Technical Report

Investigations and Monitoring Group

Coastal water quality in selected bays of Banks Peninsula

2001 - 2007

Environment Canterbury

Your regional council

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2001 - 2007

Report R08/52
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Executive Summary

This report presents and interprets water quality data collected by Environment Canterbury in selected bays of Banks Peninsula over two time periods: November 2001-June 2002 and July 2006-June 2007. Over 2001-2002 the concentrations of nitrogen and phosphorus based determinands (nutrients) were measured while over 2006-2007 the concentrations of nutrients, chlorophyll-a, total suspended solids, enterococci, and salinity were measured.

The bays sampled were primarily selected to represent a range of geographic locations around the peninsula. These bays varied in regard to aspect of the entrance, length, width and land use. The bays sampled over both time periods were Pigeon Bay, Little Akaloa, Okains Bay, Le Bons Bay, Otanerito and Flea Bay. Hickory Bay and Te Oka Bay were also sampled over 2001-2002 but not over 2006-2007 while Port Levy and Tumbledown Bay were sampled over 2006-2007 but not over 2001-2002.

Median concentrations of the nutrients ammonia nitrogen (NH_3N), nitrate-nitrite nitrogen (NNN), total nitrogen (TN), dissolved reactive phosphorus (DRP) and total phosphorus (TP) were typically comparable to those reported from sites north and south of Banks Peninsula but some differed from those in Akaroa and Lyttelton harbours. There was considerable variability in NH_3N, NNN, TN, DRP, TP, chlorophyll-a, total suspended sediment and salinity concentrations between sampling occasions. This variability suggests that concentrations are influenced by a range of factors.

All NH_3N concentrations were below the ANZECC (2000) trigger value. No other determinand concentrations were compared to ANZECC (2000) values as there are no New Zealand specific trigger values. Enterococci concentrations were low which indicates little or no faecal contamination of the sea water within the bays.

There were significant differences in NH_3N, NNN, TN, DRP, TP, chlorophyll-a and total suspended solid concentrations and salinity between two or more of the bays. These differences indicate bay specific sources of nutrients, sediment and fresh water and may be due to:

- differences in the volumes of fresh water flowing into the bays via the streams,
- differences in land use within a catchment for example grazing compared to forest covered,
- differences in the area of active erosion scars between bays

There was a similarity between the grouping of some of the bays based on bay length and/or aspect of the entrance and their groupings based on the concentrations of N and/or P based determinands. Water circulation within the bays is predominantly driven by tidal flows and wind. The aspect of the bay entrance likely results in differences between bays in water circulation because of differences in exposure to the prevailing wind. Bay length likely influences the retention time of water within a bay and affects wind strength (funnelling) and hence water circulation. The results suggest that water circulation and water retention time within a bay influence nearshore nutrient concentrations. Rainfall has a significant impact on the nearshore water quality. Using correlations it was determined that rainfall affects nearshore NNN concentrations and can also influence nearshore total suspend sediment concentrations. Notable high concentrations of NH_3N, NNN, TN and TP occurred in one or more bays after heavy rainfall. Seabed re-suspension by wave action is a significant contributor of sediment to the water column in some of the bays. High volume flows from the Rakaia River, some 66 km south of the peninsula, can affect the salinity of southern bays, and hence also likely influences other water quality parameters in these bays.

The information in this report provides:

- a baseline against which any large changes in water quality can be assessed.
- information that will be useful to resource managers in assessing the suitability of water quality for the uses and values associated with this part of the coast.
- information that will be useful to future resource consent applicants for, for example, aquaculture or discharges to the coast.

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1 Introduction

1.1 Banks Peninsula bays water quality

In 2000-2001 Environment Canterbury initiated a coastal water quality monitoring programme to support the then proposed Regional Coastal Environment Plan for the Canterbury region (RCEP). For the purposes of this monitoring programme the Canterbury coast was divided into five areas; the bays of Banks Peninsula were in one of these areas. The monitoring programme then typically consists of routine water sampling at sites in each area over a year, every five years. The Banks Peninsula bays were sampled over November 2001 - June 2002 and July 2006 - June 2007. The water quality data collected over these two periods are the focus of this report.

1.2 Objectives of this study

1. Document the coastal water quality in representative bays of Banks Peninsula.
2. To investigate:
   - if there was a significant difference in water quality between bays;
   - differences in water quality between sampling periods;
   - factors that may account for any differences in water quality between bays and between sampling periods.

1.3 Background information

Banks Peninsula protrudes some 45 km into the Pacific Ocean from the predominantly low-lying coastline of Canterbury (Figure 1.1). Initially the peninsula was an offshore volcanic island but became attached to the South Island as alluvial fans from the Southern Alps extended the eastern edge of the mainland. The Banks Peninsula of today is the eroded remnant of the once active Lyttelton and Akaroa volcanoes and minor volcanic centres. The main Lyttelton volcano was active 10.4-11 m.y. ago while the Akaroa volcano was active 8-9 m.y. ago (Sewell *et al*, 1992). Geologic evidence suggests that the eruptions took the form of lava-outpourings (Gage, 1969). The lava flow resulted in the formation of radial valleys around the outer flank of the volcanic cones. Over time these radial valleys have eroded to form embayments (i.e. the bays) and a cliffed coastline. Infilling of the floor of the valleys has resulted in flat land and sandy beaches in many of the bays.

Most of the hillsides of the bays are farmed with farms and settlements occupying the relatively flat land within the bays (Figure 1.2). The farmland is typically grazed by sheep or cattle, but there are some dairy farms. Pockets of natural vegetation occur within the bays, with many of these pockets now protected by covenant. In recent times there has been an increase in the area of peninsula land reverting to natural vegetation, the most notable being at Otanerito. Streams flow down each valley across the flat land and into the sea in each bay. The size and number of streams varies between bays (Appendix I). These streams typically have a large spring fed baseflow component. The variable quantity of water within these streams is driven by rainfall while the quality of the water is influenced by land use and other activities within the catchment.

There are sealed or unsealed roads to most bays and as a result the bays are frequented not only by residents but by day visitors and holiday makers from Christchurch and further afield. The permanent residents are farmers, lifestylers and retirees. The holiday makers either have permanent holiday homes or make use of the motor camps that are present in some bays. In recent years there has been an increase in the number of holiday homes in Port Levy, Little Akaloa and Le Bons Bay in particular. New housing subdivisions are in the pipeline for Port Levy and Okains Bay. Residences within the bays are not connected to reticulated wastewater systems. Each house has a septic tank for sewage treatment while stormwater typically flows to land and/or a nearby waterway. Septic tanks are a potential source of nutrients and micro-organisms. The stormwater that flows from buildings, sealed roads and other impervious surfaces can carry litter, sediments, micro-organisms, organic matter and chemical contaminants such as heavy metals, petroleum-derived compounds and nutrients.

With increasing human presence and land use intensification there is potential for the water quality in the streams to deteriorate. As the streams flow to the sea there is potential for activities within a bay to indirectly impact upon the quality of the sea water within the bay. Therefore, there could be differences in coastal water quality between bays. In addition the water quality within a bay could change over time. Hence the need to collect and analyse coastal water quality data to investigate the spatial and temporal water quality of selected bays of Banks Peninsula.

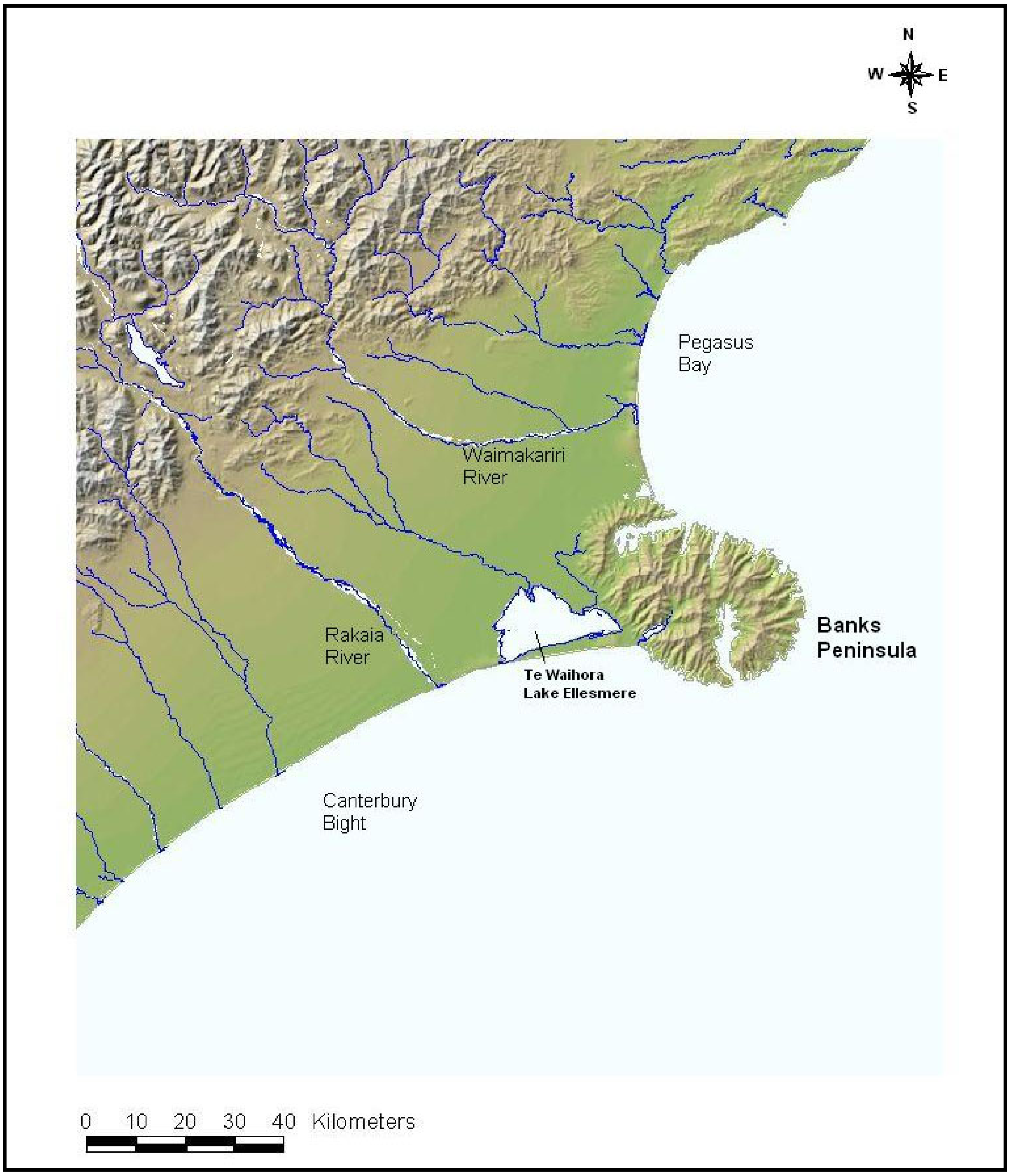

Figure 1.1 Banks Peninsula and the Canterbury Plains

Pigeon Bay

Little Akaloa

Okains Bay

Le Bons Bay

Flea Bay

Tumbledown Bay

Figure 1.2 Some of the bays of Banks Peninsula

2 Methods

2.1 Sites and depths

Water samples were collected from different bays (Figure 2.1). The bays sampled were primarily selected by geographic location around the peninsula. However, land use within a bay was also considered. Details on each of the sampled bays are given in Appendix I. Details of the sites sampled in each bay are given in Appendix II. At each site the surface water (0 – 0.5 m depth) was sampled.

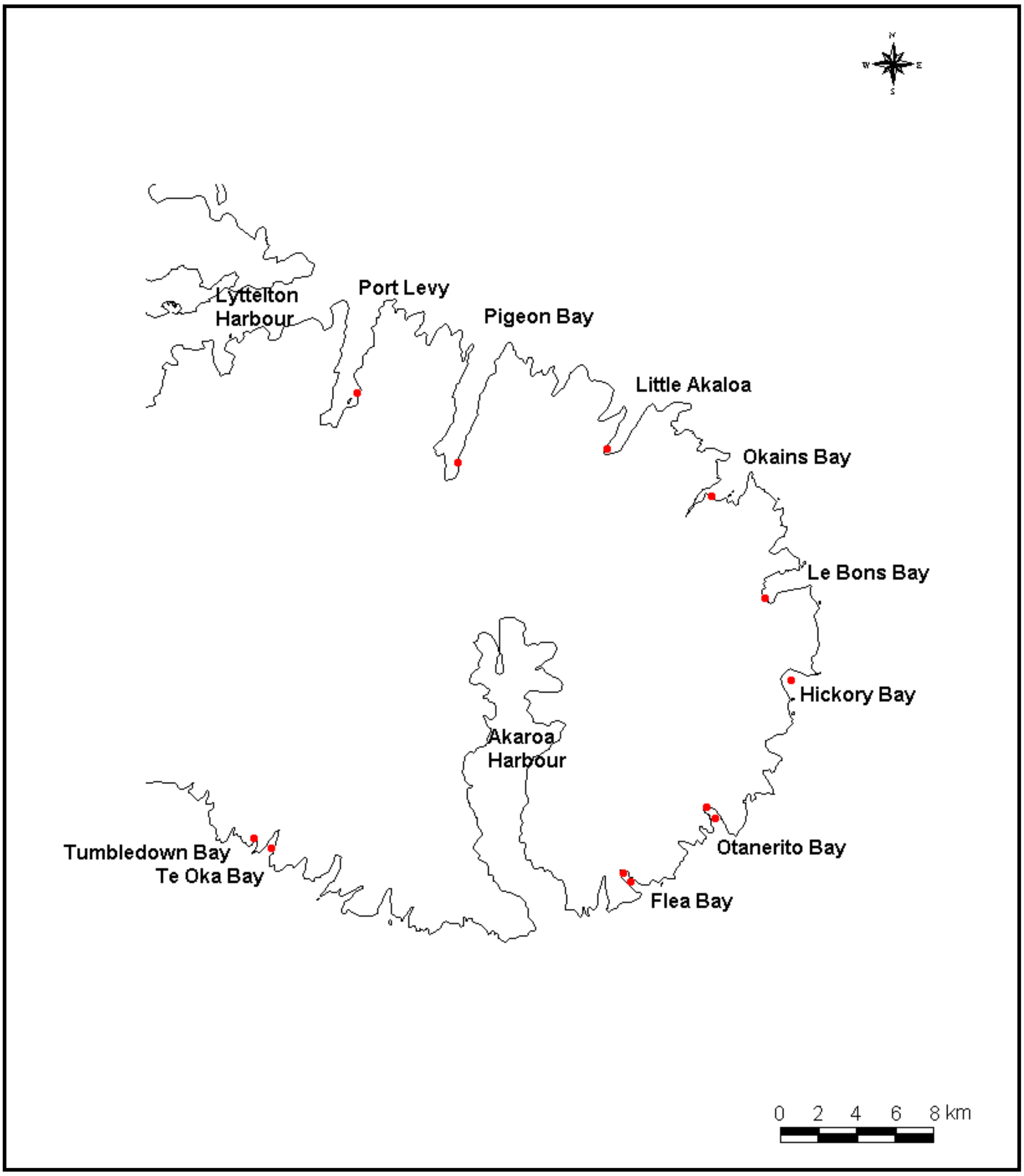

Figure 2.1 Bays sampled with the location of each sampling site

2.2 Sampling regime

Sites were sampled from November 2001 - June 2002 and July 2006 - June 2007. Over 2001-2002 samples were collected fortnightly between late November and mid March, then monthly between mid March and June. Over 2006-2007 samples were collected approximately every six weeks.

2.3 Sample collection

All 2001-2002 samples were collected by Environment Canterbury staff. Over 2006-2007 water samples from Flea Bay and Otanerito were collected by a resident of each bay; those from all other bays were collected by Environment Canterbury staff.

Over 2001-2002 all samples were collected from a helicopter. At sites from Le Bons Bay north the samples were collected from just behind the breakers at the beach while at sites south of Le Bons Bay they were collected from the middle of each bay some distance from shore. Over 2006-2007 the samples were collected from shore either off the end of a jetty (Port Levy, Pigeon Bay, Little Akaloa) or at the water's edge (Okains Bay, Le Bons Bay, Otanerito, Flea Bay and Tumbledown Bay).

At the time of sampling the weather conditions (cloud cover, wind direction, wind strength) were recorded. In addition, over 2001-2002 water temperature and over 2006-2007 water temperature and salinity were measured using field meters.

One water sample from collected from each site on each sampling occasion. All water collected was stored in specially prepared bottles provided by the laboratory undertaking the analyses, and kept cooled in chilly bins until delivery to the laboratory.

2.4 Sample analyses

The samples collected over 2001-2002 were analysed for nitrogen and phosphorus-based chemical determinands (nutrients) and water temperature (Table 2.1). A detailed description of these determinands is given in Appendix III.

Samples collected over 2006-2007 were analysed for each of the determinands listed in Table 2.1.

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, biological and physical determinands

Ammonia nitrogen (NH_3N)
Nitrate and nitrite nitrogen (NNN)
Total nitrogen (TN)
Dissolved reactive phosphorus (DRP)
Total phosphorus (TP)
Chlorophyll-a
Enterococci
Total suspended solids
Salinity
Water temperature

Figure 2.2 Sampling in Pigeon Bay on a winter day

2.5 Data analyses

Microsoft Excel 2000, Systat (version 9) (SPSS, 1999), Statistica (version 7) and PRIMER (version 6) 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 nutrient (NNN, NH_3N, TN, DRP and TP) and other determinands, between bays the Wilcoxon signed rank test (Systat V9) was used. These analyses were carried out on the data from each year-long sampling period. Differences in the sample collection method and location of sampling sites within a bay precluded statistical analysis for significant differences between sampling periods.

Two-dimensional MDS ordination plots were produced to depict the relative similarity between bays for each of the sampling periods based on the concentrations of:

- the nitrogen-based nutrients
- the phosphorus-based nutrients
- total suspended solids (2006-2007 data only)

To generate an MDS ordination the data for each bay were averaged then normalised. The Euclidean distance measure was then applied to the normalised data to produce a similarity matrix. From this similarity matrix a 2-dimensional MDS ordination was generated.

Interpretation of an MDS ordination is based on the closeness of the sites on the plot. The closer the sites are, the more similar they are with respect to the parameters used to generate the plot. For each plot a stress value (goodness-of-fit) is given. Stress is a measure of the accuracy of the 2-dimensional ordination of points on the MDS plot in representing the actual values in the similarity matrix (Clarke and Warwick, 2001).

The correlation between five environmental factors (total rainfall at Kaituna, total rainfall at Coopers Knob, wind direction at Taumutu, median wave height at the wave buoy, median wave direction at the wave buoy (east of Banks Peninsula)) and determinand concentrations was investigated using matrix plots. For each environmental factor the data from the day of sampling were not taken into account, rather it was the environmental data from each of days one to five prior to sampling that were used.

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 analysis.

3 Results

3.1 Nutrients

The data for the nitrogen- and phosphorus-based determinands (nutrients), collected in each bay are summarised in Appendix V. The results of the Wilcoxin two-tailed sign test, used to determine if, over each sampling period, there was a statistically significant difference in the concentration of each nutrient between sites, are presented in Appendix VI. Plots of the concentrations of each nutrient in each bay over both sampling periods are given in Appendix VII.

3.1.1 Ammonia nitrogen (NH_3N)

Ammonia nitrogen concentrations ranged from <0.005 to 0.17 mg/L. The concentrations recorded were below the ANZECC (2000) trigger value (0.5mg/L) providing protection for 99% of marine species.

Between sites

Over 2001-2002 NH_3N concentrations were significantly[1] higher in Pigeon Bay than in Little Akaloa, Okains Bay, Le Bons Bay and Te Oka (Figure 3.1A).

Over 2006-2007 NH_3N concentrations were significantly higher in:

- Le Bons Bay than in Otanerito and Flea Bay.
- Pigeon Bay and Tumbledown Bay than in Otanerito (Figure 3.1B).

Over time

The range in NH_3N concentrations in each bay was larger over 2001-2002 than over 2006-2007 (Figure 3.1).

Over 2006-2007 the pattern of NH_3N concentrations was similar in all of the bays (Figure 3.2). In general there was an increase in concentrations over spring, maximum concentrations in summer and a decrease in concentrations during autumn. At all sites this seasonal pattern was interrupted by a drop in concentration in early March. This pattern in concentrations did not occur over 2001-2002 (Figure 3.2). However, in 2001-2002 there was a peak in concentrations in most of the bays in the March-April period as there was over 2006-2007. The comparability of the March-April peaks can be seen clearly on the NH_3N plots in Appendix VII.

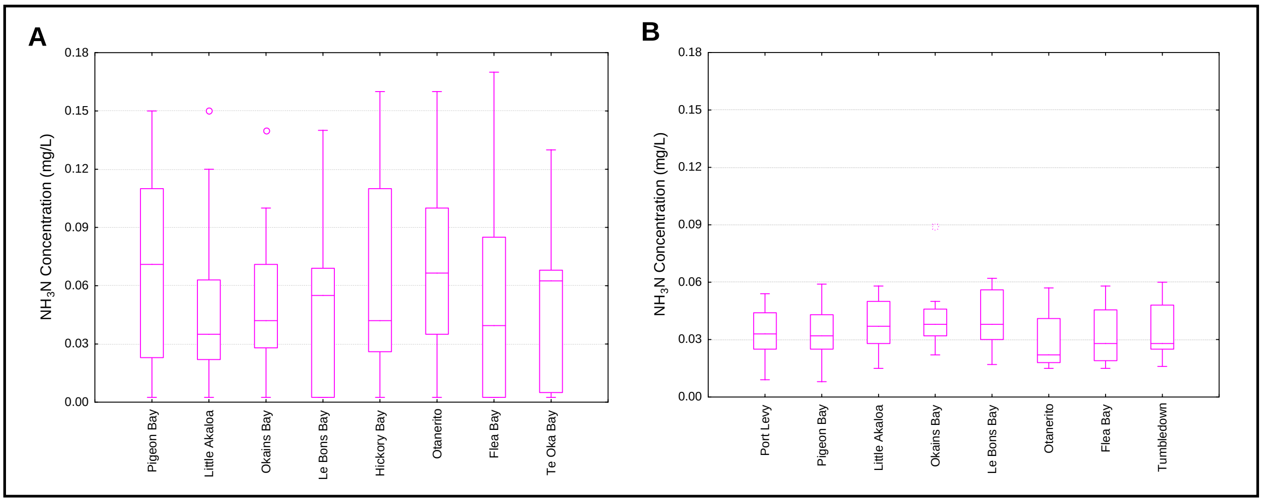

Figure 3.1 Ammonia nitrogen concentrations (mg/L) A: 2001-2002 B: 2006-2007

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

[1] Significance refers to statistical significance at $p < 0.05$

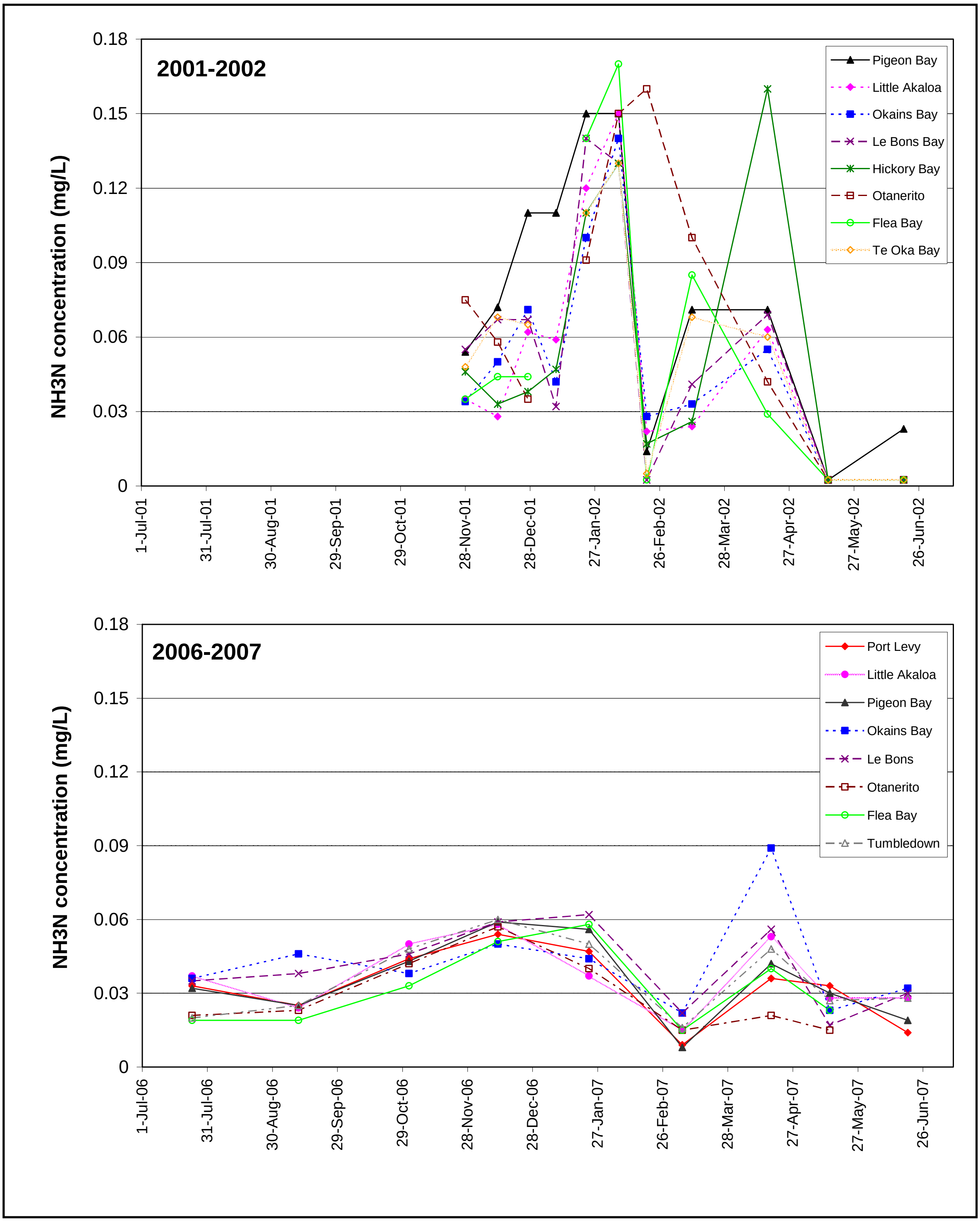

Figure 3.2 Ammonia nitrogen concentrations (mg/L) in each bay over each sampling period

3.1.2 Nitrate-nitrite nitrogen (NNN)

Nitrate-nitrite nitrogen concentrations ranged from <0.005 to 0.45 mg/L.

Between sites

There were no significant differences in NNN concentrations between bays over 2001-2002 (Figure 3.3A).

Over 2006-2007 NNN concentrations were significantly higher in:

- Okains Bay and Le Bons Bay than in Pigeon Bay and Little Akaloa
- Le Bons Bay than in Port Levy (Figure 3.3B).

Over time

The range in NNN concentrations in each bay differed between 2001-2002 and 2006-2007 (Figure 3.3). There was a larger range in concentrations in Pigeon Bay, Little Akaloa and Flea Bay in 2001-2002 than in 2006-2007 while in Okains Bay, Le Bons Bay and Otanerito the concentration range was larger over 2006-2007 than over 2001-2002.

Over 2006-2007 there was a seasonal pattern to NNN concentrations in all of the bays (Figure 3.4). Concentrations were highest in the winter, decreased during spring, were low over summer and then increased during the autumn. For the period sampled over 2001-2002 this seasonal pattern was interrupted by a concentration peak in January in each of the bays. The comparability of the concentrations between sampling periods in each bay can be seen clearly on the NNN plots in Appendix VII.

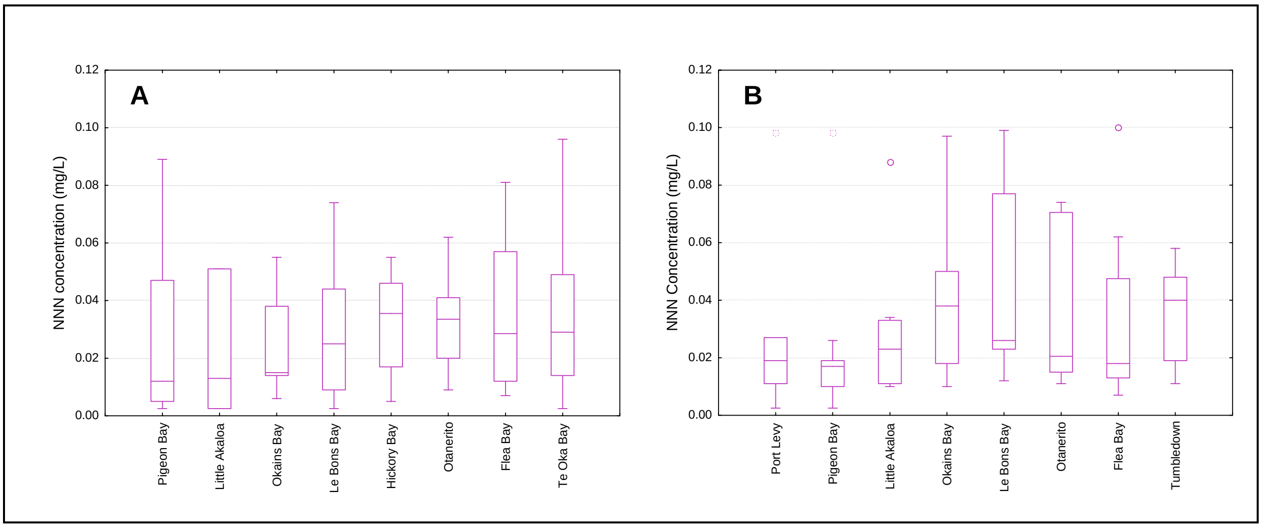

Figure 3.3 Nitrate-nitrite nitrogen concentrations (mg/L) A: 2001-2002 B: 2006-2007

Note: horizontal bar = median, box = interquartile range, whisker ends = % and 95%iles,
* = outlier values, o = extreme values
The outlier and extreme values for 2001-2002 are not shown

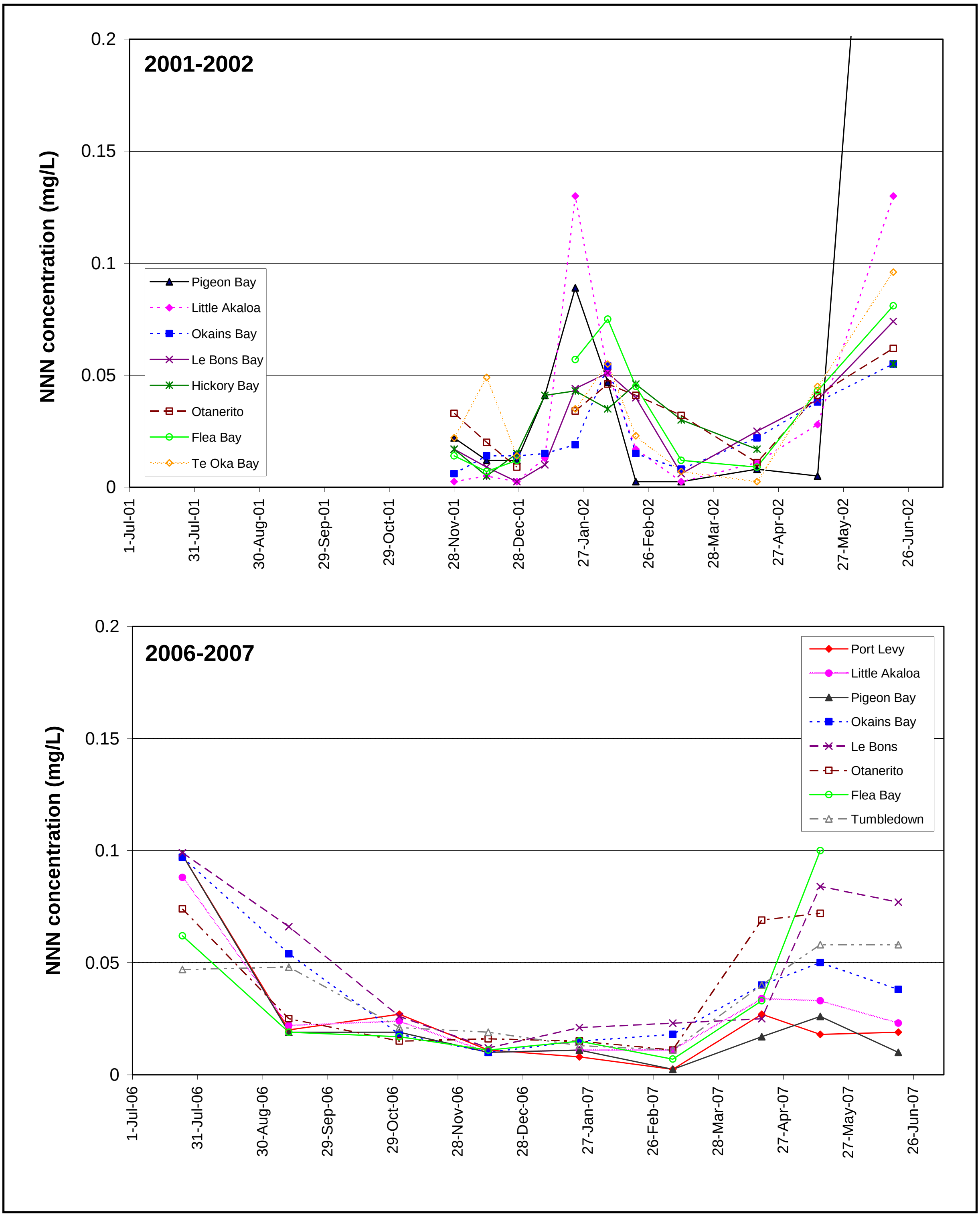

Figure 3.4 Nitrate-nitrite nitrogen concentrations (mg/L) in each bay over each sampling period

3.1.3 Total nitrogen (TN)

Total nitrogen concentrations ranged from < 0.08 to 0.74 mg/L.

Between sites

Over 2001-2002 TN concentrations were significantly higher in Te Oka Bay than in Flea Bay (Figure 3.5A).

Over 2006-2007 TN concentrations were significantly:

- higher in Port Levy than in Little Akaloa, Otanerito and Flea Bay
- higher in Pigeon Bay and Okains Bay than in Little Akaloa and Flea Bay
- lower in Flea Bay than in six out of the other seven bays sampled (Figure 3.5B).

Over time

The range in TN concentrations in each bay differed between 2001-2002 and 2006-2007 (Figure 3.5). In general the range of concentrations in each bay was larger over 2001-2002 than over 2006-2007. The largest variability in TN concentrations occurred in Pigeon Bay over 2001-2002.

Over 2001-2002 TN concentrations in each bay were variable over time with no obvious seasonal pattern. Over 2006-2007 the temporal pattern in TN concentrations was similar in all bays. Concentrations typically vacillated around 0.2 mg/L with a decrease in concentrations in early December (Figure 3.6). The comparability of the concentrations between sampling periods in each bay can be seen clearly on the TN plots in Appendix VII.

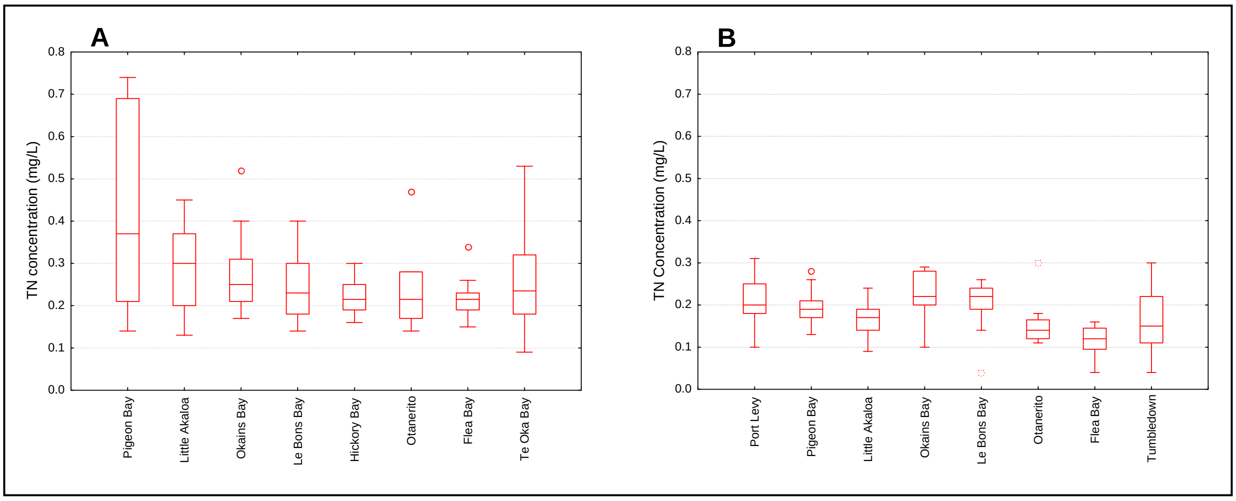

Figure 3.5 Total nitrogen concentrations (mg/L) A: 2001-2002 B: 2006-2007

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

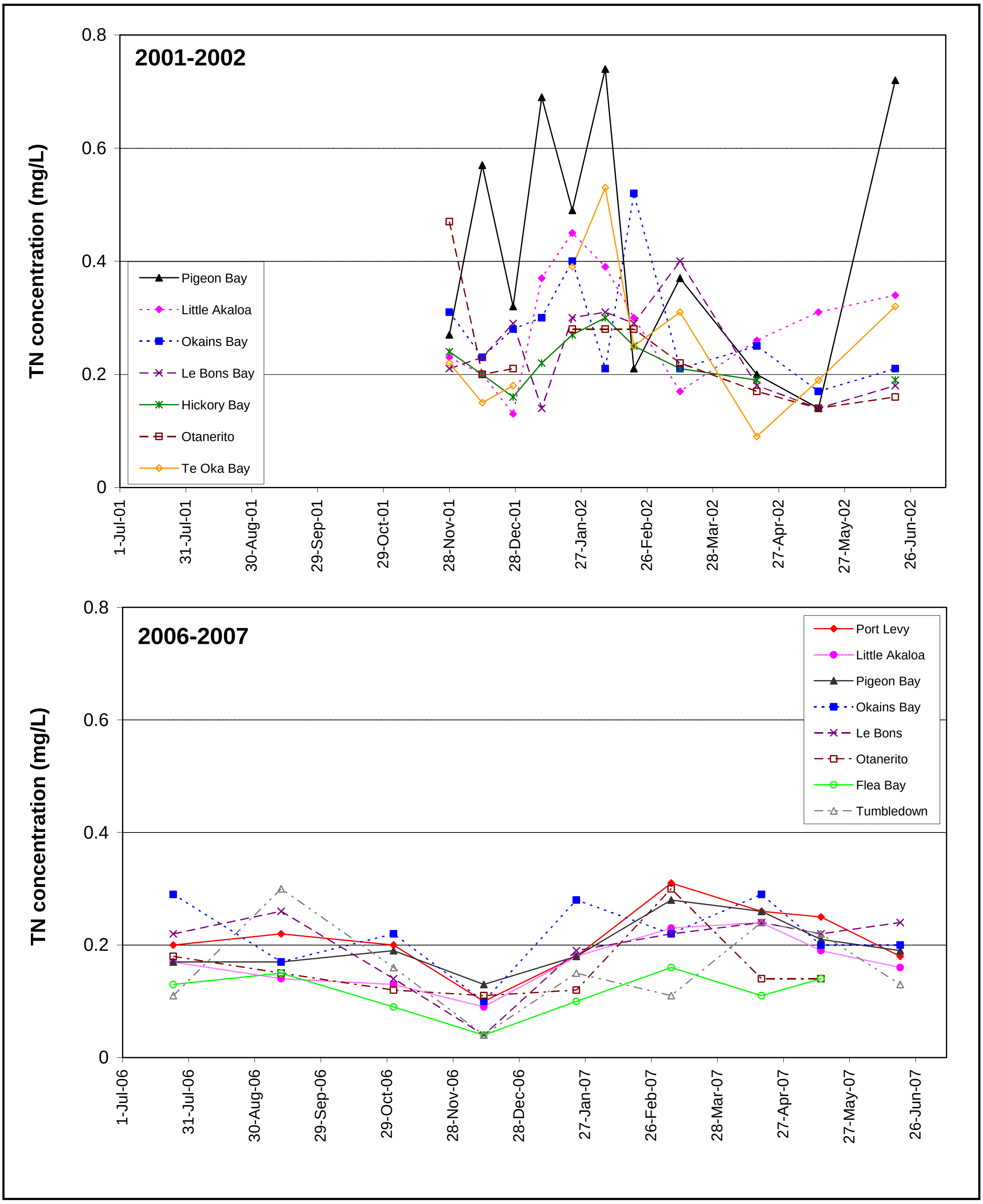

Figure 3.6 Total nitrogen concentrations (mg/L) in each bay over each sampling period

3.1.4 Dissolved reactive phosphorus (DRP)

Dissolved reactive phosphorus concentrations ranged from 0.001 to 0.054 mg/L.

Between sites

Over 2001-2002 DRP concentrations were significantly higher in Pigeon Bay than in Little Akaloa, Okains Bay, Le Bons Bay and Te Oka Bay (Figure 3.7A).

Over 2006-2007 there were no significant differences in DRP concentrations between bays (Figure 3.7B).

Over time

The range in DRP concentrations in each bay differed between 2001-2002 and 2006-2007 (Figure 3.7).

Over 2006-2007 there was a seasonal pattern to DRP concentrations in all of the bays. Concentrations were generally lowest over summer and increased during the autumn (Figure 3.8). This pattern was not obvious in the 2001-2002 data. The comparability of the concentrations between sampling periods in each bay can be seen clearly on the DRP plots in Appendix VII.

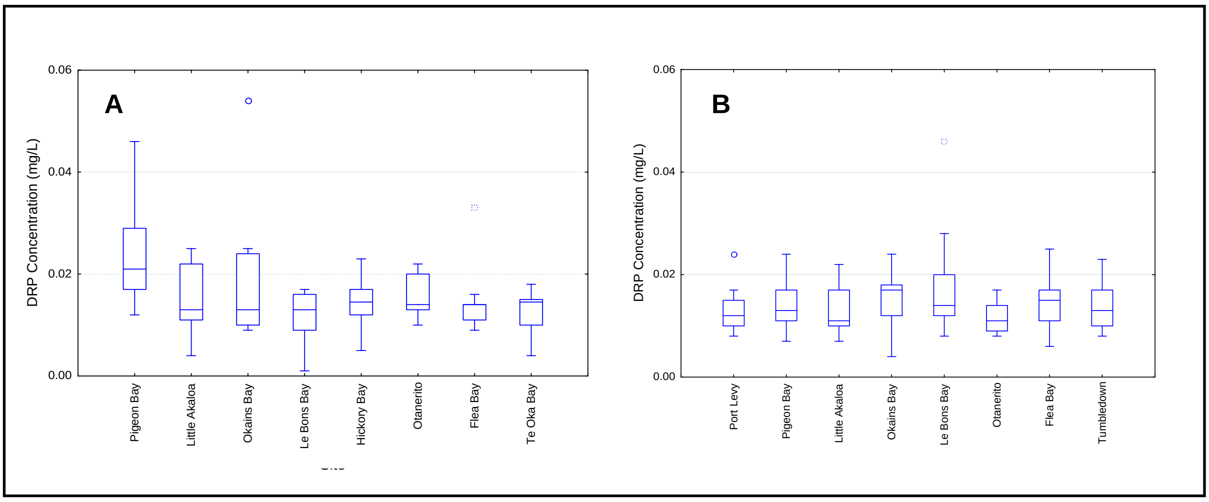

Figure 3.7 Dissolved reactive phosphorus concentrations (mg/L) A: 2001-2002 B: 2006-2007

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

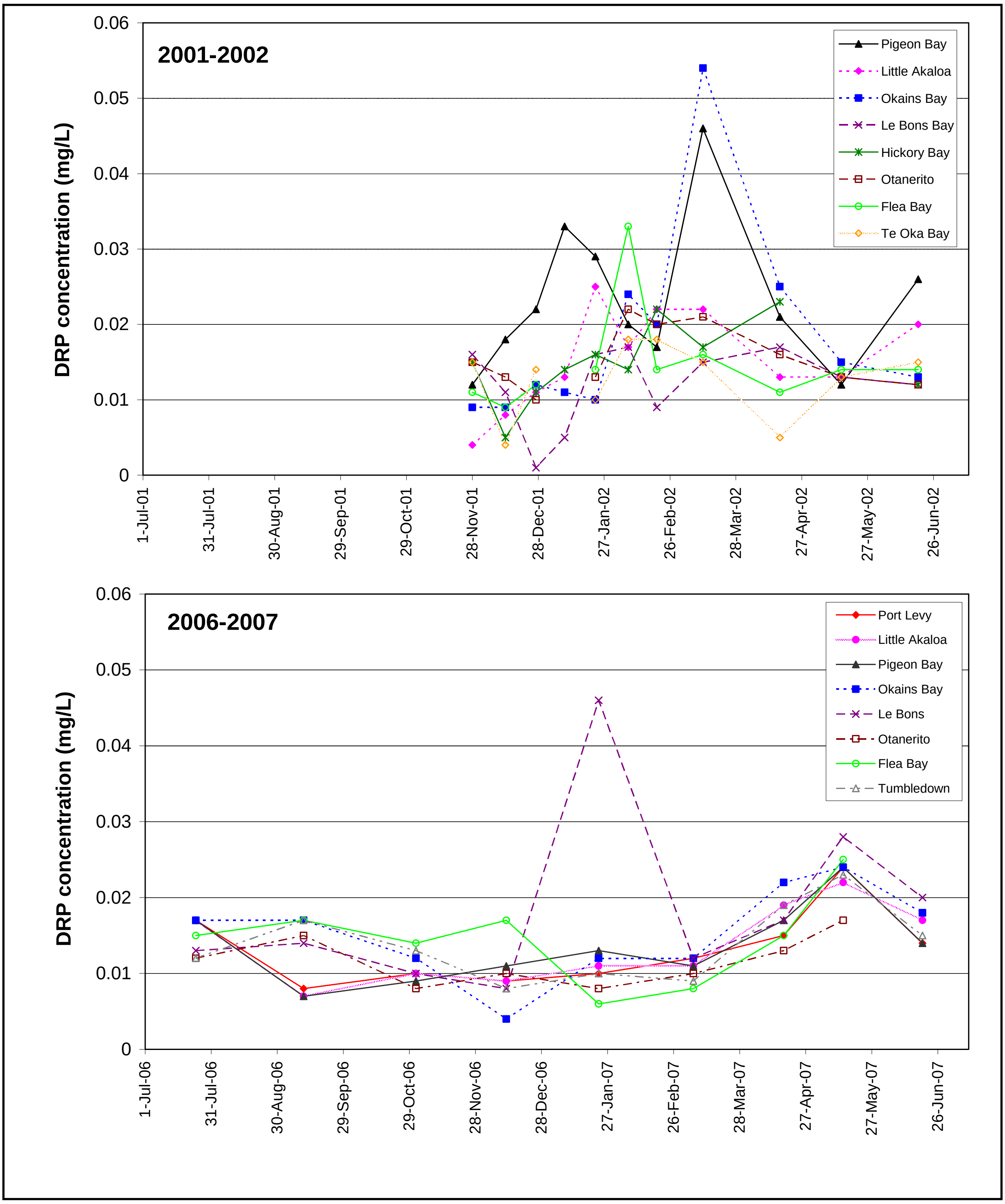

Figure 3.8 **Dissolved reactive phosphorus concentrations (mg/L) in each bay over each sampling period**

3.1.5 Total phosphorus (TP)

Total phosphorus concentrations ranged from <0.008 to 0.19 mg/L.

Between sites

Over 2001-2002 TP concentrations were significantly higher in:

- Pigeon Bay than in the other seven bays
- Little Akaloa than in the eastern (Le Bons, Hickory and Otanerito) and southern bays (Flea and Te Oka) of the peninsula
- Okains Bay than in the eastern bays (Le Bons, Hickory and Otanerito) of the peninsula (Figure 3.9A)

Over 2006-2007 TP concentrations were significantly higher in:

- Okains Bay than in Pigeon Bay, Little Akaloa and Le Bons Bay
- Port Levy, Pigeon Bay and Le Bons Bay than in Little Akaloa (Figure 3.9B)

Over time

The range in TP concentrations in each bay differed between 2001-2002 and 2006-2007 (Figure 3.9). The range of concentrations in Pigeon Bay was larger over 2001-2002 than over 2006-2007 while in the other bays the range was larger over 2006-2007 than over 2001-2002.

Over both sampling periods there was no obvious seasonal pattern in TP concentrations. The TP concentrations typically vacillated around 0.03 - 0.04 mg/L, with occasional high concentrations (Figure 3.10). The comparability of the concentrations between sampling periods in each bay can be seen clearly on the TP plots in Appendix VII.

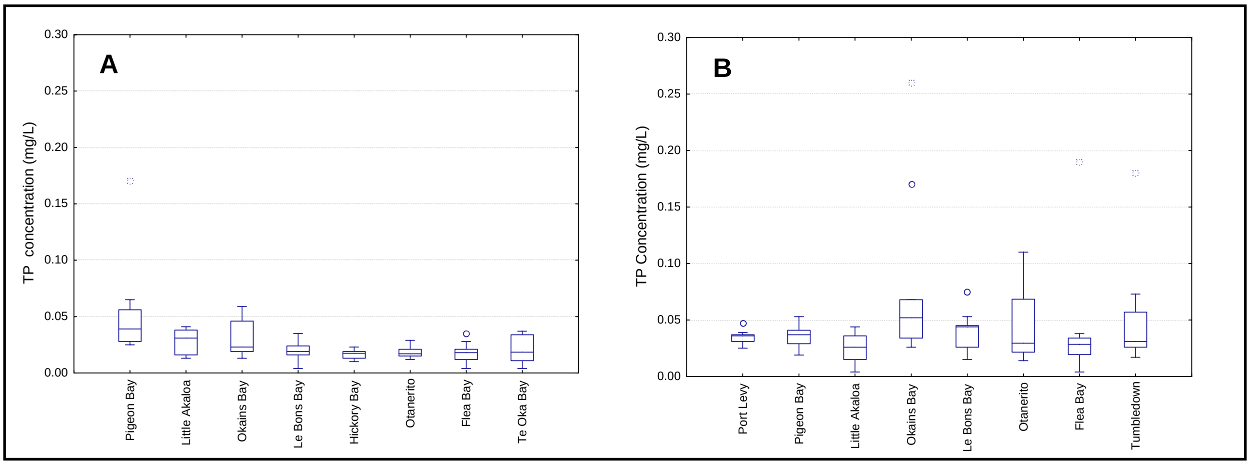

Figure 3.9 Total phosphorus concentrations (mg/L) A: 2001-2002 B: 2006-2007

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

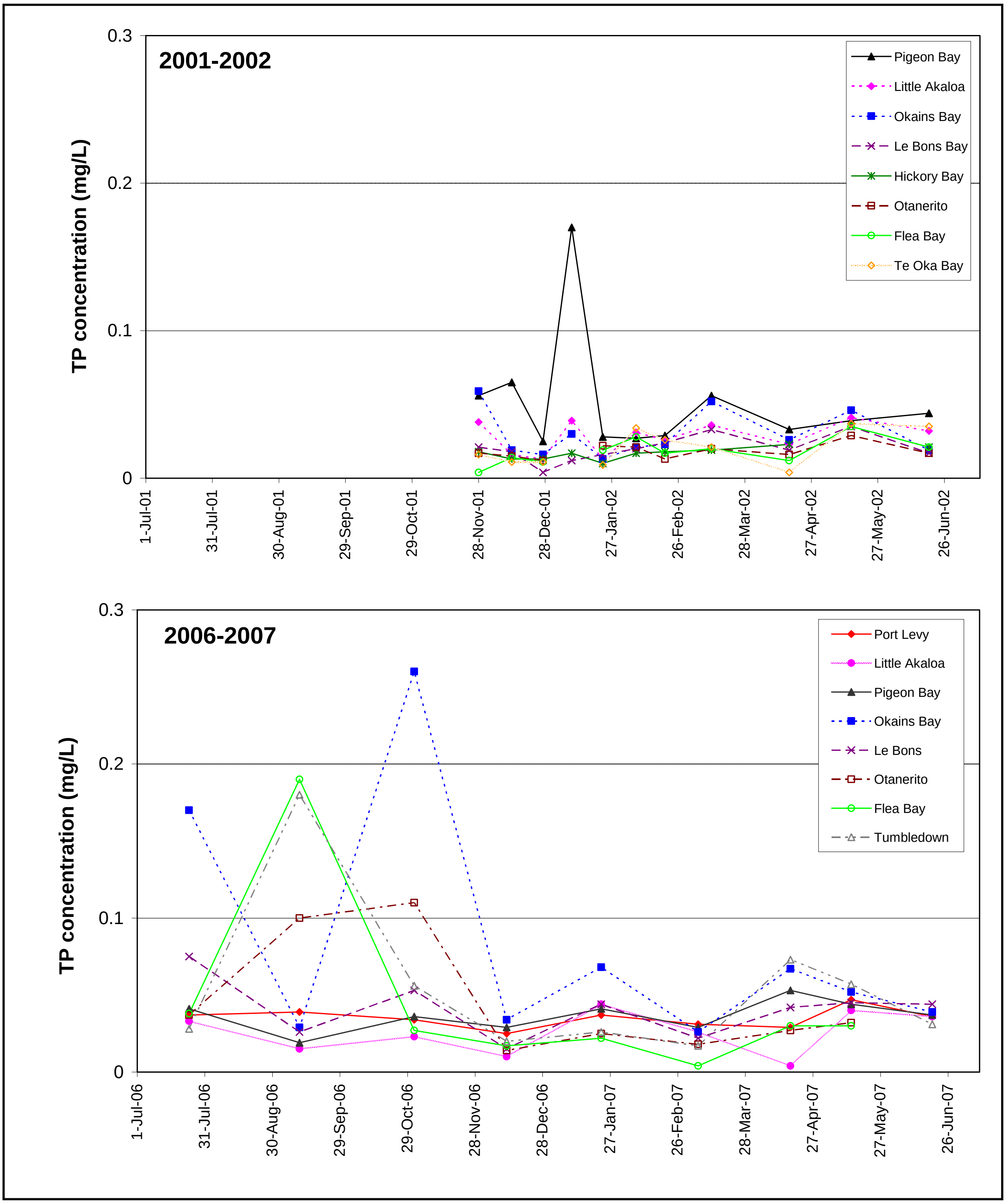

Figure 3.10 Total phosphorus concentrations (mg/L) in each bay over each sampling period

3.2 Other determinands

3.2.1 Chlorophyll-a

Chlorophyll-a concentrations ranged from 0.2 to 9.2 µg/L.

Between sites

Chlorophyll-a concentrations were significantly higher in:

- Port Levy, Pigeon Bay and Okains Bay than in Little Akaloa, Otanerito, Flea Bay and Tumbledown Bay
- Le Bons Bay than in Little Akaloa (Figure 3.11).

The range in chlorophyll-a concentrations varied between sites (Figure 3.11).

Over time

Chlorophyll-a concentrations were typically lowest over winter with higher but variable concentrations over spring, summer and early-mid autumn (Figure 3.12). This is typical of primary productivity patterns in near shore coastal waters.

3.2.2 Total suspended solids (TSS)

Total suspended solids concentrations ranged from 3.1 to 70 mg/L.

Between sites

TSS concentrations were significantly higher in:

- Tumbledown Bay than in Port Levy, Pigeon Bay, Little Akaloa, Otanerito and Flea Bay
- Okains Bay than in Port Levy, Pigeon Bay, Little Akaloa, Otanerito and Flea Bay
- Le Bons Bay than in Little Akaloa and Flea Bay
- Port Levy and Pigeon Bay than in Flea Bay (Figure 3.13).

The range in total suspended solids concentrations varied between sites (Figure 3.13).

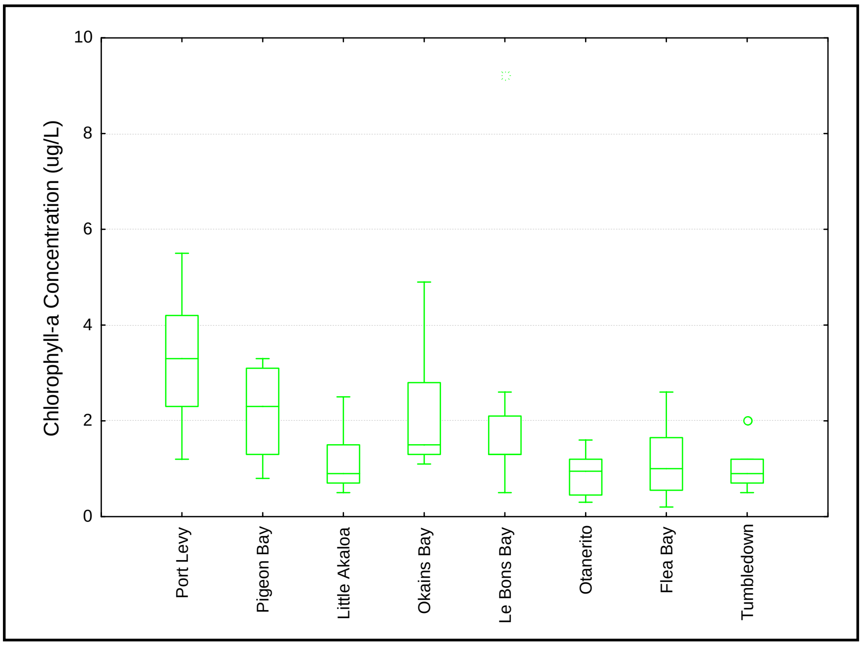

Figure 3.11 Chlorophyll-a concentrations (µg/L) over 2006-2007

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

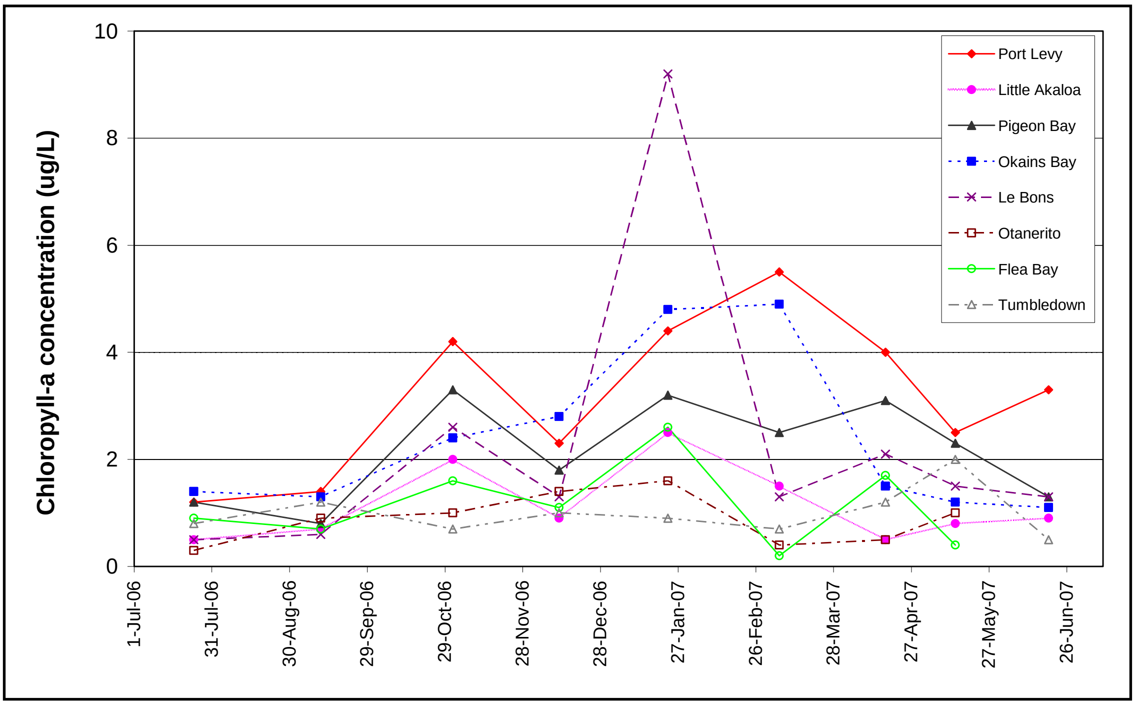

Figure 3.12 Chlorophyll-a concentrations (µg/L) in each bay over 2006-2007

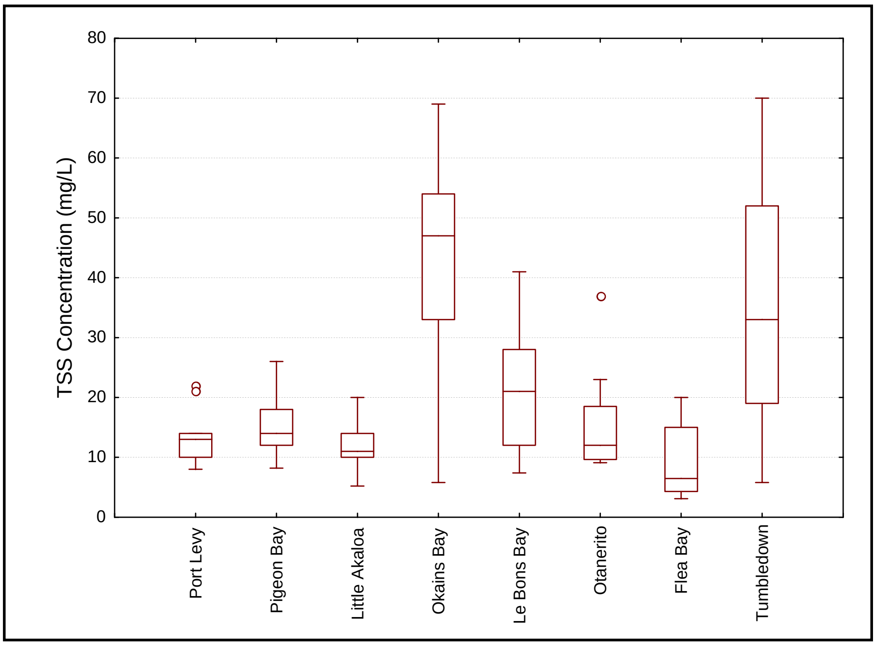

Figure 3.13 Total suspended solids concentrations (mg/L) over 2006-2007

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

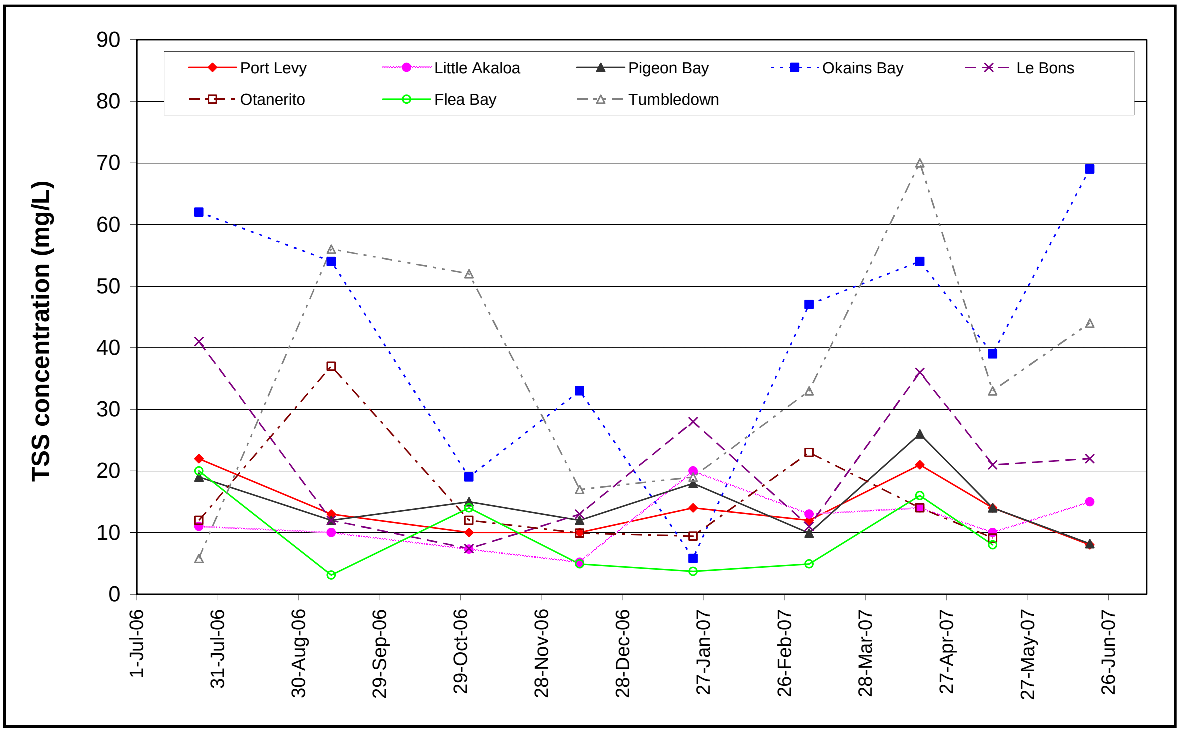

Figure 3.14 Total suspended solids concentration (mg/L) in each bay over 2006-2007

Over time
Total suspended solid concentrations were highly variable over time at some sites with no seasonal pattern in concentrations (Figure 3.14).

3.2.3 Salinity

The salinity ranged from 28.1 to 37.86 ppt (parts per thousand).

Between sites
The salinity in Otanerito was significantly higher than in Le Bons Bay (Figure 3.15).

The salinity range varied between sites (Figure 3.15).

Over time
Salinity was variable over time at some sites with no seasonal pattern (Figure 3.16).

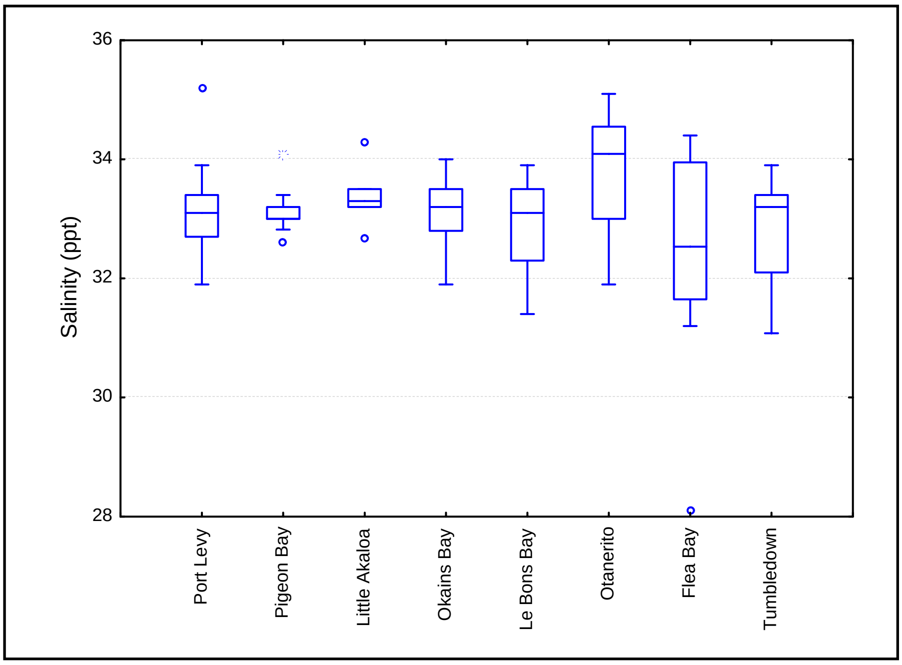

Figure 3.15 Salinity (ppt) over 2006-2007

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

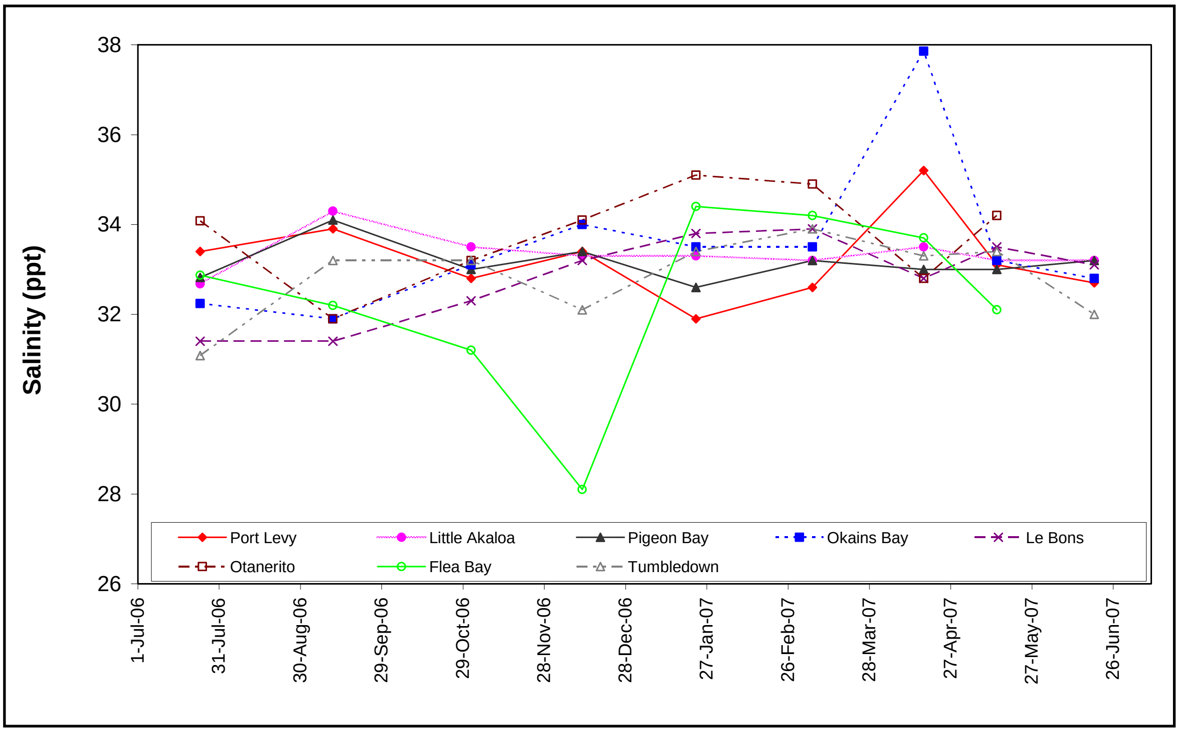

Figure 3.16 Salinity (ppt) in each bay over 2006-2007

3.2.4 Enterococci

Enterococci (faecal indicator organism) concentrations ranged from <1 to 21/100 mL. These concentrations are below the MfE/MoH (2003) alert trigger concentration of 140/100 mL (for contact recreation).

Between sites

Enterococci concentrations were more variable in Okains Bay and Flea Bay than in the other bays (Figure 3.17). There were typically three or fewer enterococci in four of the eight bays sampled.

3.2.5 Water temperature

The water temperature ranged from 8.8 to 19.8 ºC. Lowest temperatures occurred in June and July and highest temperatures occurred in December to February (Figure 3.18).

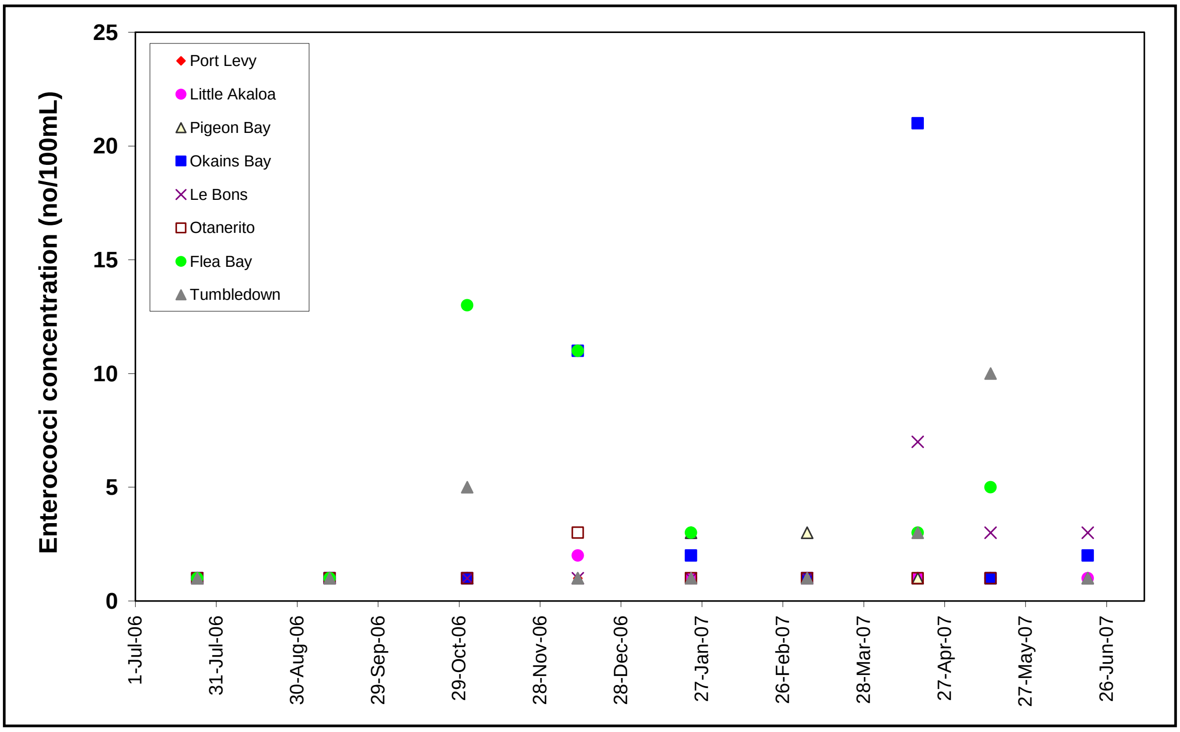

Figure 3.17 Enterococci concentration (no/100mL) in each bay over 2006-2007

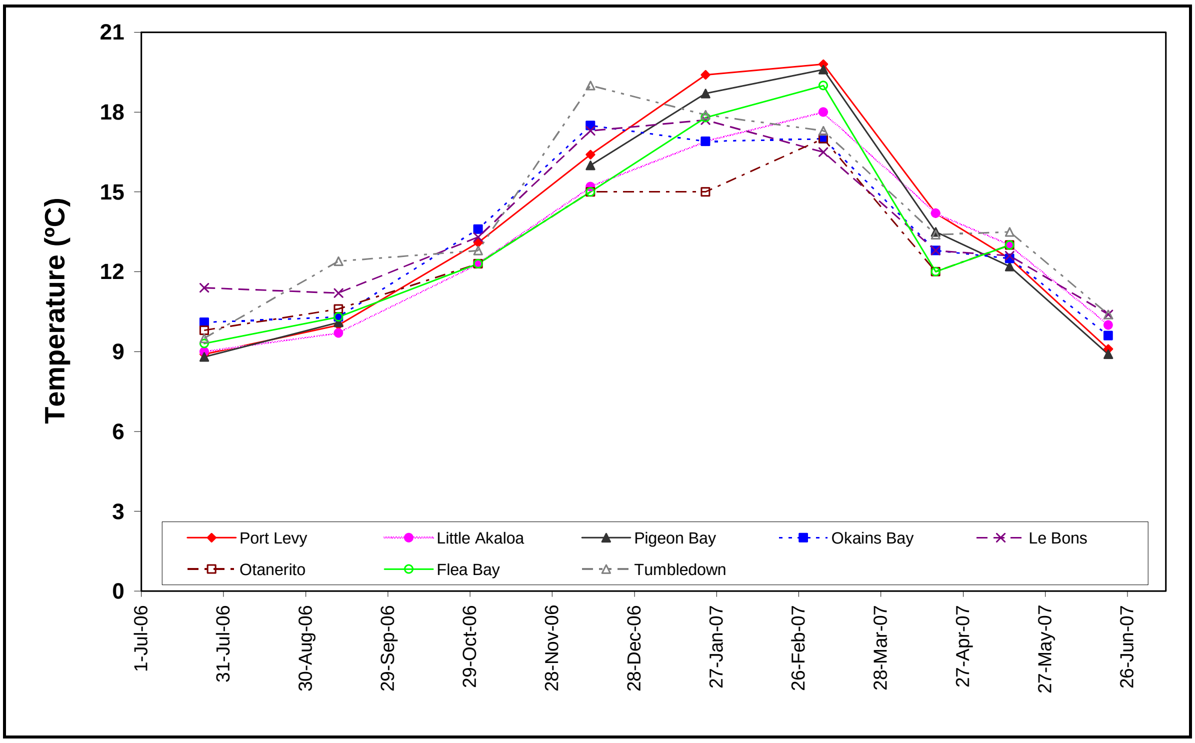

Figure 3.18 Temperature (ºC) in each bay over 2006-2007

3.3 Similarity between bays

MDS ordinations have been used to investigate the similarity in the water quality between bays for each sampling period (Figures 3.19 – 3.21). These plots were based on the average concentrations of:

- the nitrogen-based nutrients
- the phosphorus-based nutrients
- total suspended solids (2006-2007 only)

Interpretation of an MDS ordination is based on the closeness of the sites on the plot. The closer the sites are, the more similar they are with respect to the parameters used to generate the plot. The stress values for the plots below indicate they are a very good representation of the data.

Typically when comparing the water quality at different sites, median concentrations are used. However, the statistical programme used to generate the ordinations does not have the capability of calculating and using median values, hence mean values were used. The mean and median values for each nutrient in each bay are given in Appendix V. Over both time periods the median and mean DRP and TP concentrations in each bay were very similar, i.e. the ordinations based on P-based nutrients are a good indication of the relative similarity in water quality between bays. For N-based nutrients and total suspended solids there were differences between the median and mean concentrations in some bays. Nonetheless the ordinations based on these determinands provide an indication of the similarity in water quality between bays.

2001-2002

N-based nutrients (Figure 3.19)

- Little Akaloa, Okains Bay, Le Bons, Flea and Te Oka Bay were very similar
- Hickory Bay and Otanerito were similar to each other and to the group described above
- Pigeon Bay was different from the other bays.

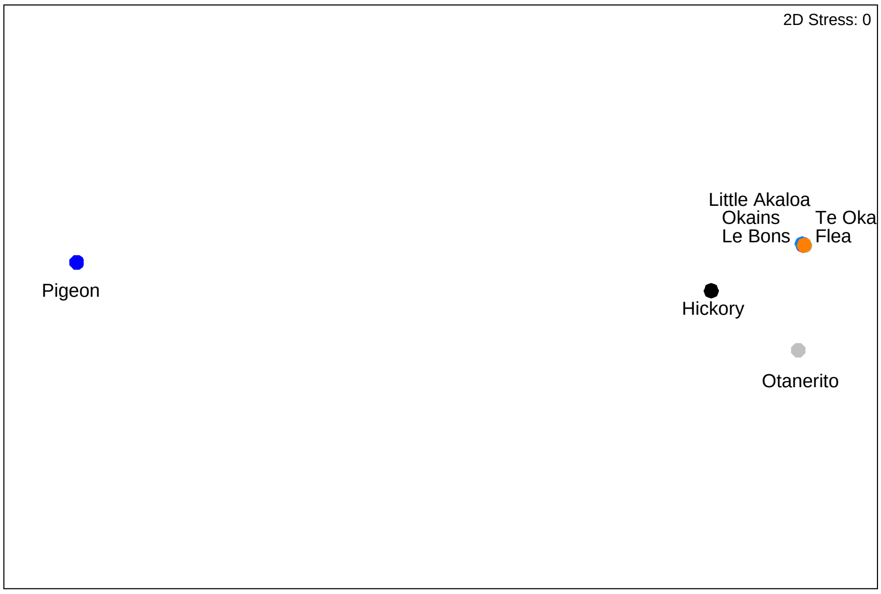

Figure 3.19 Similarity of bays based on N-based nutrient concentrations, 2001-2002

P-based nutrients (Figure 3.20).

- Hickory Bay, Flea Bay and Otanerito were very similar
- Le Bons Bay and Te Oka Bay were very similar
- Little Akaloa and Okains Bay were similar
- Pigeon Bay was the most different of the bays.

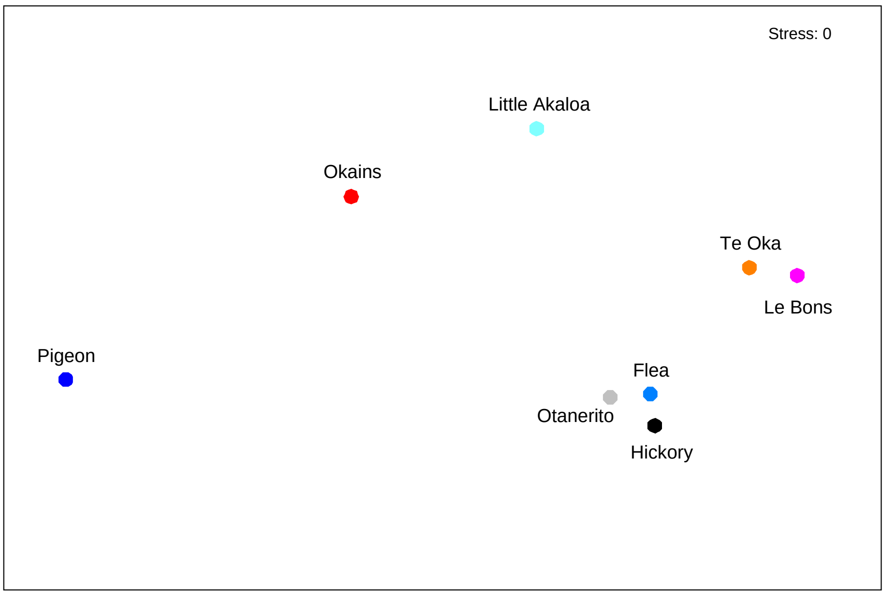

Figure 3.20 Similarity of bays based on P-based nutrient concentrations, 2001-2002

2006-2007

N-based nutrients (Figure 3.21)

- Port Levy and Pigeon Bay were very similar
- Little Akaloa and Tumbledown Bay were similar
- Otanerito and Flea Bay were similar
- Okains Bay and Le Bons Bay were similar but differed from the other bays

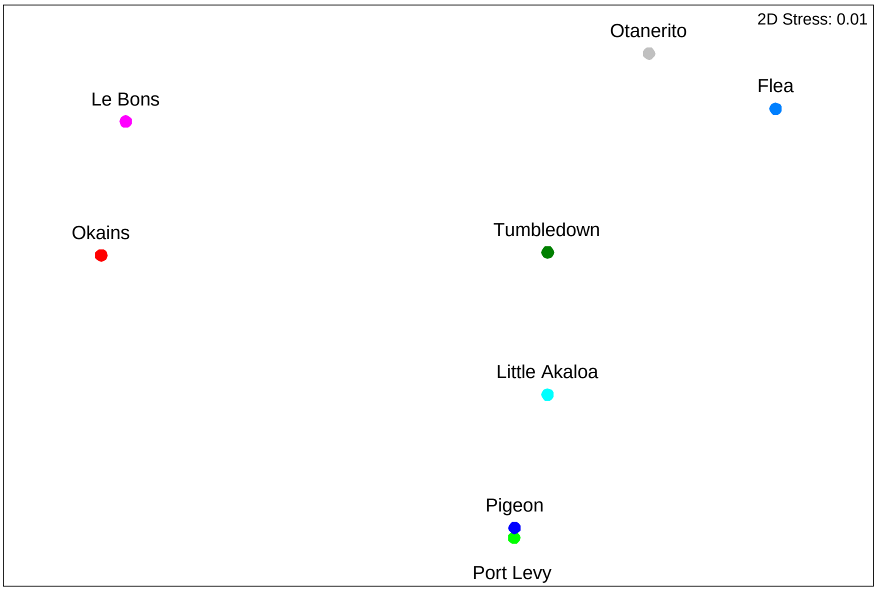

Figure 3.21 Similarity of bays based on N-based nutrient concentrations, 2006-2007

P-based nutrients (Figure 3.22)

- Port Levy and Pigeon Bay were very similar
- Flea Bay and Little Akaloa were similar to Port Levy and Pigeon Bay
- Tumbledown Bay and Otanerito were similar to Flea Bay, Port Levy and Pigeon Bay
- Okains Bay and Le Bons Bay differed from the other bays

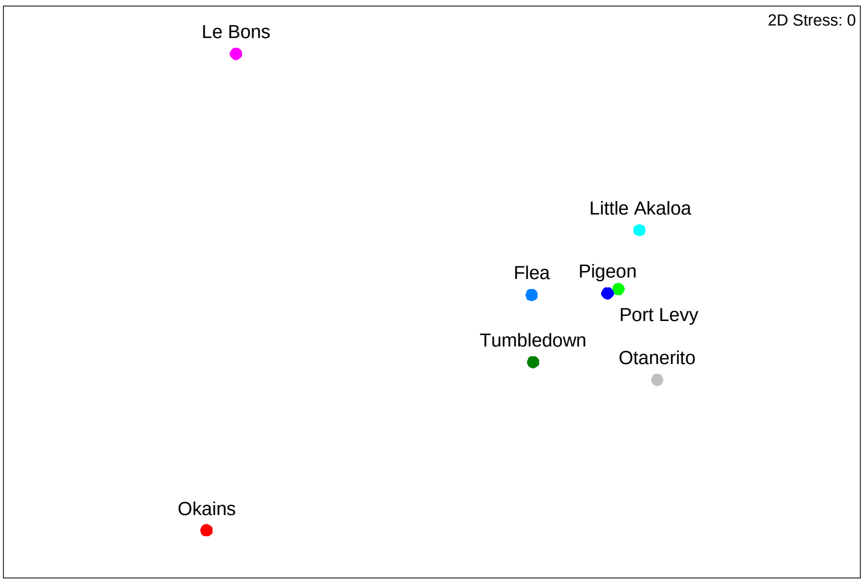

Figure 3.22 Similarity of bays based on P-based nutrient concentrations, 2006-2007

Total suspended solids (Figure 3.23)

- Port Levy, Pigeon Bay and Otanerito were very similar
- Little Akaloa, Flea Bay and Le Bons Bay were similar to each other and to Port Levy, Pigeon Bay and Otanerito
- Okains Bay and Tumbledown Bay were similar but differed from the other bays

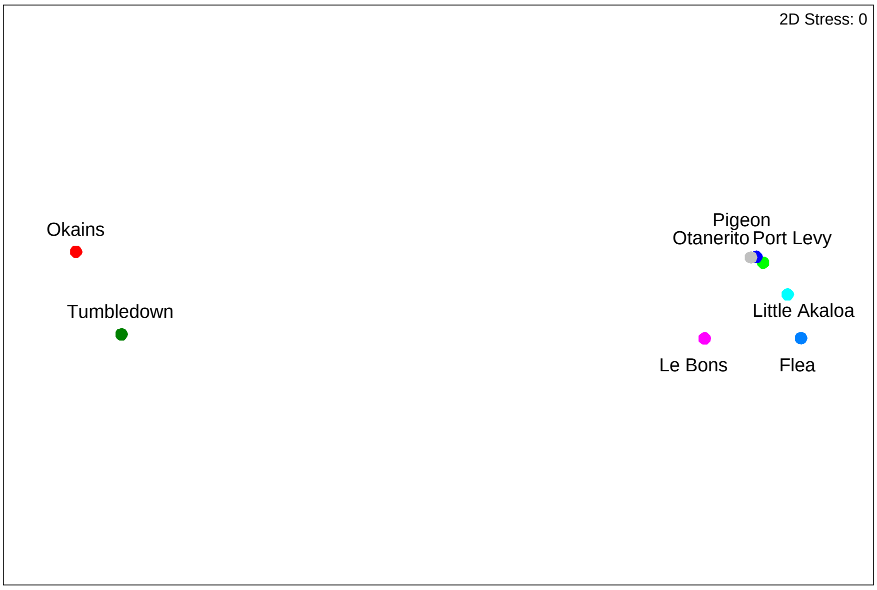

Figure 3.23 Similarity of bays based on total suspended solids concentrations, 2006-2007

3.4 Correlations between determinand concentrations and environmental factors

The correlation between determinand concentrations and four environmental factors was investigated. Within each sampling period the determinand data from all sampling occasions were used. Environmental data for each sampling occasion were extracted from Environment Canterbury environmental databases.

The correlation between the concentrations of each of the determinands to:

- total daily rainfall at Kaituna
- total daily rainfall at Coopers Knob

was investigated for both of the sampling periods.

The correlation between total suspended solid concentrations to:

- median wave height at the wave buoy
- median wave direction at the wave buoy (east of Banks Peninsula)

was investigated for the 2006-2007 sampling period.

For each environmental factor the data from the day of sampling were not taken into account because it takes a period of time for sea water quality to be affected by an environmental factor such as rainfall on land. Hence it was the data from each of days one to five prior to sampling that were used.

3.4.1 Correlation between environmental factors and the determinands

The correlations, between environmental factors and the determinands, with an r^2 value of higher than 0.6 are presented in Appendix VIII.

There were positive correlations between rainfall and NNN concentrations in all bays except Otanerito and Tumbledown Bay. Rainfall up to five days prior to sampling influenced the NNN concentrations in the sea. NNN concentrations in:

- Port Levy and Little Akaloa were correlated to rainfall 4 to 5 days prior to sampling

- Pigeon and Okains Bay were correlated to rainfall 1, 2, 4 or 5 days prior to sampling
- Le Bons Bay were correlated to rainfall 1 day prior to sampling
- Te Oka Bay were correlated to rainfall 1 and 3 days prior to sampling
- Hickory Bay and Flea Bay were correlated to rainfall 1 or 2 days prior to sampling

There was also a correlation between rainfall 4 days prior to sampling and total suspended solid concentrations in Le Bons Bay and Flea Bay.

Total suspended solid concentrations in Flea Bay and Port Levy were correlated to the median wave height at the wave buoy (east of Banks Peninsula). In Flea Bay these correlations were to the wave height 2, 3 and 4 days prior to sampling while in Port Levy they were to the wave height 4 and 5 days prior to sampling. There was no correlation between median wave direction at the wave buoy and total suspended sediment concentrations in any of the bays.

4 Discussion

Banks Peninsula protrudes 45 km off the east coast of the South Island and into the path of the oceanic Southland Current. This current is the northward flow of water along the south eastern coast of the South Island. The core of the current is offshore of the Southland Front (a stable narrow front that separates a band of relatively warm subtropical water inshore on the continental shelf from fresh subantartic water to the east). Off Otago this front is some 35 km from shore while the current extends 130 km from shore and the core of the current 52 km from shore (Sutton, 2003). While the core of the current is some distance from shore there is a coastal current which is the inshore extreme of the Southland Current. As this coastal current flows north up the Canterbury Bight it receives freshwater inputs from the numerous rivers, streams, drains and other discharges into the Bight. In addition, water flows into the Bight from land locked Lake Ellesmere/Te Waihora and Lake Forsyth/Wairewa (just south of the peninsula) when they are opened artificially.

The Southland Current flows around Banks Peninsula following the continental shelf and then forks north of the peninsula to flow in two directions. The actual influence of the Southland Current on water circulation, and hence water quality, around the peninsula has not been established (Reynolds-Fleming and Fleming, 2005). However, many of the drift cards released south of Banks Peninsula were recovered from Pegasus Bay beaches to the north of the peninsula (Carter and Herzer, 1979). This suggests that the influence of the Southland Current does extend all around the peninsula. Close to shore water circulation is a combination of tidal, wind-driven, freshwater and differential heating induced barocline currents in combination with influences from the Southland Current (Reynolds-Fleming and Fleming, 2005). On the open northern coast of Banks Peninsula the net water flow close to shore is north-easterly. This net flow is about 2.6 km/day at a water depth of 4 m depth and 1.4 km/day at a water depth of 8 m (Fenwick *et al.,* 2003). Overall currents along this northern coast are strongly influenced by an east-west (parallel to the general shore orientation) tidal oscillation (Ross and Image, 2001). The mean current speeds are 13 – 14 cm/s, with currents of around 20 cm/s near the headlands that protrude into the tidal stream (Stenton-Dozey *et al.*, 2006). There is no information on currents and net water flow along the open eastern and southern coasts of Banks Peninsula. However, it is assumed that the forcing mechanisms are comparable to those for the northern coast, that is, tides and the inshore component of the Southland Current. Given that there could be different oceanographic conditions north and south of the peninsula and hence differences in nearshore water quality between northern and southern bays and possibly even eastern bays, the MDS ordinations of the bays based on nutrient concentrations (Figures 3.19 – 3.22) were examined. There are no groupings of northern bays, southern bays and eastern bays on these plots, that is, large scale oceanographic conditions do not account for differences in the water quality between bays.

The water circulation within the bays and harbours of the peninsula is predominantly driven by tidal flows and wind. Within Akaroa Harbour strong winds induce a significant surface current either into (southerly) or out of (northerly) the harbour (Heuff *et al.*, 2005a and 2005b). During periods of light winds tidal flows are the dominant forcing mechanism in this harbour. Within Lyttelton Harbour tides, wind and long-term equilibrium mixing processes drive the circulation patterns (Spigel, 1993). Within this harbour the general water circulation is asymmetric and water does not simply flow up and down the harbour rather the tide appears to flood more strongly on the south side of the harbour and ebb more strongly on the north side (Garner and Ridgeway, 1955). Also deduced, but not directly measured, are large scale tidal 'gyres' that flow clockwise on the ebb tide and counter-clockwise on the flood tide in the outer half of the harbour (Curtis, 1985). Water circulation has been investigated in outer Port Levy and Pigeon Bay but not in the other bays in this study. In Port Levy and Pigeon Bay water flow is along the axis of the bay. Within these bays the tidal currents are weaker than on the open coast with the mean current speed near the eastern shore of Port Levy being 8 – 9 cm/s and in the middle of Pigeon Bay being 7 – 8.5 cm/s (Fenwick and Ross, 2002; Ross and Image, 2001). The circulation studies in these bays have found evidence of ‘estuarine circulation’ superimposed on the tidal flow, with water flowing out of the bay at the surface being replaced by inflowing water beneath. For the other bays in this study it is assumed that water circulation driving forces are comparable to those described above.

The water within the bays will consist of oceanic and near shore water mixed with localised freshwater inputs from streams. The concentrations of the nutrients and other determinands within the streams are likely influenced by catchment size and land use. There are no water quality data for the streams within the bays of Banks Peninsula. The impact of the freshwater inputs on sea water quality within a bay will be influenced by determinand concentrations within the freshwater, freshwater volumes and water mixing processes. There is recent flow data for the Okains Bay stream only. Given the paucity of stream water quality and flow data any impact of freshwater on the water quality at the sampling sites in the bays can only be speculated upon.

The bays sampled in this study differed in length and width. These physical attributes can affect water circulation and mixing processes and water residence time within a bay. These in turn influence the quality of the sea water within a bay particularly when there are localised inputs of freshwater, nutrients, sediments and other contaminants. When the sea water remains within a bay for some time and there are no localised nutrient inputs there is the potential for nutrient concentrations to decrease as a result of uptake by the phytoplankton, algae and other aquatic plants. The aspect of the entrance will also influence water mixing processes within a bay and the movement of oceanic and nearshore water into a bay through the action of ocean swells and wind. The influence of these two forces will differ between bays with different entrance aspects. For example, during a south-easterly storm the swell waves will have an unimpeded fetch and roll directly into Hickory Bay, Otanerito and Flea Bay and the wind will funnel up these bays. There will be no such direct impact of a south-easterly storm on other bays, but Te Oka and Tumbledown bays with their south-westerly aspect will bear some brunt of the swell and wind. In a north-easterly the wind will funnel into Little Akaloa and Okains Bay resulting in wind-generated surface water mixing and waves at the beach. Therefore the differences in length, width and aspect between bays could account for some of the differences in water quality between bays. In addition they could also account for differences in water quality over time (between sampling occasions, between years) within a bay.

A comparison of the grouping of the bays based on N and P nutrient concentrations (Figures 3.18 – 3.21) and a grouping of the bays based on bay length, aspect of entrance and bay length and aspect of the entrance combined (Appendix I) does indicate similarities in bay groupings. For example:

1. In 2001-2002 Pigeon Bay was clearly separated from other bays by N and P concentrations (higher concentrations) and bay length.
2. In 2001-2002 Otanerito, Flea Bay and Hickory Bay were grouped together by P concentrations, bay length, aspect of entrance and bay length and aspect of the entrance combined.
3. In 2001-2002 Little Akaloa and Okains Bay were grouped together by N and P concentrations, bay length, aspect of entrance and bay length and aspect of the entrance combined.
4. In 2006-2007 Pigeon Bay and Port Levy were grouped together by N concentrations, bay length and aspect of entrance and bay length and aspect of the entrance combined.
5. In 2006-2007 Pigeon Bay, Port Levy and Little Akaloa were grouped together by P concentrations and aspect of the entrance.
6. In 2006-2007 Otanerito, Flea Bay and Tumbledown Bay were grouped together by P concentrations and aspect of the entrance.
7. In 2006-2007 Le Bons and Okains Bay were grouped together by N concentrations and bay length, aspect of entrance and bay length and aspect of the entrance combined.

These similarities suggest that the nutrient concentrations in the bays were influenced by bay length, width and aspect and hence water circulation, water mixing, water residence time, oceanic swells and wind. However, the processes are complex and considerable quantities of water quality and oceanographic data collected from a number of sites within a bay and over time would be required to investigate these influences further.

The grouping of bays based on the concentrations of N and P nutrients did differ between sampling periods. This indicates that there are also other factors, other than those described above that influence water quality in the bays of Banks Peninsula. These other factors are likely to be rainfall, wind and sea conditions (wave height and wave direction). With significant rainfall comes water runoff from the land resulting in increased volumes of water in the streams flowing into the sea. As this rain flows across pastures and impervious surfaces it picks up nutrients, micro-organisms, soil and other water contaminants. The higher the rainfall the higher the volumes of freshwater flowing into the sea and the greater the potential for the rain to disturb and pick up particles. This typically results in high concentrations of total suspended sediments flowing into the sea. Wind can influence the water circulation and mixing processes thereby indirectly influencing the water quality within a bay. Sea conditions and in particular stormy conditions, when there are high swell waves with an unimpeded fetch, can influence the water circulation and mixing processes, and disturb the seabed thereby indirectly influencing the water quality within a bay.

The correlation of rainfall and sea conditions (wave height and wave direction) to determinand concentrations was investigated. Given that the rainfall on the day of sampling would be unlikely to influence sea water quality, the effect of rainfall on days prior to sampling was investigated. The effect of sea conditions prior to sampling was also investigated given that these factors have an indirect influence on water quality with the influence likely to take a period of time to express itself. In all bays except Otanerito and Tumbledown Bay there was a positive correlation between rainfall 1-5 days prior to sampling (depending on the bay) and NNN concentration. This effect is attributed to the increase in volume of freshwater flowing into the sea via the streams. Rivers and streams are well recognised as contributors of NNN to the sea, for example the Avon and Heathcote Rivers contribute high NNN concentrations to the Avon-Heathcote Estuary/Ihutai (Bolton-Ritchie and Main, 2005). There was also a positive correlation between rainfall four days prior to sampling and total suspended solid concentrations, in Le Bons Bay and Flea Bay. This suggests that over 2006-2007, notably in these two bays, rainfall moved quantities of soil off the land and into the sea.

There were positive correlations between wave height and total suspended solid concentrations in Flea Bay and Port Levy. That is, lowest suspended sediment concentrations occurred when the waves were low with concentrations increasing with increasing wave height. This is attributed to the disturbance and hence re-suspension of seabed sand and mud particles into the water column by wave action. The correlation of suspended sediment concentrations to wave height is an obvious correlation but it is puzzling that this correlation only occurred in two of the bays with a sandy beach. It should be noted that some of the bays have cobble/rock beaches with the cobble/rock likely to extend some distance from shore and hence there is not the quantity of sand or mud particles as occurs in some bays. This could well explain why there was no correlation between total suspended sediment concentrations and wave height in these bays. It is difficult to account for the Port Levy correlation as this is a long bay where the site within the inner bay would not receive the brunt of southerly storm waves. However, northerly generated waves would affect inner Port Levy as they have a long fetch.

The correlations discussed above provide an indication of factors affecting the water quality in the bays of Banks Peninsula. However, these correlations were based on limited data. More water quality data, including sampling over a range of rainfalls, wind directions and wave directions, are required to get more accurate information on the impacts of these environmental factors on the water quality in these bays.

Median nutrient concentrations in the bays were compared to those reported from other areas of the Canterbury Coast (Bolton-Ritchie, 2004, 2005, 2006, 2007). The results from the other areas are for different year long periods, not 2001-2002 and 2006-2007. This is a very general comparison as the data in this study indicate that median concentrations do vary between sampling periods (Appendix IV).

- The median NH_3N and NNN concentrations were comparable to those at sites along the Kaikoura Coast, the Hurunui Coast, Pegasus Bay and around Timaru but were higher than those in Lyttelton and Akaroa harbours.
- The median TN concentrations over 2001-2002 were comparable to those at sites along the Kaikoura Coast, the Hurunui Coast, Pegasus Bay and around Timaru but were higher than those in Lyttelton and Akaroa harbours. The median TN concentrations over 2006-2007 were comparable to those at sites in Akaroa and Lyttelton harbour and at sites along the Kaikoura Coast, Pegasus Bay and around Timaru.

- The median DRP concentrations were comparable to those at sites in inner Akaroa Harbour, all sites in Lyttelton Harbour and at some sites along the Kaikoura Coast, the Hurunui Coast, Pegasus Bay and around Timaru.
- The median TP concentrations in the eastern and southern bays over 2001-2002 were low compared those at other Canterbury coast sites. All other median TP concentrations were comparable to those at sites in Akaroa and Lyttelton harbour and at sites along the Kaikoura Coast, Pegasus Bay and around Timaru.

Ammonia nitrogen can be toxic to marine life at high concentrations. Hence recorded concentrations were compared to ANZECC (2000) trigger values. All concentrations were below the ANZECC (2000) trigger value (0.5mg/L) providing protection for 99% of marine species and therefore are unlikely to affect marine life. No other determinand concentrations were compared to ANZECC (2000) values as there are no New Zealand specific trigger values.

Chlorophyll-a concentration is a proxy value for the concentration of phytoplankton and hence is also an indicator of primary productivity. The chlorophyll-a concentrations ranged from 0.2 to 9.2 µg/L. Is possible that the concentration of 9.2 µg/L in Le Bons Bay on 23 January 2007 and the concentration of 5.5 µg/L in Port Levy on 7 March 2007 caused some discolouration of the water as a chlorophyll-a concentration of 5 µg/L has been found to cause physical discolouration of surface waters (Eppley *et al*., 1977). In general the highest concentrations occurred over mid-late spring, summer and early-mid autumn and the lowest concentrations occurred in winter. Phytoplankton abundance is seasonal because it is influenced by water temperature and light. Weather and sea conditions, dissolved nutrient concentrations, the N:P ratio and the availability of other chemicals such as silica and iron (ANZECC, 2000) also influence phytoplankton abundance and persistence.

Enterococci concentrations are used as an indicator of faecal contamination of sea water. The sources of faecal contamination within the bays are likely to be livestock, birds and possibly septic tanks. The enterococci concentrations ranged from <1 to 21/100 mL. These are low concentrations and indicate that there is typically little or no faecal contamination of the sea water within the bays. It has been found that at coastal sites in close proximity to a freshwater source, enterococci concentrations can be in the thousands after heavy rainfall. There was no heavy rainfall on any of the sampling days and only on the 1 November, 2006 was there heavy rainfall 2 days prior to sampling. That is, the data collected do not allow for an assessment of the impact of rainfall on enterococci concentrations in the sea water in these bays.

The salinity that was recorded ranged from 28.1 to 37.86 ppt. A salinity of 37.86 ppt is an anomaly and cannot be explained. The salinity of sea water is typically around 34- 35 ppt with the sea water in Pegasus Bay some 2.8 km from shore being 34.1 ppt (Zeldis and Gall, 1999) and 10 km from shore being 34.5 ppt (Stenton-Dozey, 2005). Concentrations lower than 34 ppt occur when there is dilution of the sea water by fresh water. The median salinity in the bays was typically 33 - 33.3 ppt but the median in Flea Bay was 32.5 ppt while in Otanerito it was 34.01 ppt. For all bays except Otanerito, these median results indicate that the nearshore water in the bays is typically slightly diluted sea water. The lowest recorded salinity of 28.1 ppt was in Flea Bay. The rainfall data for up to 5 days prior to this result indicate that the low salinity was not caused by recent rainfall. However, large volumes of water (1037 cumecs) flowed from the Rakaia River (some 66 km from Flea Bay) twelve days prior to sampling. The mean flow of the Rakaia River is 221 cumecs. That is, the low salinity in Flea Bay could be due to the influence of Rakaia River water on the water in this bay. The volumes that flowed from the Rakaia River prior to other sampling occasions were typically around or below mean values. Patches of low salinity water have been recorded in outer Akaroa Harbour with these salinities considered to be due to the influence of the Rakaia River (Grange, 2000). Freshwater from the Rakaia River has been found to intrude into Akaroa Harbour after periods of heavy rainfall (Heuff *et* al, 2005).

There were significant differences in determinand concentrations between some of the bays over both periods of sampling. These differences are likely to be due to a range of factors including those already discussed above. In addition, the number and or size (and hence volumes) of the streams discharging into a bay and catchment attributes such as type and amount of livestock and area of active erosion will have influenced the spatial differences. For example:

- Over 2006-2007 NNN concentrations were higher in Le Bons Bay and Okains Bay than in Pigeon Bay and Little Akaloa. The Opara stream in Okains Bay and the Le Bons Stream in Le Bons Bay are bigger than the streams in Little Akaloa and Pigeon Bay. Thus differences in the volume of freshwater inputs likely account for the differences in concentrations between bays given streams are a significant contributor of NNN to the sea.

- Over 2006-2007 NH_3N concentrations were lower in Otanerito than in three of the other bays. NH_3N is a breakdown product from sewage, animal effluent and other organic matter. The hillsides of Otanerito are forest covered while those in the other bays are not. This suggests that in Otanerito there is little, if any livestock effluent reaching the sea in this bay.
- Over 2001-2002 DRP and TP concentrations were higher in Pigeon Bay than in four (DRP) to all (TP) of the bays sampled. The volcanic soils of Banks Peninsula contain high concentrations of phosphorus with streams the conduit of this phosphorus to the sea (Bolton-Ritchie, 2004 and Bolton-Ritchie, 2005). These 2001-2002 results suggest may have been more erosion in Pigeon Bay than in other bays over this time period. There are no suspended sediment data to back up this statement.

Over 2001-2002 there were typically fewer significant differences in the concentration of nitrogen-based nutrients between bays than over 2006-2007. This is attributed to the high variability in the concentration of these nutrients in some or all of the bays over 2001-2002 (Figures 3.1, 3.3 and 3.5) but not over 2006-2007. The occurrence of, in particular, high concentrations of nutrients can be seen in Figures 3.2, 3.4 and 3.6. Analysis of high nutrient concentrations on specific 2001-2002 sampling occasions reveals that:

- heavy rainfall prior to the 23rd of January, 7th of February and 19th of June 2002 likely accounts for the high concentrations of NNN, NH_3N and TN in one or more of the bays.
- rainfall prior to the 13th of December 2001 and 9th of January could account for the high concentrations of TN and TP in Pigeon Bay in particular.

However, rainfall does not account for the high NH_3N concentrations in Hickory Bay on 17 April 2002 or the high DRP concentrations on 13 March 2002 in Okains and Pigeon bays. There are no obvious explanations for the high values on these sampling occasions. The high NNN and DRP concentrations on various occasions over the summer and early autumn of 2001-2002 mask any seasonal patterns in concentrations. There were seasonal patterns in NNN and DRP concentrations over 2006-2007.

There were occasional high concentrations of some nutrients over 2006-2007 with a high:

- NH_3N concentration in Okains Bay on 17 April 2007.
- DRP concentration in Le Bons Bay on 23 January 2007.
- TP concentrations in Flea and Tumbledown bays on 11 September 2006
- TP concentrations in Okains Bay on 24 July and 1 November, 2006.

Heavy rainfall, 4 and 5 days prior to 24 July and 1 day prior to 1 November, likely account for the high TP concentrations in Okains Bay. Rainfall does not account for the high nutrient concentrations on other occasions nor do the other investigated environmental factors. However, as TP concentrations can be influenced by suspended sediment concentrations it is possible that the TP results for 11 September (Flea and Tumbledown bays) are due to the re-suspension of sea bed sediment by the high waves (3.3 m at the wave buoy) from slightly west of south (around 190 degrees) on the day of sampling. The other results suggest localised inputs on nutrients. It is possible that the high DRP in Le Bons Bay in January was as a result of seepage from the numerous septic tanks from the settlement just behind the beach. While some of the residents in this settlement are permanent, many are holiday makers. This results in a large increase in the number of occupants over the holiday period and hence an increase in the volume of septic tank seepage. At the same time as the peak in DRP concentration in Le Bons Bay on 23 January 2007 there was also a notable peak in chlorophyll-a concentration. That is, the elevated DRP concentration could have stimulated phytoplankton growth in the bay. There is no obvious explanation for the high concentration of NH_3N concentration in Okains Bay on 17 April 2007.

The total suspended sediments concentrations were highly variable. In Okains Bay on 7 of 9 and in Tumbledown Bay on 6 of 9 sampling occasions the results were high. There are no data on the type/source of sediment particles present within the water column, i.e. from the seabed or from the land, when concentrations were high. The high total suspended sediment concentrations could have been caused by a combination of environmental factors including rainfall, wave height, wave direction and possibly wind direction. However, there was no correlation of suspended sediment concentrations in these two bays to rainfall, wave height and wave direction. This suggests that the causal factor and hence the source of the sediment differed between sampling occasions.

5 Conclusions

The objectives of this report were to document the water quality in representative bays of Banks Peninsula and investigate:

- if there was a significant difference in water quality between bays.
- differences in water quality between sampling periods.
- factors that may account for any differences in water quality between bays and between sampling periods.

Water quality of selected bays of Banks Peninsula
Median concentrations of the nutrients were typically comparable to those reported from sites north and south of Banks Peninsula.

The median concentrations of ammonia nitrogen (NH_3N) and nitrate-nitrite nitrogen (NNN) in the bays were higher than those reported from Lyttelton and Akaroa harbours. Median dissolved reactive phosphorus (DRP) concentrations in the bays were comparable to those reported from sites in inner Akaroa Harbour and all sites in Lyttelton Harbour. For total nitrogen (TN) median concentrations over 2001-2002 were higher than, while those over 2006-2007 were comparable to, those reported from Lyttelton and Akaroa harbours. For total phosphorus median concentrations in the eastern and southern bays over 2001-2002 were low, while all other concentrations were comparable to, those reported from Lyttelton and Akaroa harbours.

NH_3N has the potential to be toxic hence concentrations were compared to the ANZECC (2000) trigger values. All concentrations were below the ANZECC (2000) trigger value (0.5mg/L) providing protection for 99% of marine species. No other determinand concentrations were compared to ANZECC (2000) values as there are no New Zealand specific trigger values.

The low concentrations of the faecal indicator organism enterococci indicate that there is typically little or no faecal contamination of the sea water within the bays.

Significant difference in water quality between bays
There were significant differences in NH_3N, NNN, TN, DRP, TP, chlorophyll-a and total suspended solid concentrations and salinity between two or more of the bays. Analysis of the influence of oceanographic and other factors including bay length, bay width, aspect of the entrance, rainfall, wave height and wave direction on the water quality within the bays indicate that some of the differences between bays are likely as a result of localised effects including inputs and water mixing processes. Therefore the differences in the concentrations of nutrients, sediment and salinity between bays may be due to:

- differences in the volumes of freshwater flowing into the bays via the streams;
- differences in land use within a catchment, for example grazing compared to forest covered;
- differences in the area of active erosion scars.

Differences in water quality between sampling periods
There was considerable variability in NH_3N, NNN, TN, DRP, TP, chlorophyll-a, total suspended sediment and salinity concentrations between sampling occasions. This variability suggests that concentrations are influenced by a range of factors.

Differences in the sample collection method and location of sampling sites within a bay precluded statistical analysis for significant differences between sampling periods.

Factors that may account for differences in water quality between bays and between sampling periods
The similarity between the grouping of some of the bays based on bay length and/or aspect of the entrance and their groupings based on the concentrations of N and/or P based determinands suggests that water circulation and mixing processes within a bay influence nearshore nutrient concentrations.

Rainfall has a significant impact on the nearshore water quality. Using correlations it was determined that rainfall affects nearshore NNN concentrations and can also influence nearshore total suspended sediment concentrations. Notable high concentrations of NH_3N, NNN, TN and TP occurred in one or more bays after heavy rainfall.

Seabed re-suspension by wave action is a contributor of sediment to the water column in some of the bays.

High volume flows from the Rakaia River some 66 km south of the peninsula, can affect the salinity of southern bays, and hence also likely influences other water quality parameters in these bays.

6 Future investigations and monitoring

To assess the quality of the sea water in the Banks Peninsula bays and determine if it is changing, there must at least be routine water sampling for a year, every five years. This monitoring should be for all the determinands measured over 2006-2007. At least two more year-long data sets should be collected before another water quality report is produced. The data collected will allow for an assessment of possible seasonality of determinands, the relationships between nutrient concentrations and primary productivity, nutrient concentrations and sediment loads in the water column and impacts of rainfall, sea conditions, river flows and wind on nutrient concentrations.

There is a need to investigate the effect of localised freshwater inputs on sea water quality in selected bays. To this end stream nutrient concentrations and stream flow data should be collected on the same day as the sea water sampling.

To investigate the impact of rainfall, wind direction and sea conditions on determinand concentrations in the bays of Banks Peninsula more data are required. Such data collection needs to include the collection of water quality data over a range of rain falls, wind directions and sea conditions.

7 Acknowledgements

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Appendix I: Details on each of the bays sampled

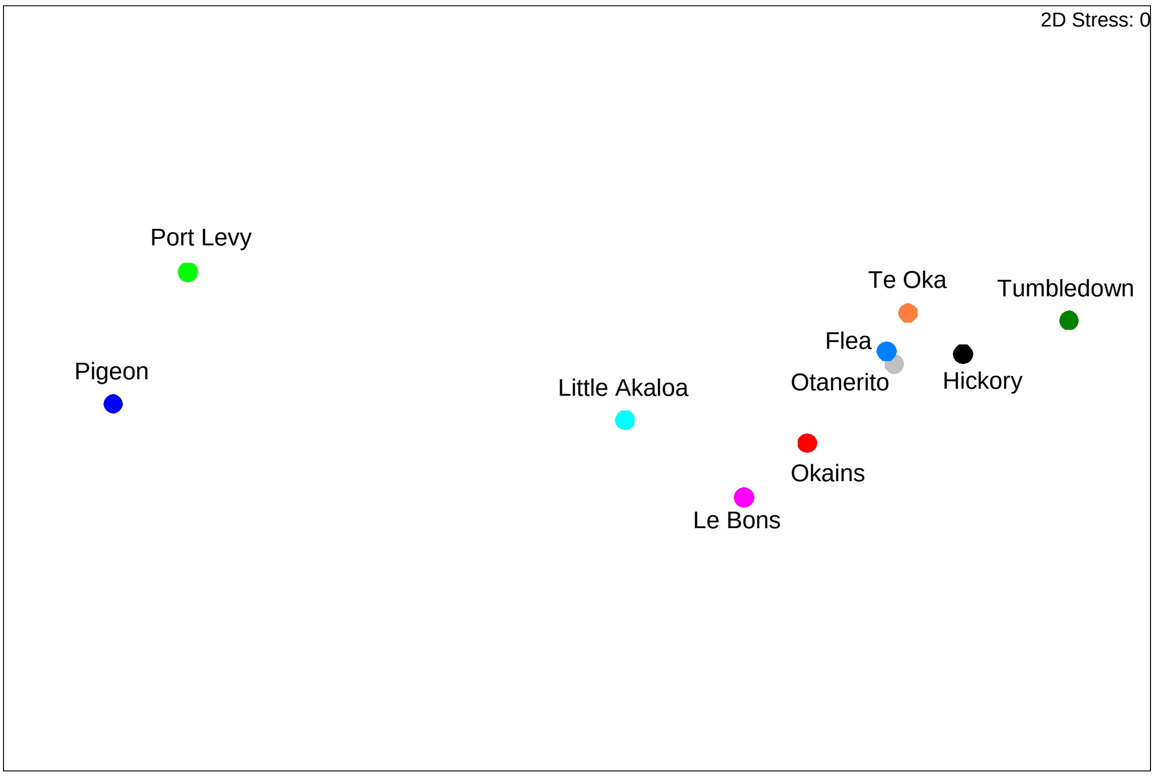
Bay	Length (m)	Width (m)	Aspect of entrance	Waterways in inner bay	Land use in bay	Other
Port Levy	6500	640-1600	North	7 small streams	Settlement in south-western corner of the inner bay. Head of the bay and hillsides are farmland with farm houses and farm buildings dotted around the bay.	Mussel farming in the outer bay
Pigeon Bay	7200	950-1500	North north-east	2 small streams	Small camping ground in south-western corner of the inner bay. Head of the bay and hillsides are farmland with farm houses and farm buildings dotted around the bay.	Mussel farming in the outer bay
Little Akaloa	3200	410-850	North-east	4 small streams	Settlement around the waterfront in the inner bay. Most of the bay is farmland with farm houses and farm buildings dotted around the bay.	
Okains Bay	2300	1400-2000	North-east	1 large stream	Large camping ground behind the beach. Most of the bay is farmland with farm houses and farm buildings dotted around the bay.	
Le Bons Bay	2500	700-950	East north-east	1 large stream	Settlement along the waterfront in the inner bay. Most of the bay is farmland with farm houses and farm buildings dotted around the bay.	
Hickory Bay	1400	820-1500	East south-east	1 small stream	Farmland with a farm house and farm buildings.	
Otanerito	1600	310-620	South-east	1 small stream	A nature reserve consisting of bush covered hillside. Some farmland with farm houses and farm buildings.	
Flea Bay	1600	350-500	South-east	2 streams	Farmland with a farmhouse and farm buildings.	The whole bay is a marine reserve
Te Oka Bay	1500	260-520	South-west	1 small stream	Farmland with farmhouses and farm buildings.	
Tumbledown Bay	700	220-380	South-west	1 small stream	Farmland	

MDS plots showing similarity between bays based on bay length and aspect of entrance

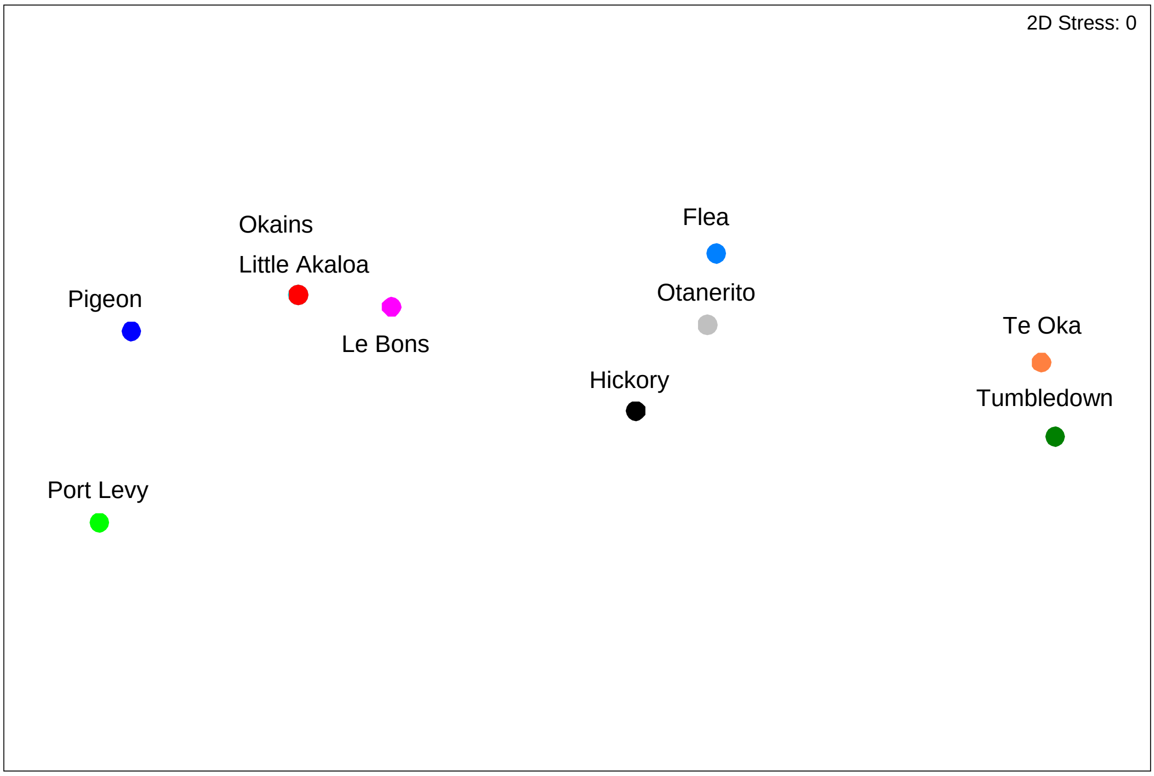
To generate these (MDS) ordination plots the Euclidean distance measure was applied to the data to produce a similarity matrix. From this similarity matrix a 2-dimensional non-metric MDS ordination of samples and sites was generated.

Interpretation of an MDS ordination is based on the closeness of the sites on the plot. The closer the sites are, the more similar they are with respect to the parameters used to generate the plot.
For each plot a stress value (goodness-of-fit) is given. Stress is a measure of the accuracy of the 2-dimensional ordination of points on the MDS plot in representing the actual values in the similarity matrix (Clarke and Warwick, 2001). The low stress values for all these plots indicate that these ordinations are a very good representation of the data.

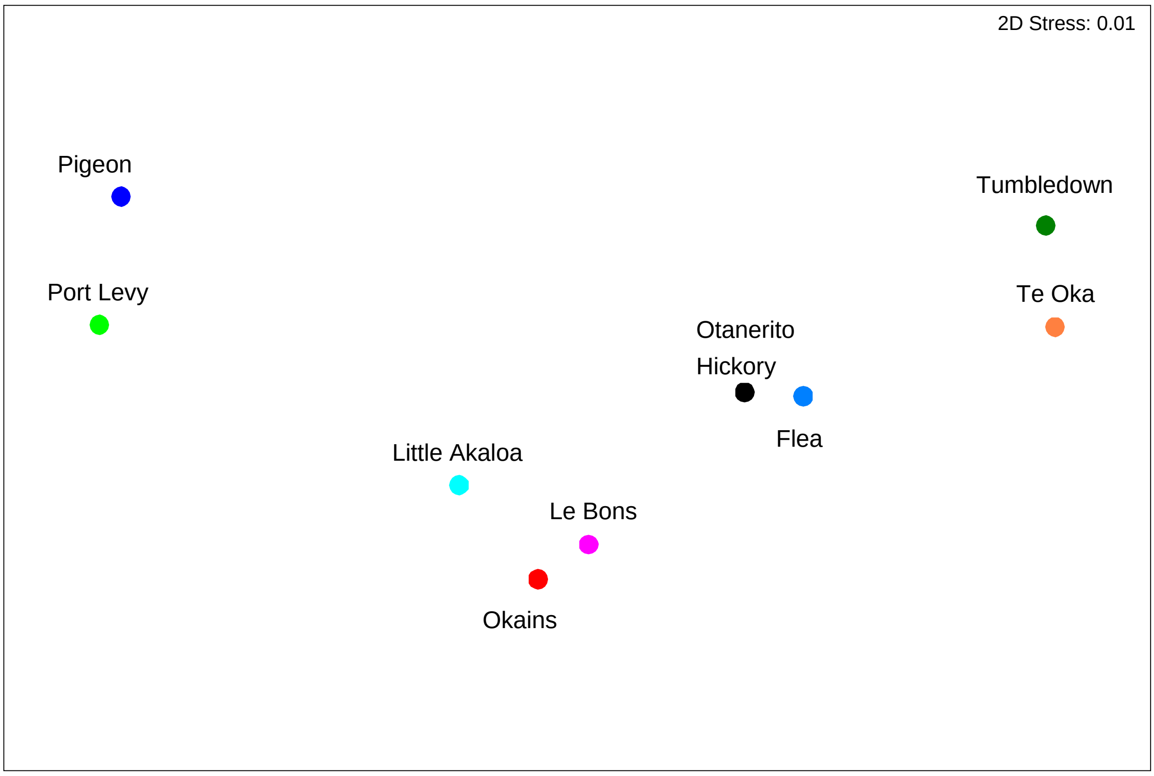
Bay Length



Bay Aspect



Bay Length and Aspect



Appendix II: Details of the sampling sites

Site ID	Site description	Sampling period	Easting	Northing
SQ303179	Port Levy, off jetty on south side (Puari)	2006-2007	2496800	5728900
SQ302699	Pigeon Bay out from jetty, behind breakers	2001-2002	2502000	5725300
SQ305049	Pigeon Bay, off jetty	2006-2007	250196	5725460
SQ302602	Little Akaloa Beach opposite toilets, behind breakers	2001-2002	2509400	5725800
SQ303255	Little Akaloa Bay, off jetty	2006-2007	2509600	5726400
SQ302604	Okains Bay middle of beach, behind breakers	2001-2002	2515000	5723600
SQ305050	Okains Bay middle of sandy beach, waters' edge	2006-2007	2515220	5723520
SQ302606	Le Bons Bay beach opposite domain, behind breakers	2001-2002	2517800	5718300
SQ305051	Le Bons Bay middle of sandy beach, waters' edge	2006-2007	2517760	5718450
SQ304489	Hickory Bay mid bay	2001-2002	2519000	5714200
SQ304490	Otanerito Bay mid bay	2001-2002	2515000	5707300
SQ305052	Otanerito Bay middle of sandy beach, waters' edge	2006-2007	2514630	5707840
SQ304491	Flea Bay mid bay	2001-2002	2511000	5703500
SQ305053	Flea Bay middle of gravel beach, waters' edge	2006-2007	2510450	5704400
SQ304492	Te Oka Bay mid bay	2001-2002	2492400	5705500
SQ305055	Tumbledown Bay middle of gravel beach, waters' edge	2006-2007	2491550	5705830

Appendix III: Description and ecological impact of determinands

Phosphorus

Phosphorus occurs in natural waters almost solely as phosphates. These are classified as orthophosphates, condensed phosphates and organically bound phosphates. They occur in solution, in particles or detritus, or in the bodies of aquatic organisms. Phosphorus is essential to the growth of organisms and, particularly in fresh water, can be the nutrient that limits the primary productivity of a body of water. In instances where phosphate is a growth-limiting nutrient, the discharge of raw or treated wastewater, agricultural drainage, or certain industrial wastes to that water may stimulate the growth of phytoplankton, algae and other aquatic plants to nuisance quantities. Phosphates also occur in bottom sediments and in biological sludges, both as precipitated inorganic forms and incorporated into organic compounds (APHA, 1998).

Dissolved reactive phosphorus is a form of dissolved phosphate (orthophosphate) that is available immediately for plant and algal growth. **Total phosphorus** is a measure of the concentration of orthophosphates, condensed phosphates and organically bound phosphates in the water. This includes both dissolved and suspended phosphates.

Nitrogen

In water, the forms of nitrogen of greatest interest are, in order of decreasing oxidation state, nitrate, nitrite, ammonia, and organic nitrogen. All these forms of nitrogen, as well as nitrogen gas (N_2) and dinitrogen oxide (N_2O), are biologically interconvertible and are components of the nitrogen cycle (APHA, 1998).

The nitrate ion (NO_3^-) is the common form of combined nitrogen found in natural waters. It may be biochemically reduced to nitrite (NO_2^-) by denitrification processes, usually under anaerobic conditions. The nitrite ion is rapidly oxidised to nitrate (Chapman, 1992). **Nitrate and nitrite-nitrogen** (NNN, also called total oxidised nitrogen) is the sum two oxidised forms of inorganic nitrogen. It is reported in terms of the sum of concentration of nitrogen that was in the forms of nitrate and nitrite.

Ammonia occurs naturally in water bodies arising from the breakdown of nitrogenous organic and inorganic matter in soil and water, excretion by biota, reduction of the nitrogen gas in water by micro-organisms and from gas exchange with the atmosphere. It is also discharged into water bodies by some industrial processes and as a component of municipal or community waste (Chapman, 1992). Compared to nitrate, ammonia is usually a very minor component of plant available nitrogen. The main concern with ammonia concentrations in water bodies is toxicity effects on aquatic ecosystems. In water ammonia occurs in two forms; the ammonium ion (NH_4^+) and un-ionised ammonia (NH_3). The proportion of these chemical forms is dependent on the pH, temperature and ionic composition of the water. The un-ionised form of ammonia (NH_3) is the most toxic, although toxicity effects also occur with the ammonium ion (ANZECC, 2000). Measurement of ammonia concentrations usually measures total ammonia (NH_3+ NH_4^+).

Dissolved inorganic nitrogen is a measure of the nitrogen available to plants, and is the sum of the concentrations of nitrate and nitrite-nitrogen and ammonia nitrogen. Nitrogen is essential to the growth of organisms and, particularly in sea water, can be the nutrient that limits the primary productivity of a body of water. In instances where nitrogen is a growth-limiting nutrient, the discharge of raw or treated wastewater, agricultural drainage, or certain industrial wastes to that water may stimulate the growth of phytoplankton, algae and other aquatic plants to nuisance quantities.

Total nitrogen is a measure of all nitrogen in the water; both inorganic and organic nitrogen forms.

Chlorophyll-a

Chlorophyll-a concentration is used as a measure of the amount of plant plankton (phytoplankton) in the water, i.e., the more plant plankton in the water the higher the chlorophyll-a concentration. Chlorophyll-a concentration of 5 µg/L has been found to cause physical discolouration of surface waters (Eppley *et al*., 1977). High chlorophyll-a concentrations occur when there is a phytoplankton bloom.

Total suspended solids

Total suspended solids (TSS) are sediment particles of all sizes within the water column. These particles can originate from nearby land or the seabed. The particles that originate from the land are generally washed into waterways during rainfall and from there flow into the sea. Factors that can contribute to high TSS concentrations in the streams include bank erosion due to lack of vegetation and/or stock trampling, soil erosion due to vegetation clearance, and earthworks. Sediment particles from the seabed can be stirred up by swell waves or wind induced waves.

Contaminants such as nutrients and heavy metals attach to fine sediment particles and are washed into the stream and then the sea where they settle to the seabed with the sediment or detach and become soluble in the water column.

Salinity

This is a measure of how salty the water is. The sea water 2.5 to10 kilometres from shore in Pegasus Bay typically has a salinity of 33 -34.5 ppt (parts per thousand).

Enterococci

Enterococci are used as an indicator of the potential presence of faecal matter in seawater. The presence of high concentrations of enterococci in water indicates the likely presence of faecal material and, with it, the possibility that other disease-causing organisms may be present. Faecal contamination of waters can occur through inadequately treated sewage, stormwater drains, septic tanks, runoff from pastoral farm land, and from wildlife such as waterfowl living in and around waterways.

Determinand	Potential effect on aquatic ecosystems
Salinity	Can decrease species diversity and health
Nutrients (nitrogen and phosphorus compounds)	Contributes to phytoplankton, algae and aquatic plant growth which can result in blooms. Some blooms can be toxic. As the polific plant life starts to decay the dissolved oxygen in the water gets used up - results in anoxic conditions. Most animals cannot live in anoxic conditions. NH_3N can be toxic to certain biota
Suspended sediments	Change to optical properties, reduction in photosynthesis and hence primary productivity. Affect the behaviour of fish and macroinvertebrates, especially the migratory and predatory species. The settling of sediment particles to the seabed can smother habitats and biota.
Enterococci	Can affect the quality of shellfish for human consumption Indicator of other faecal contaminants

Appendix IV: Details of the analyses, Environment Canterbury Laboratory

Determinand	Analytical method	Detection limit	Units
Nitrate-nitrite nitrogen (NNN)	APHA 4500-NO3 F (autoanalyser)	0.005	mg/L
Ammonia nitrogen (NH_3N)	APHA 4500 NH3-F	0.005	mg/L
Total nitrogen (TN)	APHA 4500-N C	0.08	mg/L
Dissolved reactive phosphorus (DRP)	APHA 4500 P B F (autoanalyser)	0.001	mg/L
Total phosphorus (TP)	APHA 4500-P B	0.008	mg/L
Chlorophyll-a	APHA 10200	0.2	ug/L
Total suspended solids (TSS)	APHA 2130 B	0.1	mg/L
Enterococci	EPA 1600	1	CFU/100mL

Appendix V: Summary of nutrient concentrations

2001- 2002

n = number of samples (one sample per sampling occasion)

2001-2002	Pigeon Bay	Little Akaloa	Okains Bay	Le Bons Bay	Hickory Bay	Otanerito	Flea Bay	Te Oka Bay
Ammonia nitrogen (mg/L)								
Minimum	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005
Median	0.071	0.035	0.042	0.055	0.042	0.067	0.040	0.063
Mean	0.075	0.052	0.051	0.055	0.061	0.072	0.055	0.056
SD	0.051	0.047	0.041	0.047	0.053	0.055	0.059	0.044
Maximum	0.15	0.15	0.14	0.14	0.16	0.16	0.17	0.13
Nitrate-nitrite nitrogen (mg/L)								
Minimum	< 0.005	< 0.005	0.006	< 0.005	0.005	0.009	0.007	<0.005
Median	0.012	0.013	0.015	0.025	0.036	0.034	0.029	0.029
Mean	0.063	0.036	0.024	0.029	0.062	0.033	0.036	0.035
SD	0.131	0.049	0.017	0.023	0.103	0.016	0.029	0.028
Maximum	0.45	0.13	0.055	0.074	0.35	0.062	0.081	0.096
Total nitrogen (mg/L)								
Minimum	0.140	0.130	0.170	0.140	0.160	0.140	0.150	0.090
Median	0.370	0.300	0.250	0.230	0.215	0.215	0.215	0.235
Mean	0.429	0.286	0.281	0.243	0.223	0.241	0.220	0.263
SD	0.223	0.099	0.102	0.082	0.042	0.095	0.052	0.129
Maximum	0.740	0.450	0.520	0.400	0.300	0.470	0.340	0.530
Dissolved reactive phosphorus (mg/L)								
Minimum	0.012	0.004	0.009	0.001	0.005	0.010	0.009	0.004
Median	0.021	0.013	0.013	0.013	0.015	0.014	0.014	0.015
Mean	0.023	0.015	0.018	0.012	0.015	0.016	0.015	0.013
SD	0.010	0.007	0.013	0.005	0.005	0.004	0.007	0.005
Maximum	0.046	0.025	0.054	0.017	0.023	0.022	0.033	0.018
Total phosphorus (mg/L)								
Minimum	0.025	0.013	0.013	< 0.008	0.010	0.012	< 0.008	< 0.008
Median	0.039	0.031	0.023	0.019	0.018	0.017	0.018	0.019
Mean	0.052	0.028	0.029	0.020	0.017	0.018	0.018	0.020
SD	0.041	0.010	0.016	0.009	0.004	0.005	0.009	0.012
Maximum	0.17	0.041	0.059	0.035	0.023	0.029	0.035	0.037
n	11	11	11	11	10	10	10	10

2006- 2007

n = number of samples (one sample per sampling occasion)

2006-2007	Port Levy	Little Akaloa	Pigeon Bay	Okains Bay	Le Bons Bay	Otanerito	Flea Bay	Tumbledown
Ammonia nitrogen (mg/L)								
Minimum	0.009	0.015	0.008	0.022	0.017	0.015	0.015	0.016
Median	0.033	0.037	0.032	0.038	0.038	0.022	0.028	0.028
Mean	0.033	0.037	0.035	0.042	0.041	0.029	0.032	0.036
SD	0.015	0.014	0.017	0.020	0.016	0.015	0.016	0.016
Maximum	0.054	0.058	0.059	0.089	0.062	0.057	0.058	0.06
Nitrate-nitrite nitrogen (mg/L)								
Minimum	< 0.005	0.01	<0.005	0.01	0.012	0.011	0.007	0.011
Median	0.019	0.023	0.017	0.038	0.026	0.0205	0.018	0.04
Mean	0.026	0.028	0.024	0.038	0.048	0.037	0.033	0.035
SD	0.028	0.024	0.029	0.027	0.033	0.029	0.032	0.019
Maximum	0.098	0.088	0.098	0.097	0.099	0.074	0.1	0.058
Total nitrogen (mg/L)								
Minimum	0.1	0.09	0.13	0.1	< 0.08	0.11	< 0.08	< 0.08
Median	0.2	0.17	0.19	0.22	0.22	0.14	0.12	0.15
Mean	0.211	0.170	0.198	0.219	0.197	0.158	0.115	0.162
SD	0.059	0.047	0.047	0.062	0.068	0.062	0.039	0.079
Maximum	0.31	0.24	0.28	0.29	0.26	0.3	0.16	0.3
Dissolved reactive phosphorus (mg/L)								
Minimum	0.008	0.007	0.007	0.004	0.008	0.008	0.006	0.008
Median	0.012	0.011	0.013	0.017	0.014	0.011	0.015	0.013
Mean	0.013	0.014	0.014	0.015	0.019	0.012	0.015	0.014
SD	0.005	0.005	0.005	0.006	0.012	0.003	0.006	0.005
Maximum	0.024	0.022	0.024	0.024	0.046	0.017	0.025	0.023
Total phosphorus (mg/L)								
Minimum	0.025	< 0.008	0.019	0.026	0.015	0.014	< 0.008	0.017
Median	0.036	0.026	0.037	0.052	0.044	0.0295	0.0285	0.031
Mean	0.035	0.026	0.037	0.083	0.041	0.045	0.045	0.054
SD	0.006	0.014	0.010	0.080	0.018	0.038	0.060	0.051
Maximum	0.047	0.044	0.053	0.26	0.075	0.11	0.19	0.18
Chlorophyll-a (ug/L)								
Minimum	1.2	0.5	0.8	1.1	0.5	0.3	0.2	0.5
Median	3.3	0.9	2.3	1.5	1.3	0.95	1	0.9
Mean	3.200	1.144	2.167	2.378	2.267	0.888	1.150	1.000
SD	1.454	0.704	0.938	1.513	2.681	0.467	0.787	0.442
Maximum	5.5	2.5	3.3	4.9	9.2	1.6	2.6	2
Total suspended solids (mg/L)								
Minimum	8	5.2	8.2	5.8	7.4	9.1	3.1	5.8
Median	13	11	14	47	21	12	6.45	33
Mean	13.778	11.722	14.900	42.533	21.267	15.800	9.325	36.644
SD	4.816	4.397	5.445	20.521	11.749	9.666	6.455	20.773
Maximum	22	20	26	69	41	37	20	70
Water temperature ºC								
Minimum	8.9	9	8.8	9.6	10.4	9.8	9.3	9.5
Median	13.1	13	12.85	12.8	12.8	12.65	12.65	13.4
Mean	13.71	13.14	13.48	13.37	13.69	13.09	13.59	14.02
SD	4.14	3.21	4.26	3.13	2.77	2.43	3.44	3.33
Maximum	19.8	18	19.6	17.5	17.7	17	19	19
Salinity (ppt)								
Minimum	31.9	32.68	32.6	31.9	31.4	31.9	28.1	31.08
Median	33.1	33.3	33	33.2	33.1	34.09	32.535	33.2
Mean	33.22	33.35	33.15	33.57	32.82	33.79	32.35	32.84
SD	0.94	0.43	0.43	1.74	0.94	1.08	2.04	0.91
Maximum	35.2	34.3	34.1	37.86	33.9	35.1	34.4	33.9
n	9	9	9	9	9	8	8	9

Appendix VI: Comparison of surface water nutrient concentrations between sites

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 between sites

Higher value across the top of the table indicates a significantly higher concentration of the listed determinands at that site than at the lower value site

2001-2002

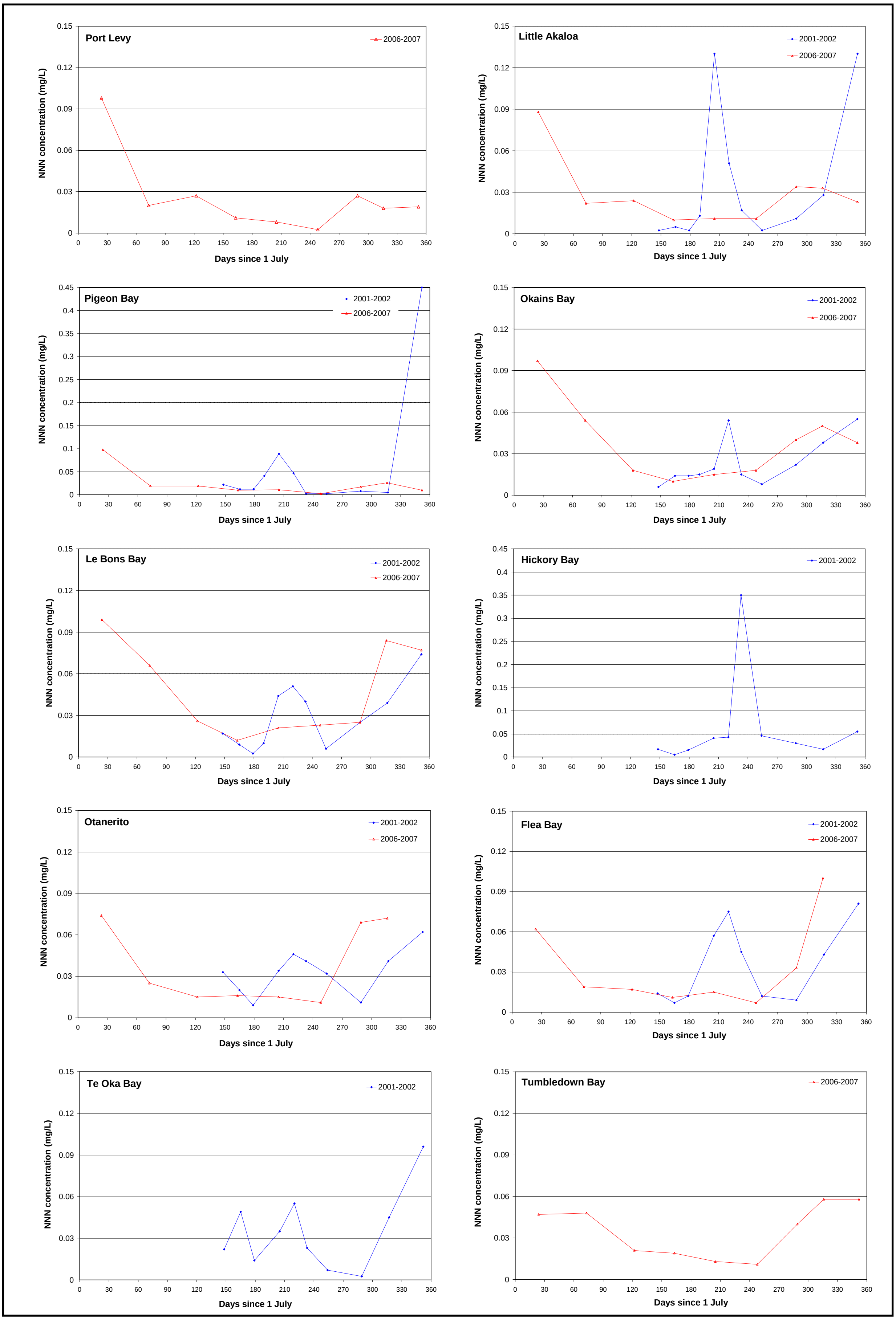
		Higher Value							
		Pigeon Bay	**Little Akaloa**	**Okains Bay**	**Le Bons Bay**	**Hickory Bay**	**Otanerito**	**Flea Bay**	**Te Oka Bay**
Lower Value	**Pigeon Bay**								
	Little Akaloa	NH3N* DRP* TP*							
	Okains Bay	NH3N** TP*							
	Le Bons Bay	NH3N* DRP* TP**	TP*	TP*					
	Hickory Bay	DRP* TN* TP**	TP*	TP*					
	Otanerito	TP**	TP*	TP*					
	Flea Bay	TN* TP**	TP*						TN *
	Te Oka Bay	NH3N* * TN* DRP* TP*	TP*						

2006-2007

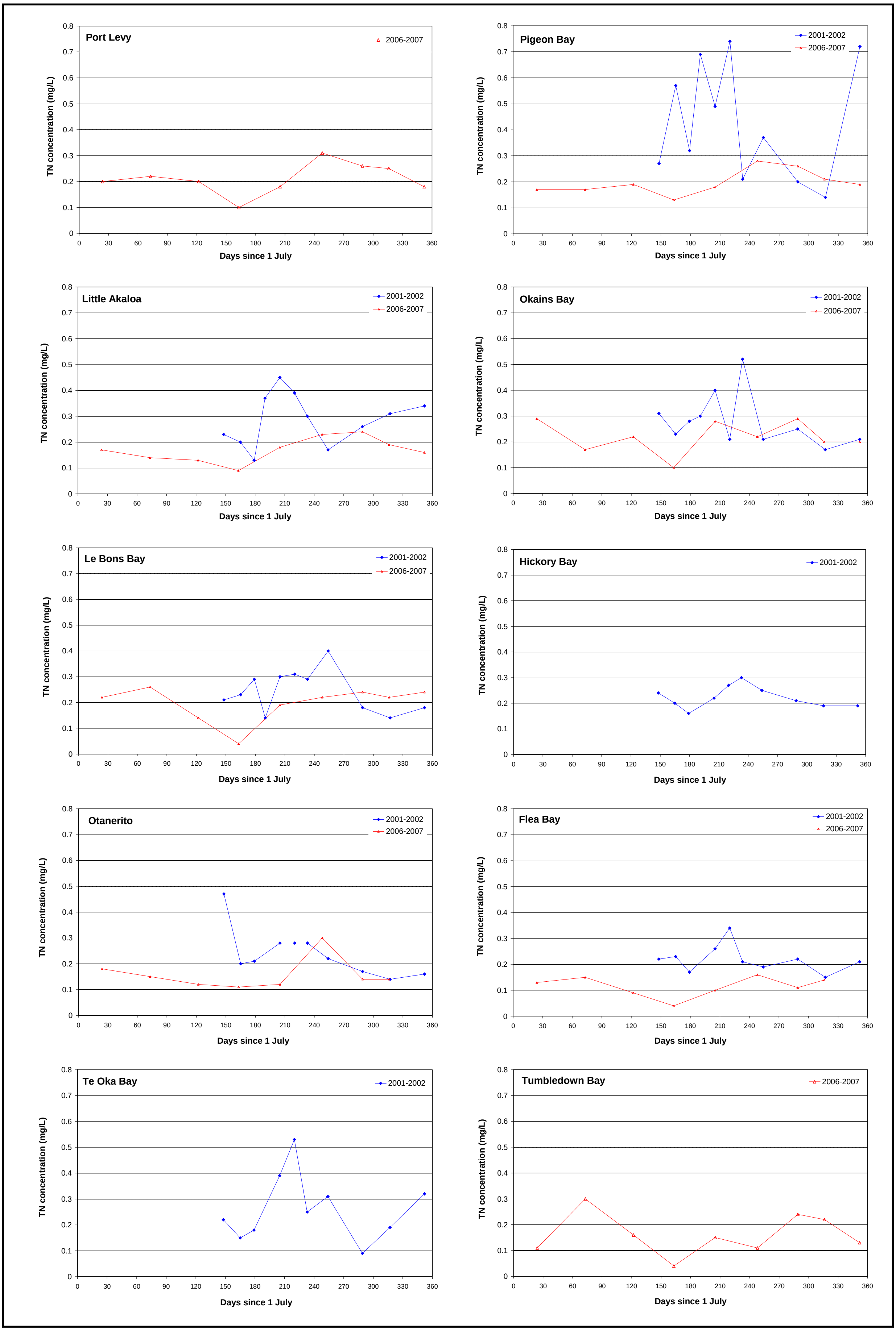
		Higher Value							
		Port Levy	**Little Akaloa**	**Pigeon Bay**	**Okains Bay**	**Le Bons Bay**	**Otanerito**	**Flea Bay**	**Tumbledown**
Lower Value	**Port Levy**				TSS*	NNN*			TSS*
	Little Akaloa	TN* TP* Chlorophyll-a*		TN* TP* Chlorophyll-a**	NNN* TN * TP* Chlorophyll-a** TSS*	NNN* TP* TSS*			TSS*
	Pigeon Bay	Chlorophyll-a**			NNN * TP* TSS*	NNN*			TSS*
	Okains Bay								
	Le Bons Bay				TP*		Salinity*		
	Otanerito	TN* Chlorophyll-a*		Chlorophyll-a*	Chlorophyll-a* TSS*	NH3N*			NH_3N* TSS*
	Flea Bay	TN* Chlorophyll-a* TSS*	TN*	TN* Chlorophyll-a* TSS*	TN* Chlorophyll-a* TSS*	NH3N* TN* TSS*	TN*		TSS*
	Tumbledown	Chlorophyll-a**		Chlorophyll-a*	Chlorophyll-a*				

Appendix VII: Nutrient concentrations in each bay over time

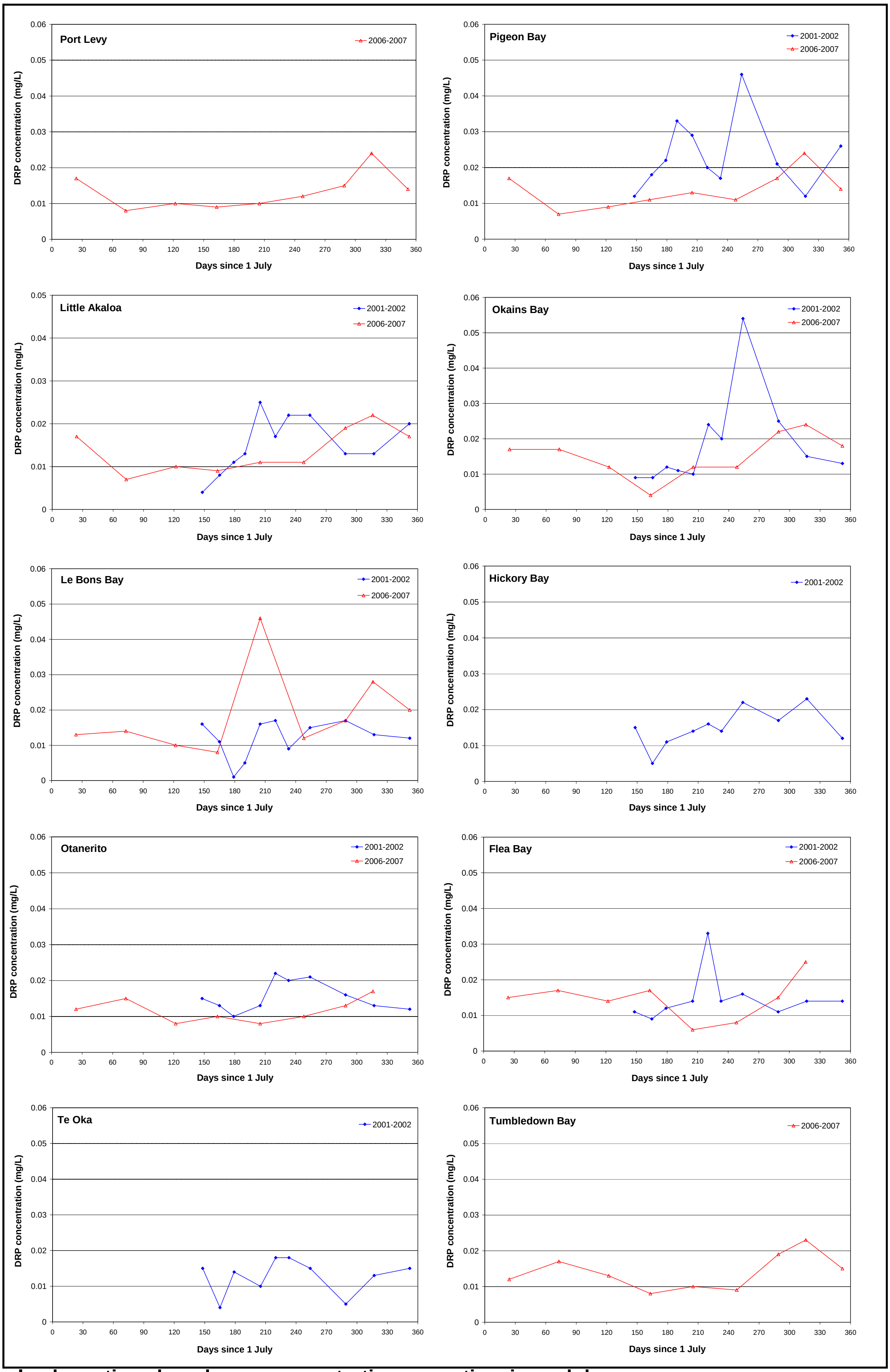
Ammonia-nitrogen concentrations over time in each bay



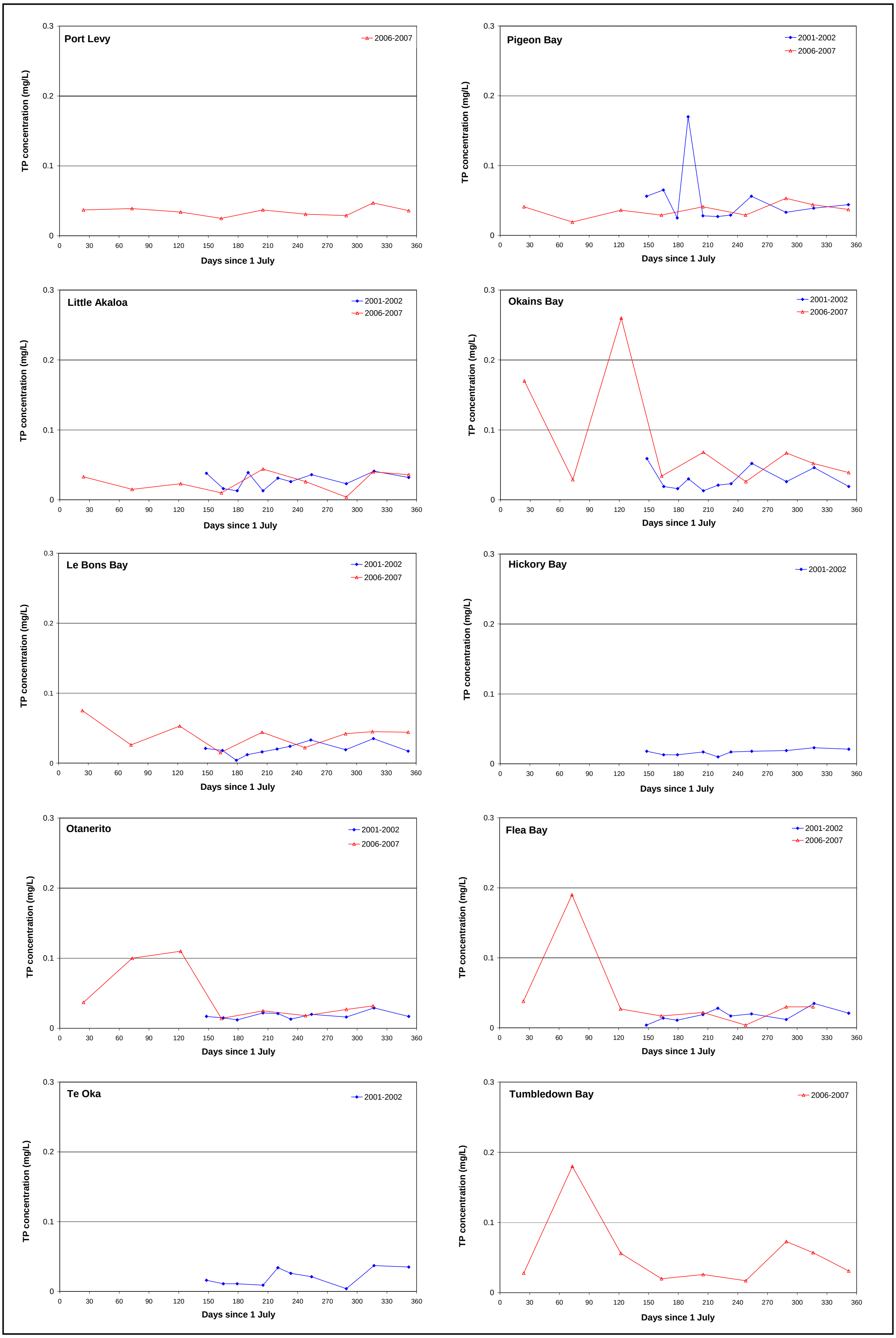
Nitrate-nitrite nitrogen concentrations over time in each bay



Total nitrogen concentrations over time in each bay



Dissolved reactive phosphorus concentrations over time in each bay



Total phosphorus concentrations over time in each bay

Appendix VIII: Correlation between environmental factors and determinands

r^2 is a measure of the correlation between factors. An r^2 value of 1 indicates a perfect correlation while a value of 0 indicates no correlation between factors. The correlations, between environmental factors and the determinands, with an r^2 value of higher than 0.6 are presented below. These correlations were investigated by plots to ensure that the correlation was not as a result of one high value. All these correlations were significant at p = 0.05.

Kaituna rainfall (mm)

	5 days before	4 days before	3 days before	2 days before	1 day before
2001-2002		**Pigeon NNN** r^2 = 0.89 **Okains NNN** r^2 =0.76		**Flea NNN** r^2 = 0.60 **Okains NNN** r^2 =0.75	**Hickory NNN** r^2 = 0.67
2006-2007					

Coopers Knob rainfall (mm)

	5 days before	4 days before	3 days before	2 days before	1 day before
2001-2002		**Pigeon NNN** r^2 = 0.87 **Little Akaloa NNN** r^2 = 0.82	**Te Oka NNN** r^2 = 0.8	**Okains NNN** r^2 = 0.71 **Hickory NNN** r^2 = 0.76	**Pigeon NNN** r^2 = 0.78 **Okains NNN** r^2 =0.67 **Le Bons NNN** r^2 = 0.63 **Flea NNN** r^2 = 0.61 **Te Oka NNN** r^2 = 0.69
2006-2007	**Port Levy NNN** r^2 =0.94 **Pigeon NNN** r^2 =0.92 **Little Akaloa NNN** r^2 = 0.90 **Okains NNN** r^2 = 0.69	**Port Levy NNN** r^2 =0.66 **Little Akaloa NNN** r^2 = 0.66 **Le Bons TSS** r^2 = 0.68 **Flea TSS** r^2=0.66			

median wave height (Hm0 (m))

	5 days before	4 days before	3 days before	2 days before	1 day before
2006-2007	**Port Levy TSS** r^2 = 0.65 **Flea TSS** r^2 = 0.73	**Port Levy TSS** r^2 = 0.66	**Flea TSS** r^2 = 0.75	**Flea TSS** r^2 = 0.88	

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