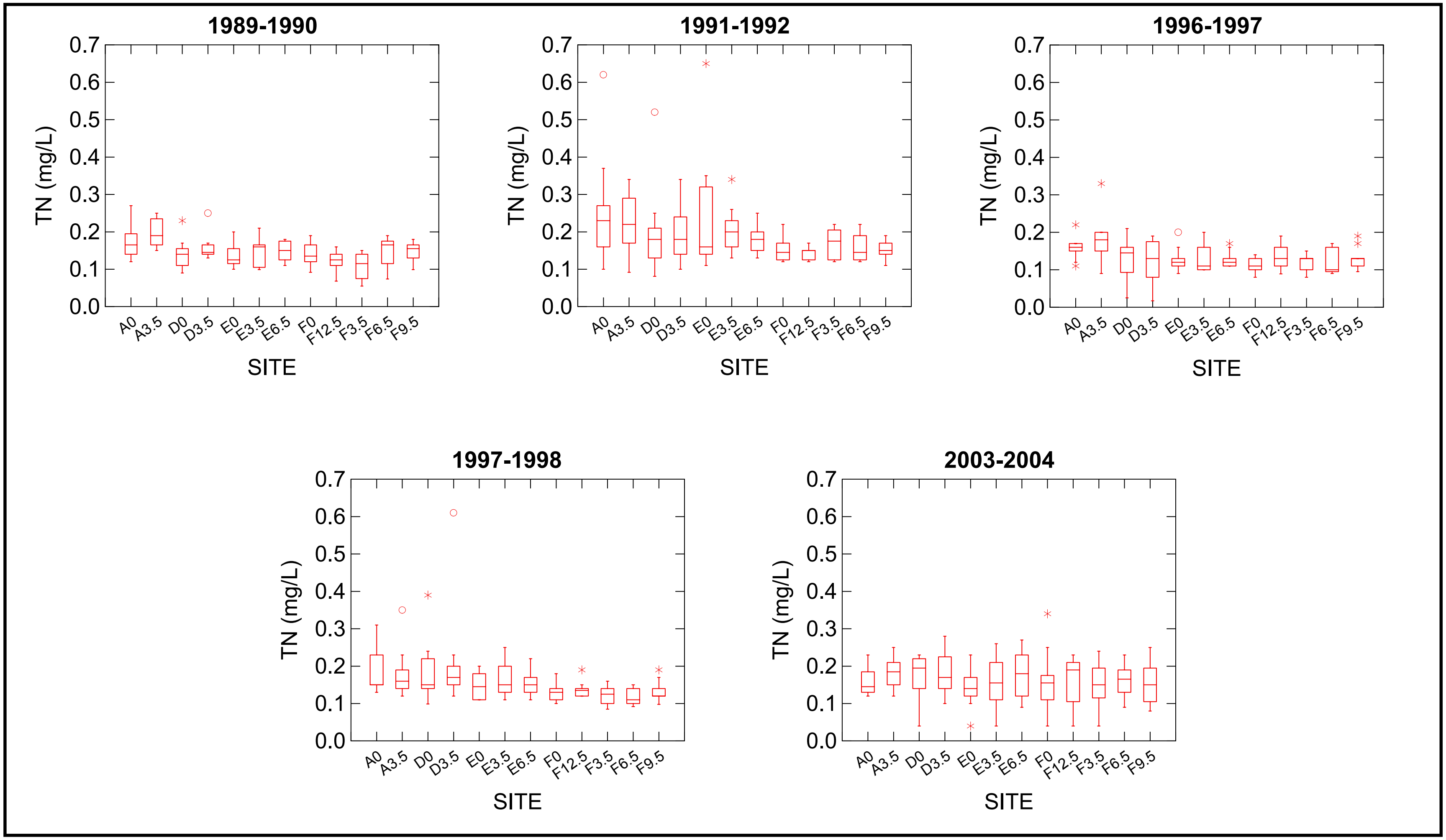


Figure 3.9 **Total nitrogen (mg/L) at different depths at four Akaroa Harbour sites, 1989-2004**

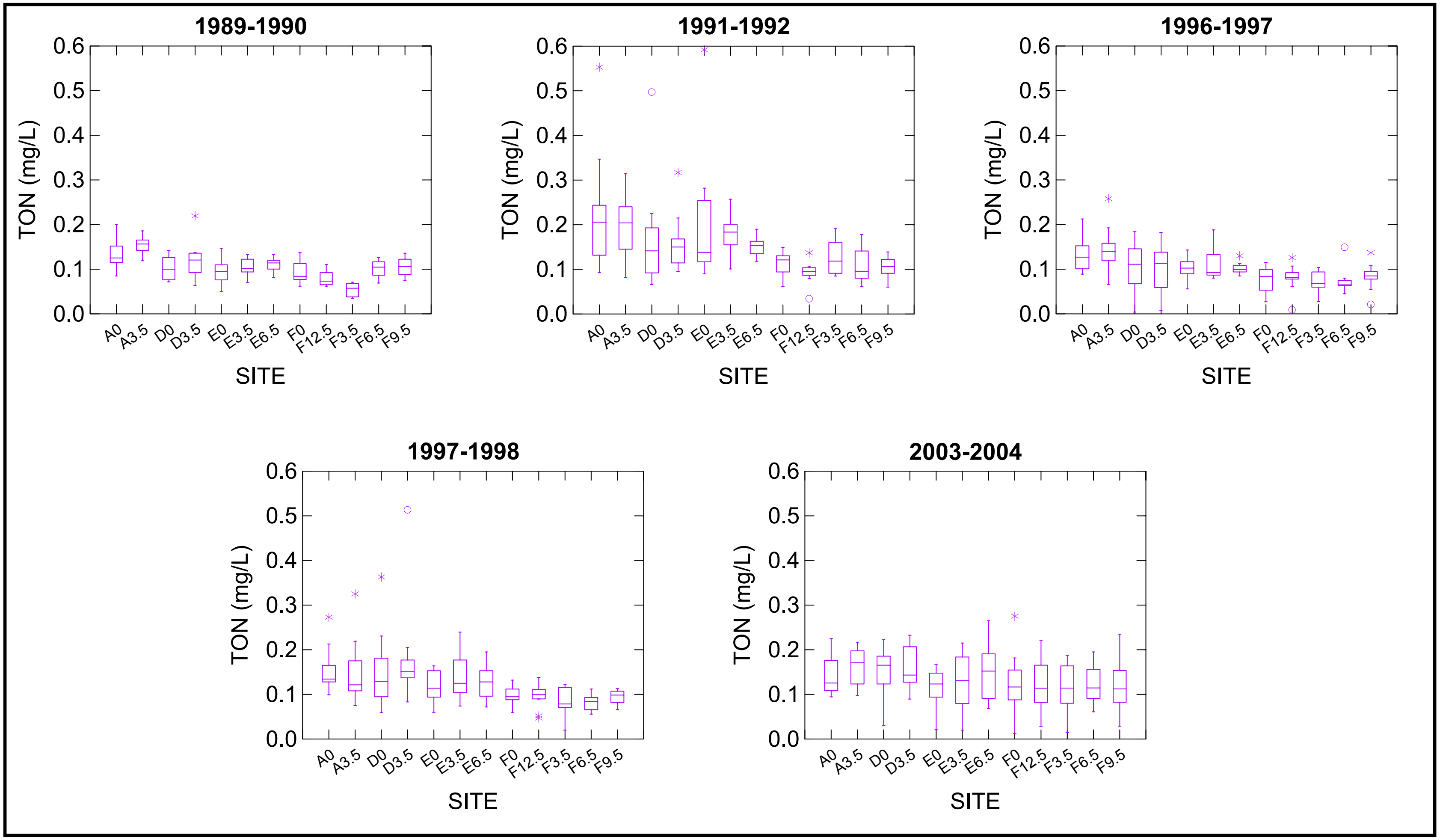


Figure 3.10 Total organic nitrogen (mg/L) at different depths at four Akaroa Harbour sites, 1989-2004

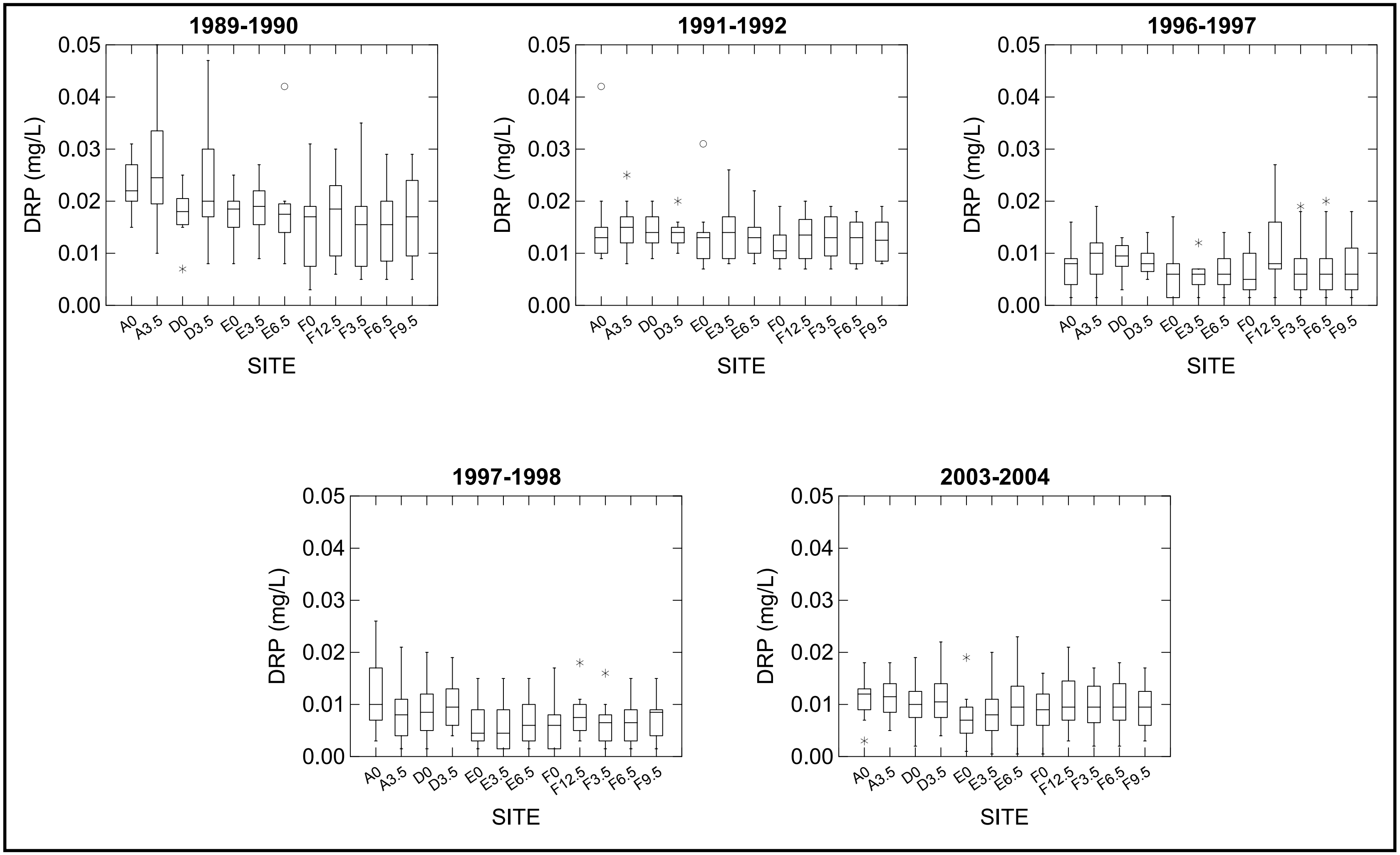


Figure 3.11 Dissolved reactive phosphorus (mg/L) at different depths at four Akaroa Harbour sites, 1989-2004

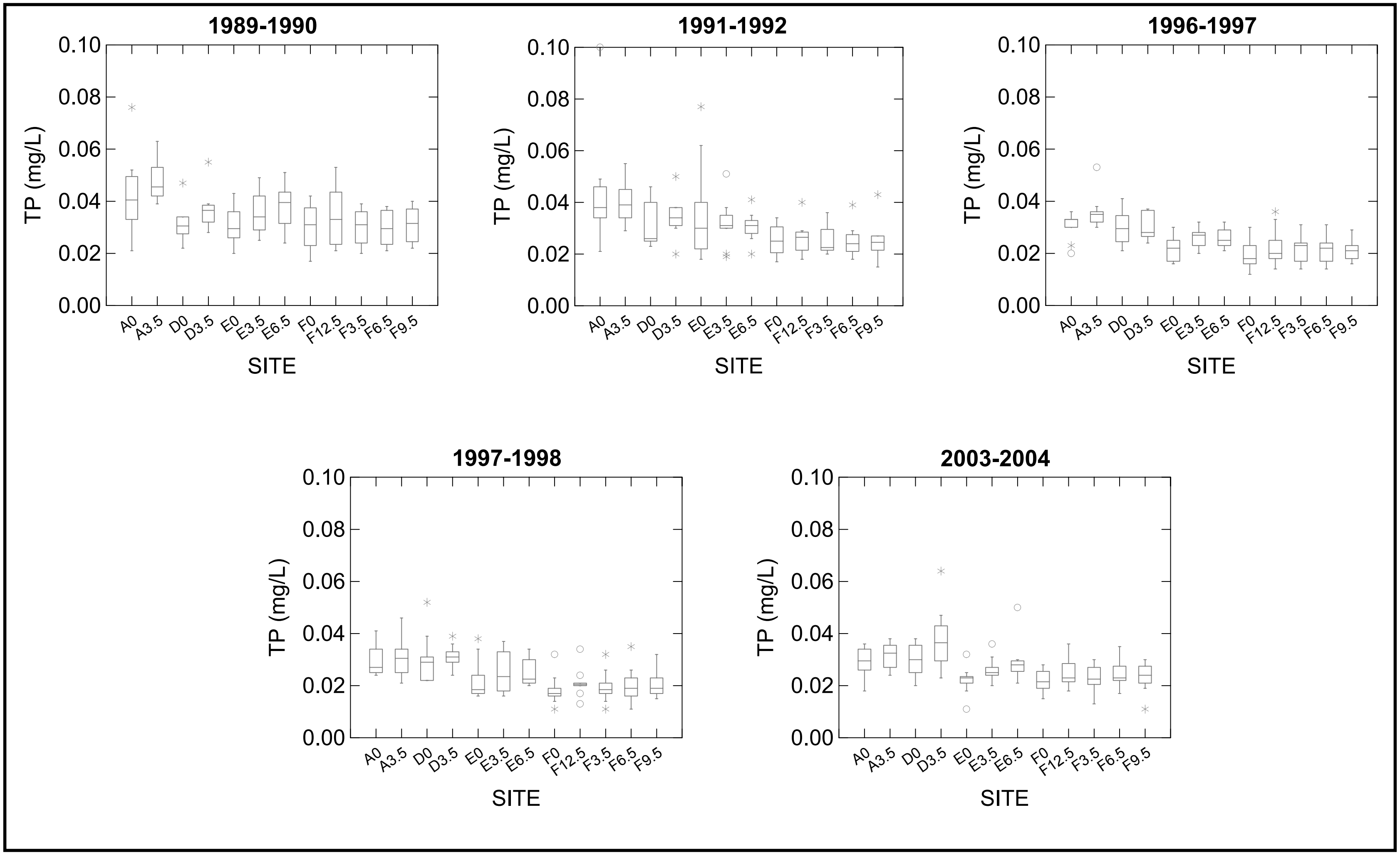


Figure 3.12 Total phosphorus (mg/L) at different depths at four Akaroa Harbour sites, 1989-2004

Table 3.2 Significant differences in the concentration of nutrients with depth at four sites in Akaroa Harbour

0, 3,5, 6,5 and 9.5, 12.5 - depth in metres

* significant difference between depths at p<0.05

** significant difference between depths at p<0.01

Blank cells - no significant difference in the concentration of any nutrients with depth

	Robinsons Bay	Childrens Bay	Kaik-Cape Three Points	Heads
1989-1990		**DRP** 3.5 > 0 *	**TP** 6.5 > 0 *	**NNN** 3.5 > 6.5 * **NNN** 3.5 > 12.5 * **TN** 6.5 > 3.5 * **TN** 6.5 > 12.5 * **TN** 9.5 > 3.5 * **TN** 9.5 > 12.5 * **TON** 0 > 3.5 * **TON** 6.5 > 3.5 * **TON** 9.5 > 3.5 * **TON** 12.5 > 3.5 * **TON** 6.5 > 12.5 * **TON** 9.5 > 12.5 * **DRP** 12.5 > 0 *
1991-1992			**NNN** 6.5 > 3.5 * **TN** 3.5 > 6.5 * **TON** 3.5 > 6.5 *	**NH3N** 12.5 > 0 * **NNN** 9.5 > 0 * **NNN** 12.5 > 0 * **NNN** 12.5 > 3.5 *
1996-1997	**NH3N** 3.5 > 0 * **DRP** 3.5 > 0 * **TP** 3.5 > 0 *			**NNN** 12.5 > 0 * **NNN** 12.5 > 6.5 * **TN** 12.5 > 6.5 * **DRP** 9.5 > 0 * **DRP** 12.5 > 0 * **DRP** 12.5 > 3.5 * **DRP** 12.5 > 6.5 * **DRP** 12.5 > 9.5 * **TP** 3.5 > 0 * **TP** 6.5 > 0 *
1997-1998	**NH3N** 0 > 3.5 *		**NH3N** 0 > 3.5 *	**NH3N** 12.5 > 6.5 * **TN** 12.5 > 6.5 * **DRP** 12.5 > 0 * **DRP** 12.5 > 3.5 * **DRP** 12.5 > 6.5 * **TP** 12.5 > 6.5 *
2003-2004	**TON** 3.5 > 0 *	**TP** 3.5 > 0 *	**TN** 6.5 > 0 * **TON** 6.5 > 0 * **DRP** 3.5 > 0 * **DRP** 6.5 > 0 ** **DRP** 6.5 > 3.5 ** **TP** 3.5 > 0 ** **TP** 6.5 > 0 **	**NH3N** 12.5 > 0 * **DRP** 3.5 > 0 * **DRP** 6.5 > 0 * **TP** 6.5 > 0 * **TP** 12.5 > 0 * **TP** 12.5 > 3.5 *

Table 3.3 Significant difference in the concentration of each nutrient at each site over time

ns - no significant difference in concentration over time
* - significant difference over time at $p<0.05$
** - significant difference over time at $p<0.01$
*** - significant difference over time at $p<0.001$

SURFACE WATER	NNN	NH3N	TON	TN	DRP	TP
Robinsons Bay	ns	**	ns	ns	***	*
French Farm	ns	**	ns	ns	**	ns
Takamatua	ns	*	ns	ns	***	ns
Childrens Bay	ns	*	ns	ns	**	ns
Kaik-Cape Three Points	ns	*	ns	ns	***	*
Heads	ns	**	ns	ns	*	**
3.5 m DEEP	**NNN**	**NH3N**	**TON**	**TN**	**DRP**	**TP**
Robinsons Bay	ns	**	ns	ns	**	**
Childrens Bay	ns	ns	ns	ns	**	ns
Kaik-Cape Three Points	ns	ns	*	ns	***	*
Heads	ns	ns	**	ns	*	*
6.5 m DEEP	**NNN**	**NH3N**	**TON**	**TN**	**DRP**	**TP**
Kaik-Cape Three Points	ns	*	*	ns	**	**
Heads	ns	*	**	*	*	*
9.5 m DEEP	**NNN**	**NH3N**	**TON**	**TN**	**DRP**	**TP**
Heads	ns	*	ns	ns	*	*
12.5 m DEEP	**NNN**	**NH3N**	**TON**	**TN**	**DRP**	**TP**
Heads	ns	ns	ns	ns	ns	*

Table 3.4 Seasonality of Akaroa Harbour nutrients at each depth at each site, 1989-2004

X - no significant seasonality
✓ - seasonality detected at α=0.05

Surface	NNN	NH3N	TON	TN	DRP	TP
Robinsons Bay	✓	x	x	x	✓	x
French Farm	✓	x	x	x	✓	x
Takamatua Bay	✓	x	x	x	✓	✓
Childrens Bay	✓	x	x	x	✓	x
Kaik-Cape Three Points	✓	x	x	✓	✓	✓
Heads	✓	x	x	✓	✓	✓
3.5 m Deep						
Robinsons Bay	✓	x	x	x	✓	x
Childrens Bay	✓	x	x	x	✓	x
Kaik-Cape Three Points	✓	x	x	x	✓	✓
Heads	✓	x	x	x	✓	✓
6.5 m deep						
Kaik-Cape Three Points	✓	x	✓	x	✓	✓
Heads	✓	x	x	x	✓	✓
9.5 m deep						
Heads	✓	x	✓	x	✓	✓
12.5 m deep						
Heads	✓	x	x	✓	✓	✓

To quantify the exceedence of the DIN, TN, DRP and TP concentrations obtained in this study with respect to the ANZECC (2000) guideline trigger values for marine water and estuarine water, the percentage of samples in which the guideline values were exceeded was calculated. These data are presented in Table 3.5.

For TN, DRP and TP there was a general trend of a decrease in the percentage of samples exceeding the marine water trigger value with increasing distance down the harbour i.e. from the inner to outer harbour. For DIN the marine water trigger value was exceeded in more of the samples collected at all depths at the heads than in the samples collected at other sites and depths within the harbour.

At each depth at the inner harbour sites, the percentage of samples in which the estuarine water trigger values for TN, DIN and TP were exceeded was less than the percentage of samples that exceeded the marine water trigger values.

Table 3.5 The percentage of samples at each site exceeding the ANZECC (2000) DIN, TN, DRP and TP guideline values in marine water, and the percentage of samples from each inner harbour site exceeding the ANZECC (2000) DIN, TN, DRP and TP guideline values in estuarine water

n = number of samples

	Site/Depth	n	DIN	TN	DRP	TP
Marine Water	**A0**	48	60	57	87	77
	A3.5	48	57	60	91	89
	B0	48	66	66	85	79
	C0	48	51	60	79	74
	D0	47	52	54	78	65
	D3.5	47	59	54	83	91
	E0	48	55	36	62	32
	E3.5	48	60	40	70	57
	E6.5	48	62	43	72	64
	F0	47	76	37	57	30
	F3.5	47	76	37	57	35
	F6.5	47	74	37	57	35
	F9.5	47	86	39	65	35
	F12.5	47	86	43	65	37
Estuarine water	**A0**	48	27	6	90	65
	A3.5	48	33	4	88	77
	B0	48	40	2	88	58
	C0	48	29	4	88	56
	D0	47	30	4	89	53
	D3.5	47	34	4	91	70

3.3.2 N:P ratios

The N:P ratio was calculated for all samples. The results are presented in Figure 3.13.

The N:P ratio in all samples on all sampling occasions at all sites at all depths in Akaroa Harbour was less that 16:1, i.e. N was the nutrient limiting primary productivity (i.e. phytoplankton growth).

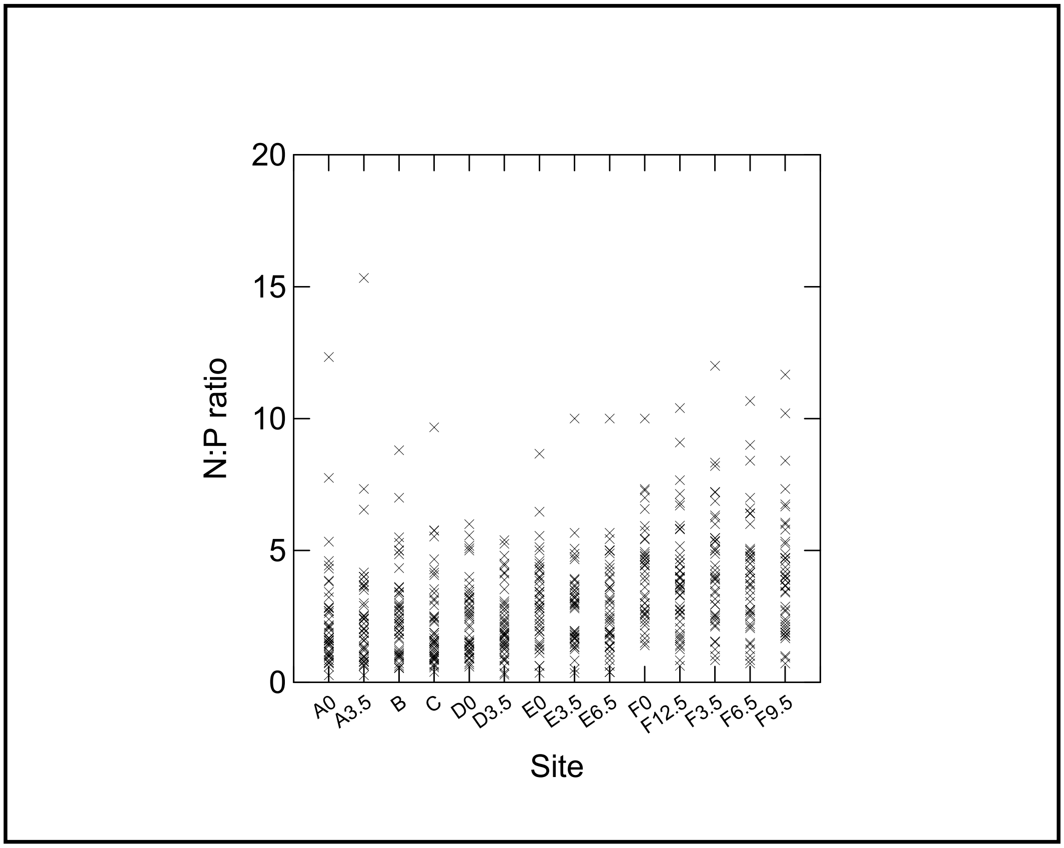


Figure 3.13 N:P ratio in water sampled at each depth at each site in Akaroa Harbour, 1989-2004

4 Discussion

The water within Akaroa Harbour consists of tidal exchange water from the Canterbury Bight in combination with the fresh water discharged into the harbour from the catchments and settlements of the harbour surrounds. While the volume of water in the harbour is not known, the estimated volume of water flushed in and out of the harbour with each tidal cycle is 81 x 10^6 m^3 (Hicks and Marra, as cited in Royds Consulting Ltd., 1996).

Freshwater flows into this harbour from non-point (land runoff including septic tank seepages) and point (streams, stormwater and sewage outfalls) discharges. The volume of freshwater input from the streams is very variable as it is influenced by rainfall. Based on the data from 6 of the 15 streams that discharge into the harbour (Appendix VII and VIII) it has been found that the volume discharged varied between 7,085 and more than 1,247,875 m^3/day. The volume of inputs from the sewage outfalls consists of:

- Akaroa (Green Point/Redhouse Bay) – the maximum permissible discharge is 2000 m^3/day, with average flows of 300 m^3/day expected (as of 1996) (Royds Consulting, 1996)
- Duvauchelle – the maximum permissible discharge is 250 m^3/day
- Tikao Bay - the maximum permissible discharge is 20 m^3/day; this sewage will not be discharged into the harbour as of mid 2005
- Wainui - the maximum permissible discharge is 40 m^3/day

There is no information on the volumes of water discharged into the harbour via stormwater outlets.

Significant differences occurred in the surface water concentrations of TN, TON, DRP and TP between some of the sites in each of the five sampling periods. For NNN and NH3N concentrations, significant differences between sites occurred over some but not all of the sampling periods. There were no significant differences between sites, over 1997-1998 for NNN concentrations, and over 1996-1997, 1997-1998 and 2003-2004 for NH3N concentrations. The pattern of the differences in TN, TON, DRP and TP concentrations between sites consisted of generally higher concentrations at the inner harbour sites i.e. Robinsons Bay, French Farm, Takamatua Bay and Childrens Bay than at the mid and outer (the heads) harbour sites. By comparison the differences in NNN concentrations consisted of higher concentrations at the heads than at the inner harbour and mid harbour sites. Significant differences in TN, TON, DRP and TP concentrations also occurred between one or more of the inner harbour sites over some sampling periods and any significant between site differences in NH3N concentrations were between inner harbour sites.

These results indicate that the water at the heads is dominated by offshore oceanic water and the water in the inner harbour is predominantly from offshore with a complex of factors influencing the concentrations. TN, DRP and TP inputs from the non-point and point discharges into the inner harbour are suggested by the results. However the fact that the mid harbour site and the site at the heads are further from land cannot be overlooked. The results indicate that the salmon and paua farms do not affect the nutrient concentrations at the heads or in the mid harbour. These sites are however, a considerable distance from these marine farms. It has been found that salmon farms from other sites in New Zealand generate nutrient loads equivalent to small to medium-sized domestic sewage outfalls (P. Gillespie, Cawthron Institute, p*ers. comm.*).

Fifteen streams discharge into Akaroa Harbour with all but 3 of them, discharging into the inner harbour i.e. inland of Cape Three Points. These streams drain bush, grazing land, vineyards, lifestyle blocks and rural communities and villages in the inner harbour. In the outer harbour they predominantly drain grazing land and bush. These streams are an additional source of nutrients to the inner harbour with the volumes discharged and the concentration of nutrients discharged being highly variable (Appendix VII and VIII). The occasional high concentration of TN and TP at one or more of the inner harbour sites (Figures in Appendix VI) likely results from a high volume of freshwater input from the streams following rainfall (Appendix VIII). Such high values did not occur at the site between the heads but on one occasion there was a relatively high TP concentration in the surface water at the mid harbour site. Millhouse (1977) also recorded higher concentrations of TP and DRP in the inner than the outer harbour and attributed this difference to agricultural runoff into the inner harbour bays. A similar harbour-wide pattern in TN, DRP and TP concentrations has been reported for 15km long Lyttelton Harbour/ Whakaroupō on the northern side of Banks Peninsula (Bolton-Ritchie, 2003). In Lyttelton Harbour the higher concentrations of DRP and TP at the inner Harbour sites likely result from the streams discharging into the inner harbour.

Irregular nutrient inputs from the various land based activities in the different stream catchments and the differences between streams in the volume discharged could account for the significant differences in the concentration of some nutrients between some of the inner harbour sites (Appendix VII). However, nutrient inputs from the sewage discharges also need to be considered. While the sewage discharge volumes are much less than is discharged into the harbour via the streams, nutrient concentrations in the sewage from Akaroa and Duvauchelle (there is no nutrient data for Tikao Bay and Wainui sewage outfalls) are much higher than concentrations in the studied streams. For example between June 2003 and June 2004 the mean DRP concentration in Akaroa and Duvauchelle sewage was 6.7 and 8 g/m^3 respectively, which in combination with maximum daily volumes results in 13.5 and 2 kg DRP per day respectively being discharged into the harbour. For TN the mean concentration in Akaroa and Duvauchelle sewage was 23.2 and 30.7 g/m^3 respectively, which in combination with maximum daily volumes results in 46.4 and 7.7 kg TN per day respectively being discharged into the harbour.

It is possible, given the values above, that nutrients from the Duvauchelle sewage discharge add to the nutrient load at the Robinsons Bay site (Figures 1.1 and 1.2). The combination of the nutrients from the sewage discharge and stream and land runoff could account for TN and TP concentrations in Robinsons Bay being significantly higher than at some of the other inner harbour sites over 1989-1990 (TN and TP) and over 1991-1992 (TP only). It is also possible that nutrient concentrations in Childrens Bay are affected by the Akaroa sewage discharge. In 1996, Royds Consulting analysed Canterbury Regional Council data (1989-1991) to assess if there was such an affect. They determined that 'monitoring data does not indicate that this site has been affected by the sewage discharge as nutrient levels are similar or less than those at other upper harbour sites close to the shore' (Royds Consulting, 1996). However, over 2003-2004 TN concentrations in Childrens Bay were significantly higher than at the inner harbour site in Takamatua Bay. Over this same time period DRP concentrations in Childrens Bay were not significantly different to those in Takamatua Bay and were significantly lower than those at the site at French Farm. As sewage contributes both N and P to the sea water, elevated nutrient concentrations resulting from sewage discharge should result in comparable significant differences in TN and TP concentrations between sites. As this was not the case the elevated concentrations of TN in Childrens Bay could result from the streams that discharge into this bay in close proximity to this site. The Tikao Bay and Wainui sewage outfalls are not in close proximity to any of the sampling sites and therefore it is not possible to determine the effect of the small volume discharges on nutrient concentrations in the inner harbour. However, it is likely that because the volumes are small, the effect of these discharges on nutrient concentrations would be localised.

In the inner harbour, sampling of the surface and 3.5 m deep water was only undertaken in Robinsons Bay and Childrens Bay. At both these sites there were significant differences in NH_3N, TON, DRP and TP concentrations with depth. These differences were not consistent with respect to depth or time and at both sites there were no significant differences in concentrations with depth over at least two of the sampling periods. As the water at the inner harbour sites is no more than 5 m deep, the wind generated waves and tidal currents that occur would, in all but the most settled weather conditions mix the water column. It is likely that higher nutrients concentrations at 3.5 m than in the surface water result from the nutrients associated with the seafloor sediments being remixed into the overlying water column by water movement (generated by the waves and currents) at the interface between the seabed and water column. The subtidal sediments at a site in close proximity to the Robinsons Bay site contain, compared to the sediments from other subtidal sites in this harbour, high concentrations of TN (1300 mg/Kg) and TP (680 mg/L) (Fenwick, 2004).

At the mid and outer harbour sites, where the water depths are 11 m and 24 m respectively, the significant differences in nutrient concentrations between depths, varied over time. For the phosphorus-based nutrients, there were no significant differences in concentration between depths over three of the sampling periods at the mid harbour site and over one of the sampling periods at the heads. At the mid harbour site over 1989-1990 TP concentrations at 6.5 m and over 2003-2004 DRP and TP concentrations at 3.5 and 6.5 m were significantly higher than in the surface water. At the heads DRP concentration differences generally consisted of higher concentrations at 12.5 m than at the surface and higher at 12.5 m than one or more of the other depths. However over 2003-2004 DRP concentrations at 3.5 and 6.5 m deep water were significantly higher than in surface water. For TP concentrations between the heads there was no pattern with depth; for example, over 1996-1997 concentrations at 3.5 m and 6.5 m were significantly higher than at the surface, over 1997-1998 concentrations at 12.5 m were higher than at 6.5 m and over 2003-2004 concentrations at 6.5 and 12.5 m were higher than at the surface. These results suggest that the phosphorus rich layer recorded at 6.5 m at the mid harbour site and at 9.5 m at the heads in 1976 (Millhouse, 1977) does not always occur. Millhouse (1977) stated 'the effect of development and sewage is probably the P rich water in the dense layer on the bottom of the harbour'. The results obtained in this study also cast doubt on Millhouses' assessment of the sources of the P-rich water in this harbour. The temporal variation in the concentration of the phosphorus-based nutrients with depth may be due to annual differences in rainfall (which in turn affects non-point source runoff and the amount of phosphorus discharged into the harbour) and stratification of the harbour water. Stratification i.e. less dense surface harbour water overlying more dense oceanic bottom water and temperature stratification (warmer water overlying colder bottom water), does occur in Akaroa Harbour (Ross, 2000). Differences in stratification from year to year would occur because climatic factors, such as temperature, duration and strength of the wind, number of storms etc., influence the presence of distinct layers in the water column.

For the nitrogen-based nutrients there were no significant differences in the concentrations of one or more of the nutrients with depth for two of the five periods sampled at the mid harbour site while at the heads they occurred over every time period. At the mid harbour site there was no temporal pattern in concentrations with depth: over 1991-1992 there were significant differences in concentrations between water at 3.5 and 6.5 m, over 1997-1998 between surface water and that at 3.5 m and over 2003-2004 TN and TON concentrations at 6.5 m were significantly higher than at the surface. At the heads differences in the concentration of the nitrogen-based nutrients over 1989-1990 generally consisted of significantly lower concentrations at 3.5 m and 12.5 m than at other water depths while over the other time periods concentrations were generally higher at 12.5 m than at one or more other depths. In 1976 (Millhouse, 1977) reported a perceptible decrease in the concentration of Kjeldahl-N (TON + NH_3N) with depth at the heads. This result is contrary to that found over all time periods of this study except 1989-1990. Temporal differences in the concentration of the nitrogen based nutrients with depth at this site likely result from temporal differences in both nutrient inputs and stratification of the water column.

Over the period 1989-2004 there were significant temporal differences in the concentrations of NH_3N and DRP at all sites. For DRP, concentrations at all sites were significantly higher over 1989-1990 than over the other sampling periods. At the same time TP concentrations at some of the sites were also significantly higher over 1989-1990 than over the other sampling periods. These results do not indicate a trend of a decrease in the phosphorus-based nutrients over time but rather that the concentration of these nutrients was elevated over 1989-1990. It is not possible to determine why concentrations were higher over 1989-1990; however the possibilities include:

1. Higher rainfall resulting in more runoff over this period
2. Intensive aerial topdressing and other fertiliser applications over this period
3. Heavier stocking rates

A comparison of the TP concentrations recorded in this study with those of 1976 (Millhouse, 1977) is suggestive of an increase in concentrations between 1976 and 1989 in some, but not all, areas of the harbour because:

- The mean TP concentration in Robinsons Bay in 1976 was lower than that any recorded concentration at this site between 1989 and 2004.
- The mean TP concentration at the mid and outer harbour sites in 1976 was lower than all but two of the concentrations recorded between 1989 and 2004.
- The mean TP concentration in Takamatua Bay in 1976 was higher than all but four of the concentrations recorded between 1989 and 2004

The differences in TP concentrations over time in Robinsons Bay and Takamatua Bay suggests that TP concentrations in each bay are highly influenced by localised inputs i.e. runoff from the immediate catchment of the bay. Such differences could arise from either the differences in the volume of freshwater discharged into each bay or from differences in the land uses and hence nutrient sources in each catchment. Unfortunately over the period that the flow and nutrient concentrations were routinely measured in the Takamatua stream (Appendix VII) which discharges into Takamatua Bay, no such measurements were made for the stream discharging into Robinsons Bay.

The significant differences in the surface water concentrations of NH_3N over time at all sites consisted of significantly lower concentrations over 2003-2004 than one or more of the other sampling periods. Of note is that the mean NH_3N concentration in 1976 at all sites except French farm (Millhouse, 1977) was higher than all but 1 to 4 of the concentrations recorded at the sites between 1989 and 2004. These results suggest that the concentrations of NH_3N in surface water have decreased over time. Ammonia is a breakdown product from sewage, animal excretion, seaweeds and other organic matter. The decrease in surface water concentrations of NH_3N in the harbour could result from decreases in NH3N concentrations in the streams. Such a decrease in the streams could result from changes in land use in the harbour catchments i.e. from predominantly grazing to the present day mix of grazing, horticulture and regeneration of native bush in some valleys.

Significant seasonal variation occurred in NNN and DRP concentrations at all sites and at all water depths. The concentrations of NNN and DRP were found to be lowest during later summer-spring and highest in late autumn winter. This seasonal pattern reflects the uptake of these nutrients by the phytoplankton in the spring and the release of nutrients back into the water column in mid-late autumn.

The concentrations of the nutrients at sites in Akaroa Harbour were compared to the ANZECC (2000) trigger levels for 'slightly disturbed marine water' and 'slightly disturbed estuarine water'. When concentrations are below the trigger levels the risk of adverse biological effects is low while at concentrations above the trigger level there is the potential for adverse biological effects (ANZECC, 2000). The adverse biological effects of nutrient over-enrichment include:

- the excessive growth of aquatic plants (phytoplankton, cyanobacteria, algae, seagrasses) i.e. eutrophication, which can result in changes in the structure and functioning of marine ecosystems, reduced biodiversity and an increase in harmful algal blooms (ANZECC, 2000; EEA, 2001).
- possible changes in the relative abundance of phytoplankton species without an overall increase in primary productivity (NRC, 2001).

It is important to note that to date marine trigger values have not yet been developed for New Zealand and in the guidelines it suggests the comparison of New Zealand values to those for south-east Australia. As a consequence the guideline values, which are for the low-nutrient (oligotrophic) waters of south-east Australia, are conservative for the nutrient concentrations in New Zealand coastal waters which are higher than those on which the guidelines were based. For example the median concentrations of NNN, NH3N and DRP recorded in the surface water at Akaroa heads were 0.016, 0.013 and 0.021 mg/L respectively, while the ANZECC (2000) guideline values for marine waters are 0.005, 0.015 and 0.01 mg/L respectively.

The concentrations of DIN, TN, DRP and TP in water from the surface and at depth at all sites frequently exceeded the ANZECC (2000) trigger values for 'slightly disturbed marine water' (south-east Australia). The pattern of differences with respect to location in the harbour, of the percentage of samples exceeding the ANZECC (2000) trigger values, are identical to those described in paragraph 3 of the discussion. The concentrations of DIN, TN, DRP and TP in water from the surface and at depth at the inner sites also exceeded the ANZECC (2000) trigger values for 'slightly disturbed estuarine water' (south-east Australia). At the inner harbour sites there was a low percentage of exceedence of the TN estuarine trigger value. This suggests that TN concentrations in the inner harbour are not high or a cause for concern. Anecdotal evidence suggests that there has been no notable excessive growth of algae within this harbour. However over the summer sea lettuce (*Ulva lactuca*) can occur in some of the inner harbour bays. This sea lettuce growth has to date not been considered excessive or as being a problem (as it has been is some parts of the Canterbury region e.g. the Avon-Heathcote/Ihutai Estuary). Of note is that the intertidal flats in some of the inner harbour bays support large areas of the seagrass *Zostera* sp.. Areas of seagrass are highly productive and support a diversity of species and abundance of individuals. The current nutrient concentrations of the inner harbour could well contribute to the maintenance of these seagrass beds.

Within Akaroa Harbour ten species of phytoplankton formed blooms (cell concentrations >10,000 L^{-1}) on one or more occasions between mid 1999 and November 2002 (Fenwick and Image, 2002). As nutrients were not monitored over this period the relationship between nutrient concentrations and phytoplankton could not be investigated. However marine phytoplankton blooms are highly variable from year to year because a large number of factors, i.e. weather and sea conditions, temperature, light, nutrient concentrations, the N:P ratio and availability of other chemicals such as silica and iron (ANZECC, 2000; NRC, 2001), influence their development and persistence. With respect to nutrients, phytoplankton growth is generally limited and regulated by the dissolved inorganic nitrogen (DIN) concentration. By evaluating DIN concentrations it is possible to assess the potential for enhanced phytoplankton growth, which could result in a bloom. In a recent study it was found that a mean DIN concentration of 0.07-0.14 mg/L over 72 hours resulted in an increase in chlorophyll-a concentration (a measure of the quantity of phytoplankton present) to around 0.002 mg/L (Zeldis and Gall, 1999). A chlorophyll-a level of 0.005 mg/L has been found to cause physical discolouration of surface waters (Eppley *et al*., 1977) and a level of 0.015 mg/L is associated with eutrophication (Harris *et al*., 1996). In this study the maximum DIN concentration at all sites and water depths was higher than 0.07 mg/L with one reading higher than 0.14 mg/L (12.5 m depth at the heads). DIN concentrations of higher than 0.07 mg/L occurred in 2 – 11% of the samples at all sites except the heads where up to 17% of samples contained concentrations higher than 0.07 mg/L. Based on DIN concentrations there is a slightly greater likelihood of enhanced phytoplankton growth at the heads than at other sites in Akaroa Harbour. However, it should be noted that optimal nutrient conditions for phytoplankton growth i.e. an N:P ratio of 16:1 did not occur in the samples collected between 1989-2004.

The nutrient concentrations recorded in Akaroa Harbour are generally lower than those in Lyttelton Harbour (the inlet adjacent to Christchurch on the northern side of Banks Peninsula (Fig. 1.1)) (Bolton-Ritchie, 2004). This is suggestive of less land and human-derived inputs into the waters of Akaroa Harbour than to the waters of Lyttelton Harbour. However, this may be a simplification because water circulation, water retention time in the harbour and the volume of tidal exchange water are different in the different harbours. The Akaroa Harbour N-based nutrient concentrations are also lower than those of Pegasus Bay (Christchurch is at the southern end of Pegasus Bay (Fig.1.1)) (Bolton-Ritchie, 2004b). For the P based nutrients, concentrations in Akaroa Harbour are comparable to those of Pegasus Bay.

5 Conclusions

Akaroa Harbour is a 17 km long body of water. This scenic harbour has considerable natural values and is a popular area for recreational (boating, water skiing, kayaking, SCUBA diving) and commercial (swim with the dolphins, dolphin watching) water-based activities. An ever-increasing number of people live, holiday or just visit this area. Consequently there are now four sewage outfalls, septic tank outflows, stormwater discharges in addition to the land runoff and stream flows, all of which add nutrients to the harbour water.

Monitoring of the nutrient status of harbour water was carried out at six sites over five year-long periods between 1989 and June 2004. The general pattern of differences in nutrient concentrations between sites consisted of, generally higher concentrations of TON, TN, DRP and TP at inner harbour (Robinsons Bay, French Farm, Takamatua Bay and Childrens Bay), than at mid (between the Kaik and Cape Three Points) and outer (between the heads) harbour sites, and higher concentrations of NNN between the heads than at inner harbour and mid harbour sites.

The results indicate that the water between the heads is dominated by offshore oceanic water and the water in the inner harbour is predominantly from offshore with a complex of inputs influencing the concentrations. Overall the volume of input of nutrients via streams and the sewage discharges is small and localised when compared to the volume of this harbour and the volume of seawater that is flushed in and out of the harbour with the tide. Thus the nutrient concentrations in the water of Akaroa Harbour are, to date, not a cause for concern.

Evaluation of DIN concentrations indicates there is a greater likelihood of enhanced phytoplankton growth at the heads than at other sites in Akaroa Harbour. N:P results indicate that the optimal nurient conditions for enhanced phytoplankton growth did not occur in the samples collected between 1989-2004.

Over time there was no overall trend of a decrease or increase in the concentrations of NNN, TN, TON, DRP and TP. These results indicate that in the time period of this study any increase in nutrient inputs into the harbour via streams, sewage and stormwater (a consequence of an ever increasing human population in the harbour surrounds) has not resulted in an increase in the concentrations of these nutrients in the water of Akaroa Harbour. The results suggest that the surface water concentrations of NH3N have decreased over time. This decrease could result from the change in land use i.e. from predominantly agriculture to the present day mix of agriculture, horticulture and native bush regeneration in the harbour catchments.

6 Future investigations and monitoring

The current monitoring programme, i.e. every 5 years, represents the minimum desirable frequency for the continued monitoring of the nutrient status of greater Akaroa Harbour. In future it would be advisable to measure the chlorophyll-a concentration and suspended sediment concentrations at all sites and water depths in addition to the concentration of the nutrients measured to date. This will allow for an assessment of the relationships between nutrient status and primary productivity and nutrient status and sediment loads in the water column.

7 Acknowledgements

The author wishes to thank Tony Rodgers, Department of Conservation staff and staff of the Canterbury Cat for running the boats used to access the sampling sites. The water samples, were collected by Julie Edwards, Amanda Byrne and Malcolm Main from the Canterbury Regional Council, and analysed by the laboratory staff of the North Canterbury Catchment Board, Cawthron Institute and the Canterbury Regional Council. The contribution of Ken Taylor, Environment Canterbury and Paul Gillespie, Cawthron Institute for their constructive comments on the draft report is greatly appreciated.

8 References

ANZECC (Australia and New Zealand Environment and Conservation Council) 2000: *Australian and New Zealand Guidelines for fresh and marine waters.* Australia and New Zealand Environment and Conservation Council. Melbourne

Bock, M.T., Miller, B.S., and Bowman, A.W. 1999. Assessment of eutrophication in the Firth of Clyde: Analysis of coastal water data from 1982 to 1996. *Marine Pollution Bulletin* 38(3): 222-231.

Bolton-Ritchie, L.A. 2003. The effect of stormwater discharge on the nearshore benthic environment of inner Wellington Harbour. Ph.D. Thesis. School of Biological Sciences. Victoria University of Wellington.

Bolton-Ritchie, L.A. 2004. Lyttelton Harbour /Whakaraupō nutrient status: April 1988 – June 2003. Environment Canterbury Report R04/14.

Bolton-Ritchie, L.A. 2004b. Coastal water quality: Kaikoura to Pegasus Bay. Review of existing data and recommendations for future work. Environment Canterbury Report .

Bonsdorff, E., Blomqvist, E.M., Mattila, J. and Norkko, A. 1997. Coastal Eutrophication: Causes, Consequences and Perspectives in the Archipelago Areas of the Northern Baltic Sea. *Estuarine, Coastal and Shelf Science* 44 (supplement A): 63-72.

Department of Conservation, 1990. First order Coastal Resource Inventory, Canterbury. Canterbury Conservancy Report.

EEA, 2001. Eutrophication in Europe's coastal waters. Environment Assessment Report 7/2001.

Eppley, R.W., Harrison, W.G., Chisholm, S.W. and Stewart, E. 1977. Particulate organic matter in surface waters off southern California and its relationship to phytoplankton. *Journal of Marine Research* 25:671-696.

Fenwick, G and Image, K. 2002. Effects of Lake Ellesmere and Forsyth openings on the Banks Peninsula coastal environment. NIWA Client Report CRC2002-036.

Harris, G., Batley,G., Fox., D., Hall, D., Jernakoff, P., Molloy, R., Murray, A., Newell, J., Parslow, G., Skyring, G. and Walker, S. 1996. Port Phillip Bay Environmental

Study, Final Report. CSIRO, Canberra, Australia.

IDT (Intelligent Decisions Technologies), 1998. Wqstat Plus. Intelligent Decisions Technologies Ltd., Longmont.

Millhouse, D. 1977. The fertility of Lyttelton and Akaroa Harbours, Banks Peninsula, New Zealand. Estuarine Research Unit Report No.7.

Morrisey, D. 1997. The muck stops here. *NZ Science Monthly* (March)

NRC, 2001. *Clean Coastal Waters: Understanding and reducing the effects of nutrient pollution.* National Academy Press, Washington D.C.

Redfield, A.C., Ketchum, B.H. and Richards, F.A. 1963. in: *The Sea: Ideas and Observations on Progress in the Study of the Seas,* ed. M.N. Hill. Vol. II. Pp 26-77. Interscience, New York.

Rosenberg, R. 1985: Eutrophication – the future marine coastal nuisance? *Marine Pollution Bulletin* 16 (6): 227-231

Ross, A. 2000. Sustainability issues related to proposed marine farm developments in Akaroa Harbour.

Royds Consulting Ltd. 1996. Description of receiving environment Akaroa sewage treatment plant effluent disposal. Report for Banks Peninsula District Council.

SPSS, 1999. Systat Inc. Illinois.

Statsoft, 2001. *STATISTICA for Windows* [Computer programme manual]. Tulsa, OK: Statsoft, Inc.

Valiela, I. 1995. *Marine Ecological Processes*. Springer-Verlag, NY. Inc.

Vincent, V.C and Thomas, M.P. 1997. Urban runoff pollution: An Overview. *Environmental Education and Information* 16(2): 185-196.

Zeldis, J.and Gall, M. 1999. Assessment of Bromley sewage effluent on phytoplankton growth at the proposed Pegasus Bay ocean outfall site. Prepared for Christchurch City Council. NIWA Client Report No. CHC99/30.

Appendix I: Details of the sampling sites and sampling depths at each site in Akaroa Harbour

Site ID	Site label	Site description	Depth (m)	Grid reference NZMS 260 map series
CRC302741	**A0**	between Robinsons Bay and Onawe Pen.	0-0.5	N36:052-152
CRC302608	**A3.5**		3.5	
CRC302630	**B0**	between French Farm and Onawe Pen.	0-0.5	N36:035-144
CRC302621	**C0**	Takamatua Bay	0-0.5	N36:063-142
CRC302742	**D0**	Childrens Bay	0-0.5	N36:070-116
CRC302612	**D3.5**		3.5	
CRC302740	**E0**	between the Kaik and Cape Three Points	0-0.5	N37:040-083
CRC302739	**E3.5**		3.5	
CRC300698	**E6.5**		6.5	
CRC302738	**F0**	between the heads	0-0.5	N37:072-014
CRC302737	**F3.5**		3.5	
CRC302736	**F6.5**		6.5	
CRC302735	**F9.5**		9.5	
CRC300699	**F12.5**		12.5	

Appendix II: Details of analyses included in the water quality monitoring programme

Determinand	Analysis provider	Method	Time Period	Detection Limit	Units
Nitrate/nitrite nitrogen (NNN)	CIN Laboratory	APHA 418C Cawthron method	1989-1992	0.005	mg/L
	CRC laboratory	Cadmium reduction by CFA	1996-1998	0.01	mg/L
	ECan laboratory	APHA 4500 NO_3 - F (20th ED)	2003-2004	0.005	mg/L
Total ammonia-nitrogen (NH3N)	CIN Laboratory	Limnology and Oceanography 1969, Cawthron method	1989-1992	0.005	mg/L
	CRC laboratory	Indophenol Blue colorimetry, Water and Soil No.38	1996-1998	0.005	mg/L
	ECan laboratory	APHA 4500 NH3-F - modified (20th ED)	2003-2004	0.005	mg/L
Total nitrogen (TN)	CIN Laboratory	Photo-oxidation then NNN Cawthron method	1989-1992		mg/L
	CRC laboratory	APHA 4500-NN.SFA. Persulphate digestion ((19th ED)	1996-1998	0.05	mg/L
	ECan laboratory	APHA 4500-N C modified (20th ED)	2003-2004	0.08	mg/L
Dissolved reactive phosphorus (DRP)	CIN Laboratory	APHA 424F modified Cawthron method	1989-1992	0.003 - 0.001	mg/L
	CRC laboratory	Ascorbic Acid Mo-Sb reagent, Water and Soil No 3	1996-1998	0.003	mg/L
	ECan laboratory	APHA 4500-P B, E modified (20th ED)	2003-2004	0.001	mg/L
Total phosphorus (TP)	CIN Laboratory	APHA 424 C3 Persulphate Digest Cawthron method	1989-1992	0.008	mg/L
	CRC laboratory	H2SO4/K2S2O8 digestion Mo-Sb reagent	1996-1998		mg/L
	ECan laboratory	APHA 4500-P B (20th ED)	2003-2004	0.008	mg/L

Appendix III: Comparison of nutrient concentration in surface water between all sites in Akaroa Harbour: results from the two-tailed Wilcoxon Signed Rank Test

* - significant difference between sites at p<0.05

** - significant difference between sites at p<0.01

blank cells indicate there was no significant difference

1989-1990		Higher concentration					
		Robinsons	French Farm	Takamatua	Childrens	Kaik -CTP	Heads
Lower Concentration	Robinsons		NH3N *				
	French Farm						
	Takamatua	TP*				NNN*	
	Childrens	TN* TON* DRP* TP*	NH3N * DRP* TP*				
	Kaik	TN* TON* DRP* TP*	NH3N * TP*				
	Heads	TN* TON* DRP*	DRP*				

1991-1992		Higher concentration					
		Robinsons	French Farm	Takamatua	Childrens	Kaik	Heads
Lower Concentration	Robinsons		NNN*				NNN*
	French Farm						
	Takamatua		NH3N**				NNN*
	Childrens	TP*	NH3N**				
	Kaik	DRP*					
	Heads	TN* TON* TP*	TN* TP*				

1996-1997		Higher concentration					
		Robinsons	**French Farm**	**Takamatua**	**Childrens**	**Kaik**	**Heads**
Lower Concentration	**Robinsons**			DRP*			NNN*
	French Farm						
	Takamatua						
	Childrens						NNN*
	Kaik	TP*		DRP* TP*	TP*		NNN*
	Heads	TN* TON* TP*		TON* TP*	TP*		

1997-1998		Higher concentration					
		Robinsons	**French Farm**	**Takamatua**	**Childrens**	**Kaik**	**Heads**
Lower Concentration	**Robinsons**						
	French Farm	DRP*					
	Takamatua						
	Childrens						
	Kaik	DRP*					
	Heads	TN* TON** DRP* TP**	TON** TP**	TON* TP**	TN* TP*	TP*	

2003-2004		Higher concentration					
		Robinsons	**French Farm**	**Takamatua**	**Childrens**	**Kaik**	**Heads**
Lower Concentration	**Robinsons**		DRP*				NNN**
	French Farm						NNN*
	Takamatua		DRP*		TN** TON*		NNN*
	Childrens		DRP*				NNN**
	Kaik	TON* DRP** TP**	DRP** TP**	DRP** TP**	DRP* TP**		NNN*
	Heads	DRP** TP*	DRP** TP*	DRP* TP**	TP**		

Appendix IV: Comparison of nutrient concentration between 3.5 m deep sites in Akaroa Harbour: results from the two-tailed Wilcoxon Signed Rank Test

* - significant difference between sites at p<0.05

** - significant difference between sites at p<0.01

blank cells indicate no significant differences

1989-1990		Higher value			
		Robinsons	Childrens	Kaik-CTP	Heads
Lower value	Robinsons				NNN*
	Childrens	TN* TP*		NNN*	NNN*
	Kaik-CTP	NH3N* TN* TON* DRP* TP*	NH3N*		NNN*
	Heads	TN* TON* DRP* TP*	NH3N* TN* TON* DRP* TP*	TN* TON*	

1991-1992		Higher value			
		Robinsons	Childrens	Kaik-CTP	Heads
Lower value	Robinsons				NNN*
	Childrens	NH3N* TN* TON* TP*			NNN*
	Kaik-CTP	NH3N* TP*			NNN*
	Heads	TP*	TP*	TON* TP*	

1996-1997		Higher value			
		Robinsons	Childrens	Kaik-CTP	Heads
Lower value	Robinsons				NNN*
	Childrens	TN* TP*			NNN*
	Kaik-CTP	DRP* TP*	DRP*		NNN*
	Heads	TN* TON* TP**	TP*	TON* TP*	

1997-1998		Higher value			
		Robinsons	Childrens	Kaik-CTP	Heads
Lower value	Robinsons		NH3N* DRP*		
	Childrens				
	Kaik-CTP	DRP*	NH3N** DRP** TP*		
	Heads	TN** TON* TP**	TN** TON* DRP* TP**	TN* TON* TP*	

2003-2004		Higher value			
		Robinsons	Childrens	Kaik-CTP	Heads
Lower value	Robinsons				NNN*
	Childrens				NNN**
	Kaik-CTP	DRP* TP**	DRP* TP**		NNN*
	Heads	TON** DRP* TP**	TN** TON** TP**		

Appendix V: Comparison in nutrient concentration in water at each depth at each Akaroa Harbour site over time: results of the Tukey pairwise comparison

* significant difference between times at p<0.05

** significant difference between times at p<0.01

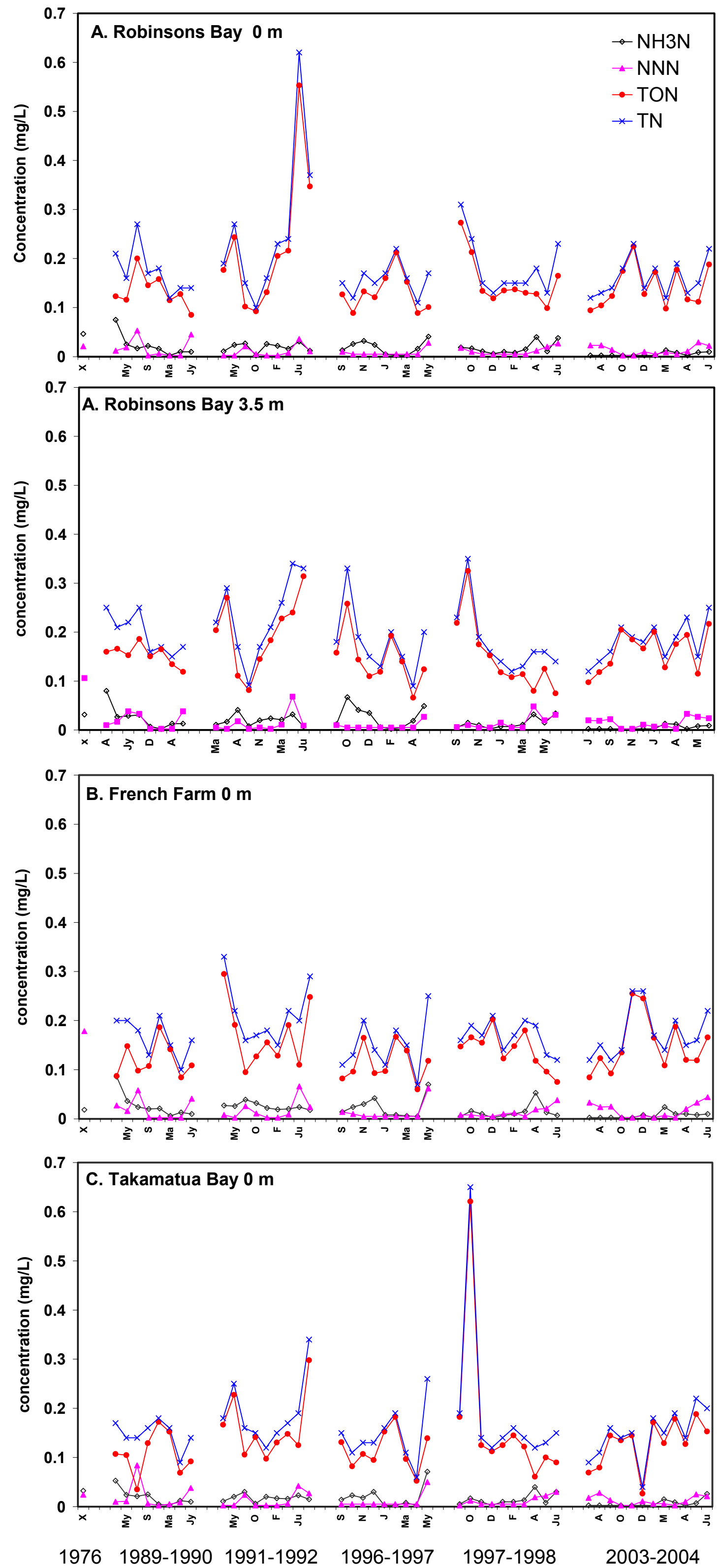
*** significant difference between times at p<0.001

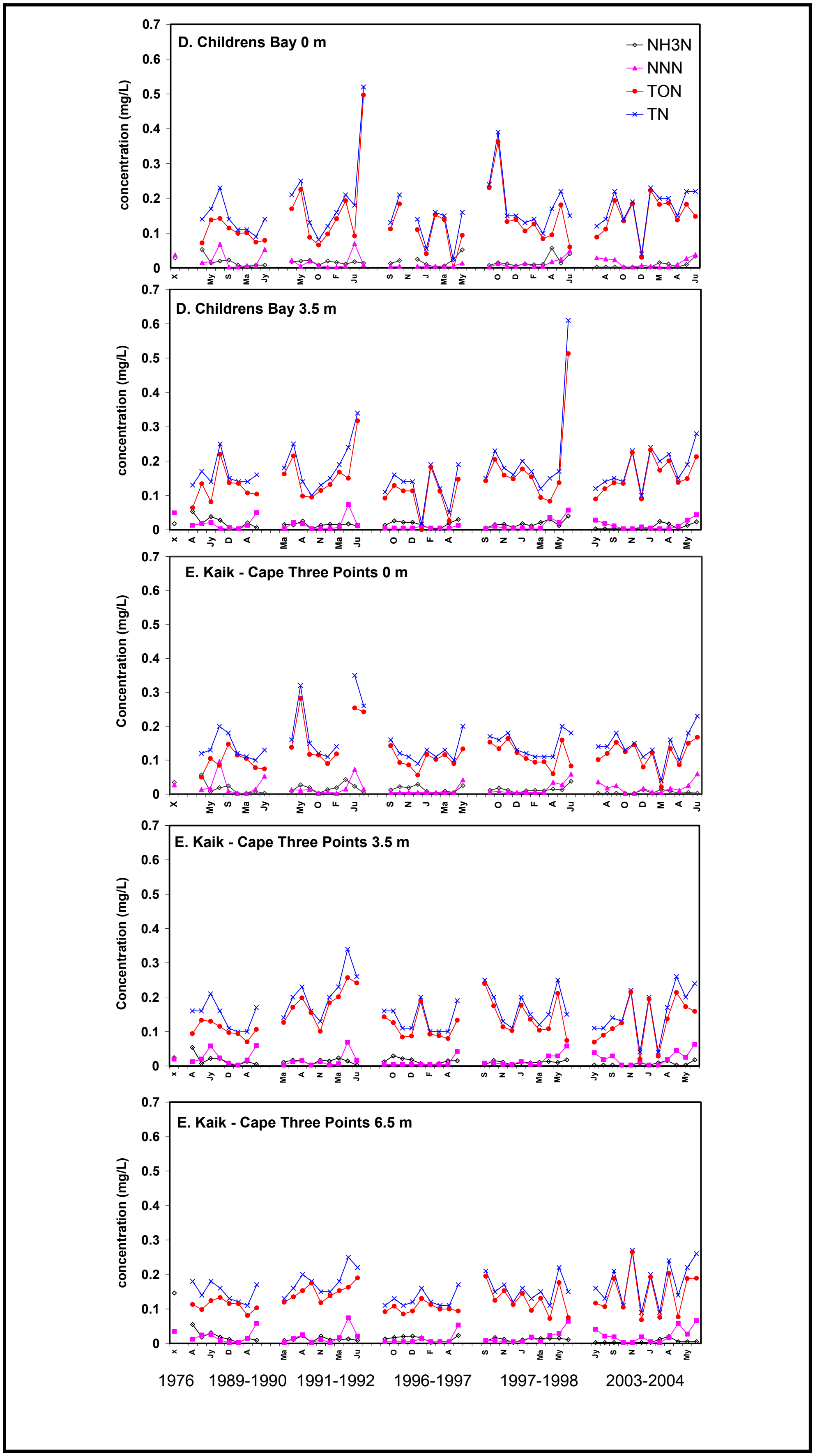
Blank cells indicate there was no significant difference
T1 = 1989-1990
T2 = 1991-1992
T3 = 1996-1997
T4 = 1997-1998
T5 = 2003-2004

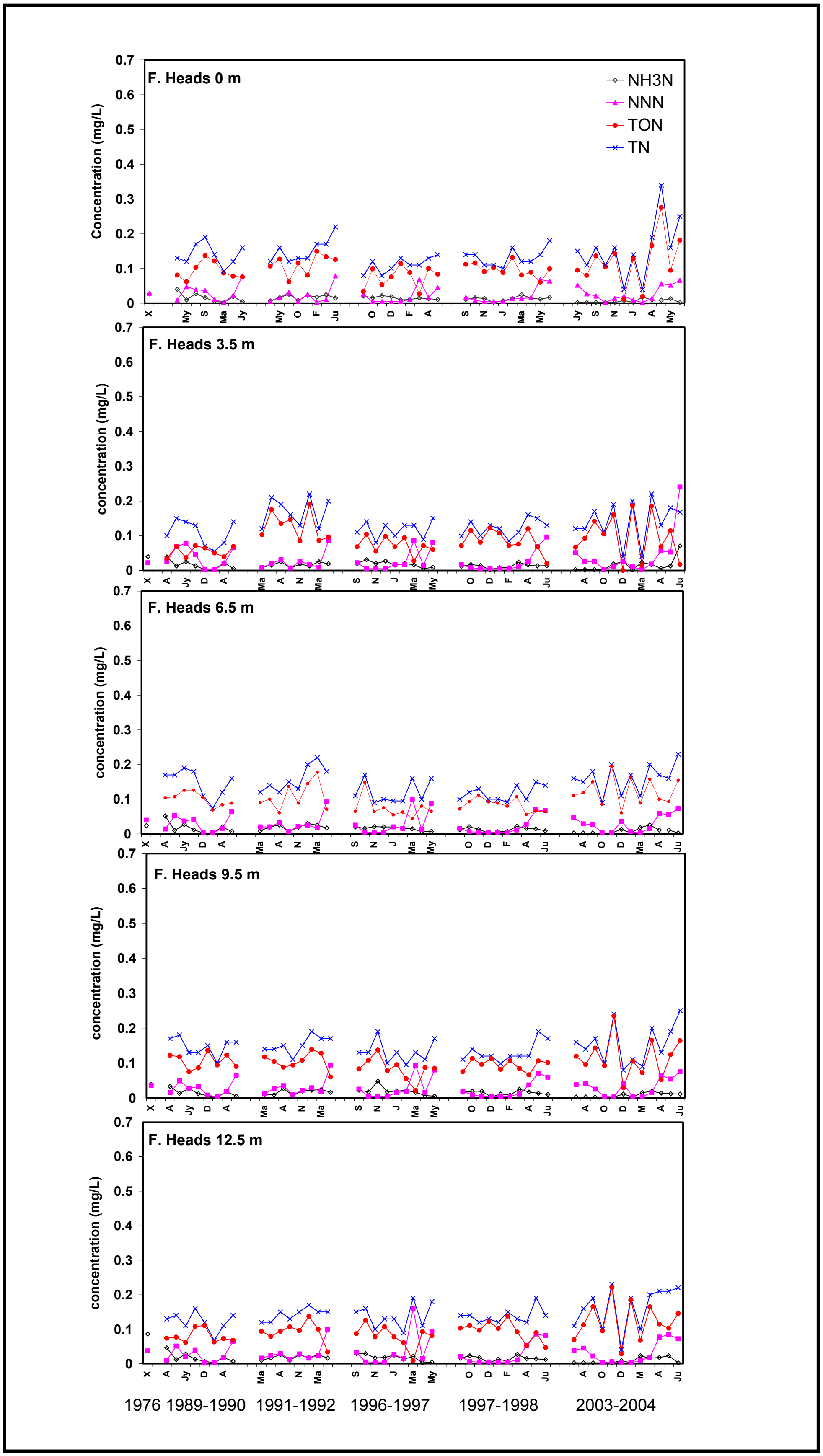
0 - 0.5m deep	NH3N	TON	TN	DRP	TP
Robinsons Bay	T2 > T5 * T3 > T5 * T4 > T5 *			T1 > T2 ** T1 > T3 *** T1 > T4 ** T1 > T5 ***	
Fench Farm	T1 > T5 * T2 > T3 * T2 > T4 ** T2 > T5 ***			T1 > T2 * T1 > T3 *** T1 > T4 *** T1 > T5 *** T2 > T4 *	
Takamatua	T2 > T5 *			T1 > T3 *** T1 > T4 *** T1 > T5 ***	
Childrens Bay	T2 > T5 *** T3 > T5 *			T1 > T3 ** T1 > T4 ** T1 > T5 **	
Kaik-Cape Three Points	T2 > T5 *			T1 > T3 *** T1 > T4 *** T1 > T5 ***	T1 > T5 *
Heads	T2 > T5 ** T3 > T5 *				T1 > T3 ** T1 > T4 ** T1 > T5 *
3.5m deep					
Robinsons Bay	T2 > T5 * T3 > T5 *			T1 > T2 * T1 > T3 *** T1 > T4 *** T1 > T5 **	T1 > T3 * T1 > T4 *** T1 > T5 ***
Childrens Bay				T1 > T3 ** T1 > T4 * T1 > T5 *	
Kaik-Cape Three Points		T2 > T1 * T2 > T3 *		T1 > T3 *** T1 > T4 *** T1 > T5 ** T2 > T3 ** T2 > T4 *	T1 > T3 * T1 > T4 * T1 > T5 *
Heads		T2 > T1 * T2 > T3 * T5 > T1 *** T5 > T3 **			T1 > T3 * T1 > T4 **

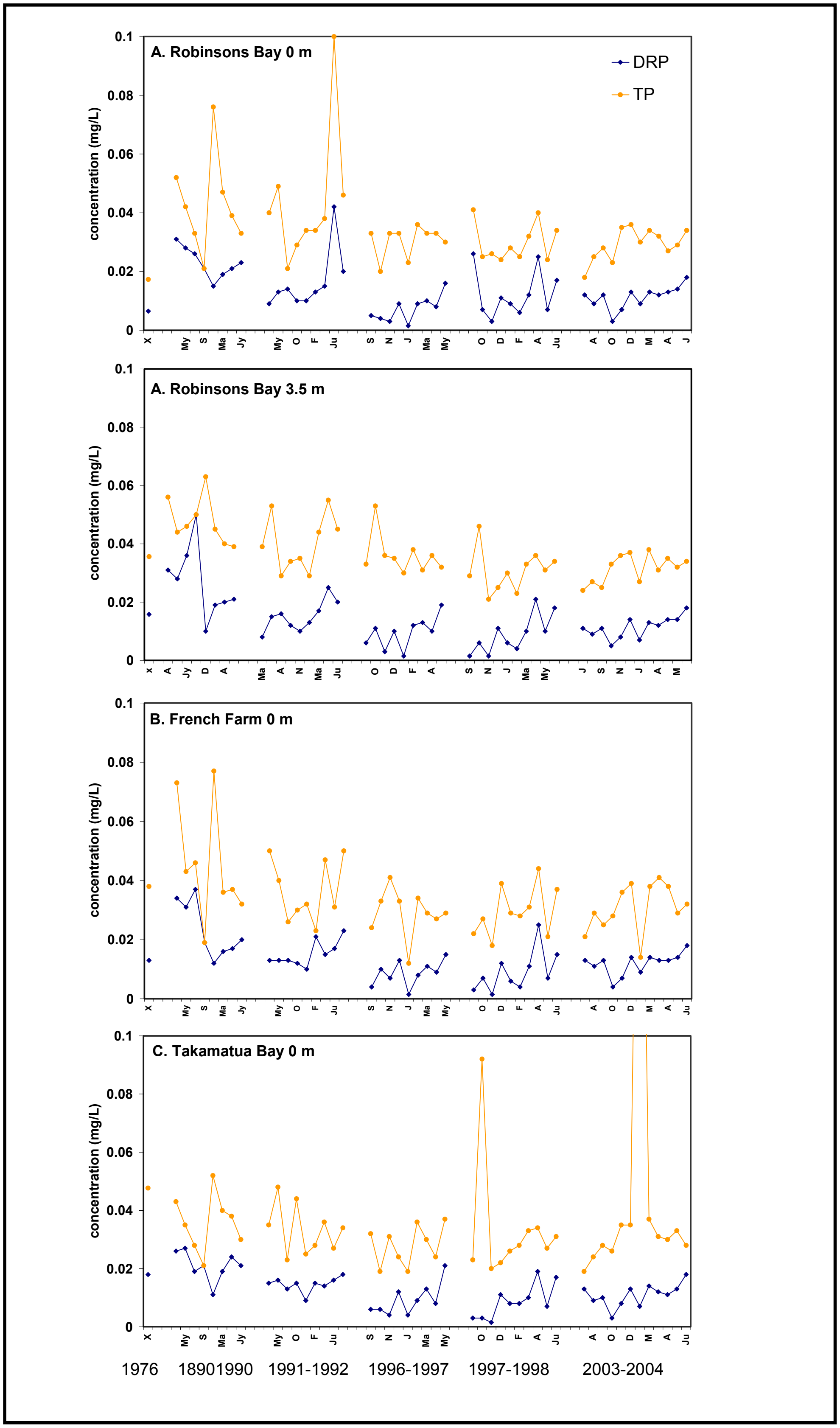
6.5m deep	NH3N	TON	TN	DRP	TP
Kaik-Cape Three Points	T1 > T5 * T3 > T5 *	T2 > T3 *		T1 > T3 ** T1 > T4 * T2 > T3 *	T1 > T3 *** T1 > T4 *** T1 > T5 **
Heads	T2 > T5 *	T5 > T3 ** T5 > T4 *	T5 > T4 *	T1 > T4 *	T1 > T4 *
9.5m deep					
Heads				T1 > T3 * T1 > T4 **	T1 > T2 * T1 > T3 ** T1 > T4 ** T1 > T5 *
12.5m deep					
Heads					T1 > T3 * T1 > T4 **

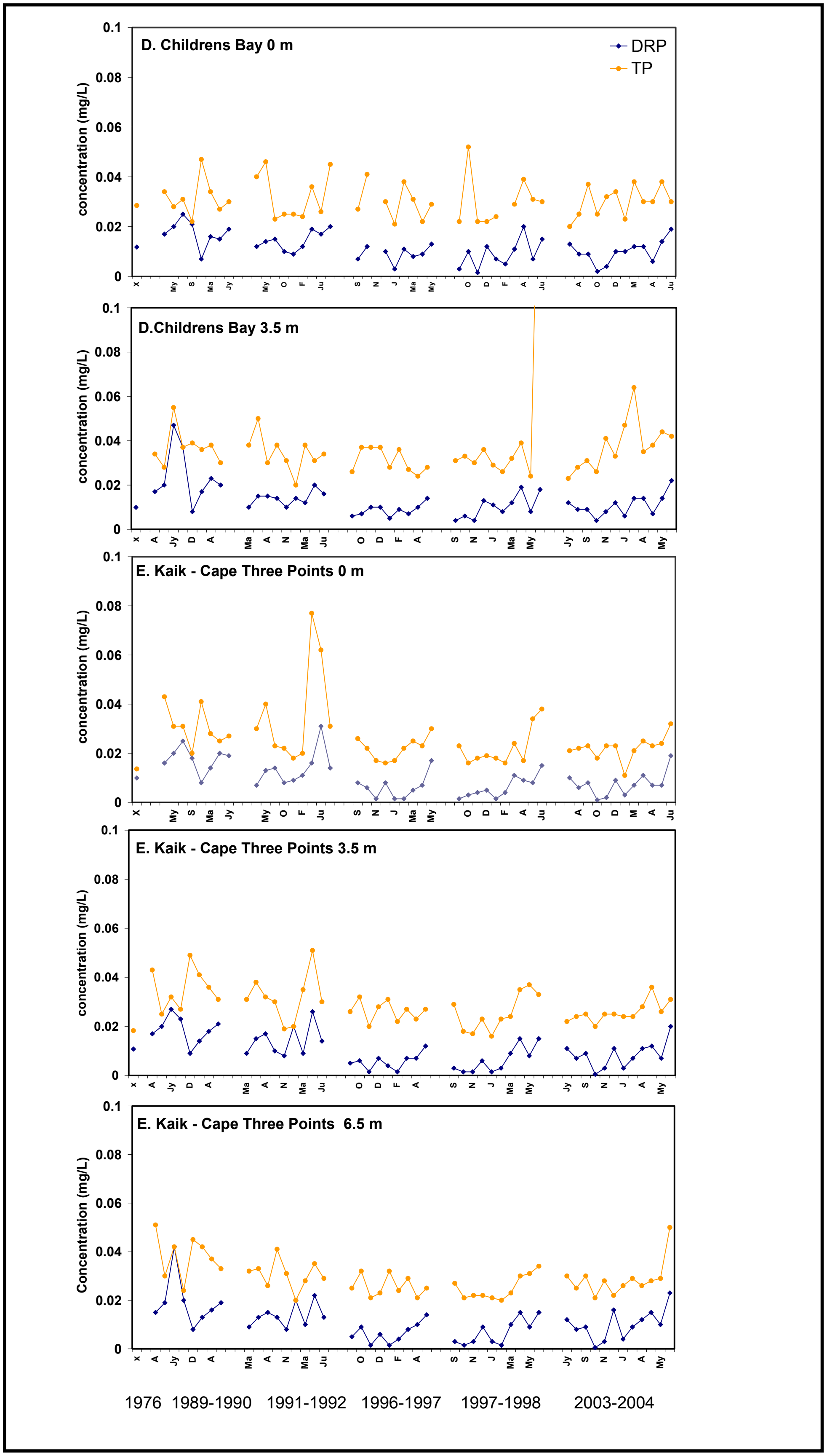
Appendix VI: Nutrient concentrations in water at each depth at each Akaroa Harbour site over time

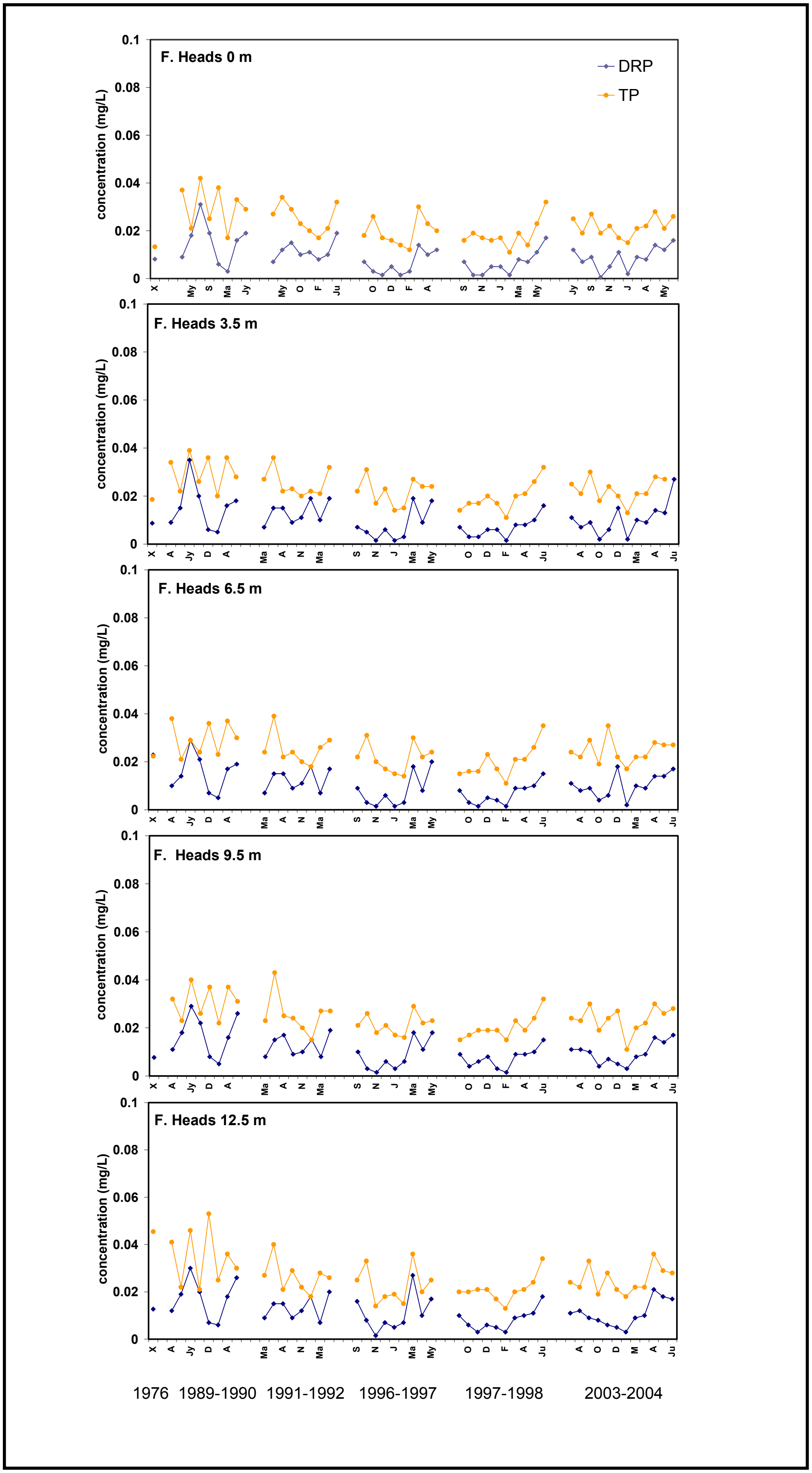

A. Robinsons Bay 0 m
NH3N
NNN
TON
TN
Concentration (mg/L)
A. Robinsons Bay 3.5 m
concentration (mg/L)
B. French Farm 0 m
concentration (mg/L)
C. Takamatua Bay 0 m
concentration (mg/L)
1976
1989-1990
1991-1992
1996-1997
1997-1998
2003-2004


D. Childrens Bay 0 m
NH3N
NNN
TON
TN
concentration (mg/L)
D. Childrens Bay 3.5 m
concentration (mg/L)
E. Kaik - Cape Three Points 0 m
Concentration (mg/L)
E. Kaik - Cape Three Points 3.5 m
Concentration (mg/L)
E. Kaik - Cape Three Points 6.5 m
concentration (mg/L)
1976 1989-1990 1991-1992 1996-1997 1997-1998 2003-2004

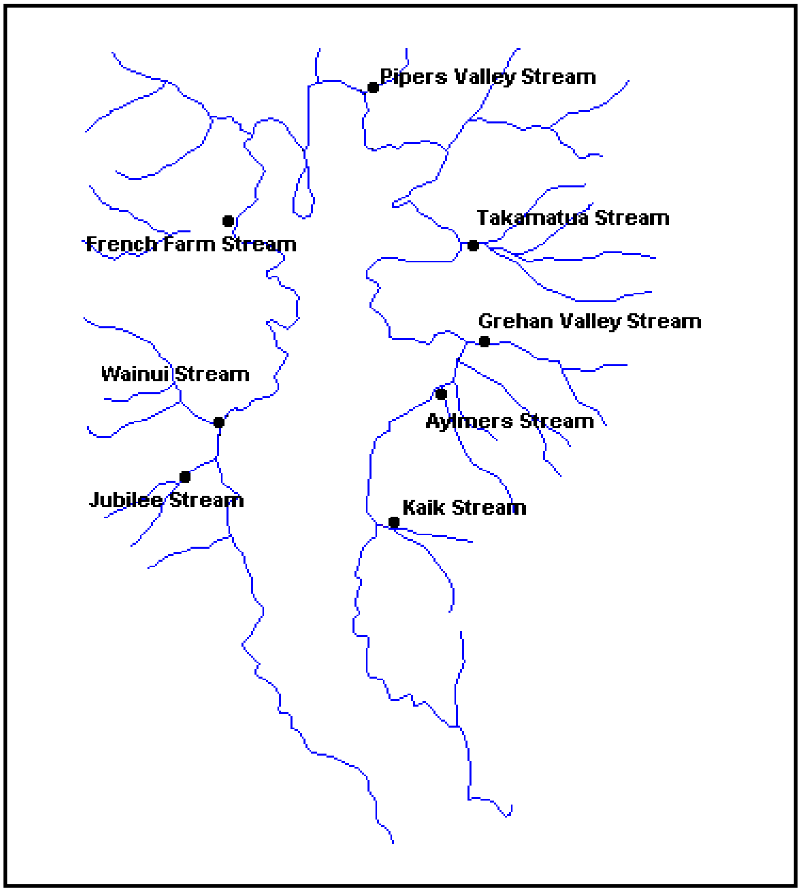

F. Heads 0 m
F. Heads 3.5 m
F. Heads 6.5 m
F. Heads 9.5 m
F. Heads 12.5 m
NH3N
NNN
TON
TN
Concentration (mg/L)
concentration (mg/L)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
1976 1989-1990 1991-1992 1996-1997 1997-1998 2003-2004


A. Robinsons Bay 0 m
DRP
TP
concentration (mg/L)
0.1
0.08
0.06
0.04
0.02
0
A. Robinsons Bay 3.5 m
B. French Farm 0 m
C. Takamatua Bay 0 m
1976
18901990
1991-1992
1996-1997
1997-1998
2003-2004


D. Childrens Bay 0 m
DRP
TP
concentration (mg/L)
0.1
0.08
0.06
0.04
0.02
0
D.Childrens Bay 3.5 m
E. Kaik - Cape Three Points 0 m
E. Kaik - Cape Three Points 3.5 m
E. Kaik - Cape Three Points 6.5 m
Concentration (mg/L)
1976
1989-1990
1991-1992
1996-1997
1997-1998
2003-2004


F. Heads 0 m
DRP
TP
F. Heads 3.5 m
F. Heads 6.5 m
F. Heads 9.5 m
F. Heads 12.5 m
concentration (mg/L)
0.1
0.08
0.06
0.04
0.02
0
1976
1989-1990
1991-1992
1996-1997
1997-1998
2003-2004

Appendix VII: Nutrient concentrations (mg/L) and flow (m3/s) in some of the streams flowing into Akaroa Harbour (January 1990 – April 1991)


Pipers Valley Stream
French Farm Stream
Takamatua Stream
Grehan Valley Stream
Wainui Stream
Aylmers Stream
Jubilee Stream
Kaik Stream

	Date	NH3N mg/L	NNN mg/L	TN mg/L	DRP mg/L	TP mg/L	Flow m3/s
Jubilee Stream							
	11-Jan-90	0.014	0.131	0.171	0.031	0.052	0.039
	13-Feb-90	0.01	0.154	0.304	0.042	0.062	0.021
	13-Mar-90	0.01	0.154	0.364	0.045	0.077	0.013
	10-Apr-90	0.009	0.15	0.34	0.039	0.063	0.012
	8-May-90		0.118	0.358	0.027	0.022	0.023
	20-Jun-90	0.01	0.325	0.425	0.021	0.034	0.088
	10-Jul-90	0.012	0.315	0.555	0.023	0.042	0.042
	9-Aug-90	0.006	0.395	0.525	0.028	0.052	0.046
	24-Aug-90	0.015	0.48	0.74	0.023	0.098	0.466
	13-Sep-90	0.017	0.61	0.81	0.023	0.04	0.136
	11-Oct-90	0.005	0.33	0.84	0.029	0.056	0.043
	14-Nov-90	0.005	0.136	0.286	0.035	0.049	0.041
	11-Dec-90	0.007	0.235	0.415	0.048	0.056	0.024
	15-Jan-91	0.014	0.16	0.34	0.04	0.064	0.014
	12-Feb-91	0.02	0.186	0.426	0.053	0.08	0.014
	12-Mar-91	0.007	0.12	0.16	0.036	0.048	0.024
	10-Apr-91	0.007	0.081	0.521	0.033	0.138	0.162
Wainui Stream	**Date**	**NH3N mg/L**	**NNN mg/L**	**TN mg/L**	**DRP mg/L**	**TP mg/L**	**Flow m3/s**
	11-Jan-90	0.055	0.059	0.189	0.02	0.051	0.057
	13-Feb-90	0.032	0.085	0.445	0.037	0.073	0.040
	13-Mar-90	0.05	0.09	0.38	0.017	0.073	0.032
	10-Apr-90	0.022	0.048	0.218	0.015	0.052	0.025
	8-May-90		0.097	0.277	0.021	0.044	0.062
	20-Jun-90	0.017	0.355	0.505	0.015	0.039	0.139
	10-Jul-90	0.026	0.31	0.61	0.013	0.044	0.118
	9-Aug-90	0.019	0.35	0.6	0.018	0.051	0.112
	24-Aug-90	0.035	0.58	1.13	0.018	0.228	2.710
	13-Sep-90	0.027	0.645	0.955	0.017	0.055	0.336
	11-Oct-90	0.013	0.33	0.56	0.02	0.056	0.126
	14-Nov-90	0.01	0.152	0.372	0.032	0.054	0.106
	11-Dec-90	0.02	0.15	0.32	0.024	0.051	0.137
	15-Jan-91	0.021	0.155	0.425	0.026	0.062	0.041
	12-Feb-91	0.032	0.104	0.374	0.044	0.069	0.036
	12-Mar-91	0.011	0.09	0.2	0.032	0.048	0.050
	10-Apr-91	0.014	0.138	0.938	0.038	0.344	0.394
French Farm Stream	**Date**	**NH3N mg/L**	**NNN mg/L**	**TN mg/L**	**DRP mg/L**	**TP mg/L**	**Flow m3/s**
	11-Jan-90	0.009	0.077	0.146	0.026	0.041	0.032
	13-Feb-90	0.011	0.046	0.225	0.035	0.053	0.020
	13-Mar-90	0.014	0.12	0.278	0.038	0.073	0.016
	10-Apr-90	0.011	0.062	0.303	0.033	0.062	0.013
	8-May-90		0.091	0.216	0.026	0.045	0.039
	20-Jun-90	0.007	0.218	0.188	0.018	0.047	0.067
	10-Jul-90	0.026	0.105	0.202	0.012	0.023	0.067
	9-Aug-90	0.01	0.24	0.163	0.023	0.045	0.055
	24-Aug-90	0.024	0.615	0.265	0.025	0.096	1.827
	25-Aug-90	0.023	0.77	0.574	0.024	0.106	1.671
	13-Sep-90	0.018	0.52	0.279	0.019	0.044	0.208
	11-Oct-90	0.012	0.31	0.244	0.024	0.048	0.070
	14-Nov-90	0.011	0.11	0.265	0.035	0.053	0.050
	11-Dec-90	0.019	0.15	0.261	0.031	0.058	0.046
	15-Jan-91	0.014	0.115	0.291	0.031	0.094	0.029
	12-Feb-91	0.015	0.092	0.264	0.044	0.049	0.018
	12-Mar-91	0.01	0.05	0.248	0.038	0.05	0.020
	10-Apr-91	0.009	0.092	0.584	0.034	0.172	0.148

Pipers Valley

Date	NH3N mg/L	NNN mg/L	TN mg/L	DRP mg/L	TP mg/L
11-Jan-90	0.07	0.063	0.562	0.042	0.082
13-Feb-90	0.025	0.094	0.457	0.037	0.099
13-Mar-90	0.037	0.15	0.826	0.046	0.15
10-Apr-90	0.013	0.029	0.377	0.037	0.112
8-May-90	0.023	0.198	0.341	0.031	0.06
20-Jun-90	0.01	0.38	0.177	0.027	0.065
10-Jul-90	0.02	1.1	0.378	0.018	0.064
9-Aug-90	0.006	0.37	0.262	0.032	0.059
24-Aug-90	0.037	1.1	0.727	0.037	0.186
13-Sep-90	0.044	0.99	0.274	0.024	0.043
11-Oct-90	0.016	0.26	0.545	0.035	0.065
14-Nov-90	0.04	0.184	0.517	0.057	0.1
11-Dec-90	0.048	0.41	0.498	0.048	0.107
15-Jan-91	0.026	0.148	0.437	0.037	0.084
12-Feb-91	0.015	0.084	0.508	0.068	0.095
12-Mar-91	0.011	0.033	0.365	0.045	0.076
10-Apr-91	0.018	0.139	0.579	0.039	0.148

Takamatua Stream

Date	NH3N mg/L	NNN mg/L	TN mg/L	DRP mg/L	TP mg/L	Flow m3/s
12-Jan-90	0.026	0.044	0.208	0.028	0.056	0.042
14-Feb-90	0.017	0.017	0.304	0.034	0.071	0.026
13-Mar-90	0.013	0.059	0.375	0.025	0.091	0.025
10-Apr-90	0.011	0.015	0.224	0.014	0.051	0.018
8-May-90	0.012	0.102	0.181	0.021	0.045	0.029
21-Jun-90	0.014	0.278	0.136	0.016	0.037	0.048
10-Jul-90	0.018	0.445	0.335	0.015	0.039	0.104
9-Aug-90	0.006	0.285	0.214	0.024	0.047	0.064
24-Aug-90	0.037	0.94	2.202	0.042	0.345	
12-Sep-90	0.021	0.8	0.243	0.023	0.056	0.251
11-Oct-90	0.016	0.23	0.394	0.034	0.059	0.099
14-Nov-90	0.012	0.19	0.276	0.046	0.06	0.059
11-Dec-90	0.017	0.39	0.331	0.031	0.062	0.054
15-Jan-91	0.015	0.33	0.213	0.023	0.054	0.028
12-Feb-91	0.011	0.035	0.333	0.043	0.064	0.020
12-Mar-91	0.009	0.052	0.187	0.037	0.052	0.036
10-Apr-91	0.007	0.115	0.453	0.043	0.132	0.217

Grehan Valley Stream

Date	NH3N mg/L	NNN mg/L	TN mg/L	DRP mg/L	TP mg/L
12-Jan-90	0.014	0.166	0.246	0.041	0.056
14-Feb-90	0.012	0.178	0.348	0.047	0.065
13-Mar-90	0.01	0.168	0.388	0.056	0.08
10-Apr-90	0.01	0.136	0.236	0.045	0.058
8-May-90	0.0025	0.144	0.344	0.038	0.051
21-Jun-90	0.007	0.39	0.55	0.029	0.042
10-Jul-90	0.012	0.405	0.585	0.031	0.047
9-Aug-90	0.008	0.4	0.57	0.036	0.056
24-Aug-90	0.03	1	2.94	0.039	0.216
25-Aug-90	0.022	1.64	2.11	0.031	0.092
12-Sep-90	0.01	1.01	1.22	0.029	0.042
11-Oct-90	0.009	0.545	0.745	0.04	0.055
14-Nov-90	0.007	0.36	0.57	0.043	0.055
11-Dec-90	0.008	0.44	0.6	0.038	0.056
15-Jan-91	0.012	0.39	0.61	0.047	0.065
12-Feb-91	0.01	0.23	0.47	0.063	0.077
12-Mar-91	0.009	0.23	0.37	0.049	0.061
10-Apr-91	0.007	0.295	0.705	0.056	0.126

Aylmers Stream

Date	NH3N mg/L	NNN mg/L	TN mg/L	DRP mg/L	TP mg/L	Flow m3/s
12-Jan-90	0.02	0.164	0.114	0.034	0.055	0.020
14-Feb-90	0.013	0.108	0.215	0.035	0.055	0.015
13-Mar-90	0.014	0.178	0.269	0.039	0.071	0.008
10-Apr-90	0.013	0.104	0.172	0.032	0.049	0.005
8-May-90	0.008	0.132	0.202	0.032	0.047	0.026
21-Jun-90	0.01	0.63	0.168	0.028	0.05	0.043
10-Jul-90	0.016	0.68	0.289	0.029	0.052	0.034
9-Aug-90	0.01	0.73	0.218	0.038	0.058	0.031
24-Aug-90	0.032	1.58	1.85	0.05	0.216	3.420
12-Sep-90	0.02	1.37	0.243	0.033	0.051	0.136
11-Oct-90	0.007	0.67	0.226	0.036	0.056	0.041
14-Nov-90	0.009	0.485	0.256	0.066	0.078	0.033
11-Dec-90	0.007	0.47	0.29	0.04	0.065	0.030
15-Jan-91	0.01	0.345	0.25	0.04	0.066	0.023
12-Feb-91	0.013	0.285	0.314	0.054	0.073	0.013
12-Mar-91	0.006	0.22	0.204	0.044	0.059	0.019
10-Apr-91	0.005	0.29	0.44	0.06	0.132	0.071

Kaik Stream

Date	NH3N mg/L	NNN mg/L	TN mg/L	DRP mg/L	TP mg/L	Flow m3/s
12-Jan-90	0.014	0.166	0.246	0.041	0.056	0.016
14-Feb-90	0.012	0.178	0.348	0.047	0.065	0.013
13-Mar-90	0.01	0.168	0.388	0.056	0.08	0.010
10-Apr-90	0.01	0.136	0.236	0.045	0.058	0.009
8-May-90	0.0025	0.144	0.344	0.038	0.051	0.014
21-Jun-90	0.007	0.39	0.55	0.029	0.042	0.033
10-Jul-90	0.012	0.405	0.585	0.031	0.047	0.024
9-Aug-90	0.008	0.4	0.57	0.036	0.056	0.026
24-Aug-90	0.03	1	2.94	0.039	0.216	6.020
25-Aug-90	0.022	1.64	2.11	0.031	0.092	1.290
12-Sep-90	0.01	1.01	1.22	0.029	0.042	0.103
11-Oct-90	0.009	0.545	0.745	0.04	0.055	0.039
14-Nov-90	0.007	0.36	0.57	0.043	0.055	0.031
11-Dec-90	0.008	0.44	0.6	0.038	0.056	0.032
15-Jan-91	0.012	0.39	0.61	0.047	0.065	0.017
12-Feb-91	0.01	0.23	0.47	0.063	0.077	0.011
12-Mar-91	0.009	0.23	0.37	0.049	0.061	0.009
10-Apr-91	0.007	0.295	0.705	0.056	0.126	0.049

Appendix VIII: Calculated volume (m^3/day) and total weight of nutrients discharged into the Harbour from six streams (Jubilee, Wainui, French Farm, Takamatua, Aylmers and Kaik) (except in the second sampling in August 1990 when the flow in Takamtua Stream was not measured) from January 1990 to April 1991

(Calculations based on water quality sampling and stream gauging on one day per month except in August 1990 when a second sample was taken during a period of high rainfall)

	m3/day	kg NH3N/day	kg NNN/day	kg TN/day	kg DRP/day	kg TP/day
Jan-90	17,798	0.49	1.62	3.20	0.49	0.92
Feb-90	11,664	0.22	1.03	3.83	0.44	0.76
Mar-90	8,986	0.22	0.98	3.17	0.28	0.70
Apr-90	7,085	0.10	0.50	1.77	0.18	0.39
May-90	16,675	0.05	1.79	4.25	0.42	0.71
Jun-90	36,115	0.44	12.60	13.14	0.70	1.46
Jul-90	33,610	0.69	11.75	14.47	0.57	1.33
Aug-90	28,858	0.33	10.53	11.71	0.71	1.46
Aug-90	1,247,875	37.65	1239.21	2412.04	44.15	248.66
Sep-90	101,088	2.09	77.67	61.24	2.25	5.04
Oct-90	36,115	0.42	12.87	17.37	1.02	2.00
Nov-90	27,648	0.26	5.66	9.23	1.11	1.57
Dec-90	27,907	0.45	7.11	9.64	0.86	1.56
Jan-91	13,133	0.20	3.09	4.55	0.42	0.89
Feb-91	9,677	0.19	1.29	3.46	0.46	0.65
Mar-91	13,651	0.12	1.43	2.83	0.50	0.70
Apr-91	89,942	0.88	12.19	60.87	3.60	19.66

Christchurch
58 Kilmore Street, PO Box 345, Christchurch

General enquiries: (03) 365-3828
Fax: (03) 365-3194

Customer services: (03) 353-9007
or: 0800 EC INFO (0800 324 636)

Timaru
75 Church Street, PO Box 550, Timaru

General enquiries: (03) 688-9069
Fax: (03) 688-9067

www.ecan.govt.nz