Technical Report

Investigations and Monitoring Group

Coastal water quality

Lake Ellesmere/Te Waihora to the Waitaki River Mouth

Report No. U06/36

Environment Canterbury

Your regional council

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Executive Summary

This study consisted of a one-off sampling programme that aimed to give a 'snapshot' of the water quality along the 200 km of coastline between Lake Ellesmere/Te Waihora and the Waitaki River mouth. The specific objectives were to investigate nutrient, salinity, Si, Fe and chlorophyll-a concentrations both along-the-shore and with distance from shore and then assess whether the coastal water quality is of ecological concern.

Sampling sites were located at 20, 50, 100 and 200 m from shore along 11 transects. Transects were 13-19 km apart. Three replicate water samples were collected from each site and each analysed for nutrient, salinity, Si, Fe and chlorophyll-a concentrations. Sampling was carried out from a helicopter on 18 and 19 November 2004.

Nutrient, salinity, Si, Fe and chlorophyll-a concentrations were significantly different both along-the-shore i.e. between transects, and with distance from shore. The along-the-shore differences are attributed to the influence of rivers, wastewater discharges, constructed stockwater races and drains, direct sediment runoff from the land adjacent to the shore and possibly groundwater upwelling in the coastal zone. The water quality along each transect reflecting its' proximity to one or more of the influences listed above. The differences in concentrations with distance from shore generally consisted of higher concentrations at 20 m than at some or all of the sites further from shore. This indicates land-derived nutrient inputs to the near-shore water become diluted with increasing distance from shore. At 500 m from shore there were still significant differences in nutrient concentrations between transects which indicates that land-derived nutrient inputs impact coastal water quality to distances greater than 500 m from shore.

The Waitaki River was found to affect coastal water quality to at least 500 m from shore and 25 km away from the river mouth. It was not possible to quantify the along-the-shore and offshore effect of the Rakaia River, Rangitata River and the smaller volume rivers on coastal water quality. However, their nutrient and freshwater inputs must be contributing to the general state of the coastal water quality. The data suggest that the freshwater discharged from the constructed stockwater races and drains does affect the nutrient concentrations and possibly salinity and Si concentrations close to the shore.

The wastewater discharged from the Timaru District Council outfall is the likely source of the NH_3N, TN, DRP, TP and Fe enriched water 1.1 km north of the discharge point.
The PPCS freezing works wastewater is the possible source of the 'patches' of NH_3N and TN enriched water 2.4 km north of the discharge point.

Along this high-energy coastline there is little potential for eutrophication. There is the potential for algae blooms and altered plankton communities, with these more likely to occur closer to than further from the shore, in the vicinity of specific nutrient sources and generally along the more northern part of the coast.

This study is the first step to a better understanding of the nutrient status of the coastal water in this area. There is a need for monitoring of the waters of this coastline and this should include water quality and plankton (phytoplankton and zooplankton) community monitoring with sampling being undertaken at a number of sites at different times of the year.

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1 Introduction

1.1 The study area

The study area was between Lake Ellesmere/Te Waihora in the north and the Waitaki River mouth in the south (Figure 1.1). This is approximately 200 km of coastline.

1.1.1 The coastline

The coastline between Lake Ellesmere/Te Waihora and the Waitaki River mouth is predominantly gravel beach, with highly variable size grade of gravel, interrupted in the Timaru area by rocky reefs, a sandy beach and the Port of Timaru.

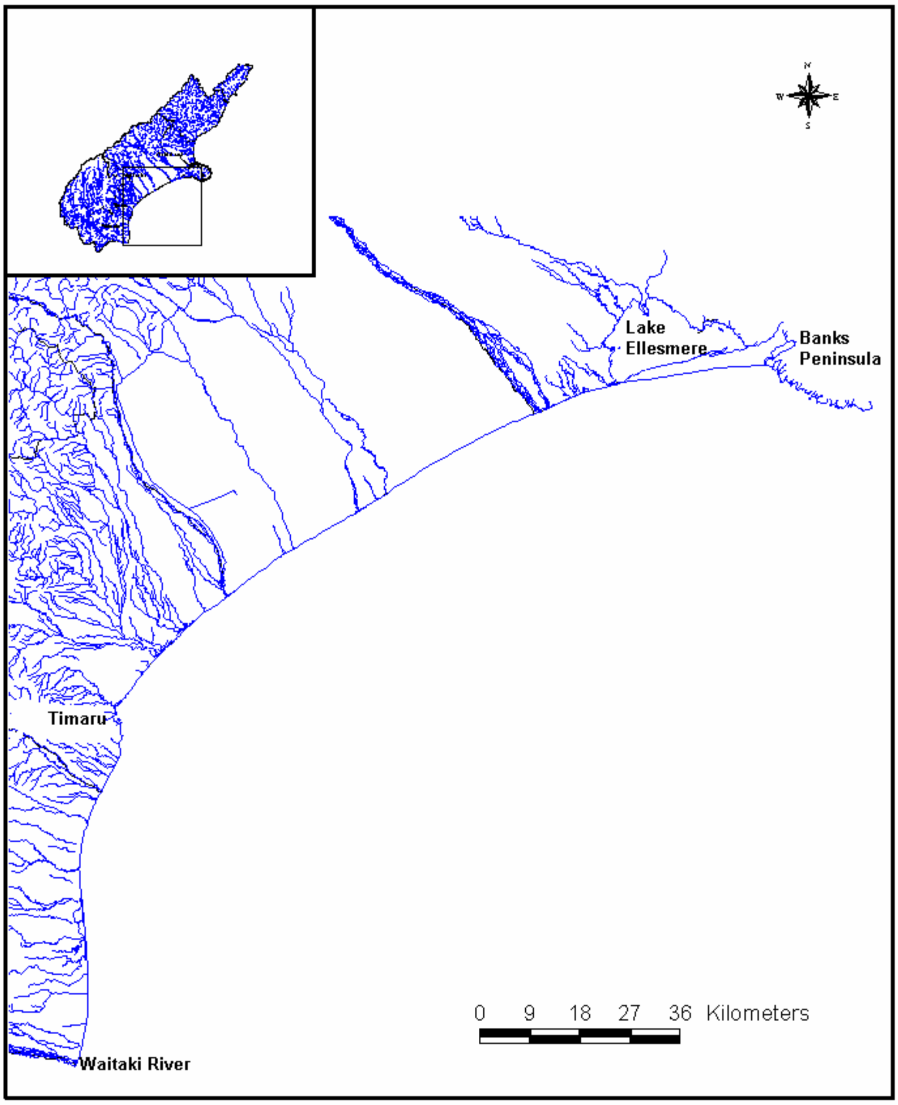

Figure 1.1 The study area

Figure 1.2 Images of the coastline of the study area

A – general view looking south towards Timaru
B – view of the Rakaia River mouth
C – gravel beach south of Timaru
D – the Port of Timaru and Caroline Bay

1.1.2 Bathymetry

The bathymetry immediately beyond the gravel coastline is unknown. It is assumed that at some unknown distance from the shore the seafloor starts its gentle slope seaward, reaching 10 m depth at 2.5 – 3 km, 20 m depth at 6.5 –11 km, 30 m depth at 9 – 18.5 km and 500 m depth at 54 – 100 km from shore. At the 12 mile limit, the depth ranges from 35 – 55 m (Hydrographer RNZN Chart NZ64).

1.1.3 Freshwater discharges

There are numerous rivers, smaller streams and creeks (Figure 1.1), coastal lagoons and constructed stockwater races and drains that discharge fresh water directly or indirectly (Figure 1.3) into the sea along the study area.

Figure 1.3 Two freshwater discharges

A – Indirect discharge of freshwater to the sea
B – Direct discharge of freshwater to the sea (Rakaia River)

The rivers discharging into the sea along the study area are the Lee, Rakaia, Ashburton, Hinds, Rangitata, Orari, Opihi (north of Timaru), Pareora, Otaio, Makikihi, Waihao, Hook and Waitaki rivers (south of Timaru).

The smaller streams, creeks and lagoons that have direct or indirect openings into the sea along the study area include (from North to south) Young Creek, Tent Burn, Jollies Brook, Cryers Creek, Wakanui Creek, Riverside Stream, Kapunatiki Creek (north of Timaru) and Hunting Creek, Waimate Creek and Whitneys Creek (south of Timaru). This is not the complete list of creeks discharging into the sea along this coastline but the names of the other creeks and streams are not known to the author.

The coastal lagoons that have direct or indirect openings into the sea along the study area are Coopers Lagoon, the lagoon north of the Orari River, Spider Lagoon and Washdyke Lagoon (north of Timaru) and the lagoon south of the Otaio River and Wainono Lagoon (south of Timaru).

The constructed stockwater races and drains discharging into the sea along the study area are concentrated along four stretches of coastline. These stretches are from the Rakaia River mouth to the Ashburton River mouth, from the Ashburton River mouth to the Hinds River mouth, from the Hinds River mouth to the Rangitata River mouth and from the Waihao River mouth to the Waitaki River mouth.

Environment Canterbury data and reports have been used to produce a preliminary estimate of the nutrient input (tonnes/year) from various rivers, creeks and stretches of coastline into the sea along this 200 km of coastline (Appendix I).

1.1.4 Wastewater discharges

At the time of sampling there were two high volume discharges of wastewater into the sea in the study area. These discharges were from the Timaru District Council wastewater outfall and from the PPCS Pareora freezing works.

The Timaru District Council has a resource consent to discharge a maximum of 40,000 m^3/day of wastewater under dry weather conditions and a maximum of 120,000 m^3/day under wet weather conditions at a maximum rate of 1390 L/s. The discharge is municipal, domestic and trade wastewater that is primary treated (screened (0.5 mm)). The wastewater is discharged through outfall diffuser ports located 300 to 400 m from the shore (Figure 1.4). A condition of the consent is to measure and record discharge volumes but there is no requirement and hence no data on the nutrient concentrations that are discharged. However, there are some nutrient data for this discharge. These data have been used for the crude estimate of the nutrient input (tonnes/year) from this discharge to the sea (Appendix I).

At the time of sampling the PPCS Pareora freezing works had a resource consent to discharge up to 15,000 m^3/day of primary treated meatworks effluent at a maximum rate of 500 L/s. The waste from the freezing works is passed through milliscreens before being discharged from a pipeline located at about the low water mark (Figure 1.4). From the nutrient concentration and volume data of the wastewater a crude estimate of the nutrient input (tonnes/year) from this discharge to the sea has been produced (Appendix I). The consent for this discharge is up for renewal at present with the long-term plan being to discharge all wastewater to land.

1.1.5 Other inputs

The groundwater that does not feed the spring-fed streams or is not extracted for irrigation will ultimately rise above the seabed beyond the coast. This groundwater is a freshwater input into the sea.

Potentially there is seepage of nutrient-rich water to the coastal water from:

- the high density beef fattening operation (5 Star Beef) located just north of the Ashburton River.
- the milk processing plant (as it operates at present) at Clandeboye located north of the Orari River. It should be noted that this plant has been granted a resource consent to discharge its wastewater to the sea via an ocean outfall. Construction of this outfall is scheduled to take place in the near future.

1.2 Rationale for this study

The coastal water of this 200 km stretch of Canterbury is a complex mix of sea water with the river, stream, creek and stockwater race/drain fresh water, groundwater, municipal, domestic, trade and freezing works wastewater and possible seepages from, as noted, two processing plants. Freshwater and wastewater inputs (Appendix I) contribute considerable quantities of nutrients to the coastal waters in this region.

The quality of the coastal water along this 200 km stretch of coastline has not been investigated to date. A detailed investigation of the nutrient status of the water in the vicinity of Timaru (Port of Timaru, Caroline Bay and out to the starboard Buoy) has been carried out by Environment Canterbury (Bolton-Ritchie, 2006) and some water quality data were collected along the coastline in the vicinity of the future outfall at Clandeboye (Barter *et al.*, 2003). Thus, Environment Canterbury identified the need to assess the water quality between Lake Ellesmere/ Te Waihora and the Waitaki River mouth. To this end a one-off sampling programme, aimed at giving a ‘snapshot’ of the water quality out to 500 m from shore along this 200 km of coastline, was undertaken in November 2004.

Figure 1.4 Wastewater discharges

A – PPCS Pareora freezing works discharge
B – Timaru District Council wastewater discharge

1.3 Objectives of this study

To investigate:

1. the longshore nutrient concentrations in the coastal waters between Lake Ellesmere/Te Waihora and the Waitaki River mouth.

2. the nutrient concentrations with distance from shore in the coastal waters between Lake Ellesmere/Te Waihora and the Waitaki River mouth.

3. the potential for ecological issues as a consequence of the water quality between Lake Ellesmere/Te Waihora and the Waitaki River mouth.

2 Methods

2.1 Sampling transects and sites

Sampling was undertaken along 11 transects between Lake Ellesmere/Te Waihora and the Waitaki River mouth (Figure 2.1; Appendix II). The northern most transect (A) was about 500 m south of the Coopers Lagoon opening and about 5 km south-west of Taumutu at the southern end of Lake Ellesmere/Te Waihora. The southern most transect (K) was approximately 8 km north of the Waitaki River mouth. Transects were 13 – 19 km apart.

The transects were perpendicular to the shore and extended seaward to 500 metres from the high water mark. Sampling was undertaken at four sites along each transect with the sampling sites being:

- just behind the breaker zone (labelled 20 m)
- 50 m from the high water mark
- 100 m from the high water mark
- 500 m from the high water mark

Five hundred metres from shore the water is 3 – 6 m deep.

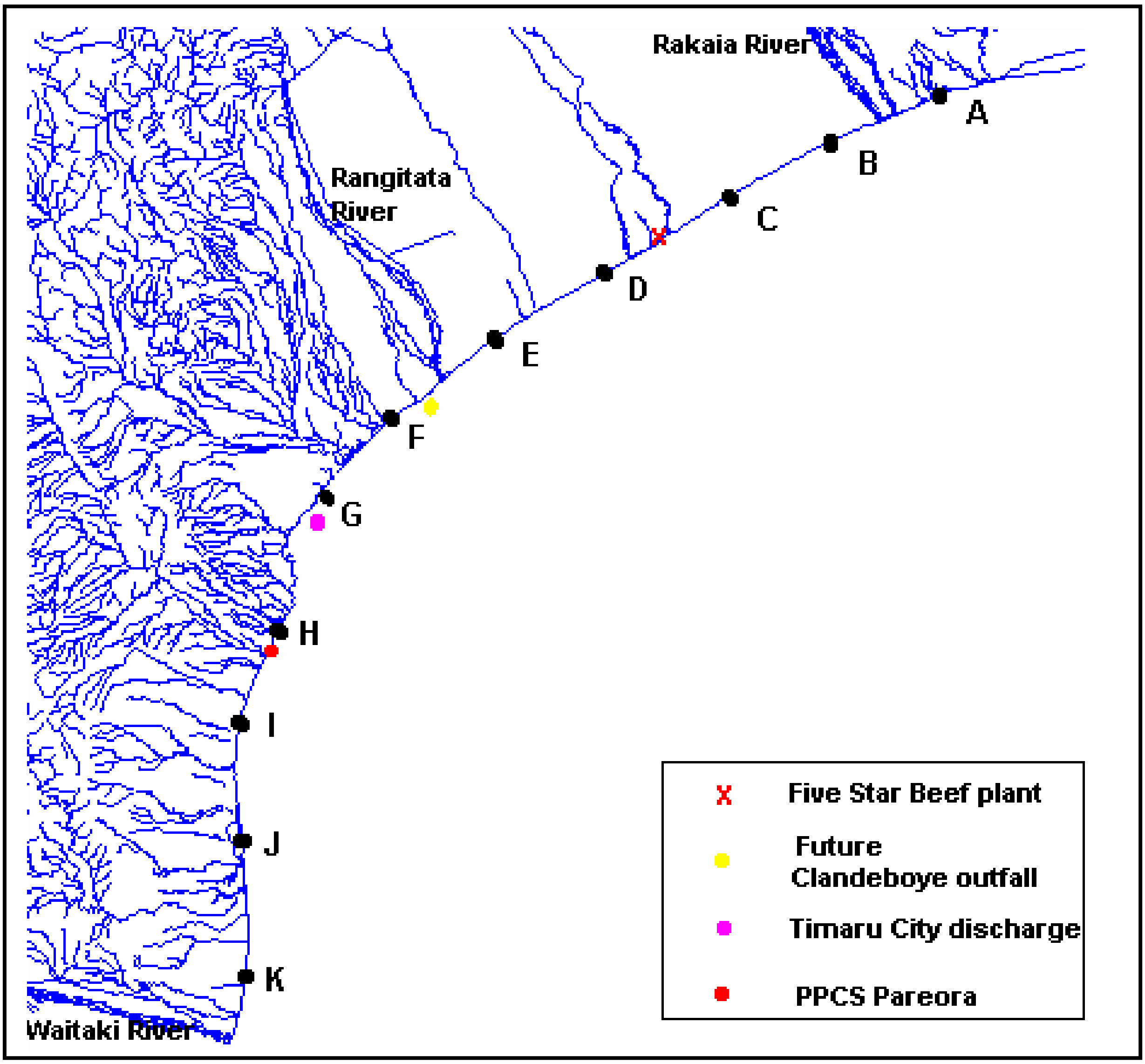

Figure 2.1 Location of transects A-K between Lake Ellesmere/Te Waihora and the Waitaki River mouth

2.2 Sample collection

Transects A, B, C, D, E and F were sampled on 17 November and transects G, H, I, J and K were sampled on 18 November 2004. The details of the weather and sea state at the time of sampling, and the river flows on the days prior to and on the days of sampling, are given in Appendix III.

Four surface water samples were collected from each site. Three of these samples were stored in specially prepared bottles provided by the laboratory undertaking the analyses, and kept cooled in chilly bins until delivery to the laboratory. The fourth sample was used to measure water temperature in the field. General weather (cloud cover, wind direction, wind strength) and sea observations (colour and clarity) were recorded at the time of sampling.

All sampling was undertaken from a helicopter (Figure 2.2).

Figure 2.2 On location for sampling

2.3 Sample analyses

The samples collected were analysed for the determinands listed in Table 2.1. The nitrogen and phosphorus-based compounds are nutrients and chlorophyll-a is a measure of the concentration of phytoplankton present. Reactive silica, which is present in fresh water in parts per million and in sea water in parts per billion, was used in conjunction with salinity to ascertain the level of freshwater influence at each site. In addition, iron, which is deficient in marine water and a required element for phytoplankton growth, was measured. The three water samples collected from each site were analysed separately.

All samples were analysed for all determinands except iron; only one sample from each site was analysed for iron concentration. All analyses were carried out in the Environment Canterbury laboratory. The details of the analytical methods are given in Appendix IV.

Table 2.1 Chemical and biological water quality determinands

Nitrate and nitrite nitrogen (NNN)
Total ammonia nitrogen (NH_3N)
Dissolved inorganic nitrogen (DIN) (= NNN+ NH_3N)
Total nitrogen (TN)
Dissolved reactive phosphorus (DRP)
Total phosphorus (TP)
Reactive silica (Si)
Iron (Fe)
pH
Salinity
Chlorophyll-a

2.4 Data analyses

Microsoft Excel 2000, Systat (version 9) (SPSS, 1999) and Statistica (V6) (Statsoft, 2001) were used for the production of summary statistics, charts, box plots and all statistical analyses.

To determine if there was a significant difference, in the concentration of each determinand (except

Fe and pH), between transects, the data were analysed using the non-parametric Kruskal-Wallis ANOVA (Analysis of Variance). These analyses were performed on the 20, 50 100 and 500 m data separately. When a significant difference between transects was detected, the only method available to determine between which transects the significant difference/s occurred, was to apply a pair-wise comparison using the Tukeys analysis in the general linear model parametric ANOVA.

To determine if there was a significant difference, in the concentration of each determinand (except Fe and pH) with distance from shore along each transect, the data were analysed using the non-parametric Kruskal-Wallis ANOVA (Analysis of Variance). When a significant difference between sites was detected, the only method available to determine between which sites the significant difference/s occurred, was to apply a pair-wise comparison using the Tukeys analysis in the general linear model parametric ANOVA.

The concentrations of DIN, TN, DRP, TP and chlorophyll-a at each site were compared to the trigger levels' concentrations for 'slightly disturbed marine water' for south-east Australia* as listed in the ANZECC (2000) guidelines to determine if the nutrient concentrations 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

3.1 Between transects at each distance from shore

The data for each determinand are presented in scatterplots (Figures 3.1 – 3.8). The results, of the Kruskal-Wallis ANOVA used to determine if there was a significant difference between sites (at 20, 50, 100 and 200 m) on different transects, and the pairwise comparisons used to determine between which sites the significant differences occurred, are presented in Appendices V and VI.

3.1.1 Salinity

The salinity concentrations ranged from 24.3 to 33.8 over all sites. The salinity range was 24.3 – 26.4 on transect K, 27.6 – 28.3 on transect J, 32.4 – 32.6 on transect D and 32.9 – 33.8 at all sites on the remaining transects (Figure 3.1).

At 20, 50, 100 and 500 m there were significant differences in salinity concentrations between sites on different transects (Appendices V and VI; Figure 3.1). At each distance from shore the salinity of transects J and K was lower than that of all other transects with the salinity of transect J higher than that of transect K. At the 20, 50 and 100 m sites of transect D the salinity was lower than that of all other transects except transects J and K.

3.1.2 Reactive silica (Si)

The silica concentrations ranged from 0.09 to 1.3 mg/L over all sites. The highest concentrations occurred along transect K and the lowest concentrations occurred along transect I (Figure 3.2).

At 20, 50, 100 and 500 m there were significant differences in silica concentrations between sites on different transects (Appendices V and VI; Figure 3.2). At each distance from shore Si concentrations on transect J and K were significantly and considerably higher and those on transects C and D were significantly higher, than the concentrations on the other transects. Si concentrations were significantly lower on transect H and I at all distances from shore and on transect A at some distances from shore, than those on other transects.

At 20, 50 and 100 m from shore there were more significant differences in Si concentrations between transects than at 500 m from shore.

3.1.3 Total ammonia nitrogen (NH_3N)

The total ammonia nitrogen concentrations ranged from <0.005 to 0.14 mg/L. The highest recorded NH_3N concentration of 0.14 mg/L occurred at the 50 m site on transect G. The NH_3N concentrations in some of the other samples from the 20, 50 and 100 m sites on transect G were also high when compared to concentrations at other sites (Figure 3.3).

* There are no ANZECC trigger values for New Zealand coastal waters and hence the ANZECC (2000) guidelines recommend using the south-east Australia values.

At 20 m there were significant differences in NH_3N concentrations between sites on different transects (Appendices V and VI; Figure 3.3). The NH_3N concentrations at the 20 m sites on transect B, G, and H were significantly higher than those at 20 m on two or more of the other transects. There was no significant difference in NH_3N concentrations between sites on different transects at 100 and 500 m from shore.

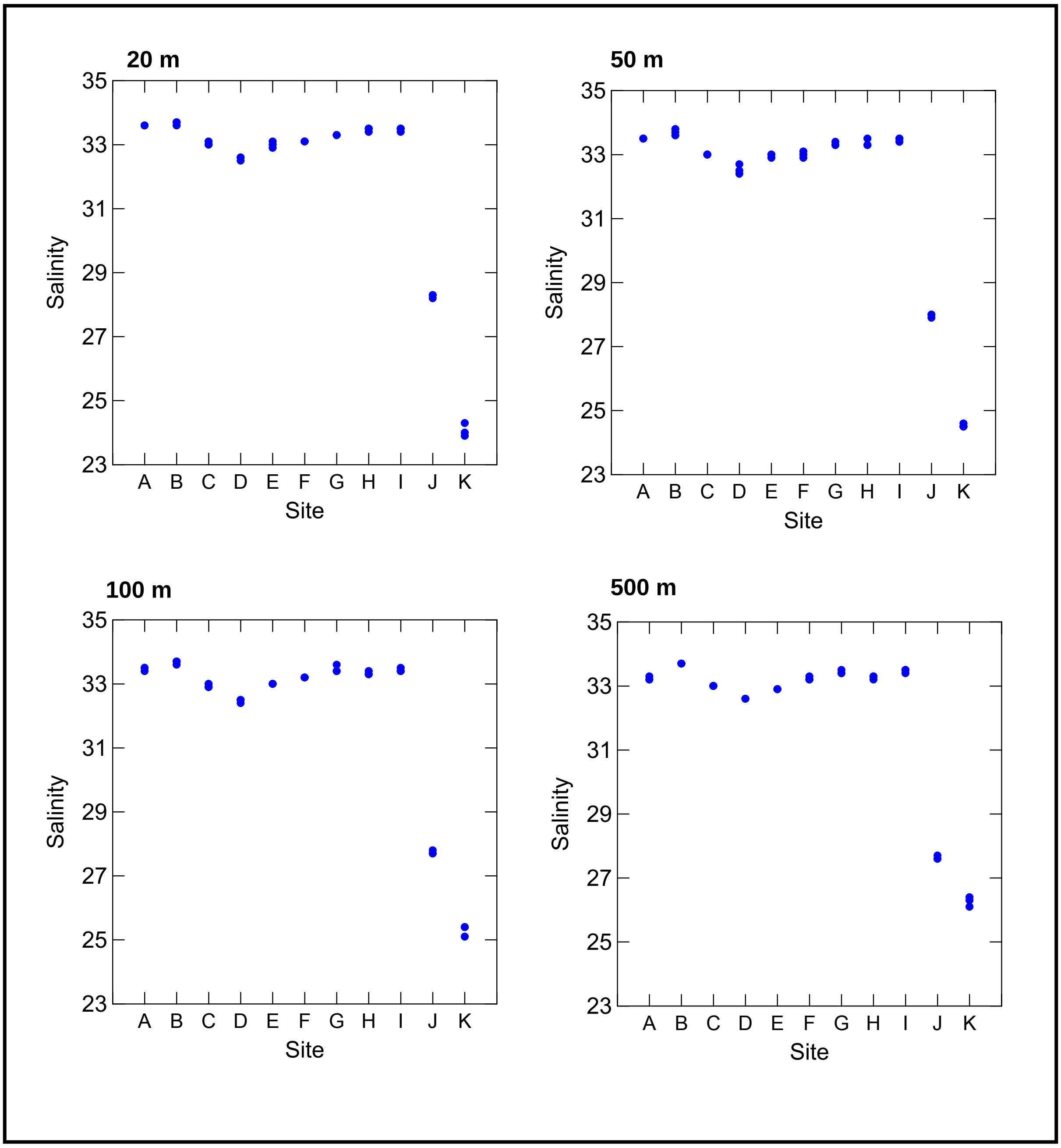

Figure 3.1 Salinity concentrations at each site on each transect

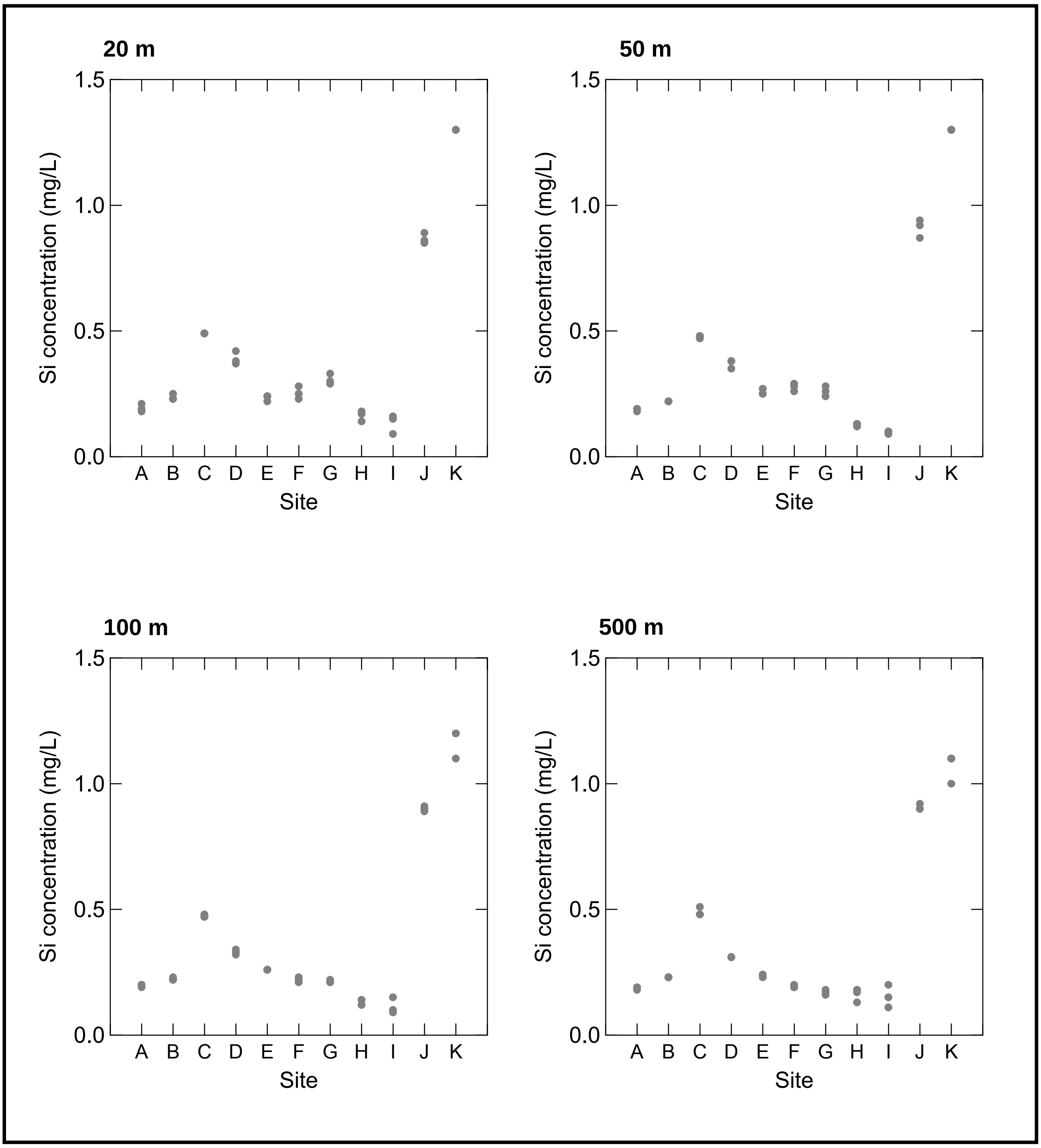

Figure 3.2 Silica concentrations at each site on each transect

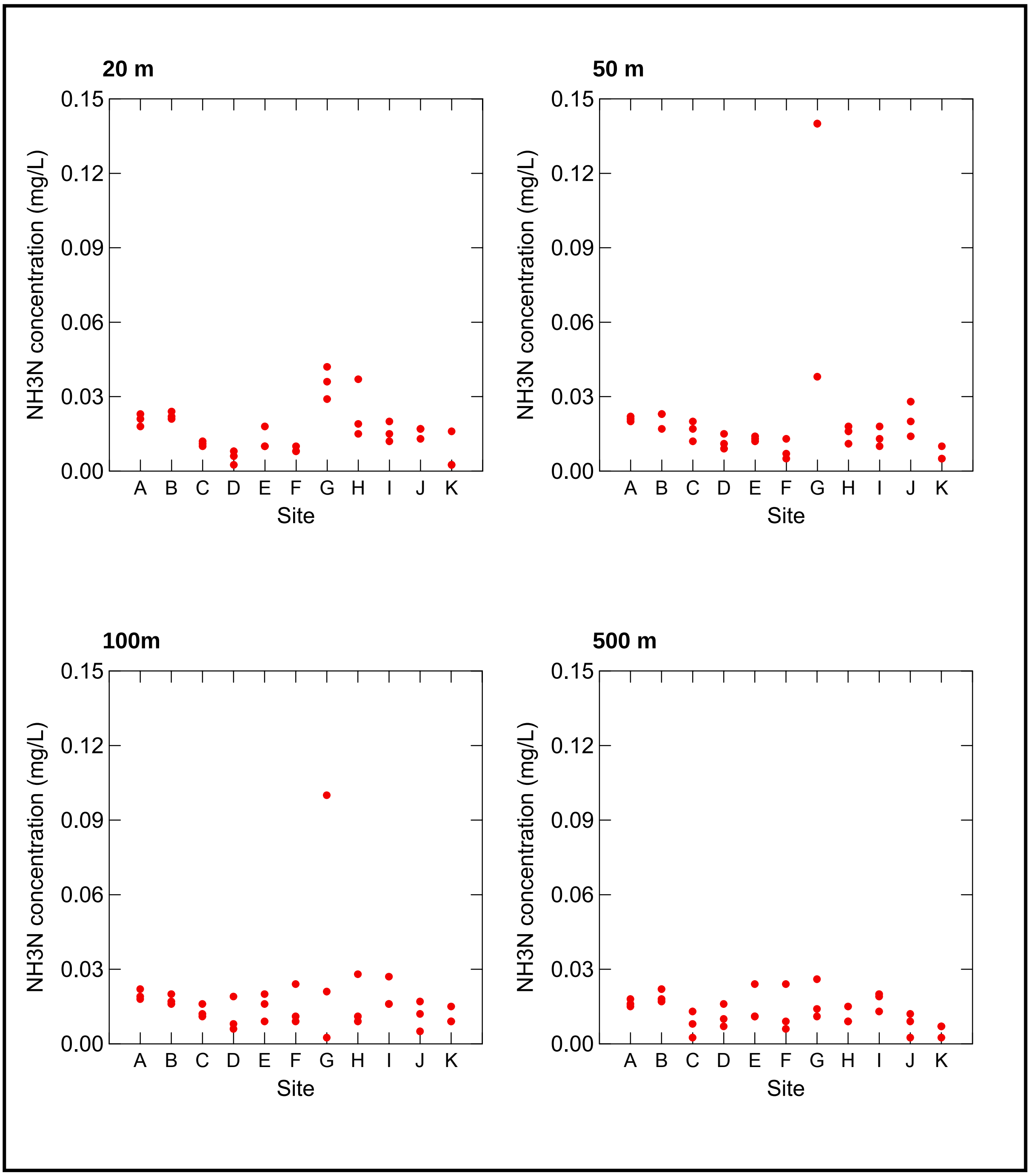

Figure 3.3 Total ammonia concentrations at each site on each transect

3.1.4 Nitrate-nitrite nitrogen (NNN)

The nitrate-nitrite concentrations ranged from < 0.005 to 0.097 mg/L. The highest concentrations occurred along transect F and the lowest concentrations occurred along transects D and E (Figure 3.4).

At 20, 50, 100 and 500 m there were significant differences in NNN concentrations between sites on different transects (Appendices V and VI; Figure 3.4). At all distances from shore the NNN concentrations on transects A, C and K were significantly higher than those at equivalent distance sites on one or more of the other transects. NNN concentrations at three of the sites on transect B and F were significantly higher than those at equivalent distance sites on four or more of the other transects. NNN concentrations were significantly lower on transect H and I at all distances from shore and on transect E and D at some distances from shore, than those on many of the other transects.

At 20 m from shore there were more significant differences in NNN concentrations between transects than there was at 50, 100 and 500 m from shore.

3.1.5 Total nitrogen (TN)

The total nitrogen concentrations ranged from 0.12 to 0.39 mg/L. The highest concentrations occurred along transect G and the lowest concentrations occurred along transect H (Figure 3.5). The range in TN concentrations (over all transects) was higher at 20 and 50 m than at 100 and 500 m from shore.

At 20, 50, 100 and 500 m there were significant differences in TN concentrations between sites on different transects (Appendices V and VI; Figure 3.5). At all distances from shore the TN concentrations on transects A, C and F were significantly higher than those at equivalent distance sites on one or more of the other transects. TN concentrations at three of the sites on transects B were significantly higher than those at equivalent distance sites on four or more of the other transects. TN concentrations were significantly lower on transect H and I at all distances from shore and on transect K, D and J at some distances from shore, than those on many of the other transects.

At 20 m from shore there were more significant differences in TN concentrations between transects than there was at 50, 100 and 500 m from shore.

3.1.6 Dissolved reactive phosphorus (DRP)

The dissolved reactive phosphorus concentrations ranged from 0.003 to 0.016 mg/L. The highest concentrations occurred along transect G and the lowest concentrations occurred along transect K (Figure 3.6). The range in DRP concentrations (over all transects) was higher at 20 m than at 500 m from shore.

At 20, 50, 100 and 500 m there were significant differences in DRP concentrations between sites on different transects (Appendices V and VI; Figure 3.6). At all distances from shore the DRP concentrations on transects A, B, C, E, F and G were significantly higher than those at equivalent distance sites on two or more of the other transects. DRP concentrations were significantly lower on transect H, I and J at all distances from shore and on transect D and K at some distances from shore, than those on many of the other transects.

3.1.7 Total phosphorus (TP)

The total phosphorus concentrations ranged from 0.017 to 0.09 mg/L. The highest concentrations occurred along transect G and the lowest concentrations occurred along transect K (Figure 3.7). The range in TP concentrations (over all transects) was higher at 20 m than at 500 m from shore.

At 20, 50, 100 and 500 m there were significant differences in TP concentrations between sites on different transects (Appendix V and VI; Figure 3.6). At all distances from shore the TP concentrations on at transects A, B, D, E, F and G were significantly higher than those equivalent distance sites on one or more of the other transects. TP concentrations were significantly lower on transect H, I, J and K at all distances from shore than those on many of the other transects.

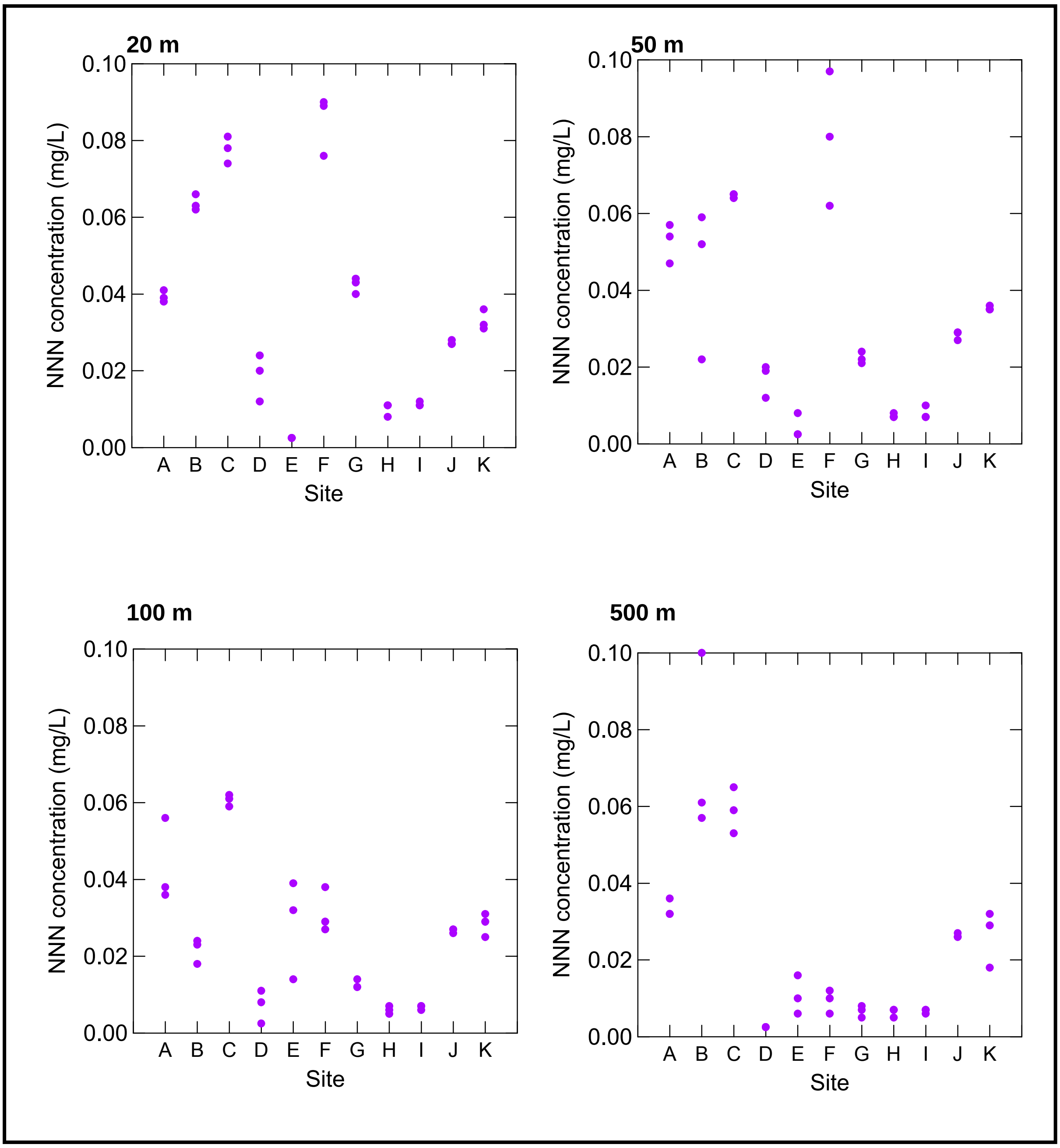

Figure 3.4 **Nitrate-nitrite concentrations at each site on each transect**

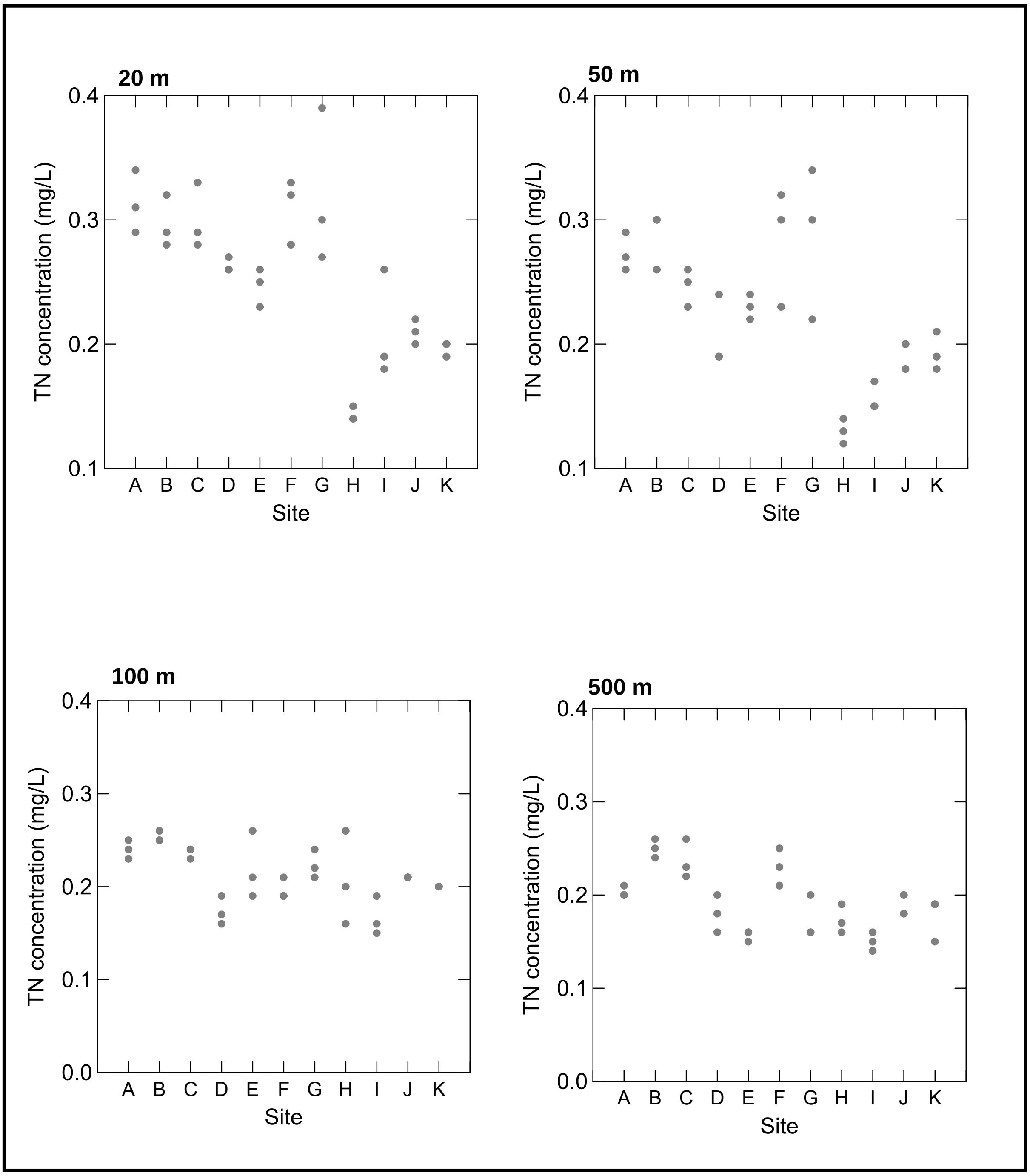

Figure 3.5 Total nitrogen concentrations at each site on each transect

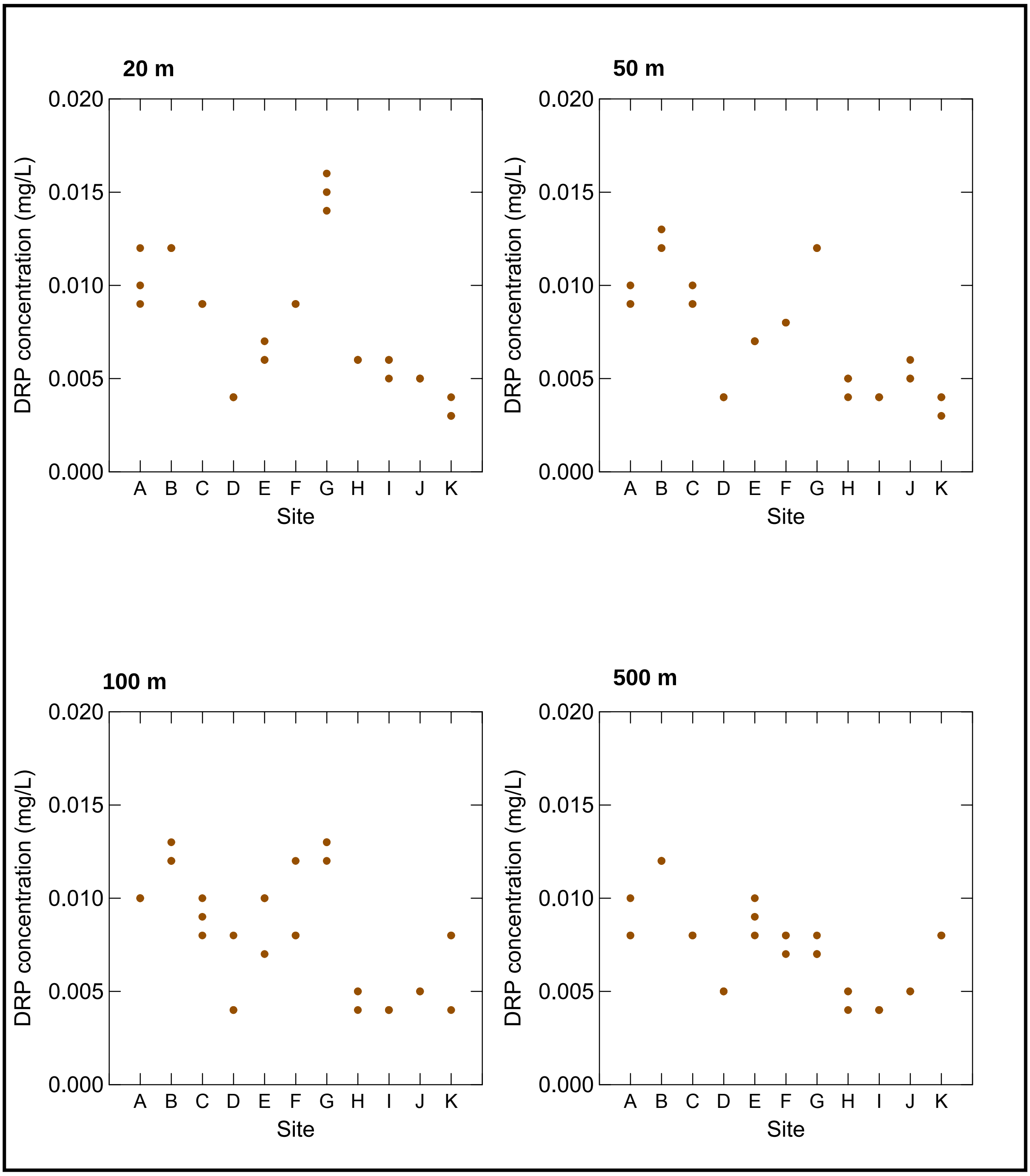

Figure 3.6 Dissolved reactive phosphorus concentrations at each site on each transect

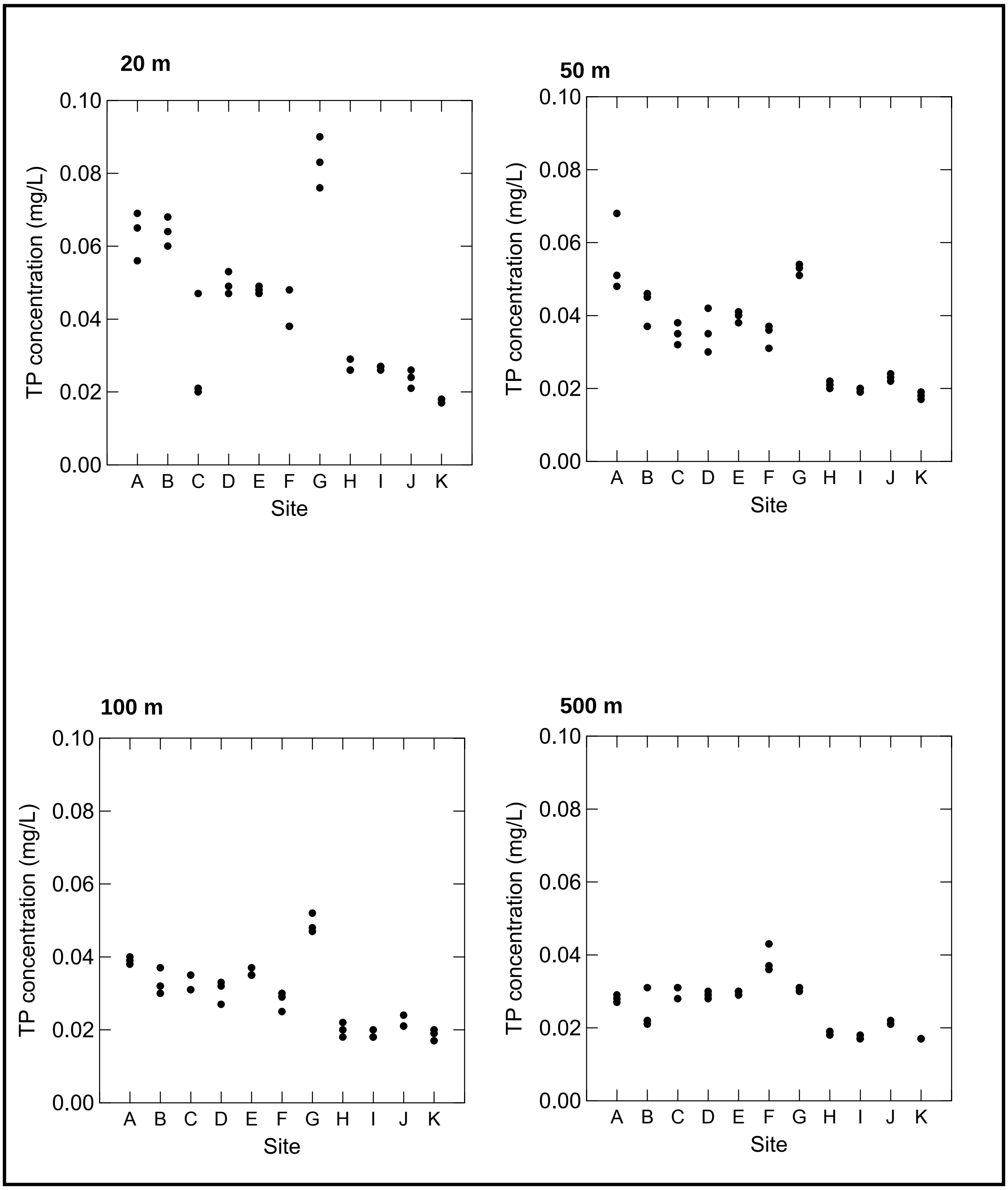

Figure 3.7 Total phosphorus concentrations at each site on each transect

3.1.8 Chlorophyll-a

The chlorophyll-a concentrations ranged from 0.1 to 3.9 µg/L. The highest concentrations occurred along transect A, and the lowest concentrations occurred along transect K and H (Figure 3.8). The range in concentrations over all transects was highest at the sites 20 m from shore.

At 20, 50, 100 and 500 m there were significant differences in chlorophyll-a concentrations between sites on different transects (Appendix V and VI; Figure 3.6). At all distances from shore the chlorophyll-a concentrations on transects A, B, C and D were significantly higher than those at equivalent distance sites on four or more of the other transects. Chlorophyll-a concentrations were significantly lower on transects H, I, J and K at all distances from shore than those on many of the other transects.

3.1.9 Iron (Fe)

The iron concentrations ranged from 0.048 to 2.2 mg/L. The highest concentrations occurred along transect A, and the lowest concentration occurred along transect H (Figure 3.9). The range in concentrations over all transects was highest at the sites 20 m from the shore and lowest at the sites 500 m from shore.

3.2 With distance from shore along each transect

The data for each determinand at each site along each transect are presented in scatterplots in Appendix VII. The results of the Kruskal-Wallis ANOVA, used to determine if there was a significant difference in the concentration of each determinand with distance from shore on each transect, are presented in Appendix VIII. The results of the pairwise comparisons used to determine between which distances on each transect the significant differences occurred, are presented in Table 3.1.

There were significant differences in salinity, Si, NNN, TN, DRP, TP and chlorophyll-a concentrations with distance from shore on some transects. There were no significant differences in NH_3N concentrations with distance from shore on any transect.

Most of the significant differences, in determinand concentration between sites along each transect, consisted of significantly higher concentrations at 20 m than at some or all of the sites further from shore. For some determinands on some transects, concentrations were also significantly higher at 50 m than at sites further from shore.

The other significant differences with distance from shore were:

- higher NNN concentrations at 50 m than at 500 m from shore along transect A.
- lower NNN concentrations at 100 m than at 20 and 500 m from shore along transect B.
- higher Si concentrations at 50 and 100 m than at 20 m from shore, higher Si concentrations at 100 m than 500 m from shore and higher NNN concentrations at 100 m than at sites closer to shore along transect E.
- lower TP concentrations at 100 m than at 20 and 500 m from shore, higher chlorophyll-a concentrations at 500 m than at 50 and 100 m from shore and higher salinity concentrations at 500 and 100 m than at 20 m from shore along transect F.
- higher TN concentrations at 100 m than at 50 m from shore along transect H.
- higher DRP and salinity concentrations at 500 and 100 m than at sites closer to shore along transect K.

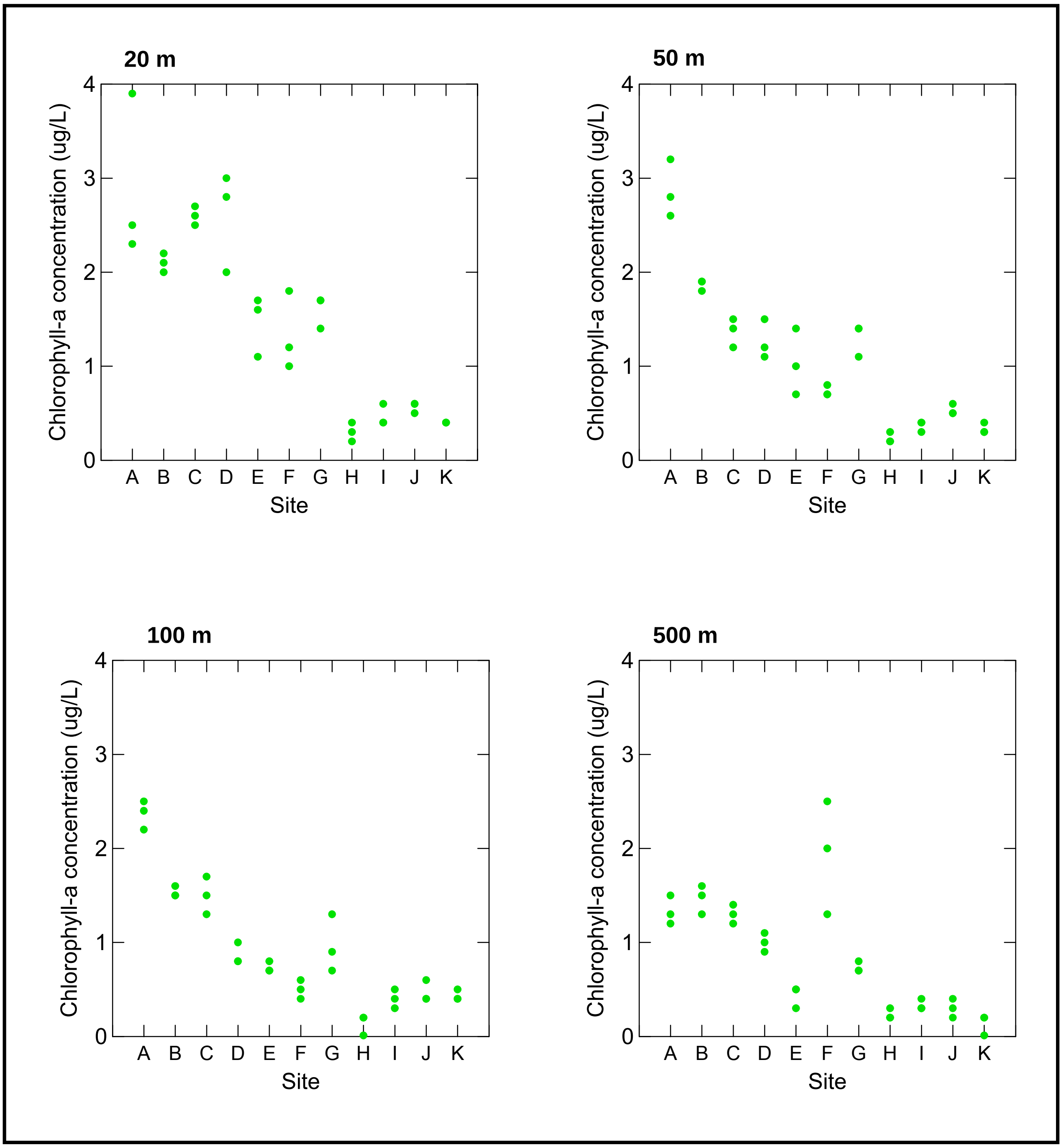

Figure 3.8 Chlorophyll-a concentrations at each site on each transect

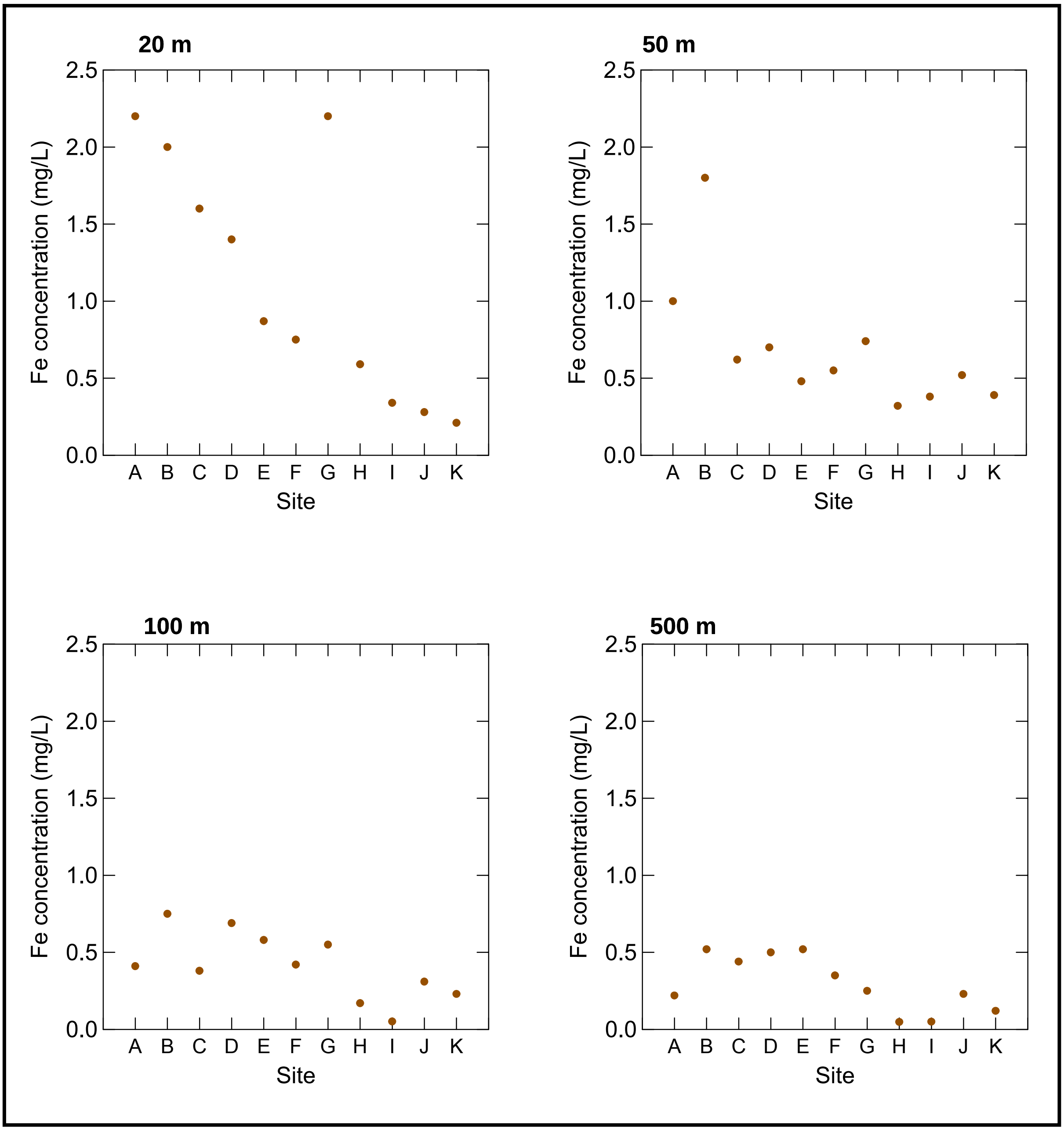

Figure 3.9 **Iron concentrations at each site on each transect.**

Table 3.1 Significant differences in determinand concentrations with distance from shore on each transect

ns – no significant difference in concentration with distance from shore (Kruskal-Wallis ANOVA)
Significant differences in concentrations are depicted as differences between distances (20, 50, 100, 200) from shore
*** -** significant difference with distance from shore (Kruskal-Wallis ANOVA), but no difference using Tukeys pairwise comparisons

	NH3N	NNN	TN	DRP	TP	Salinity	Si	Chlorophyll-a
A	ns	50 > 500	20 > 100, 500; 50 > 500	ns	20 > 100, 500; 50 > 500	20, 50 > 500; 20 > 100	ns	20, 50 > 500
B	ns	20, 500 > 100	ns	ns	20 > 50, 100, 500; 50 > 500	ns	*	20, 50 > 100, 500
C	ns	20 > 50,100, 500	ns	ns	ns	ns	ns	ns
D	ns	20 > 100, 500; 50 > 500	20 > 50, 100, 500	ns	20 > 50, 100, 500	ns	20 > 100, 500;50 > 500	20 > 50, 100, 500
E	ns	100 > 20, 50	ns	*	20 > 50 > 100 > 500	ns	100 > 20, 500; 50 > 20	20 > 100, 500
F	ns	20, 50 > 100, 500	20 > 100, 500; 50 > 100	ns	20, 500 > 100	100, 500 > 20	20, 50 > 500; 50 > 100	500 > 50, 100
G	ns	20 > 50 > 100 > 500	20 > 500	20 > 50, 100 > 500	20 > 50, 100 > 500	*	20 > 100, 500; 50 > 100 > 500	20, 50 > 500; 20 > 100
H	ns	20 > 100, 500	100 > 50	ns	20 > 50, 100, 500	ns	ns	ns
I	ns	20 > 50, 100, 500	ns	20 > 50, 100, 500	20 > 50, 100, 500; 50 > 500	ns	ns	ns
J	ns	ns	ns	ns	ns	20 > 50 > 100, 500	ns	ns
K	ns	ns	ns	500 > 20, 50; 100 > 20	ns	500 > 100 > 50 > 20	20, 50 >100, 500	20, 50, 100 > 500

3.3 Comparison of determinand concentrations to guideline values

In the ANZECC (2000) Guidelines, trigger values in 'slightly disturbed marine water' are given for DIN (= NO_x (≡ NNN) + NH_4^+ (≡ NH3N)), TN, FRP (≡ DRP), TP and chlorophyll-a. The trigger values for these determinands are DIN (0.02 mg/L), TN (0.12 mg/L), DRP (0.01 mg/L), TP (0.025 mg/L) and chlorophyll-a (1µg/L). The guideline trigger values are the concentrations below which there is a low risk of adverse effects. 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.

For each distance from shore (across all transects) and for each transect (all distances from shore), the percentage of samples in which the guideline values for DIN, TN, DRP, TP and chlorophyll-a concentrations were exceeded was calculated. These data are presented in Tables 3.2 and 3.3.

Table 3.2 The percentage of samples at each distance from shore exceeding the ANZECC (2000) DIN, TN, DRP, TP and chlorophyll-a trigger values in marine water.

Number of samples at each distance = 33

	20 m	50 m	100 m	500 m
DIN	91	84.8	84.8	69.7
TN	100	97	100	100
DRP	21.2	18.2	21.2	9.1
TP	78.8	63.6	60.6	57.6
Chlorophyll-a	63.6	51.5	30.3	39.4

Table 3.3 The percentage of samples on each transect exceeding the ANZECC (2000) DIN, TN, DRP, TP and chlorophyll-a trigger values in marine water.

Number of samples on each transect = 12

	A	B	C	D	E	F	G	H	I	J	K
DIN	100	100	100	50	58.3	91.7	75	58.3	75	100	100
TN	100	100	100	100	100	100	100	91.7	100	100	100
DRP	8.3	16.7	0	0	0	8.3	75	0	0	0	0
TP	100	83.3	83.3	100	100	91.7	100	25	25	8.3	0
Chlorophyll-a	100	100	100	58.3	33.3	41.7	41.7	0	0	0	0

There was, in general, a decrease in the percentage of samples in which the ANZECC (2000) trigger values for DIN, TN, DRP, TP and chlorophyll-a were exceeded, with distance from shore (Table 3.2).

The percentage of samples in which the ANZECC (2000) trigger values for DIN, TN, DRP, TP and chlorophyll-a were exceeded differed between transects (Table 3.3).

3.4 N:P ratios

The N:P ratio was calculated for all samples using the DIN and DRP values. The results are presented in Figure 3.10.

The N:P ratio in all but one sample (from site K20) was less than 16:1. The ratio in the sample from site K20 was 17:1.

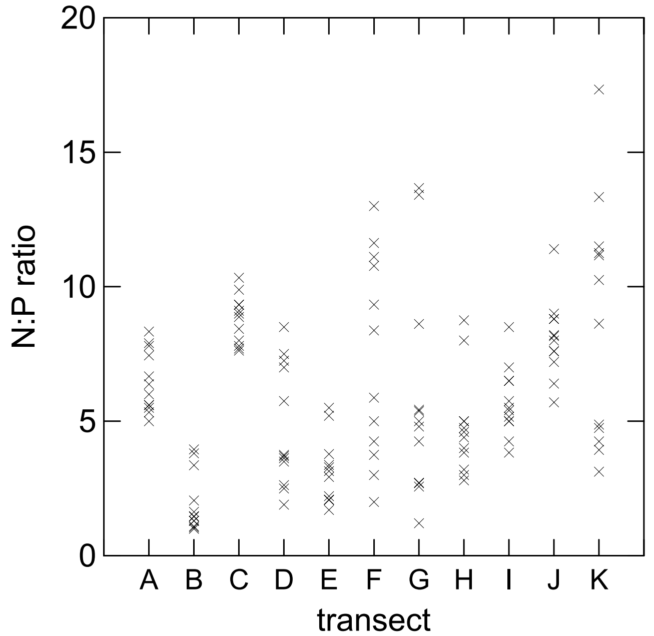

Figure 3.10 N:P ratio in the water from all sites on each transect

4 Discussion

4.1 Hydrodynamics

The hydrodynamic characteristics of the 200 km of coastal water between Lake Ellesmere/Te Waihora and the Waitaki River mouth are not known in detail. However, there is information on the hydrodynamic driving forces along this coastline. These forces are the wave climate, tidal currents and the Southland Current.

The wave climate along this coastline is likely to be similar to that at the wave buoy moored some 17 km east of Steep Head, Banks Peninsula, in approximately 76 m of water. That is, the frequencies of wave heights and wave directions at the buoy give an indication of conditions along this coastline. For example over 2004 the following wave conditions occurred at the buoy (Walsh, 2005):

- the significant wave height H_{m0} ranged between 0.80 m and 6.84 m with the mean significant wave height being 2.19 m.
- wave heights of less than 1.5 m occurred 22 % of the time.
- approximately 79% of the high energy waves (i.e. waves with heights of 4.0 m and above) originated from between 180º and 225º (south to south west).
- 55% of the waves originated from approximately south-south-east through to south west (160º to 225º).

Tidal currents are an important driving force in the hydrodynamics of the South Island east coast inshore water (Reynolds-Fleming and Fleming, 2005). Heath (1985) reported that the water travels south to north along this coast on a rising tide resulting in a residual tidal current to the north. The Southland Current is the other major hydrodynamic driving force along this coastline (Heath, 1985). This current persistently flows through Foveaux Strait and northwards along the east coast shelf break towards Banks Peninsula (Heath 1985; Chiswell, 1996).

Thus in the nearshore zone, net water movement in calm weather is north-east, parallel to the coast as a result of tides, the north-eastern flowing

Southland Current and swell. The gales and storms that occur in this region are mainly from the south, and add to the extent and rate of the prevailing north-east water flow.

Specific information on the hydrodynamic regime along this coastline has been obtained at two sites north of Timaru, these being at:

- Seaforth (~ 5 km north of Timaru) in the vicinity of the Timaru District Council wastewater discharge (CH2M Beca Ltd, 2002).
- Clandeboye (~ 25 km north of Timaru) in the vicinity of the proposed Fonterra wastewater outfall (Barter, 2003).

At Seaforth, sampling was undertaken over February - March 1999. The currents recorded in this area over this period were light and variable most of the time. The median recorded current velocity was 7 cm/sec and the highest recorded velocity was 50 cm/sec. In 7m of water seaward of the outfall the strongest currents were alongshore and to the north and largely independent of wind direction. Onshore and offshore currents were also recorded at times. With slight current speeds from variable directions it was found that there was radial dispersal of dye from the outfall with distinct dye dispersal plumes parallel to shore to the north or to the south with north-flowing or south-flowing (associated with persistent winds from the north) currents.

At Clandeboye, sampling was undertaken over January – March 2003. The currents recorded in this area over this period were generally light. The median recorded surface current velocity was just under 9 cm/sec and velocities exceeding 30 cm/sec occurred around 3 % of the time. The tidally reversing current was predominantly alongshore (northeast-southwest) with a stronger southerly component in the surface water and a weaker and more variable offshore (easterly) component in the bottom waters. There were notable occasions when the currents maintained a consistent southerly direction for several days at a time. This southerly flow was generally associated with strong summer NE winds along the coast, but local meteorological data did not support this, indicating that the southerly flow was broad scale and the influential winds were further north.

4.2 Influence of the three large rivers on coastal water quality

4.2.1 Waitaki River

The salinity and Si data indicate that the Waitaki River has a major effect on the coastal water quality along transects K and J (7.6 km and 25.1 km respectively north of the river mouth). At all sites along transects J and K the salinity was considerably lower (24.3 – 28.3) than that at any of the sites along the other transects (32.4 – 33.8). The salinity along transect J was significantly higher than that along transect K. That is, this river influences the coastal water quality to more than 25 km alongshore and 500 m offshore of the river mouth with the water becoming more saline with increasing distance away from the river. At 7.6 km north of the Waitaki River the salinity increased with increasing distance from shore, i.e. with increasing distance from shore there was an increase in the mixing of the fresh water with sea water. This was not the case 25 km north of the river mouth where the water 20 and 50 m from shore was more saline than at 100 and 500 m from the shore.

The concentrations of total nitrogen and the phosphorus-based compounds within the Waitaki River water are generally lower than those in the water of the other rivers discharging into the sea along this 200 km of coastline (Appendix I). The nitrogen and phosphorus poor water of the Waitaki River likely accounts for the generally lower TN, DRP and TP concentrations at the sites along transects J and K than along all the transects north of Timaru. There are no data on NNN concentrations in the Waitaki River, but nitrate concentrations (NO_3) in the river suggest that NNN concentrations in this river are relatively low (Appendix I). Therefore, there is no obvious explanation for NNN concentrations along transects J and K being higher than those along transects H and I (south of Timaru) at all distances from shore (Figure 3.4).

Along both transects J and K there were no significant differences in NH3N, NNN, TN and TP concentration from shore. This reinforces the salinity data that clearly shows that the influence of the Waitaki River extends at least 500 m seaward on both transects. The DRP concentrations were not significantly different with distance from shore along transect J but along transect K the concentrations at 500 m from the shore were significantly higher than those at 20 and 50 m from shore and those at 100 m were significantly higher than those at 50 m from the shore. These differences in DRP concentration with distance from shore are similar to those for salinity, which suggests a greater mixing of the fresh water with the sea water at 100 and 500 m than at 20 and 50 m from the shore along transect K.

On the days prior to and on the day of sampling the daily mean flows of 208.5 – 314.6 cumecs (Appendix III), were 51 – 77 % of the daily mean flow of 408.1 cumecs (Appendix I). That is, it is more than likely that the along-the-shore influence, of the Waitaki River water on coastal water quality, would usually be further than was found in this study i.e. to at least 25.1 km north of the river mouth, with the extent of the influence being further still when the river is in flood. The highest recorded flow for the Waitaki River at SH1 in the last 17 years was 2900 cumecs (NIWA data).

4.2.2 Rakaia River

The mean daily mean flow in the Rakaia River is 221 cumecs. On the days prior to and on the day of sampling the daily mean flows were 217 – 268.5 cumecs (Appendix III). The median nutrient concentrations in the river water are low when compared to other rivers along this 200 km of coastline, but higher concentrations do occur at times (Appendix I).

The closest transects to the Rakaia River were A and B. Transect A was approximately 8 km north and transect B was 7 km south of the river mouth. The salinity and Si concentrations along these transects, show no apparent influence of Rakaia River water on sea water quality along these transects. At the time of sampling it seems that the water flowing from the Rakaia River did not have an over-riding influence on coastal water quality 7-8 km from the river mouth, rather the fresh water discharged mixed with the sea water and contributed to the general state of the coastal water quality.

4.2.3 Rangitata River

The mean daily mean flow in the Rangitata River is 100 cumecs. On the days prior to and on the day of sampling the daily mean flows were 117.6 – 163.4 cumecs (Appendix III). The median concentrations of NNN and TN in the river water are high, when compared to the Waitaki and Rakaia rivers, with even higher concentrations occurring at times (Appendix I). The median concentrations of DRP are comparable to those in the Rakaia River but higher than those in the Waitaki River while the median concentrations of TP are comparable to those in the Waitaki River but higher than those in the Rakaia River.

The closest transects to the Rangitata River were E and F. Transect E was approximately 7.5 km north and transect F was 9 km south of the Rangitata River mouth. These transects were also influenced by other rivers with transect E approximately 6.5 km south of the Hinds River and transect F approximately 1.5 km north of the Orari River. In addition transect E was along a stretch of coastline where there are a number of constructed stock water races and drains. The salinity along these transects was lower and the Si concentrations were higher than that on some of the other transects. In addition there were significant differences in salinity and Si concentrations with distance from shore along one or both of these transects. Along transect F the salinity was higher at 100 and 500 m than at 20 m from shore and the Si concentrations were higher at 20 and 50 m than at 100 and/or 500 m from shore. Along transect E Si concentrations were significantly higher at 50 and 100 m that at 20 m from shore. These results are suggestive of the influence of fresh water on the water quality closer to than further from shore along transect F and at 50-100 m from shore (at least) along transect E. Given the other fresh water inputs (Hinds River, Orari River, stock water races and drains) it is not possible to attribute these effects to just the water from the Rangitata River. Rather than the Rangitata River water having an over-riding influence on coastal water quality 7-9 km from the river mouth it is likely that the river water was mixed with the sea water and the fresh water from the other sources and contributed to the general state of the coastal water quality along this part of the coastline.

4.3 Influence of the outfalls

At the time of sampling wastewater was being discharged into the sea from the Timaru District Council wastewater outfall and from the PPCS Pareora freezing works (Figure 1.3). On 18 November the plumes of both discharges were observed to be flowing south (Figure 1.4). The waste plume from the PPCS Pareora freezing works, which discharges waste into the sea at about the low water mark, extended a considerable distance along the shore and no more than 100 - 150 m off shore. The waste plume from the Timaru District Council wastewater outfall, which discharges wastewater at 300 – 400 m from shore, extended some distance along the shore spreading out with increasing distance from the discharge point. That is, the inshore edge of the plume got closer to shore (50 – 100 m from the shore) and the offshore edge of the plume got further offshore (Figure 1.4). These observations were made as the tide was ebbing and there was a light north-east wind.

Transect G was approximately 1.1 km north of the Timaru District Council outfall (Figure 3.1). At the 20 m site of transect G:

- the NH_3N concentration was significantly higher than at 20 m from shore on seven of the other transects.
- the DRP and TP concentrations were significantly higher than those at 20 m from shore on all of the other transects.
- the Fe concentration was higher than at 20 m from shore on all of the other transects except transect A.

At the 50 m site of transect G the DRP and TP concentrations were significantly higher than those at 50 m from shore on nine and eight of the other transects respectively. And, at the 100 m site of transect G the TP concentration was significantly higher than at 100 from shore on all of the other transects. In addition, there was a large variability in NH_3N and TN concentrations between samples at the 50 m site and a large variability in NH_3N concentrations between samples at the 100 m site. The larger variability in NH_3N and TN concentrations at these sites than at any other sites along other transects, is suggestive of 'patches' of water enriched with NH_3N and TN.

The effluent dispersion rate reported for the Timaru District Council discharge at Seaforth has been reported as 40 m/hour (CH2M Beca Ltd, 2002). This extrapolates to 27.5 hours to travel 1.1 km. Thus the significantly higher concentrations and high variability in the concentrations of some of the nutrients at transect G sites could well result from wastewater discharged 1 – 1.5 days prior to sampling. As noted above, at the time of sampling the wastewater plume was flowing south. This north to south flow could be tidally induced as the tide was ebbing at the time of sampling. Given that in the nearshore zone the net water movement is north-east and parallel to the coast (as a result of tides, the north-eastern flowing Southland current and swell), it is likely that even though the plume was observed to be flowing south, the elevated nutrient concentrations and NH_3N and TN rich patches of water at sites along transect G originated from the outfall. At 1.1 km away from the outfall the impact of the discharge on nutrient concentrations was larger closer to (20, 50, 100 m) than further (500 m) from the shore.

Transect H was approximately 2.4 km north and transect I approximately 10.5 km south of the PPCS Pareora freezing works outfall. At the 20 m site of transect H the between sample variability in NH_3N concentrations was larger than that between samples at this distance from shore on any of the other transects. At the 100 m site of transect H the between sample variability in NH_3N concentrations was larger than that between samples at this distance from shore on all other transects except transect G and the between sample variability in TN concentrations was larger than that between samples at this distance from shore on all other transects. The large variability in NH_3N and TN concentrations 2.4 km north of the PPCS outfall could result from 'patches' of freezing works wastewater.

4.4 Along-the-shore

4.4.1 Salinity and Si concentrations

The salinity and Si data from transects C and D indicate freshwater influences out to 500 m from shore. Transect C was located 9 km north of Wakanui Creek, 14.5 km north of the Ashburton River, 22 km south of the Rakaia River and in the vicinity of stock water races and drains. Transect D was located 4 km south of the Ashburton River, approximately 10 km north of the Hinds River and in the vicinity of stock water races and drains. There are no data on the water flows in the Hinds River while the mean daily flows in the Ashburton River prior to and on the day of sampling were 11.5 to 14.5 cumecs. When compared to the flows from the Waitaki, Rakaia and Rangitata rivers the flows from the Ashburton River are small. Hence, based on the extent of the influence of the larger rivers on salinity and Si concentrations in coastal water it would seem unlikely that the Asburton River would have a large influence on salinity and Si concentrations along transect C. It is possible that that the freshwater from the Ashburton River affected the water quality along transect D. The most likely source of the freshwater influences along transect C appears to be the numerous stock water races and drains in the vicinity. The source of the freshwater influences on transect D could be the Ashburton and Hinds rivers in combination with the stock water races and drains.

4.4.2 Nitrogen-based determinands

At each distance from shore there were significant differences in NNN and TN concentrations between sites on different transects. For NNN, the concentrations were generally higher at all distances from shore on transects A, B and C than on the other transects. In addition, the variability in NNN concentrations at 50 m and 100 m on transect F, 500 m on transect B and 500 m on transect K was greater (variability at these sites ranged from 0.022 - 0.043 mg/L) than that at all other sites where the variability in concentrations was typically <0.01 mg/L. For TN, the concentrations were generally higher at 20 and 50 m from shore on transects A - G than on transects H - K. In addition, the variability in TN concentrations at 20 m on transects G and I, at 50 m on transects F and G and at 100 m on transects E and H was greater (variability at these sites ranged from 0.07 - 0.12 mg/L) than that at all other sites where the variability in concentrations was typically $\leq$ 0.05 mg/L. The larger variability in TN and NNN concentrations at some sites is:

- suggestive of pockets of NNN and TN enriched water.
- an indication of the incomplete mixing of coastal water.
- an indication of nutrient inputs affecting coastal water quality.

4.4.3 Phosphorus-based determinands

At each distance from shore there were significant differences in DRP and TP concentrations between sites on different transects. For DRP, the concentrations were generally higher at 20, 50 and 100 m from shore on transects A – G than on transects H to K. For TP the concentrations were generally higher at all distances from shore along transects A – G than along transects H to K. A possible reason for this is that the phosphorus loads in the rivers discharging into the sea south of Timaru are generally lower than those in the rivers discharging into the sea north of Timaru. The variability in DRP concentrations at 20 on transect A and 100 m on transects D, E, F and K was greater (variability at these sites ranged from 0.003 - 0.004 mg/L) than that at all other sites where the variability in concentrations was typically $\leq$ 0.002 mg/L. In addition the variability in TP concentrations at 20 m on transect C (variability of 0.027 mg/L) was larger than that at all other sites where the variability in concentrations was typically $\leq$ 0.014 mg/L. The larger variability in DRP and TP concentrations at some sites is:

- suggestive of pockets of DRP and TP enriched water.
- an indication of the incomplete mixing of coastal water.
- an indication of nutrient inputs affecting coastal water quality.

4.4.4 Fe concentrations

At all distances from shore the Fe concentrations were higher on transects A – G than on transects H – K. At 20 m from shore the Fe concentrations increased from south to north along the coast with the exception being the high Fe concentration on transect G. The high Fe concentration at 20 m on transect G is attributed to the discharge from the Timaru District Council wastewater discharge. This south to north trend in Fe concentrations did not occur at 50, 100 and 500 m from shore. However, the highest Fe concentrations at 50 m from the shore were on transects A and B. These results indicate that Fe inputs are at or near to shore and there were either more inputs or higher concentration inputs when going from south to north. The likely sources of the Fe are:

- river, streams, stock water races and drains
- direct sediment runoff from the land adjacent to the shore
- seabed sediment stirred up by wave action on the shore
- groundwater upwelling.

4.4.5 Chlorophyll-a concentrations

Chlorophyll-a concentration is a measure of the phytoplankton biomass in the water. Phytoplankton use DIN (NNN + NH_3N) and DRP for growth, with growth also requiring Fe. At each distance from shore there were significant differences in chlorophyll-a concentrations between sites on different transects. In particular, the concentrations on transects A – D were significantly higher than those on transects H – K. This along-the-shore pattern in chlorophyll-a concentrations does not mirror that of Fe concentrations. However, the Fe concentrations on transects A – D likely contribute to, or result from, the higher chlorophyll-a concentrations along these four transects. The lower chlorophyll-a concentrations on transects H – K than on transects A - D could also be a reflection of the influence of Waitaki River water on phytoplankton growth. No phytoplankton species analyses were undertaken in this study. It could well be that given the large influence of the Waitaki River on the salinity and nutrient concentrations of the nearshore coastal water, the phytoplankton species composition in the zone of influence of this river is different to that in the northern part of the study.

4.4.6 Other considerations

The DRP, TP and chlorophyll-a concentrations were significantly lower at the sites south of Timaru than at sites north of Timaru. The lower concentrations at southern sites could reflect the influence of the Waitaki River in combination with the small phosphorus-based nutrient loads from the rivers and creeks along this coastline. The possibility that the temporal difference in sampling i.e. over two days could account for this difference was also considered. This has been discounted on the grounds that the nutrient concentrations along transect G north of Timaru, sampled on the same day as transects H, I, J, and K south of Timaru, are generally comparable to those along transects A – F sampled the day before.

It is possible that the geography of this coastline influences the northward flow of near-shore water. South of Timaru the coastline has a north-south orientation, the 5km of coastline in the vicinity of Timaru has a north-west orientation and north of Timaru the coastline is orientated north-east (Figure 2.1). If the water from south of Timaru flows north without following the coastline it would not have a direct influence on near-shore water quality north of Timaru but could influence the water quality some 5½ - 6 km from the shore. Support for this idea comes from the comparison of nutrient concentrations at the starboard buoy (22 samples) some 500 m offshore of the mole of Timaru Harbour (Environment Canterbury data, reported in Bolton-Ritchie, 2006) with the nutrient concentrations 500 m from shore at sites south (4 transects, 12 samples) of and north of Timaru (7 transects, 21 samples). The NH3N, DRP and TP concentrations at the starboard buoy were significantly higher (Kruskal-Wallis ANOVA) than those south of Timaru but there was no significant difference between concentrations at the starboard buoy and those north of Timaru.

4.5 With distance from the shore

There were significant differences in NNN, TN, DRP, TP, salinity, Si and chlorophyll-a concentrations with distance from shore along three or more of the transects. In general, these differences with distance from shore consisted of higher concentrations at 20 m than at some or all of the sites further from shore. For NNN, TN, DRP and TP this indicates land-derived nutrient input to the near-shore water. The potential nutrient sources for each transect where this pattern occurred are:

- Transect A (TN and TP) - Youngs Creek, Coopers Lagoon, land run-off.
- Transect B (NNN and TP) - stockwater races and drains, land run-off.
- Transect C (NNN) - stockwater races and drains, land run-off.
- Transect D (NNN, TN, TP, Si) - freshwater source/s in particular stockwater races and drains.
- Transect E (TP) - stockwater races and drains, land run-off.
- Transect F (NNN, TN, Si) - freshwater source/s including seepage from coastal lagoons, land runoff and stockwater races and drains.
- Transect G (NNN, TN, DRP, TP, Si) - freshwater source/s including stockwater races and drains, land runoff and possibly the Timaru District Council wastewater outfall.
- Transect H (NNN and TP) - creek flow and land runoff.
- Transect I (NNN, DRP and TP) - seepage from coastal lagoon, creek flow and land runoff.

Along transects A, B, E, F, H and K there were also significant differences in the concentration of one or more determinands between sites but these differences were not a decrease in concentrations with increasing distance from shore. Along transects K and F the salinity and concentration of one or more of the other determinands were significantly higher at 100 and 500 m than at sites closer to shore. This reflects the increase in the mixing of the fresh water (transect K - from the Waitaki River, transect F - from seepage from coastal lagoons, land runoff and stockwater races and drains) with sea water with distance from shore. Along transects A, B, E and H there was no obvious pattern in the significant differences in the concentration of one or more determinands with distance from shore. The differences with distance from shore along these transects are suggestive of patches of enriched water. The significant difference in Si concentration between transect E sites indicates a freshwater source for localised areas of enrichment. The significant difference in TN concentration between transect H sites is suggestive of patchy TN enriched water with the TN source possibly being the PPCS wastewater discharge.

4.6 Is there cause for concern?

The input of nutrients to the sea via rivers, streams, creeks, stockwater races and drains and general land runoff is resulting in detectable effects on neashore coastal sea water. High nutrient concentrations can result in:

- eutrophication.
- algae blooms.
- altered plankton communities.
- increased nutrients in the waters reaching Banks Peninsula.
- altered biological communities.
- physical and physiological effects in marine species.

There are no data on any of these parameters for this coastline. Given that this is a high-energy coastline eutrophication and its' effects are highly unlikely. However, the other potential effects cannot be discounted especially if over time there is an increase in the mass loads of nutrients entering the nearshore coastal water. This increase is likely as a result of continuing land use changes, increased irrigation and an additional wastewater discharge (from the Clandeboye milk processing plant). The results from this study indicate that any effect is more likely to occur close to than further from shore, in the vicinity of specific nutrient sources and generally along the more northern part of the coast. This suggests an ongoing need to monitor the near-shore water quality between Lake Ellesmere/Te Waihora and the Waitaki River mouth. The water samples collected should be analysed for the determinands measured in this study and plankton (phytoplankton and zooplankton) community structure.

Concentrations of DIN (NNN + NH_3N), TN, DRP, TP and chlorophyll-a were compared to ANZECC (2000) trigger values for 'slightly disturbed marine water'. When concentrations are below the trigger values the risk of adverse biological effects is low while at concentrations above the trigger value there is the potential for adverse biological effects (ANZECC, 2000). It is important to note that to date marine guideline values have not been developed for New Zealand, therefore the guidelines recommend the comparison of New Zealand values to those for south-east Australia. As a consequence the trigger 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 NNN, NH_3N and DRP concentrations at 20 m from shore were 0.032, 0.015 and 0.006 mg/L respectively, at 500 m from shore they were 0.012, 0.012 and 0.008 mg/L respectively, while the ANZECC (2000) trigger values for marine waters for south-east Australia are 0.005, 0.015 and 0.01 mg/L respectively.

At 20, 50, 100 and 500 m from shore the ANZECC (2000) trigger values for DIN, TN, DRP, and TP were exceeded in some or all of the samples. However, with increasing distance from shore there was a decrease in the percentage of samples exceeding trigger values. For TN there was no change in the percentage of samples exceeding the trigger value with distance from shore. These results support the finding of generally higher nutrient concentrations closer to than further from the shore. Along-the- shore there were differences, between transects, in the percentage of samples exceeding the trigger values for DIN, DRP and TP, but no differences between transects with respect to TN. The most obvious difference between transects was for DRP with 75% of the samples on transect G exceeding the trigger value. The trigger value for DRP was not exceeded on seven transects and on the other three transects the trigger value was exceeded in 17 % or less of the samples. This result is suggestive of DRP input to coastal water from the Timaru District Council wastewater discharge. For TP there was an obvious geographical difference, with trigger values exceeded in 25% or less of samples from south of Timaru and 83 –100% of samples from north of Timaru. For DIN, 100 % of the samples along the northern-most and southern-most transects, i.e. A, B, C, J and K, exceeded the DIN trigger values while on transects D, E, F, G, H and I the trigger values were exceeded in 50-92% of samples. The DIN trigger value exceedences on transects A, B, C, J and K are attributed to the coastal water loading of NNN.

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. 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 concentration 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 highest recorded DIN concentration was 0.161 at 50 m on transect G with concentrations greater than in 0.07 mg/L in one or more of the samples at sites A50, A100, B20, B50, B100, C20, C50, C100, C500, F20, F50, G20 and G50. Chlorophyll-a concentrations in excess of 0.002 mg/L were recorded at sites A20, A50, A100, B20, C20 and D20. The highest recorded chlorophyll-a concentration of 0.004 mg/L is below the concentration found to cause physical discolouration of surface sea water. However, higher chlorophyll-a concentrations could occur along this coastline because the optimal water temperature, light and sea conditions required for phytoplankton growth are less likely to occur in mid-November (when the sites were sampled) than in summer and early autumn. Hence, the need to sample the near-shore water between Lake Ellesmere/Te Waihora and the Waitaki River mouth at different times of the year to determine if this is the case. The chlorophyll-a, Fe, DRP and DIN concentrations indicate that phytoplankton blooms along this coastline are most likely to occur north of the Ashburton River and in the vicinity of the Timaru District Council wastewater discharge.

5 Conclusions

A one-off sampling programme, aimed at giving a 'snapshot' of the water quality along the 200 km of coastline between Lake Ellesmere/Te Waihora and the Waitaki River mouth was undertaken on 18 and 19 November, 2004. Sampling sites were located at 20, 50, 100 and 200 m from the shore along each of 11 transects; the transects were 13-19 km apart. Three replicate water samples were collected from each site and each then analysed for nitrogen- and phosphorus-based determinand concentrations and Si, Fe and chlorophyll-a concentrations.

The Waitaki River had a significant effect on coastal water quality to at least 500 m from shore and 25 km away from the river mouth. It was not possible to quantify the effects of the Rakaia River, Rangitata River and the smaller volume rivers on coastal water quality. However, their nutrient and freshwater inputs contribute to the general state of the coastal water quality. The data suggest that the freshwater discharged from the constructed stockwater races and drains affects nutrient concentrations and possibly salinity and Si concentrations close to the shore. The wastewater discharged from the Timaru District Council outfall was found to impact the NH_3N, TN, DRP, TP and Fe concentrations some 1.1 km away from the discharge point, while the 'patches' of NH_3N and TN-enriched water 2.4 km north of the PPCS freezing works discharge point could have originated from the discharged wastewater.

Nutrient, salinity, Si, Fe and chlorophyll-a concentrations were significantly different both along-the-shore, i.e. between transects, and with distance from shore. The along-the shore-differences are attributed to the influence of rivers, wastewater discharges, stockwater races and drains, direct sediment runoff from the land adjacent to the shore and possibly groundwater upwelling in the coastal zone. With nutrient concentration influences at each of these sites being localised, i.e. from proximate sources of nutrients from one or more of the above-listed influences. The difference in concentrations with distance from shore generally consisted of higher concentrations at 20 m than at some or all of the sites further from shore. This indicates land-derived nutrient inputs to the near-shore water, these nutrients become diluted with increasing distance from shore. At 500 m from shore there were still significant differences in nutrient concentrations between transects. That is, the rivers, discharges and other land-derived nutrient inputs impact coastal water quality to distances greater than 500 m from shore. If this was not the case then the nutrient, salinity and Si concentrations at the 500 m sites should have been very similar to each other as the water would only be oceanic in origin.

Along this high-energy coastline there is little potential for eutrophication, however there is the potential for algae blooms, altered plankton communities and nutrient-enriched water flowing towards Banks Peninsula. The data indicate that algal blooms and altered plankton communities are more likely to occur closer to than further from the shore, in the vicinity of specific nutrient sources and generally along the more northern part of the coast.

6 Recommendations

This study is the first step to a better understanding of the nutrient status of the coastal water in this area. It provides data against which future data can be compared. With the postulated increase in the mass loads of nutrients entering the nearshore coastal water over time between Lake Ellesmere/Te Waihora and the Waitaki River mouth, there is a need for future monitoring of the waters of this coastline. This monitoring should include both coastal water quality and plankton (phytoplankton and zooplankton) community monitoring with sampling being undertaken at a number of sites and over time.

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Appendix I Nutrient concentrations and mass loads from rivers, creeks, water races, constructed drains and wastewater discharges

A. Nutrient concentrations (mg/L) in various rivers and creeks.

All data except the Waitaki River data was collected by Environment Canterbury
Waitaki Data collected by NIWA
n = number of samples

	NH_3N	NNN	TN	DRP	TP
Taumutu Creek (at Gullivers Road)					
Minimum	0.005	1.5	1.5	0	<0.008
Mean	0.026	2.960	3.060	0.006	0.055
Median	0.015	3.15	3.4	0.006	0.018
Maximum	0.095	3.7	3.8	0.02	0.76
n	22	10	10	22	22
Youngs Creek End of McEvedys Rd					
Minimum	<0.005	1.2	1.2	0.005	<0.008
Mean	0.01155	1.41	1.44	0.0058	0.0072
Median	0.009	1.4	1.4	0.0055	0.006
Maximum	0.028	1.6	1.8	0.007	0.014
n	10	10	10	10	10
Rakaia River at SH1					
Minimum	<0.005	0.006	0.04	<0.001	0.004
Mean	0.02	0.059	0.108	0.0038	0.04
Median	0.009	0.047	0.04	0.003	0.006
Maximum	0.082	0.29	0.67	0.01	0.76
n	24	24	24	24	24
Wakanui Creek at Corbetts Road					
Minimum	<0.005	6.4	6.6	0.001	0.004
Mean	0.0136	7	7.4	0.003	0.008
Median	0.009	6.8	7.2	0.002	0.004
Maximum	0.028	7.5	8	0.008	0.016
n	5	5	5	5	5
Ashburton River at mouth					
Minimum	0.003	0.1	0.04	0.002	0.004
Mean	0.014	0.779	0.835		
Median	0.013	0.62	0.23	0.011	0.021
Maximum	0.073	2.6	2.9	0.077	0.27
n	62	68	58	68	58
Rangitata River at mouth					
Minimum	<0.005	0.089	0.12	<0.001	<0.008
Mean	0.2	0.243	0.396	0.004	0.079
Median	0.011	0.19	0.32	0.003	0.012
Maximum	0.16	0.98	1.134	0.028	1
n	39	39	39	39	39
Ohapi Creek Above Orari Confluence					
Minimum	0.006	0.21	0.4	0.005	0.016
Mean	0.031	0.865	1.142	0.029	0.058
Median	0.021	0.67	0.83	0.018	0.041
Maximum	0.2	5	7.7	0.33	0.62
n	43	43	43	43	43
Orari River Parke Rd					
Minimum	< 0.005	0.013	< 0.08	0.001	< 0.008
Mean	0.032	1.114	1.230	0.065	0.083
Median	0.01	1.45	1.45	0.0045	0.0065
Maximum	0.15	1.9	2.5	0.37	0.46
n	6	6	6	6	6

A. continued

	NH_3N	NNN	TN	DRP	TP
Opihi River Orakipaoa, Waipopo huts					
Minimum	<0.005	0.13	0.24	<0.003	<0.008
Mean	0.019	0.553	0.666	0.016	0.023
Median	0.014	0.515	0.65	0.01	0.015
Maximum	0.067	1.4	1.4	0.148	0.23
n	46	46	39	55	38
Opihi River Opihi mouth/Milford Lagoon					
Minimum	0.005	0.038	0.32	<0.001	<0.008
Mean	0.034	0.527	0.781	0.010	0.030
Median	0.026	0.54	0.76	0.0075	0.019
Maximum	0.12	1.4	1.5	0.063	0.14
n	35	35	28	44	27
Pareora River at SH1					
Minimum	<0.005	<0.01	<0.08	<0.003	<0.008
Mean	0.027	0.23	0.44	0.008	0.014
Median	0.018	0.18	0.3	0.006	0.001
Maximum	0.094	0.96	1.8	0.027	0.034
n	20	20	20	20	20
Otaio River, 50 m downstream of SH1 bridge					
Minimum	<0.005	0.064	0.14	0.004	<0.008
Mean	0.019	0.628	0.883	0.008	0.012
Median	0.018	0.42	0.66	0.007	0.01
Maximum	0.045	1.9	2.5	0.02	0.031
n	11	11	11	11	11
Waihao River, Poingdestres Rd.					
Minimum	0.011	0.005	0.27	<0.003	<0.008
Mean	0.065	0.502	0.832	0.021	0.051
Median	0.042	0.51	0.77	0.012	0.038
Maximum	0.26	1.6	2.2	0.16	0.26
n	33	33	23	33	33
Waitaki @ SH1 Bridge					
Minimum	0		0.045	0	0.001
Mean	0.006		0.151	0.004	0.021
Median	0.005		0.12	0.001	0.015
Maximum	0.016		1.3	0.06	0.531
n	182		178	194	190

* NO_3 only, not NNN

B. Details on water flows (cumecs) in the creeks and rivers discharging into the sea in the study area

data from either the ECan website or provided by ECan staff (unless otherwise indicated)

River/Creek	Site	Mean Flow
Taumutu Creek	Beach Road	0.2
Youngs Creek	McEvedys Road	0.384
Rakaia River	Fighting Hill	221
Ashburton River	SH1	18.3
Rangitata River	Klondyke	100
Orari River #	Upstream of Ohapi confluence	1.41
Ohape Creek #	Browns Road	1.72
Opihi River	Rockwood	5.5
Pareora River	Huts	3.7
Otaio River	Gorge	0.7
Waihao River	McCullochs	3.7
Waitaki River *	SH1	408.1

Calculated from data in Scarf, 2003

* Calculated from data provided by NIWA

C. Estimated mass loads (tonnes/year) of nutrients from various creeks, rivers and drainage zones

	NH_3N	NNN	TN	DRP	TP
Taumutu Creek	0.09	19	21	0.04	0.11
Youngs Creek	0.11	17	17	0.07	0.07
Rakaia River	63	328	279	21	42
Rakaia to Ashburton *	0.28	3	6	0.09	0.57
Ashburton River	8	358	133	6	12
Ashburton to Hinds **	3	422	464	1	
Hinds to Rangitata **	11	969	1077	4	6
Rangitata River	35	599	1009	9	38
Orari River #	1	109	116	1	2
Opihi River	5	94	132	1	3
Pareora River	2	21	35	0.7	0.12
Waihao River	5	60	90	1	4
Otaio River	0.4	9	15	0.15	0.22
Whitneys Creek	0.1	2	4	0.46	0.59
Waitaki River	64		1540	14	135

* From Meredith and Smith, 2004

** From Meredith *et al.,* 2005

\# calculated by adding the concentrations and flows of:
Ohapi Creek above Orari confluence and of Orari River at Parke Rd
It does not include the nutrients from the drain that discharges near the river mouth

D. Estimated mass loads (tonnes/year) of nutrients from two wastewater discharges

	NH_3N	NNN	TKN	DRP	TP
PPCS Pareora	38		196		28
Timaru District Council outfall		307		61	

Calculations
PPCS
based on a discharge volume of 2,000,000 m^3 per year (Prattle Delamore Partners Ltd., 2005)
based on daily loadings of wastewater (Prattle Delamore Partners Ltd., 2005) and operating for 304 days/year
Timaru District Outfall
based on a daily average discharge volume of 16,000 m^3 per day (Beca, 2002).
based on concentrations (g/m^3) of the nutrients (Beca, 2002)

Appendix II Description and details of each sampling site

Site description	Grid Ref.	Site No.
Transect A		
Ocean - South of Coopers Lagoon, offshore from McEvedys Rd, 20 m from shore	M37:5372-0378	CRC304719
Ocean - South of Coopers Lagoon, offshore from McEvedys Rd, 50 m from shore	M37:5373-0375	CRC304720
Ocean - South of Coopers Lagoon, offshore from McEvedys Rd, 100 m from shore	M37:5374-0370	CRC304721
Ocean - South of Coopers Lagoon, offshore from McEvedys Rd, 500 m from shore	M37:5386-0332	CRC304722
Transect B		
Ocean - 7km south of Rakaia River Mouth, north of Mainwarings Rd, 20 m from shore	L37:3980-9773	CRC304723
Ocean - 7km south of Rakaia River Mouth, north of Mainwarings Rd, 50 m from shore	L37:3981-9770	CRC304724
Ocean - 7km south of Rakaia River Mouth, north of Mainwarings Rd, 100 m from shore	L37:3984-9766	CRC304725
Ocean - 7km south of Rakaia River Mouth, north of Mainwarings Rd, 500 m from shore	L37:3998-9729	CRC304726
Transect C		
Ocean - 1km south of Seafield Rd, 20 m from shore	L37:2689-9079	CRC304727
Ocean - 1km south of Seafield Rd, 50 m from shore	L37:2691-9077	CRC304728
Ocean - 1km south of Seafield Rd, 100 m from shore	L37:2694-9072	CRC304729
Ocean - 1km south of Seafield Rd, 500 m from shore	L37:2711-9037	CRC304730
Transect D		
Ocean - South of Ashburton River Mouth, just north of Williams Rd, 20 m from shore	L37:1091-8108	CRC304731
Ocean - South of Ashburton River Mouth, just north of Williams Rd, 50 m from shore	L37:1093-8106	CRC304732
Ocean - South of Ashburton River Mouth, just north of Williams Rd, 100 m from shore	L37:1096-8102	CRC304733
Ocean - South of Ashburton River Mouth, just north of Williams Rd, 500 m from shore	L37:1115-8067	CRC304734
Transect E		
Ocean - 6.5 km south of the Hinds River, between Crows & Brogdens Rd, 20 m from shore	K38:9717-7264	CRC304735
Ocean - 6.5 km south of the Hinds River, between Crows & Brogdens Rd, 50 m from shore	K38:9719-7262	CRC304736
Ocean - 6.5 km south of the Hinds River, between Crows & Brogdens Rd, 100 m from shore	K38:9722-7258	CRC304737
Ocean - 6.5 km south of the Hinds River, between Crows & Brogdens Rd, 500 m from shore	K38:9745-7226	CRC304738
Transect F		
Ocean - 9 km south of the Rangitata River, 1-1.5 km north of the Orari River, 20 m from shore	K38:8409-6267	CRC304759
Ocean - 9 km south of the Rangitata River, 1-1.5 km north of the Orari River, 50 m from shore	K38:8411-6264	CRC304760
Ocean - 9 km south of the Rangitata River, 1-1.5 km north of the Orari River, 100 m from shore	K38:8415-6261	CRC304761
Ocean - 9 km south of the Rangitata River, 1-1.5 km north of the Orari River, 500 m from shore	K38:8443-6232	CRC304762
Transect G		
Ocean - 7 km south of the Opihi River Mouth, just south of Kereta Rd, 20 m from shore	K38:7374-5167	CRC304739
Ocean - 7 km south of the Opihi River Mouth, just south of Kereta Rd, 50 m from shore	K38:7377-5166	CRC304740
Ocean - 7 km south of the Opihi River Mouth, just south of Kereta Rd, 100 m from shore	K38:7381-5163	CRC304741
Ocean - 7 km south of the Opihi River Mouth, just south of Kereta Rd, 500 m from shore	K38:7412-5137	CRC304742
Transect H		
Ocean - 4 km north of the Paraeora River Mouth, off Trig 1.2 km south of Craiges Rd, 20 m from shore	J39:6965-3568	CRC304743
Ocean - 4 km north of the Paraeora River Mouth, off Trig 1.2 km south of Craiges Rd, 50 m from shore	J39:6968-3566	CRC304744
Ocean - 4 km north of the Paraeora River Mouth, off Trig 1.2 km south of Craiges Rd, 100 m from shore	J39:6972-3564	CRC304745
Ocean - 4 km north of the Paraeora River Mouth, off Trig 1.2 km south of Craiges Rd, 500 m from shore	J39:7006-3543	CRC304746
Transect I		
Ocean - 3 km south of Otaio River Mouth, south of Springbank Rd, 20 m from shore	J39:6468-2395	CRC304747
Ocean - 3 km south of Otaio River Mouth, south of Springbank Rd, 50 m from shore	J39:6471-2394	CRC304748
Ocean - 3 km south of Otaio River Mouth, south of Springbank Rd, 100 m from shore	J39:6476-2393	CRC304749
Ocean - 3 km south of Otaio River Mouth, south of Springbank Rd, 500 m from shore	J39:6515-2383	CRC304750
Transect J		
Ocean - Just south of Wainono Lagoon, between 2 Stopbanks, 20 m from shore	J40:6488-0880	CRC304751
Ocean - Just south of Wainono Lagoon, between 2 Stopbanks, 50 m from shore	J40:6491-0880	CRC304752
Ocean - Just south of Wainono Lagoon, between 2 Stopbanks, 100 m from shore	J40:6496-0880	CRC304753
Ocean - Just south of Wainono Lagoon, between 2 Stopbanks, 500 m from shore	J40:6536-0883	CRC304754
Transect K		
Ocean - Between McLeays & Archibald Rds, off from a 1 m Trig, 20 m from shore	J40:6539-9165	CRC304755
Ocean - Between McLeays & Archibald Rds, off from a 1 m Trig, 50 m from shore	J40:6542-9165	CRC304756
Ocean - Between McLeays & Archibald Rds, off from a 1 m Trig, 100 m from shore	J40:6547-9166	CRC304757
Ocean - Between McLeays & Archibald Rds, off from a 1 m Trig, 500 m from shore	J40:6587-9166	CRC304758

Appendix III Weather and sea state at the time of sampling and river flows prior to and on the days of sampling

Weather conditions

17th of November

10-15 knot westerly wind, clear day, some high cloud

18th of November

Light north-easterly wind, clear day, cloudy

Sea state

17th of November

The sea was calm beyond the onshore break but offshore there was a 1m SW swell.

All samples were collected between 1055 and 1330 (day light saving time).
According to the LINZ tide tables the high tide at Timaru (2.4) was at 756 (daylight saving time) and low tide (0.6) was at 1416 (daylight saving time).

Transect A B, C, D and E were sampled as the tide was ebbing while transect F was sampled at approximately low tide.

18th of November

The sea was choppy but there was no big onshore break.

All samples were collected between 840 and 1430 (daylight saving time).
According to the LINZ tide tables the high tide at Timaru (2.4) was at 858 (daylight saving time) and low tide (0.6) was at 1518 (daylight saving time).

Transects K was sampled at approximately high tide while transects G, H, I and J were sampled as the tide was ebbing.

River Flows

Table 1: Daily mean flows in cumecs

River	Site	13/11/2004	14/11/2004	15/11/2004	16/11/2004	17/11/2004	18/11/2004
Rakaia	Fighting Hill (NIWA)	217.0	241.4	268.5	263.7	240.2	198.1
Ashburton	No 1 SHB	13.3	12.7	14.1	14.5	11.5	9.1
Rangitata	Klondyke	117.6	129.5	163.4	152.3	124.7	104.9
Opihi	No 1 SHB	14.1	13.4	10.4	11.8	11.1	10.2
Pareora	Huts	2.9	2.4	3.7	6.9	3.7	2.9
Otaio	Gorge	0.34	0.32	0.37	0.78	0.44	0.40
Waihao	McCulloughs Br	1.12	1.02	1.27	4.86	3.48	2.38
Waitaki	Kurow	314.6	312.7	208.5	272.6	297.4	312.8

Appendix IV Details of the water quality analyses

Determinand	Analysis provider	Method	Detection Limit	Units
Nitrate-nitrite nitrogen (NNN)	ECan laboratory	APHA 4500 NO_3 - F (20th ED)	0.005	mg/L
Total ammonia-nitrogen (NH_3N)	ECan laboratory	APHA 4500 NH3-F (20th ED) - modified	0.005	mg/L
Total nitrogen (TN)	ECan laboratory	APHA 4500-N C (20th ED) - modified	0.08	mg/L
Dissolved reactive phosphorus (DRP)	ECan laboratory	APHA 4500-P B, F (20th ED)	0.001	mg/L
Total phosphorus (TP)	ECan laboratory	APHA 4500-P B5 (20th ED) -Autoanalyser	0.008	mg/L
Reactive Silica (Si)	ECan laboratory	APHA 4500-Si E (20th ED) - modified		mg $Si0_2$/L
Iron digested (Fe)	ECan laboratory	NI-APHA 3030 E, 3113 B (20th ED) acid digested		mg/L
Chlorophyll-a	ECan laboratory	APHA 10200 (20th ED) - Fluorimetry		µg/L
pH	ECan laboratory	APHA 4500 – H B (20th ED) - meter		
Salinity	ECan laboratory	Inhouse – from conductivity		ppt
Water temperature	Field	Thermometer		ºC

Appendix V p values (Kruskal-Wallis ANOVA) for between sites differences in determinand concentration at each distance from shore

values in black - significant difference between sites
values in blue - no significant difference between sites

	20 m	50 m	100 m	500 m
Salinity	0.0005	0.0006	0.0006	0.0005
Si	0.0005	0.0005	0.0005	0.0008
NH_3N	0.0032	0.005	0.5697	0.0661
NNN	0.0005	0.0008	0.0012	0.0011
TN	0.00018	0.0025	0.0136	0.003
DRP	0.0005	0.0005	0.0025	0.0009
TP	0.001	0.0009	0.0009	0.0015
Chlorophyll-a	0.0008	0.0007	0.0008	0.0008

Appendix VI Significant differences in determinand concentrations between sites at each distance from shore

	20 m	50 m	100 m	500 m
Salinity	A > C, D, E, F, G, J, K	A > C, D, E, F, J, K	A > C, D, E, F, J, K	A > C, D, E, J, K
	B > C, D, E, F, G, J, K	B > C, D, E, F, G, H, J, K	B > C, D, E, F, H, I, J, K	B > A, C, D, E, F, G, H, I, J, K
	C > D, J, K	C > D, J, K	C > D, J, K	C > D, J, K
	D > J, K	D > J, K	D > J, K	D > J, K
	E > D, J, K	E > D, J, K	E > D, J, K	E > J, K
	F > D, J , K	F > D, J , K	F > C, D, J , K	F > C, D, E, J , K
	G > C, D, E, J, K	G > C, D, E, F, J, K	G > C, D, E, F, J, K	G > C, D, E, F, J, K
	H > C, D, E, F, J, K	H > C, D, E, F, J, K	H > C, D, E, J, K	H > C, D, E, J, K
	I > C, D, E, F, J, K	I > C, D, E, F, J, K	I > C, D, E, J, K	I > C, D, E, F, J, K
	J > K	J > K	J > K	J > K
Si	A > I	A > H, I	A > H, I	
	B > H, I	B > H, I	B > H, I	B > I
	C > A, B, D, E, F, G, H, I	C > A, B, D, E, F, G, H, I	C > A, B, D, E, F, G, H, I	C > A, B, D, E, F, G, H, I
	D > A, B, E, F, G, H, I	D > A, B, E, F, G, H, I	D > A, B, E, F, G, H, I	D > A, B, E, F, G, H, I
	E > H, I	E > A, H, I	E > A, H, I	E > A, H, I
	F > A, H, I	F > A, B, H, I	F > H, I	
	G > A, B, E, H, I	G > A, H, I	G > H, I	
	J > A, B, C, D, E, F, G, H, I	J > A, B, C, D, E, F, G, H, I	J > A, B, C, D, E, F, G, H, I	J > A, B, C, D, E, F, G, H, I
	K > A, B, C, D, E, F, G, H, I, J	K > A, B, C, D, E, F, G, H, I, J	K > A, B, C, D, E, F, G, H, I, J	K > A, B, C, D, E, F, G, H, I, J
NH_3N	B > D, K			
	G > C, D, E, F, I, J, K			
	H > D, K			
NNN	A > D, E, H, I, J	A > D, E, G, H, I, J	A > B, D, G, H, I	A > D, F, G, H, I
	B > A, D, E, G, H, I, J, K	B > D, E, H, I		B > A, D, E, F, G, H, I, J, K
	C > A, B, D, E, G, H, I, J, K	C > D, E, G, H, I, J, K	C > A, B, D, E, F, G, H, I, J, K	C > A, D, E, F, G, H, I, J, K
	D > E			
			E > D, H, I	
	F > A, B, D, E, G, H, I, J, K	F > A, B, D, E, G, H, I, J, K	F > D, G, H, I, J	
	G > E, H, I, J			
	J > E, H, I		J > D, H, I	J > D
	K > E, H, I	K > E, H, I	K > D, H, I	K > D

	20 m	50 m	100 m	500 m
TN	A > H, I, J, K	A > H, I	A > B, D, G, H, I	A > I
	B >H , I, J, K	B >H , I, J, K		B > D, E, G, H, I, J, K
	C > H, I, J, K	C > H, I	C > A, B, D, E, F, G, H, I, J, K	C > D, E, G, H, I, J, K
	D > H			
	E > H	E > H	E > D, H, I	
	F > H, I, J, K	F > H, I, J, K	F > D, G, H, I	F > D, E, G, H, I, K
	G > H, I, J, K	G> H, I, J, K		
			J > D, H, I	
			K > D, H, I	
DRP	A > D, E, H, I, J, K	A > D, E, F, H, I, J, K	A > D, H, I, J	A > D, H, I, J
	B > C, D, E, F, H, I, J, K	B > A, C, D, E, F, H, I, J, K	B > D, H ,I, J, K	B > A, C, D, E, F, G, H, I, J, K
	C > D, E, H, I, J, K	C > D, E, F, H, I, J, K	C > H, I	C > D, H, I, J
	E > D, K	E > D, H, I, J, K	E > H, I	E > D, G, H, I, J
	F > D, E, H, I, J, K	F > D, H, I, J, K	F > H, I, J	F > D, H, I, J
	G > A, B, C, D, E, F, H, I, J, K	G > A, C, D, E, F, H, I, J, K	G > D, K, H, I, J	G > D, H, I, J
	H > K			
	I > K			
		J > K, I		
				K > D, H, I, J
TP	A > C, F, H, I, J, K	A > B, C, D, E, F, H, I, J, K	A > C, D, G, H, I, J, K	A > H, I, J, K
	B > C, F, H, I, J, K	B > H, I, J, K	B > H, I, J, K	B > I
		C > H, I, K	C > H, I, J, K	C > H, I, J, K
	D > C, H, I, J, K	D > H, I, J, K	D > H, I, J, K	D > H, I, J, K
	E > C, H, I, J, K	E > H, I, J, K	E > F, H, I, J, K	E > H, I, J, K
	F > J, K	F > H, I, K	F > H, I, J, K	F > A, B, C, D, E, G, H, I, J, K
	G > A, B, C, D, E, F, H, I, J, K	G > C, D, E, F, H, I, J, K	G > A, B, C, D, E, F, H, I, J, K	G > H, I, J, K
Chloro-a	A > E, F, G, H, I, J, K	A > B, C, D, E, F, G, H, I, J, K	A > B, C, D, E, F, G, H, I, J, K	A > E, H, I, J, K
	B > H, I, J, K	B > D, E, F, G, H, I, J, K	B > D, E, F, G, H, I, J, K	B > E, G, H, I, J, K
	C > E, F, H, I, J, K	C > F, H, I, J, K	C > D, E, F, G, H, I, J, K	C > E, H, I, J, K
	D > E, F, H, I, J, K	D > F, H, I, J, K	D > H, I, K	D > E, H, I, J, K
	E > H, K	E > H, I, K	E > H	
				F > C, D, E, G, H, I, J, K,
	G > H, I, K	G > F, H, I, J, K	G > F, H, I, J, K	

Appendix VII Graphs of determinand concentrations with distance from shore on each transect

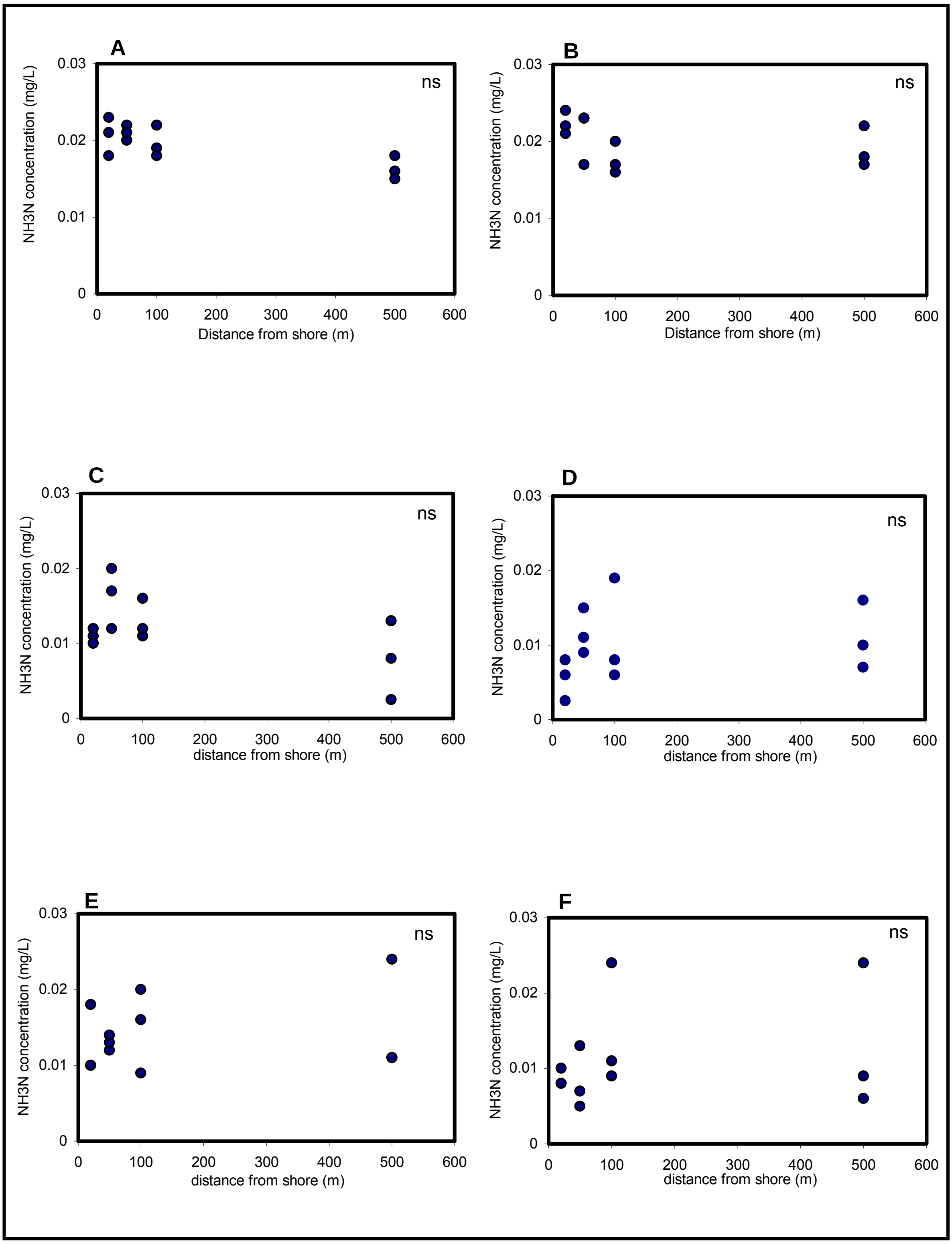

Figure 1: NH_3N concentration (mg/L) with distance from shore on each transect

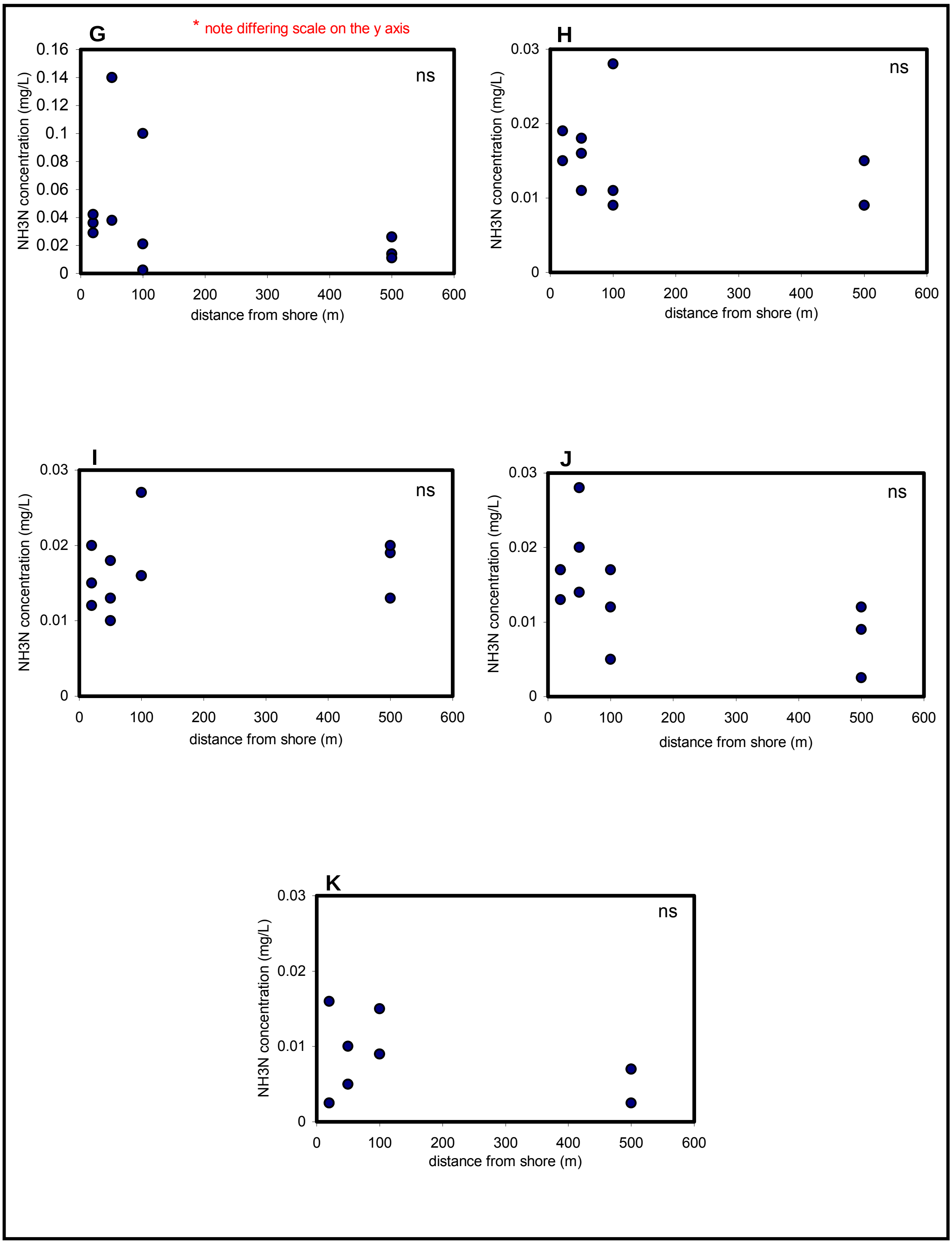

Figure 1 (continued)**: NH_3N concentration (mg/L) with distance from shore on each transect**

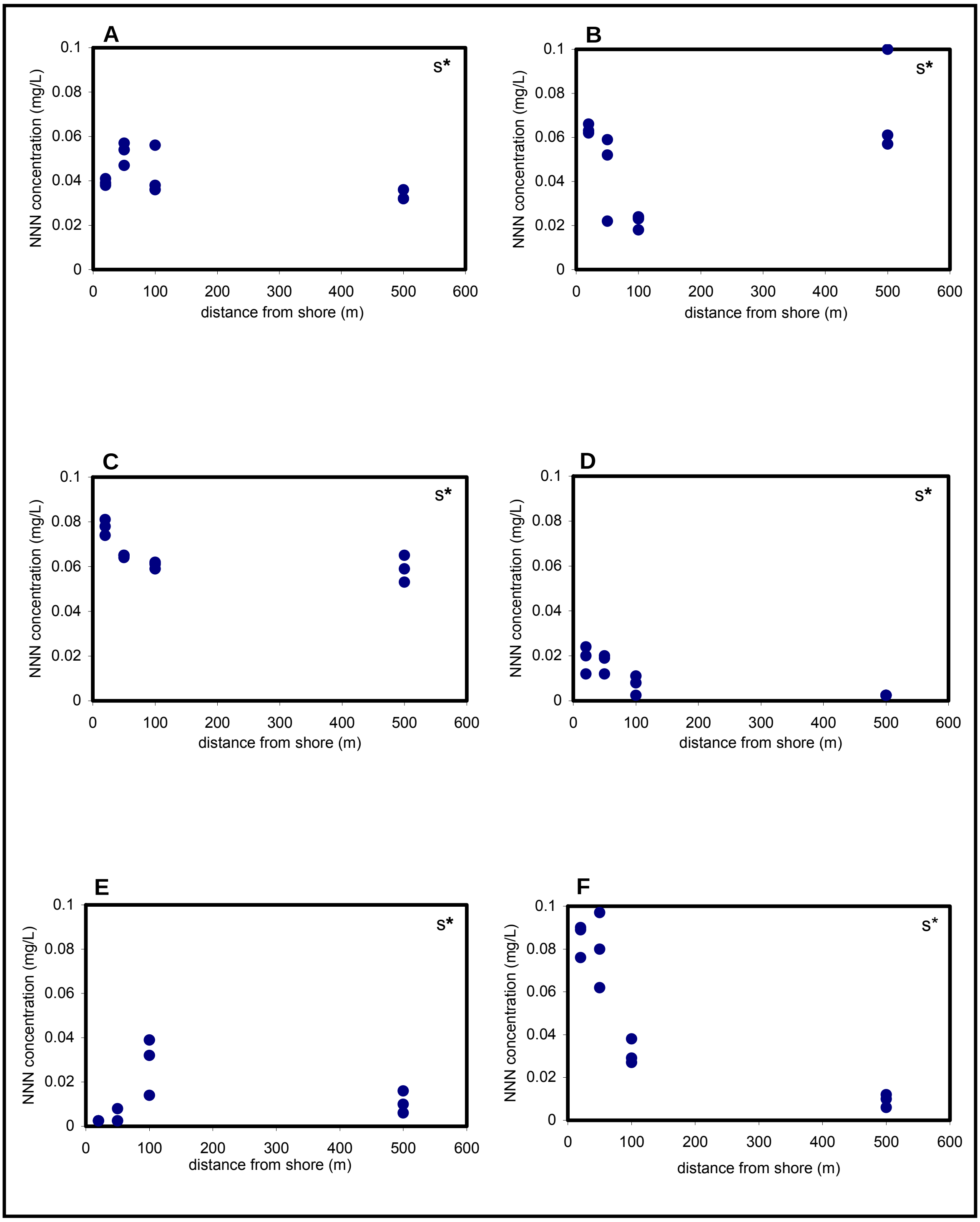

Figure 2: NNN concentration (mg/L) with distance from shore on each transect

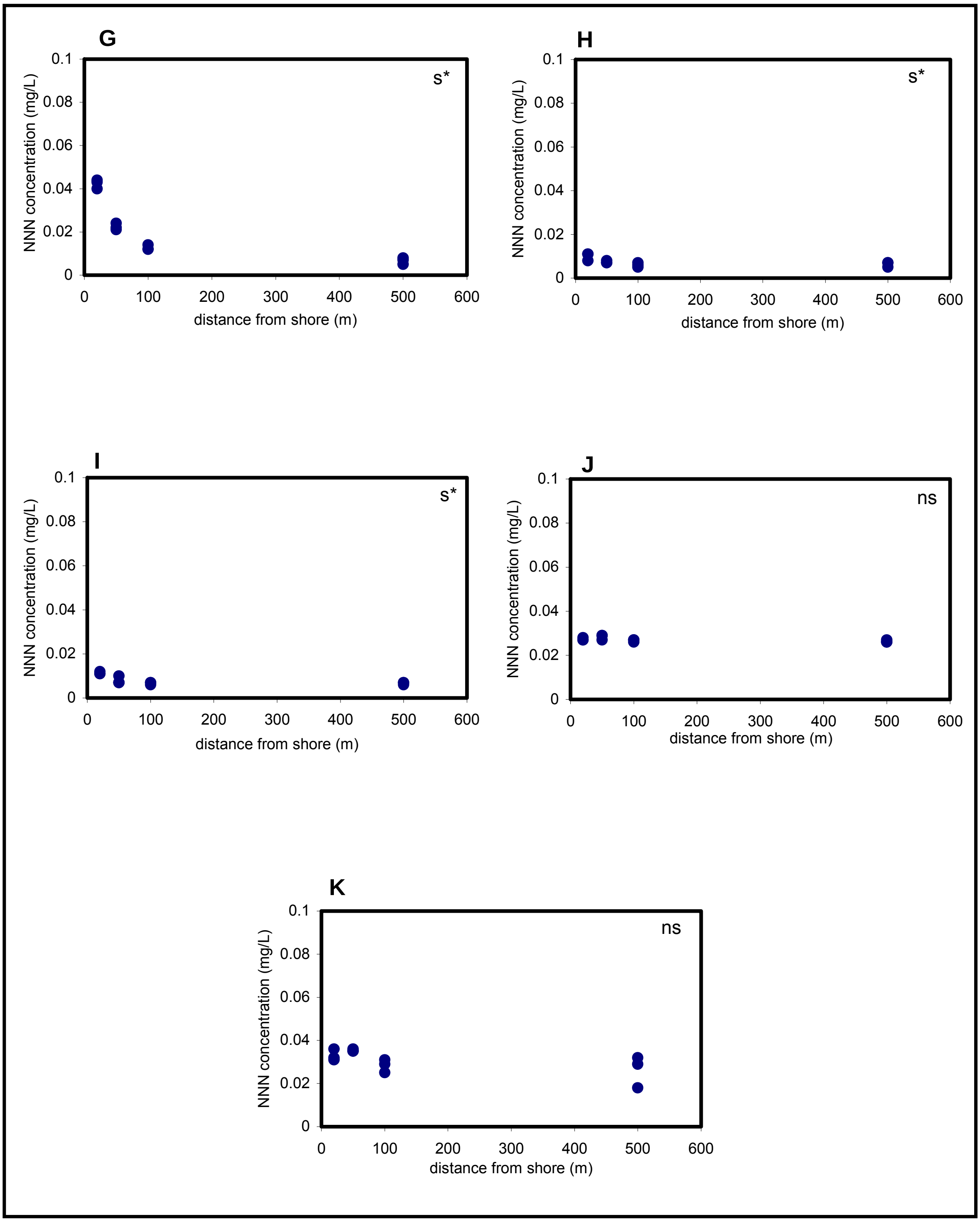

Figure 2 (continued)**: NNN concentration (mg/L) with distance from shore on each transect**

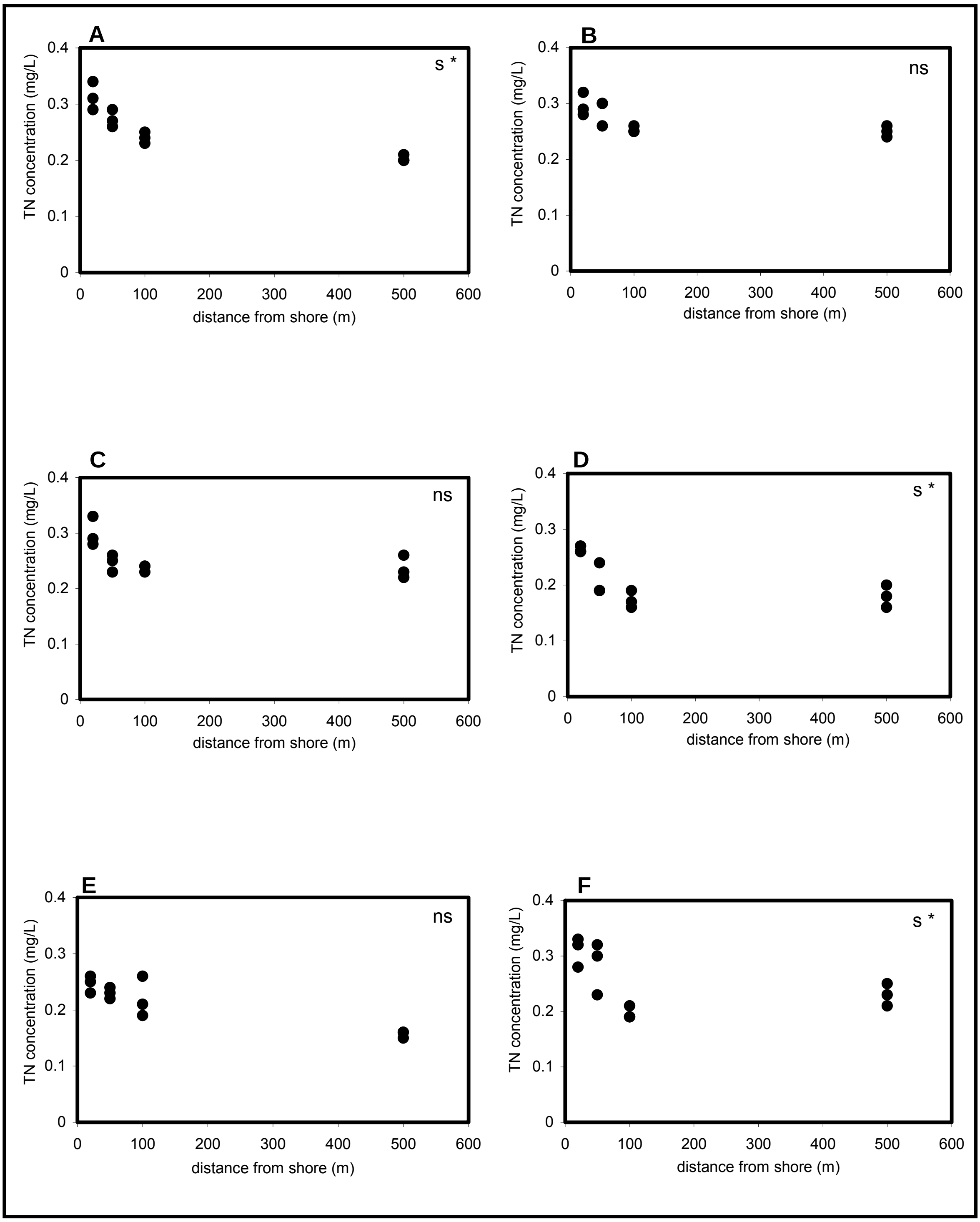

Figure 3: TN concentration (mg/L) with distance from shore on each transect

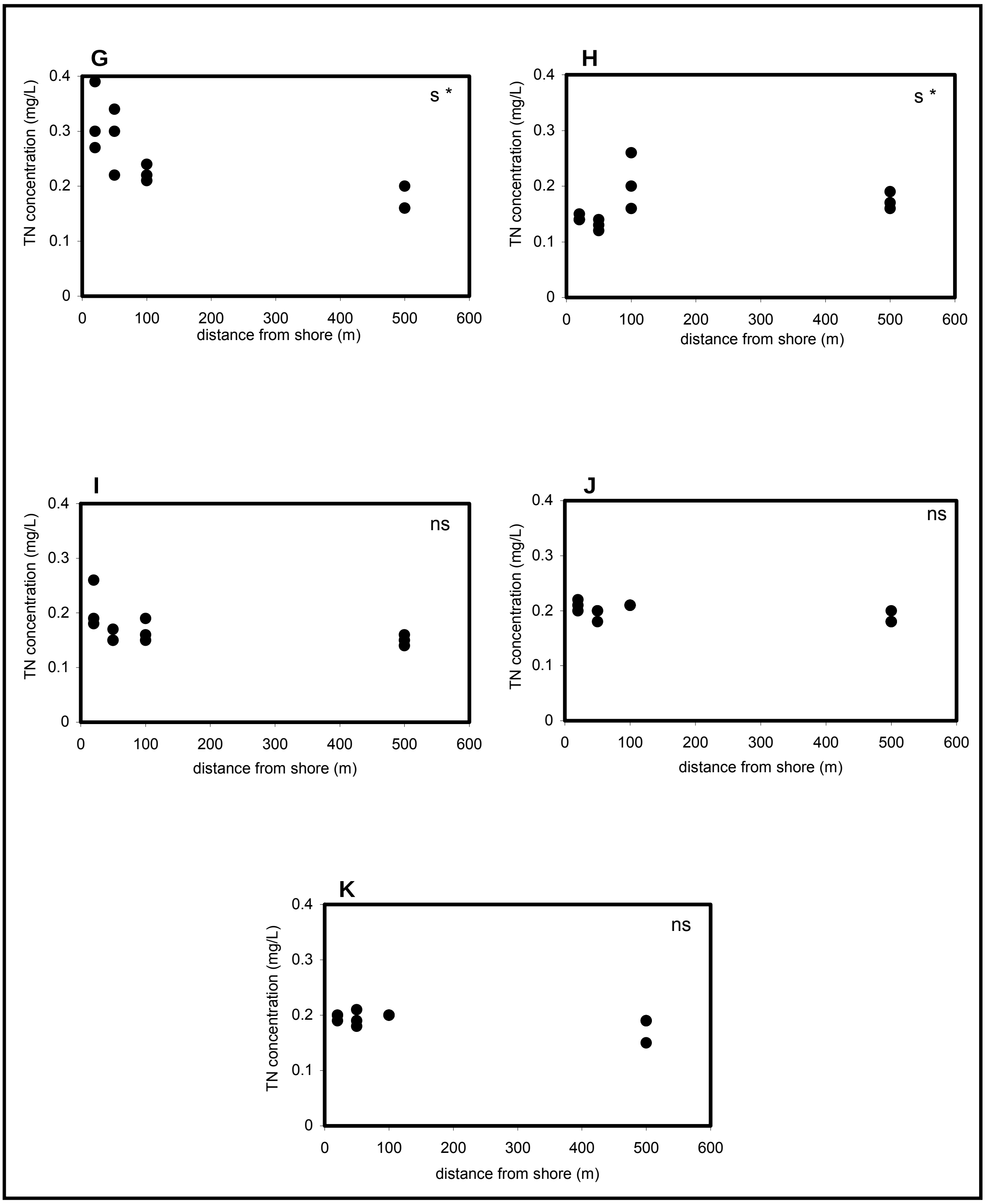

Figure 3 (continued)**: TN concentration (mg/L) with distance from shore on each transect**

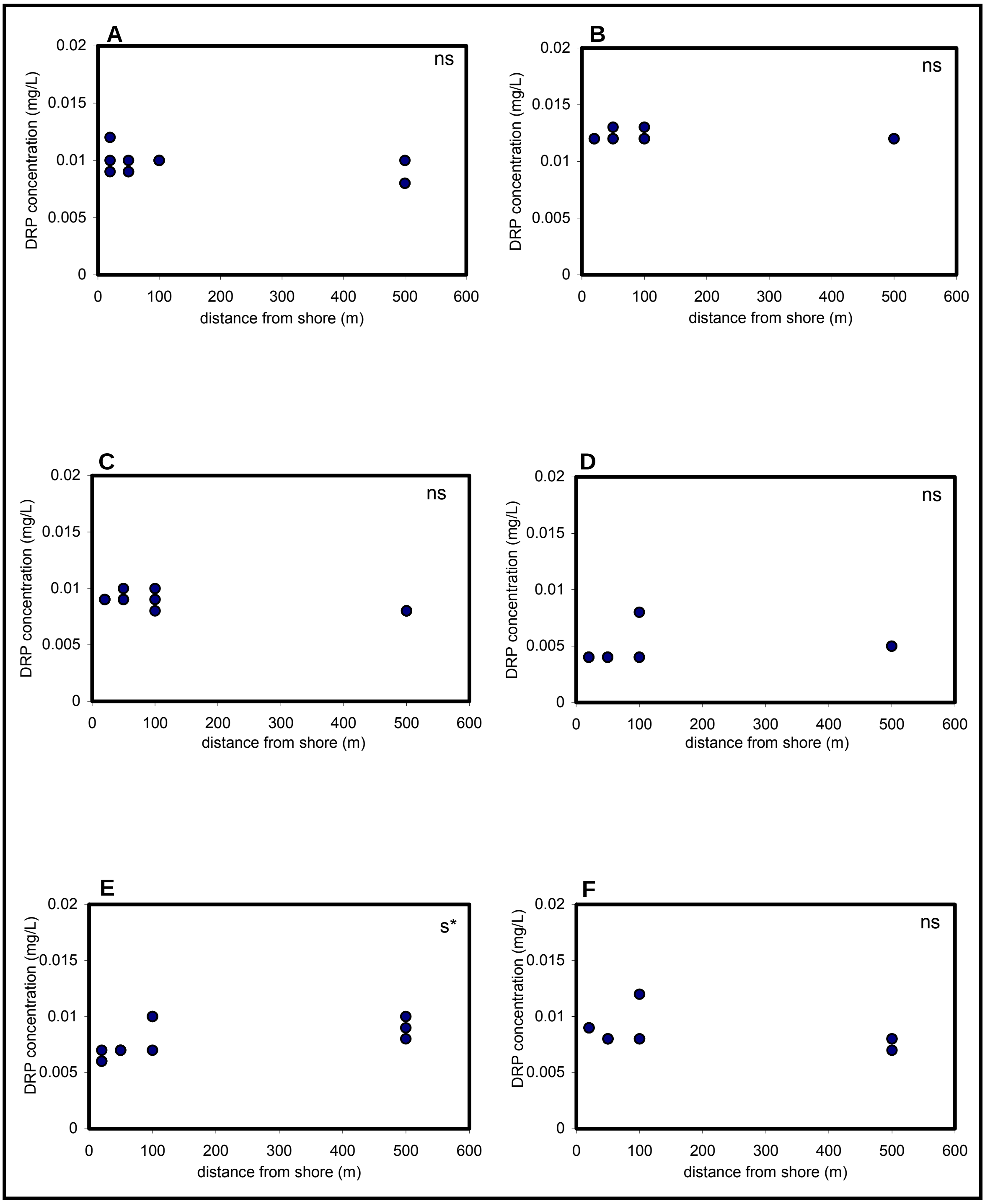

Figure 4: DRP concentration (mg/L) with distance from shore on each transect

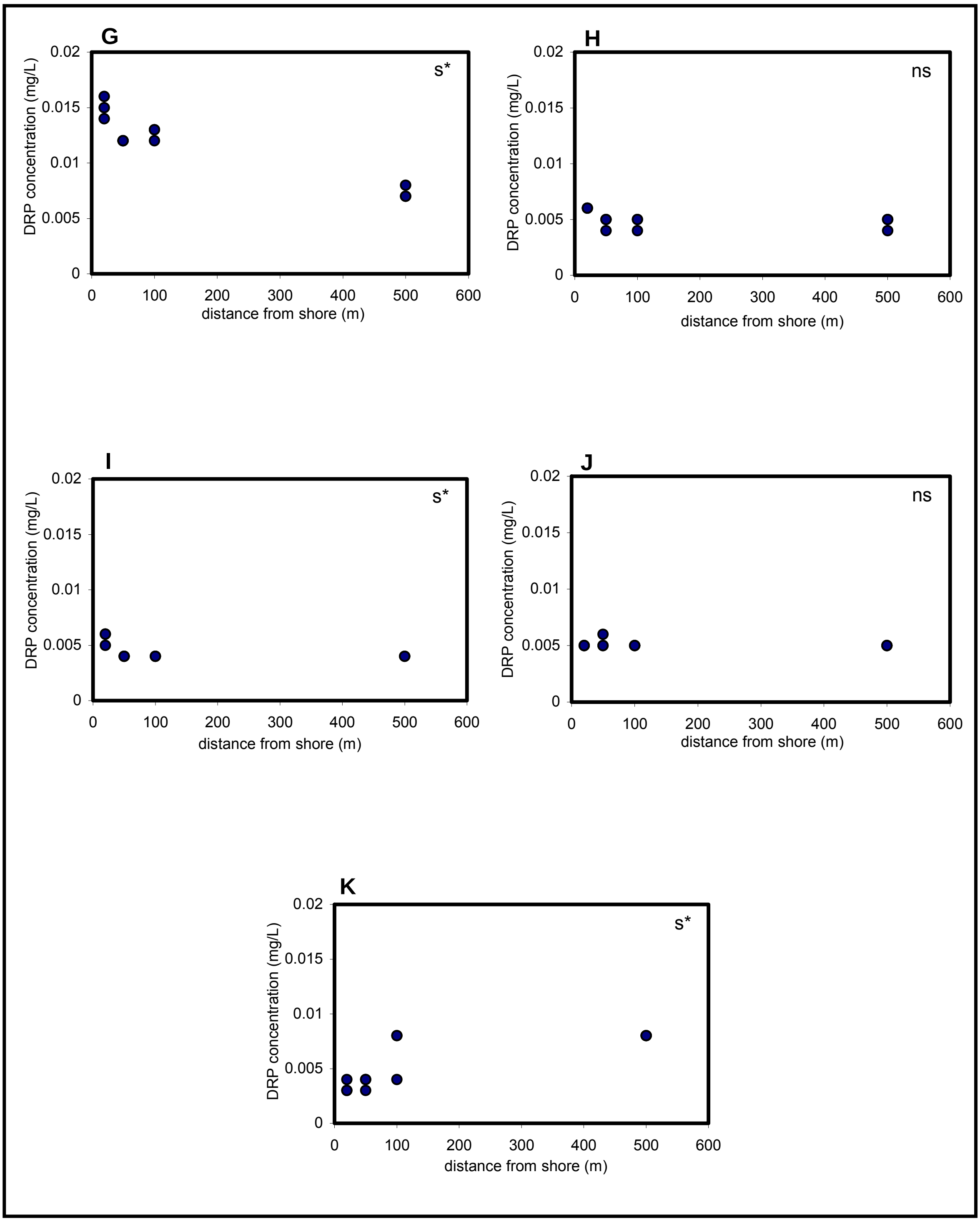

Figure 4 (continued)**: DRP concentration (mg/L) with distance from shore on each transect**

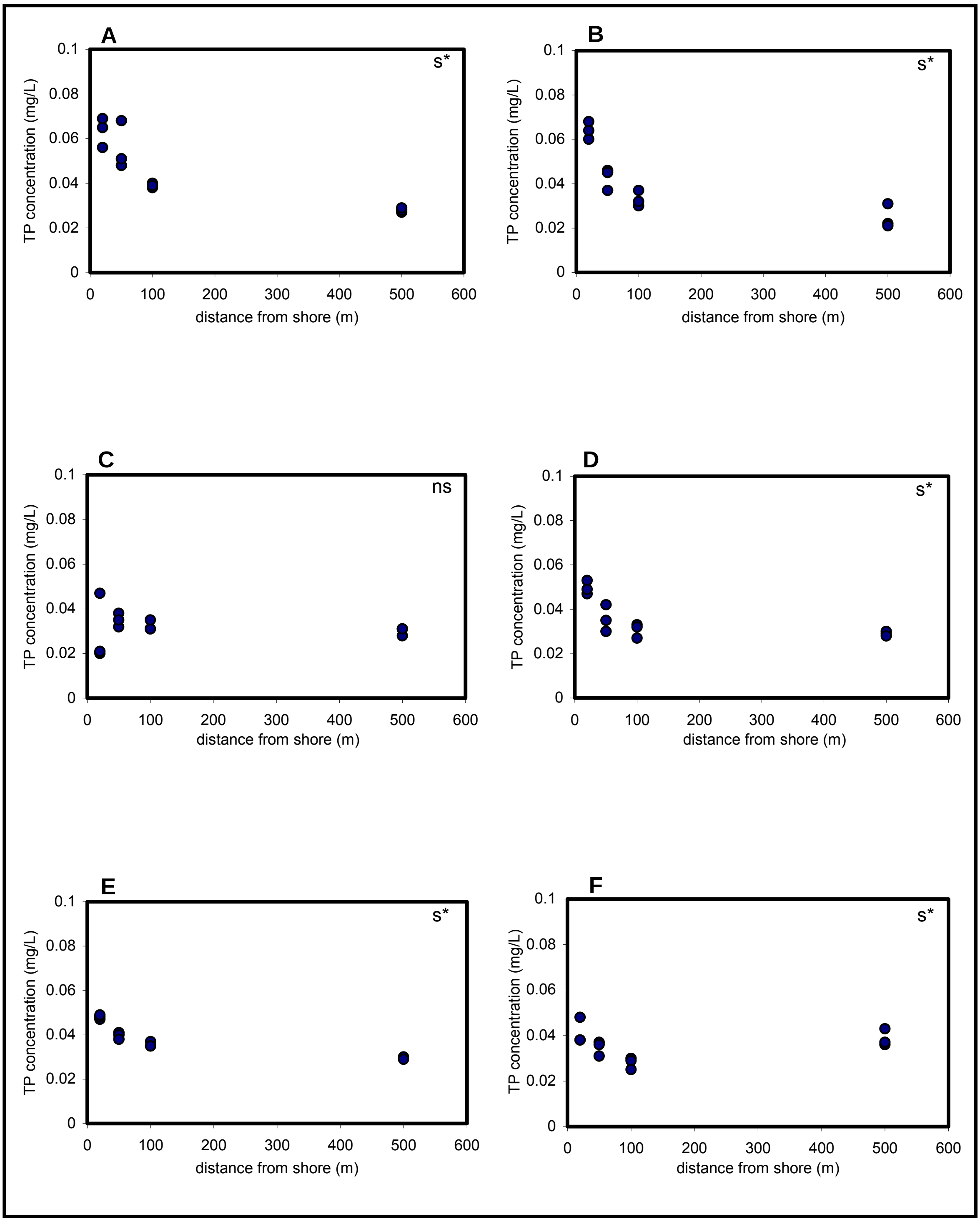

Figure 5: TP concentration (mg/L) with distance from shore on each transect

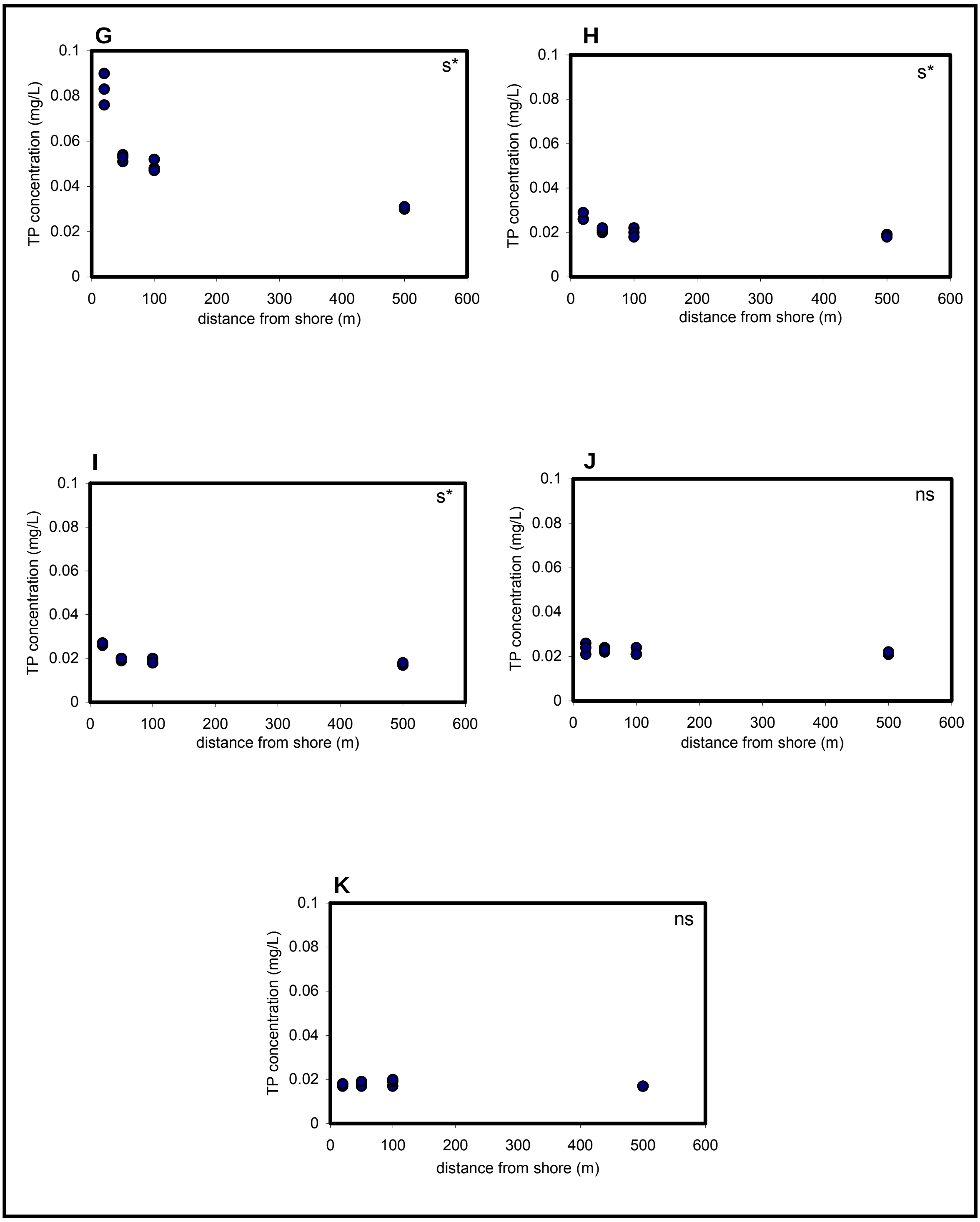

Figure 5 (continued)**: TP concentration (mg/L) with distance from shore on each transect**

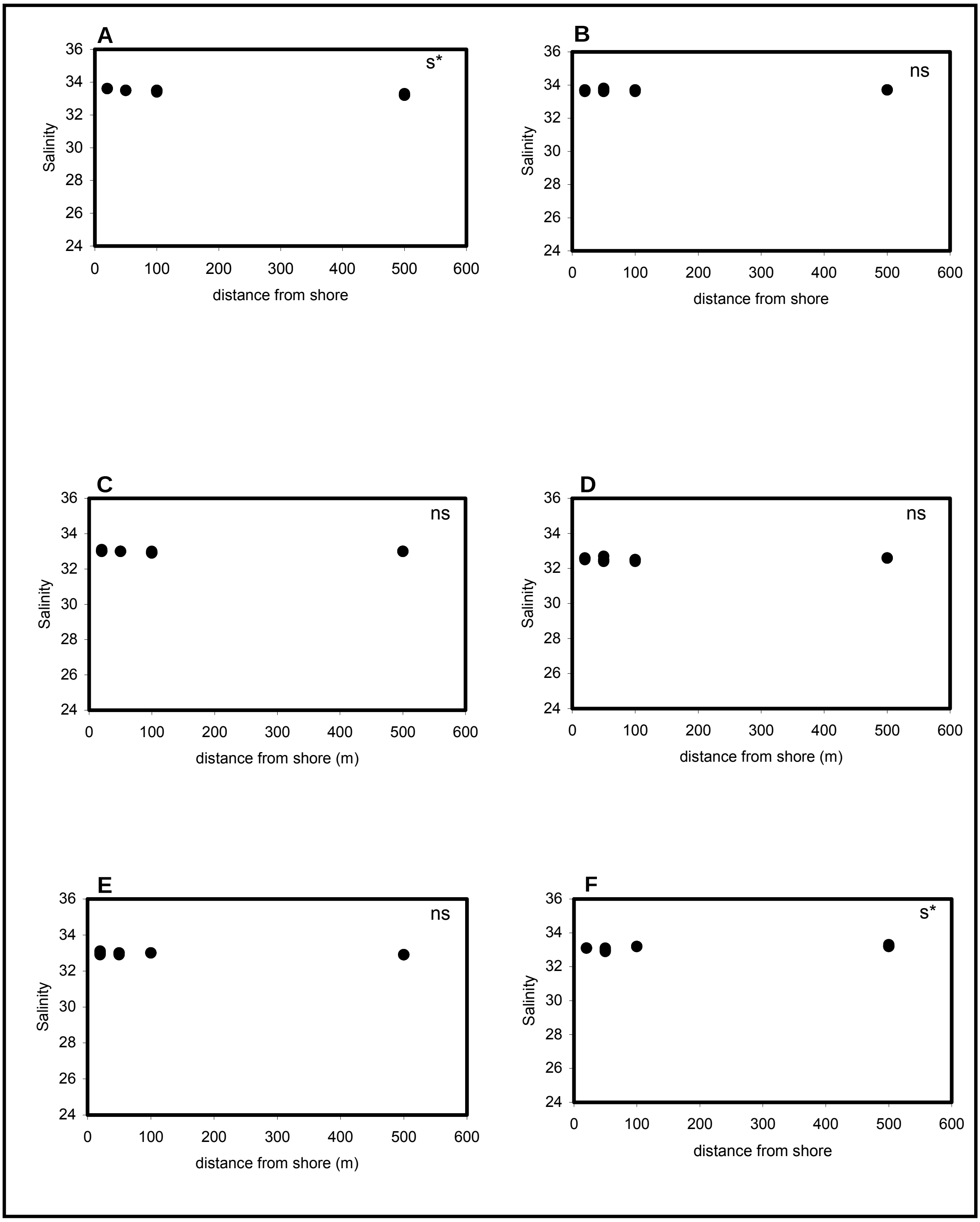

Figure 6: Salinity with distance from shore on each transect

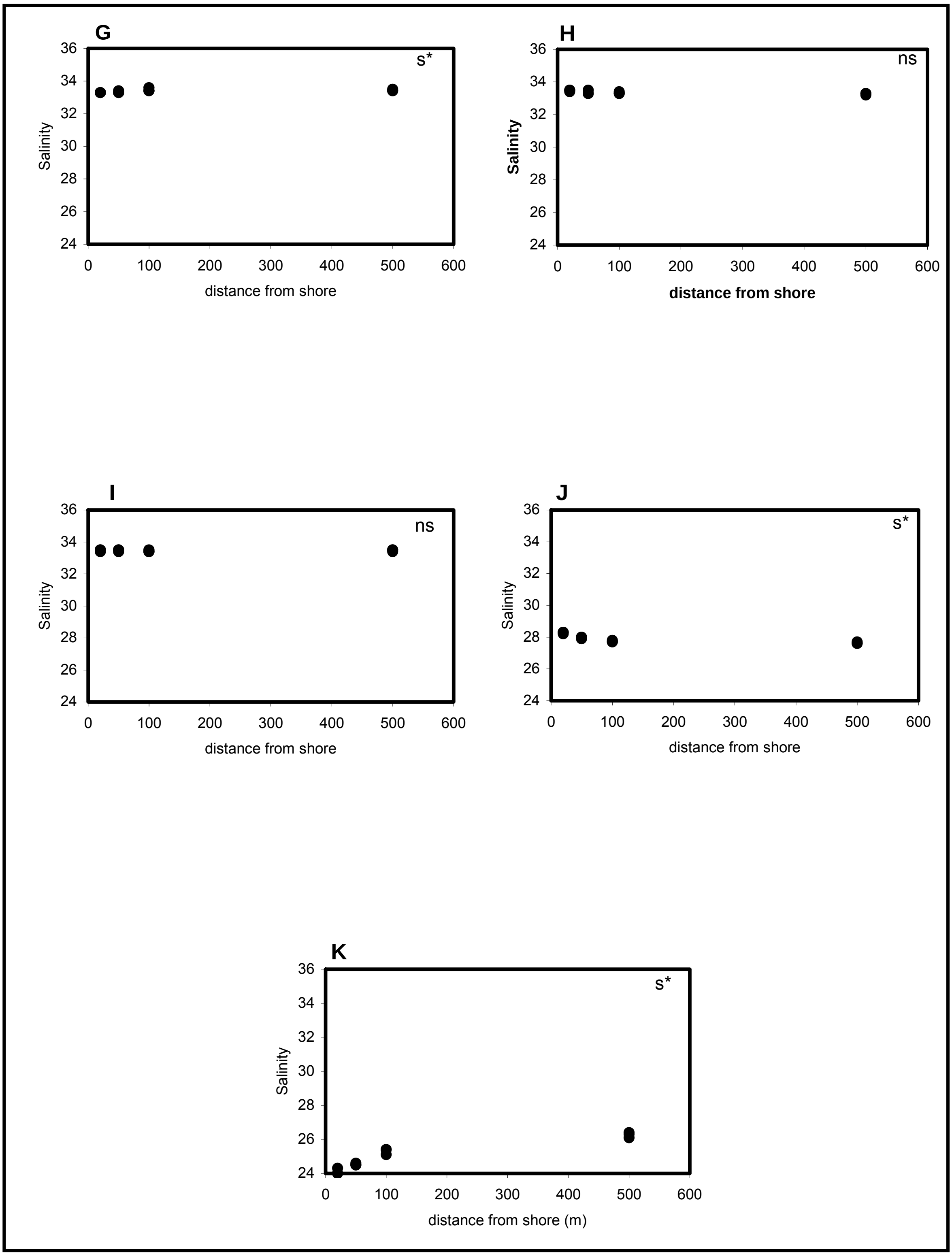

Figure 6 (continued)**: Salinity with distance from shore on each transect**

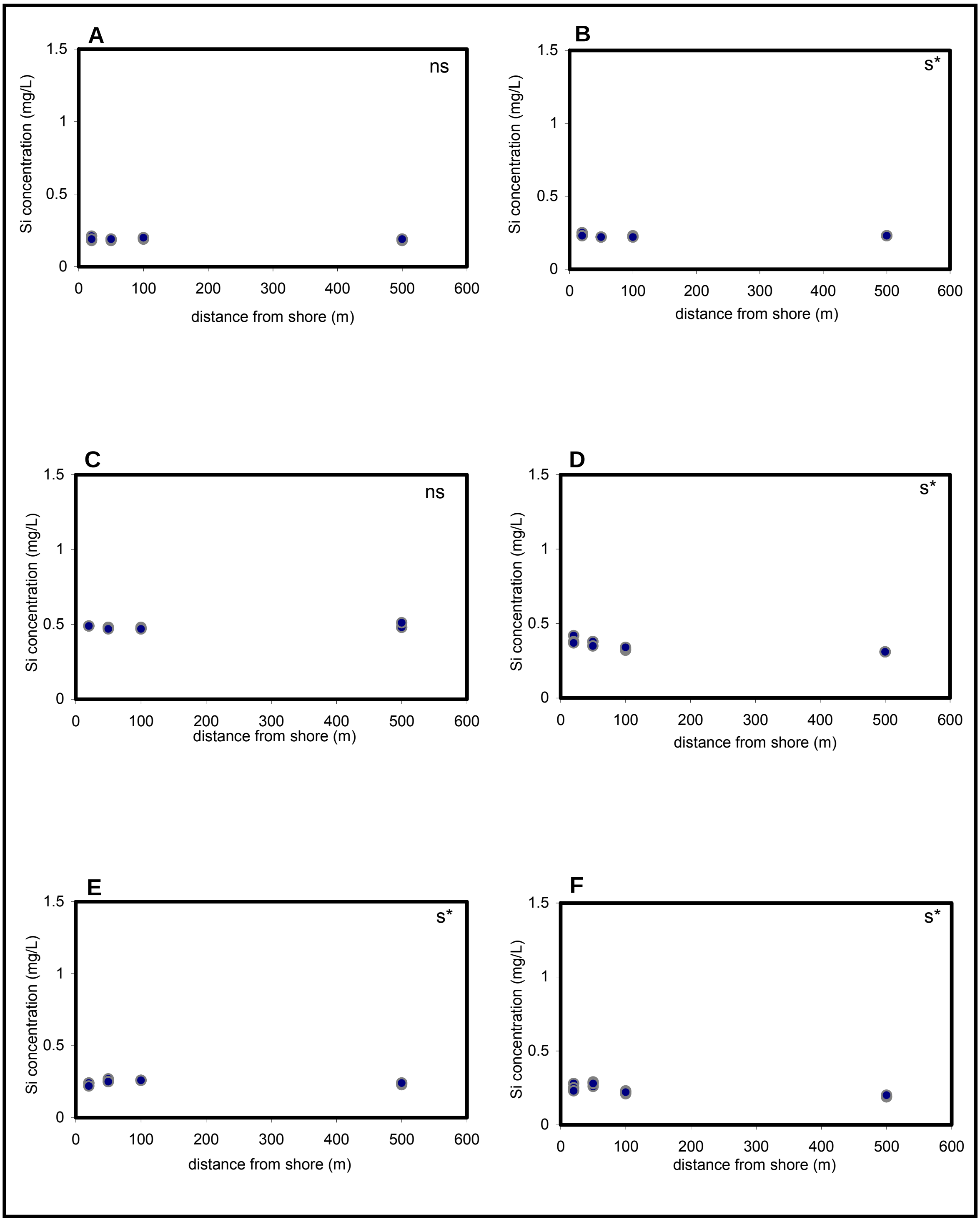

Figure 7: Silica concentration (mg/L) with distance from shore on each transect

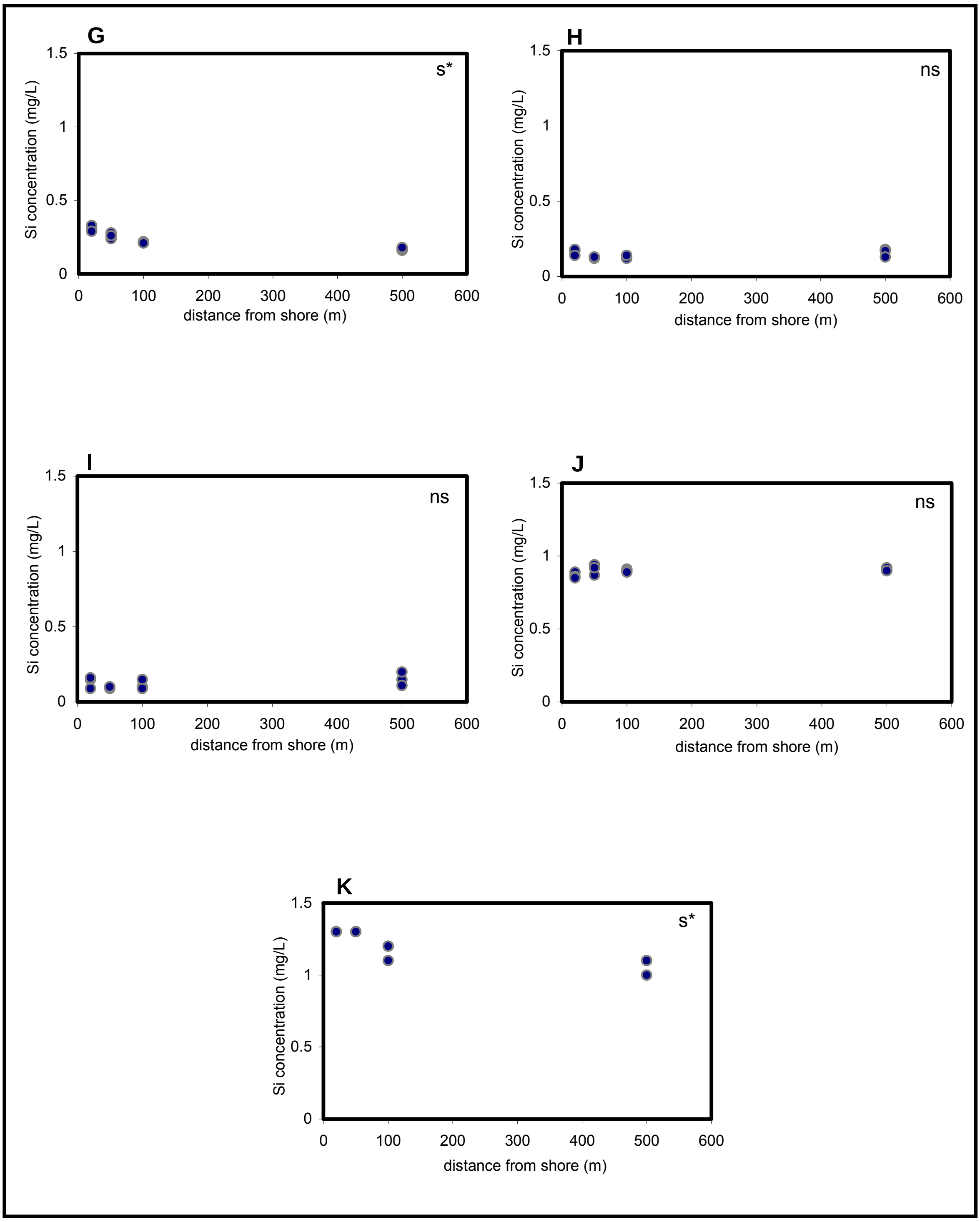

Figure 7 (continued)**: Silica concentration (mg/L) with distance from shore on each transect**

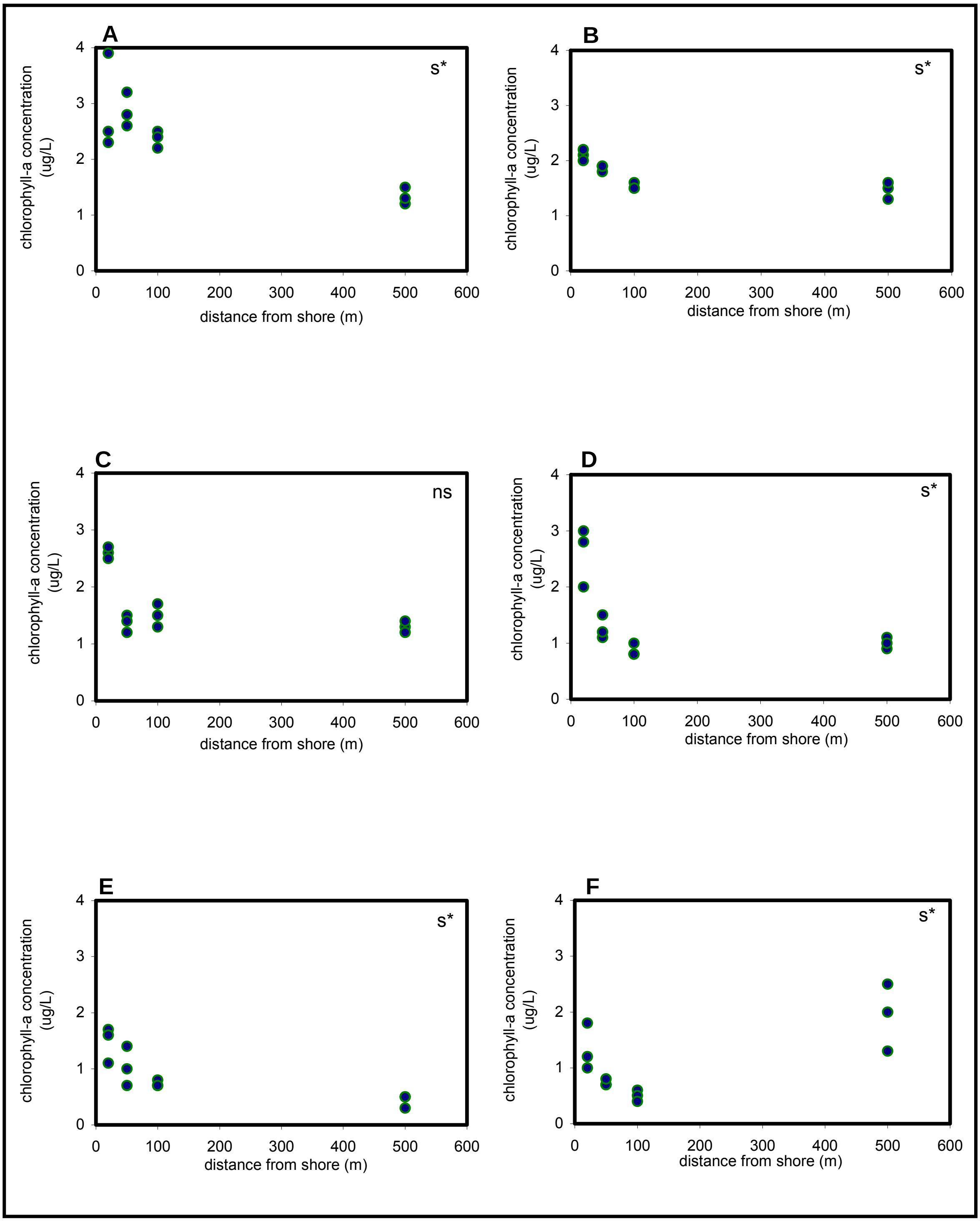

Figure 8: Chlorophyll-a concentration (µg/L) with distance from shore on each transect

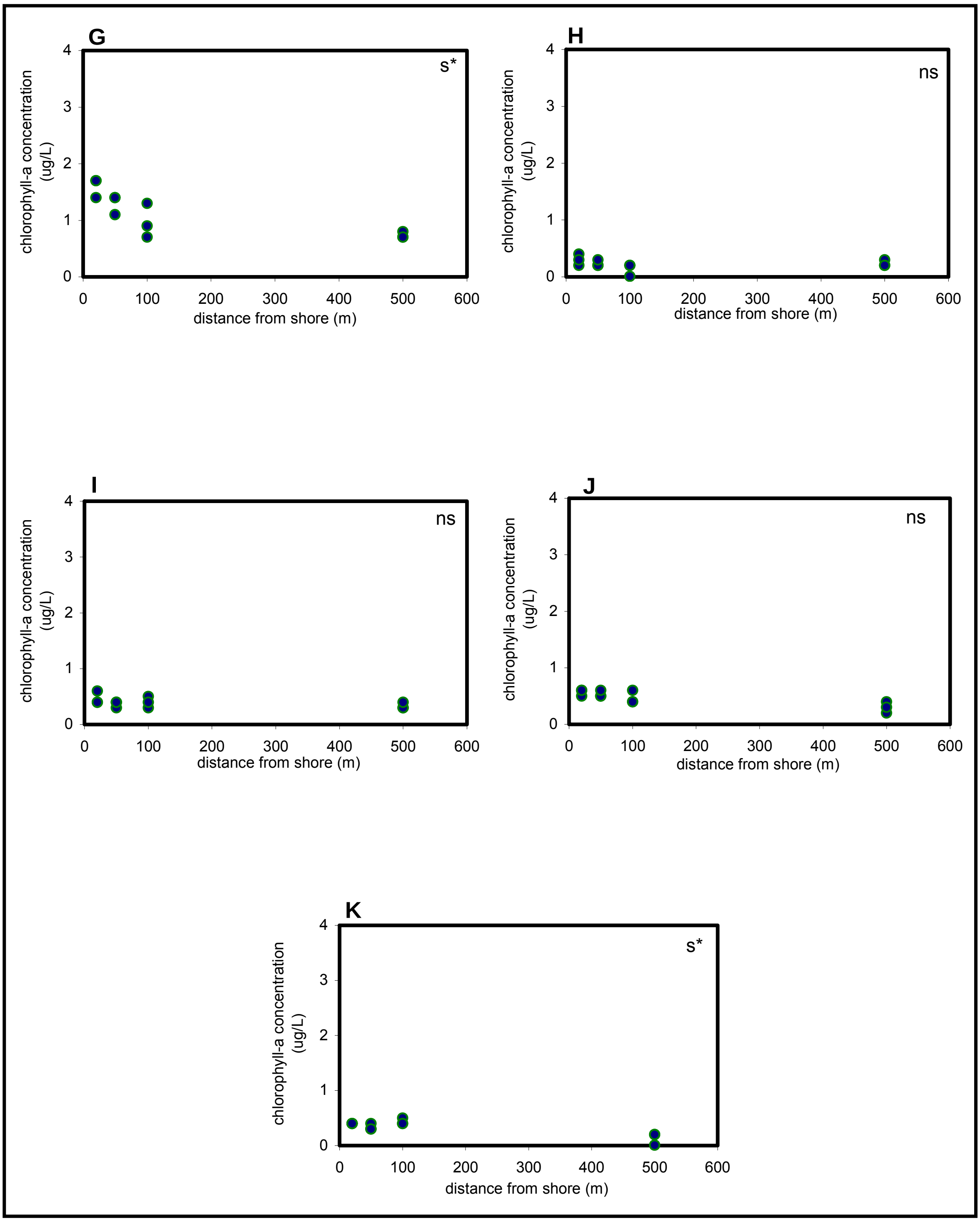

Figure 8 (continued)**: Chlorophyll-a concentration (µg/L) with distance from shore on each transect**

Appendix VIII p values (Kruskal-Wallis ANOVA) for between distance from shore differences in determinand concentration on each transect

Values in black - significant difference with distance from shore
Values in blue - no significant difference with distance from shore

	NH3N	NNN	TN	DRP	TP	Salinity	Si	Chloro-a
A	0.118	0.049	0.017	0.262	0.022	0.016	0.37	0.041
B	0.187	0.044	0.051	0.532	0.021	0.815	0.04	0.022
C	0.164	0.041	0.076	0.098	0.316	0.107	0.068	0.057
D	0.235	0.026	0.048	0.077	0.043	0.234	0.021	0.022
E	0.874	0.028	0.062	0.048	0.015	0.234	0.031	0.025
F	0.492	0.025	0.034	0.079	0.032	0.015	0.022	0.018
G	0.093	0.015	0.034	0.017	0.018	0.046	0.015	0.03
H	0.217	0.044	0.026	0.062	0.039	0.093	0.09	0.242
I	0.48	0.041	0.095	0.013	0.023	0.815	0.269	0.335
J	0.073	0.095	0.05	0.392	0.351	0.017	0.145	0.073
K	0.43	0.067	0.214	0.039	0.277	0.015	0.016	0.027

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