# Spatio-Temporal Distribution and Diversity of Zooplankton in Zoo Ponds Relative to Water Quality Parameters

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# Abstract

Little is known of the distribution and abundance of zooplankton in New Zealand, and the environmental variables that affect their spatial and temporal dynamics. Furthermore, smaller pond habitats have often been overlooked in favour of larger lake systems. To redress this gap, I focused on a series of six shallow interconnected ponds at the Hamilton Zoo. Ponds were sampled twice monthly for twelve months and examined for spatial and temporal variability in water quality parameters (e.g. chlorophyll *a*, suspended solids, nutrients and bacteria) relative to the distribution and seasonal dynamics of zooplankton.

Taxon richness comprised thirty-eight rotifers, five cladocerans, three copepods and one ostracod taxa were identified from the pond system. Considerable spatial variability in zooplankton composition was found among the various ponds. In contrast, there was comparatively little temporal variation in any of the ponds.

Physical and chemical parameters also showed considerable spatial as well as temporal variability among the ponds. Chlorophyll *a* was found to be the most important environmental variable determining zooplankton community composition in the ponds. Pond 1 had low chlorophyll *a*, and low zooplankton species abundance and richness. In contrast, Ponds 2 and 3 had high chlorophyll *a* levels and had the highest zooplankton species abundance and richness of all the ponds. pH and temperature were also important in determining community composition.

This study demonstrates the conservation potential of small ponds from a biodiversity perspective. Specifically, the considerable spatial variability in zooplankton composition among ponds may be important for preserving a wide range of taxa on a relatively small spatial scale, particularly when compared to larger lake habitats.

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# Chapter 1: General Introduction

## 1.1 Artificial ponds

Artificially constructed ponds are common in both urban and rural landscapes (Fairchild *et al.* 2004, Birth and McCaskie 1999). In rural areas, such ponds are often used for the treatment of waste, to facilitate drainage, and to provide water for stock or crop irrigation (Geddes 1986, Bronmark & Hansson 2002). Consequently, they may be of low importance from a conservation perspective owing to the presence of more natural habitat (e.g. ponds in the flood plains of larger rivers). However, in urban settings, artificial ponds may represent a significant resource in terms of biodiversity as well as being important from recreation and amenity perspectives (Birth and McCaskie 1999). In the urban environment, shallow lakes and ponds are likely to be eutrophic to hypereutrophic (Moss *et al.* 1997, Fairchild *et al.* 2004) because of their small size and consequently proportionally high internal and external nutrient loading (Wetzel 2001, Biggs *et al.* 2005). This can be potentially problematic for pond maintenance and management (Wetzel 2001). For example, where the purpose of a pond is to provide amenity value, this will be lowered if the pond has high algal growth and/or is overgrown with aquatic weeds due to excessive nutrient inputs.

However, these same features may also be important from a conservation perspective. At the extremes, a chlorinated, concrete-lined pond is likely to harbour little in the way of biological resources, whereas a constructed, eutrophic wetland with natural substrate may harbour a great diversity of biological life

(Boon & Howell 1997, Biggs *et al.* 2005). Accordingly, from a conservation perspective, it is important to understand the relationship between the biota and factors influencing distribution and abundance.

## 1.2 Influences on biota in ponds

Biota of a given water body may be determined by features such as algal biomass, suspended solids, nutrients (Stoianov *et al.* 2000) and by contributions from the surrounding catchment such as erosion and runoff which contribute to the allochthonous nutrient inputs of the system (Boon & Howell 1997). Thus, many management strategies include macrophytes and invertebrates as tools for monitoring ecosystem health, as variation occurs in ponds of different water quality (Momo *et al.* 2006). While macroinvertebrates, in particular, have been well studied, smaller animals such as zooplankton have been comparatively overlooked. This is unfortunate because zooplankton are highly sensitive to changes in physical and chemical conditions in water (Bērziņš & Pejler 1987, Chapman & Green 1987, Norlin *et al.* 2005,) and community composition is variable along water quality gradients (Jeppensen *et al.* 2000). Furthermore, environmental sensitivity and species tolerance allows zooplankton to be used as an indicator taxa to help define water quality and trophic status (Attayde and Bozelli 1998, Duggan *et al.* 2002, Holt *et al.* 2003, Vandysh 2004, Castro *et al.* 2005). This makes zooplankton very important from a conservation perspective as they are a major component to biodiversity by also having great variation in community distribution spatially and temporally (Shurin *et al.* 2000). Accordingly, we targeted a small network of urban ponds in New Zealand and used multivariate statistics to relate zooplankton distribution and abundance to the physical and chemical features of each pond.

Ponds have a close relationship with the terrestrial environment because of their ratio of volume to perimeter (Rettig *et al.* 2006) and therefore a higher interchange between the two environments (allochthonous effects). Ponds are more isolated from other water sources and have a more insular nature whereas large lakes may have various inflow sources and often have much larger catchment areas (Biggs *et al.* 2005). Ponds are also likely to have proportionally more stagnant water and areas that favour certain species of flora and fauna creating a more heterogeneous environment with compositional dissimilarity between sites (De Meester *et al.* 2005). Shallow lakes and ponds are more protected from wind driven mixing than lakes with a larger surface area and fetch (Fairchild *et al.* 2005). These will also favour various different types of biota (Søndergaard *et al.* 2005). Light penetration means that submerged and floating-leaved macrophytes, such as *Egeria densa* have the potential to cover large areas or even whole ponds (Søndergaard *et al.* 2005), which in turn creates habitat and a food source for various aquatic organisms. Changes in seasonal temperature, the effects of turbulence caused by storm events which increase suspended solids and nutrients, and the effects of land use and its associated nutrient enrichment are also more extreme in shallower waters than in larger lakes (Fairchild *et al.* 2004, Biggs *et al.* 2005). Sediments are more likely to affect water column nutrients in small shallow ponds with few inflows of water, due to enhanced benthic-pelagic coupling (Søndergaard *et al.* 2005).

Fluctuations of environmental variables in ponds are also likely to be greater temporally than those in larger lakes, such as the effects of climate on mixing and temperature patterns (Green *et al.* 1987). Physical and chemical parameters have been reported to vary between ponds even in close proximity, such as temperature (Burns *et al.* 1984) and pH (Zaman *et al.* 1993).

A greater intensity of environmental fluctuations temporally is likely to influence zooplankton communities, causing greater fluctuations in composition and abundance through time. Due to their small size, zooplankton are sensitive to environmental conditions such as turbidity and trophic state (Duggan *et al.* 2002).

## 1.3 Previous studies on ponds

Previous study of biota in ponds has been limited in comparison to studies of larger lakes, despite the former being more numerous and widespread (Søndergaard *et al.* 2005). The overall biodiversity of shallow lakes and ponds has higher per unit area than that of larger lakes (Biggs *et al.* 2005, Søndergaard *et al.* 2005, Oertli *et al.* 2002, Gee *et al.* 1997). For example Oertli *et al.* (2002) found that a set of small ponds had more species and a higher conservation value than larger ones. Gee *et al.* (1997) also concluded two small ponds are likely to support more species than one large pond.

## 1.4 New Zealand examples

The study of pond biota in New Zealand has been limited to date. The first attempted study was carried out by Byars (1960) who documented seasonal periodicity of zooplankton populations (Cladocera, Copepoda, Ostracoda and large Rotifera) in an Otago pond over one year and recognised factors that regulated the communities as light, temperature, chemical conditions and food materials. However, zooplankton nets used had a large mesh size (about 400 μm) that would have lost a high proportion of the smaller zooplankton. Barclay (1966) examined the temporal distribution of macroinvertebrates, including larger zooplankton (Cladocera, Copepoda and Ostracoda), over two years in a temporary Auckland pond with an average life of six months and compared this with permanent ponds, finding that permanent ponds of similar size supported only slightly different faunas. This study also used a large mesh size of 104 μm which would have lost all smaller zooplankton such as rotifers. Stout (1964) conducted a similar study of temporary ponds in Canterbury, examining insects, molluscs and various species of Crustacea, including Cladocerans and Ostracods. She concluded that species composition among ponds was most strongly related to whether ponds were temporary or permanent ponds. Spiller and Forsyth (1970) studied an urban pond in the Auckland Domain, looking at water quality and biota, including listing zooplankton (Cladocera and Rotifera), but focusing on Chironomids. Burns *et al.* (1984) studied the invertebrates, macroalgae, mollusks, crustaceans and insects in relation to the chemical features of 42 permanent and temporary ponds in the South Island of New Zealand, including zooplankton (Cladocera and Copepoda), but largely ignored the potentially diverse and abundant rotifers by also using a large mesh size (64μm). They concluded that differences in species composition may be related to whether ponds are natural or constructed.

Little is therefore known of the distribution and dynamics of zooplankton (in particular the smaller components such as rotifers) and the environmental variables that affect these dynamics, in small water bodies in New Zealand. The ecology of zooplankton from North Island ponds is virtually unknown.

### *1.5 Aims and objectives*

This study will examine chemical, physical and biological aspects of six interconnected North Island ponds and define relationships between the physical and chemical measurements of water quality with zooplankton. Specifically, we will test the hypothesis that spatial and temporal differences in the composition and density of zooplankton communities will occur among ponds of different water quality. As we show, spatial structuring in small ponds may be more important than the temporal structuring commonly found in larger systems (e.g. lakes).

# Chapter 2: Methods

## 2.1 Study site

The Hamilton Zoo considers the water quality of the ponds flowing through their grounds to be problematic. The six interconnected ponds studied are used as water features, housing various bird-life, fish and terrapins, and therefore their amenity value is high. However, they are also used for effluent collection and treatment, and may thus experience nutrient enrichment and associated problem algal growths. The ponds are also shallow, and may become turbid due to mixing by wind, or convective currents (Hamilton & Mitchell 1995). Such features may inhibit the aesthetic values of the ponds. However, the exact nature of the water quality problems has not been identified.

Land use surrounding the zoo is predominantly farming, which is well known to negatively affect waterways by nutrient export. This is widely reported in the Waikato region (Vant 2001; Bolan *et al.* 2004), and elsewhere in the world (Randall and Tsui 2002; Magesan *et al.* 1997). The main nutrients exported are nitrogen and phosphorus, which are essential to plant and algal growth in freshwater systems. Chlorophyll *a* (algal biomass) has been identified as an indictor of water quality and is used in the Trophic Level Index (TLI) as described by Burns *et al.* (1999) (Couillard & Lefebvre 1985, Carlson 1977).

The Hamilton Zoo ponds are interconnected, all flowing to the same outflow point. The water quality is visually different among ponds, and even within the same pond, because they receive water from different sources, have different areas and depths, and likely receive different loads of nutrients and sediment. There are also different bird, fish and terrapin species among ponds, so factors influencing zooplankton can be expected to differ at each pond. The zooplankton community composition, dynamics and distribution between ponds can therefore be expected to be different.

Hamilton Zoo has six main ponds (Fig. 2.1). Pond 1, the most recently created (constructed in 1996) is in a fully covered free flight aviary enclosure; the water here is recycled from the pond to a small top reservoir, where it returns down a waterfall. The surface area of Pond 1 (including top pool) is approximately 522 $m^2$ (new inputs of water come from rain and runoff collected from the roofs of zoo buildings). When the main pond is full, water flows into an overflow drain to Pond 2. At the top of Pond 2 there are a series of input pipes, from the aviary (Pond 1) overflow and from a filter bed receiving effluent from a tapir enclosure, a chimpanzee enclosure, runoff from public toilets and main buildings. Pond 2 flows directly into Pond 3. Ponds 2 and 3 have surface areas of approximately 1497 $m^2$ and 1227 $m^2$, respectively.

Pond 4 has no connection with Ponds 1, 2 or 3. Pond 4 drains neighbouring farmland through groundwater flow, and has a surface area of 312 $m^2$ no marginal vegetation. Pond 5, a wetland, is the largest of all the ponds (surface area of approximately 2077 $m^2$), and has the most vegetation surrounding and in the pond. Water enters the wetland from Ponds 3 and 4, and exits through a pipe into Pond 6. Pond 6 is the outflow pond, and is the shallowest (<1 meter) and smallest (surface area ~ 151 $m^2$) of all the ponds monitored. From the outflow the water drains out to a neighbouring property (Fig. 2.1), and ultimately into Lake Rotokauri.

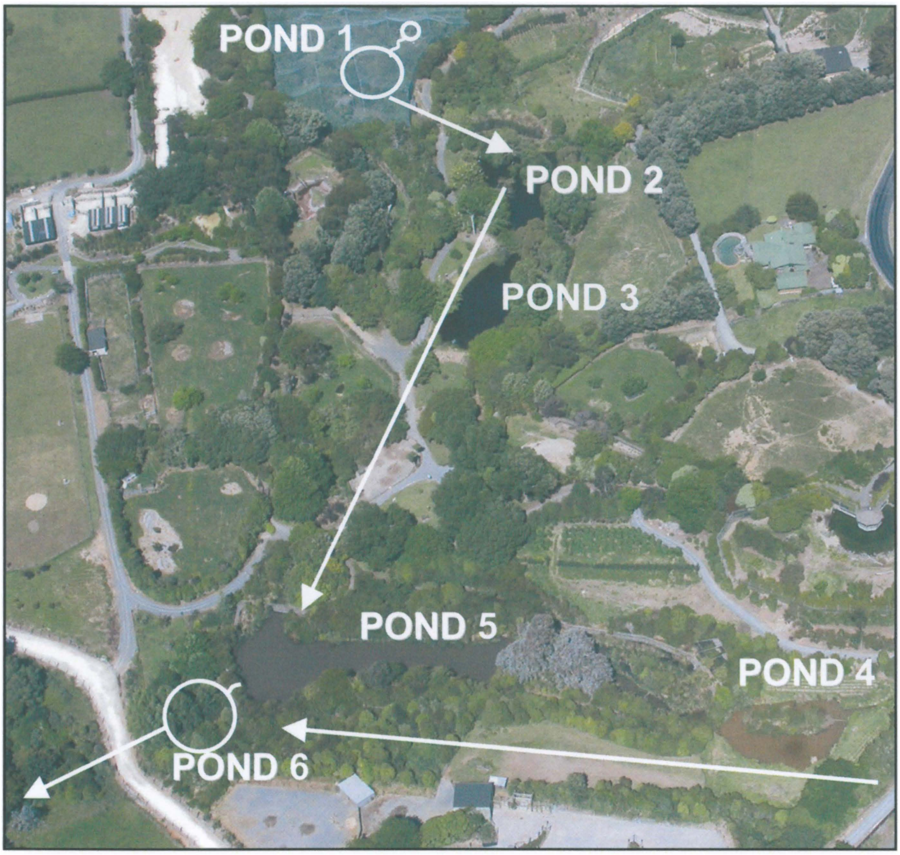



Fig. 2.1. Aerial photo of the study site at Hamilton Zoo. Ponds labelled accordingly (1-6) with direction of the flow of water in the ponds indicated by arrows.

## *2.2 Physical and chemical parameters*

Dissolved oxygen, conductivity, temperature, pH, suspended solids, chlorophyll *a*, and Secchi depth were measured twice monthly at each site. Samples were taken approximately twice monthly for 12 months, on a total of 25 occasions between November 2004 and November 2005. For pH, chlorophyll *a* and suspended solids, a single 250 mL water sample was collected from 2-5 cm beneath the surface and immediately stored on ice for return to the laboratory. Dissolved oxygen, temperature and conductivity were measured *in situ* using a hand-held YSI model 55 for dissolved oxygen and a YSI model 30 for temperature and conductivity. A 20 cm Secchi disk was used to determine clarity of the water, as described by Welch (1948). pH was measured immediately on return to the lab (within 2 hours) using a MeterLab™ Standard pH meter model PHM210. On each sampling occasion, the presence of fish and bird species was recorded at each pond.

For chlorophyll *a*, a known volume of water was then filtered through a Whatman GF/C filter paper (nominal pore size 1.2 µm), wrapped in tin foil and frozen. Within one month, the filters were homogenized with 90% acetone buffered with magnesium carbonate ($MgC0_3$), to 10 mL and left to steep refrigerated overnight. They were put in a centrifuge at 3300 rpm for 10 minutes. The supernatant was poured into a cuvette and the fluorescence measured on a Turner 10-AU fluorometer, 0.3 mL of 0.1N HCl was added and left for 90 seconds before it was measured again (Strickland & Parsons 1972).

Suspended solids were measured according to standard methods (APHA 1992). A known volume of water was filtered through a pre-washed Whatman GF/C filter paper, which were dried at 105°C for at least one hour or until a constant weight was reached, papers were left to cool in dessicator and weighed. If analysis could not be carried out immediately the samples were frozen.

Ammonia ($NH_4$), nitrite ($NO_2$), nitrate-nitrite ($NO_3$-$NO_2$), total nitrogen (TN), phosphate ($PO_4$) and total phosphorus (TP) were analysed monthly at each site. Nutrients were collected using plastic tube with bungs on each end to collect a sample from the entire water column. Collected water was put into acid washed 50 mL vulcan tubes and immediately put on ice. All samples were taken in duplicate at each site. Samples for total nutrients (TN and TP) were transferred in to acid washed 14 mL vulcan tubes, and the dissolved nutrients ($NO_3$, $NO_2$, $NH_4$ and $PO_4$) were filtered through Whatman GF/C filter papers (nominal pore size 1.2 μm) and transferred to 14 mL vulcan tubes. Samples were frozen until analysis. Nutrient analyses were performed on a QuikChem® 8000 Flow Injected Analyser (FIA) using the methods from the Ominion FIA procedures manual (1999).

## 2.3 Bacteria

CHROMagar ECC was used to quantify coliform bacteria and *Escherichia coli* in the water monthly at each site. Coliform counts do not differentiate between faecal and non-faecal matter, so *E. coli* was used to indicate the presence of faecal matter; this species is naturally found in intestinal tracts of warm blooded animals and is often a dominant faecal coliform (Alonso *et al.* 1996). One mL of water from each pond was added to Petri dishes containing CHROMagar ECC medium and incubated at 37°C for 24 hours. *E. coli* colonies appear blue and total coliforms red under natural light; these were identified and counted.

## 2.4 Zooplankton

Zooplankton were sampled quantitatively twice monthly from six sites using an open-ended P.V.C pipe vertically inserted down the water column. Once inserted, the top was sealed using a bung, the tube was lifted to just below the water surface, and the bottom sealed. The known volume of water was sieved through a 37 μm mesh net; this is sufficient to collect smaller zooplankton (e.g., rotifers) while preventing clogging from phytoplankton and suspended sediments (Orcutt and Pace 1984; Berner- Frankhauser 1987; Burger *et al.* 2002). Zooplankton samples were preserved with 90 % ethanol until they were processed.

From a known volume of sample (usually ~30 mL), 5 mL sub-samples were viewed in a grided counting tray at 30× magnification using a stereo microscope. Sub-samples were counted until at least 300 individuals were recorded, or until the whole sample was counted. Zooplankton were identified to species level using a compound microscope based on body and trophus morphology, where appropriate. Rotifer trophi were eroded from body tissue using 10% sodium hypochlorite. Identifications were made using Shiel (1995).

## 2.5 Statistical analysis

Multivariate analyses were performed to determine whether distinct groupings of zooplankton species occurred in ponds either spatially or temporally, and to infer relationships between the measured environmental variables and the spatial and temporal groupings of zooplankton. Multi-dimensional scaling (MDS) and cluster analysis were used to determine whether patterns existed in zooplankton community composition in terms of species abundance among ponds and sampling date. Zooplankton species were included in analyses if their abundance was ≥4% in any one sample, and occurred in four or more samples overall. Data was fourth-root transformed so that dominant species did not have undue influence in analyses (Clarke & Warwick 1994). MDS and cluster analysis were performed on a similarity matrix based on the Bray-Curtis similarity coefficient calculated from the spatial and temporal zooplankton data. A one-way analysis of similarity (ANOSIM) was used to test whether differences in composition among samples, as shown by the MDS and cluster analysis, were statistically significant. ANOSIM was performed on the Bray-Curtis similarity matrix using 999 permutations. MDS, cluster analysis and ANOSIM were performed using the PRIMER statistical package (Clarke & Gorley 2001). Canonical correspondence analysis (CCA) was performed to examine the relationships between the physical, chemical and environmental factors of the water with the composition of zooplankton between and within the ponds. CCA was performed using CANOCO version 4.0 (ter Braak & Smilauer 1998).

# Chapter 3: Results

## 3.1 Water Quality

Water temperatures ranged from 8.0°C (Pond 1 in July) to 25.0°C (Pond 3 in February 2005). Temperatures were generally highest in Pond 4 and lowest in pond 1 (Table 3.1). The maximum difference among ponds within any given sampling date was 7°C (December 2004) (Table 3.2). Pond 1 consistently had the lowest temperatures (Fig. 3.1) and was up to 7°C cooler than the other ponds on the same sampling date. In summer (December 2004 – March 2005) Pond 1's average temperature was 15.4°C, whereas Pond 3's was 20.8°C. Water temperatures showed the least variation between ponds in winter, with maximum and minimum average temperatures ranging from 10.8-12.8°C (Fig. 3.1). Pond 3 had the highest seasonal variation compared with the other ponds ranging from a summer high of 25.1°C and a low of 9.5°C in winter (range 16.65) (Table. 3.1).

Dissolved oxygen levels varied considerably between ponds and even within a single sampling date (Table 3.1). For example, in summer Pond 4 experienced low dissolved oxygen levels, 10.8% saturation (1.1 mg/L), while Ponds 2 and 3 had similarly high levels with Pond 3 having 198.0% saturation (18.2 mg/L) and Pond 2 with 161.5% saturation (13.9 mg/L). Pond 1 had the most consistent oxygen readings ranging from 57.4-112.5% saturation, and 7.1-10.6 mg/L, while Pond 3 varied from 57.4-197.9% saturation and 8.1-18.2 mg/L.

Pond 4 had the largest range of specific conductance values (135.4-290.3 $mS.cm^{-1}$ @ 25°C) whereas Pond 3 showed the least variation (171.5-211.6 $mS.cm^{-1}$ @ 25°C) (Table 1). Pond 1 had the highest average specific conductance (213 $mS.cm^{-1}$ @ 25°C) (Table 3.1). pH in all ponds ranged from 5.97 (Pond 4 in August 2005) to 8.88 (Pond 3 in December 2004 and Pond 1 in March 2005). Levels within individual ponds remained relatively constant with maximum fluctuations recorded in Pond 3 (6.56–8.88).

Secchi depth was always low in Pond 4, with a minimum value of 16.5 cm April 2005 (Table 1). In contrast, Pond 5 always had the deepest Secchi depths with a maximum of 130.0 cm in October 2005 (Table 1). Suspended solids (Fig. 3.2) increased throughout the year and were highest in spring (Sept-Nov 2005). On average, high suspended solid values (0.028 mg/L in Pond 1) were found throughout the ponds (Fig. 3.3), but were generally lower in Pond 5 (0.017 mg/L).

The lowest chlorophyll *a* levels were recorded in winter and highest in autumn (Fig. 3.2). Pond 4 had the lowest recorded chlorophyll *a* level of 2.48 µg/L (Fig. 3.3), and Pond 6 had the highest recorded level of 8798.59 µg /L in autumn (Figs. 3.3 & 3.4). Pond 1 had the lowest chlorophyll *a* range (3.03-697.49 µg /L) and Pond 6 had the greatest range (4.22-8798.59 µg /L) (Table 1, Fig. 3.4). Bacteria (total coliform and *Escherichia coli*) numbers decreased from summer (December 2004–March 2005) through to winter (June 2005-August 2005) and increased again in spring (Fig. 3.5). Pond 5 had the lowest average values with 1 and 4 cells/mL for *E. coli* and total coliform respectively (Fig. 3.6). Pond 2 had the most fish and waterfowl taxa observed over the year (Table 3.3).

Total phosphorus (TP) levels were very similar among all ponds except for Pond 6 which had slightly higher levels (Fig. 3.7). This contrasted with dissolved reactive phosphorus (DRP) levels which were lowest in Pond 6. DRP levels were highest in summer and lowest in spring (Fig. 3.8).

Nitrite ($NO_2$) increased through the pond system (Fig. 3.9), and was highest in the last 3 ponds (4, 5, and 6) which indicates additional inputs other than those influencing the first 3 ponds (1, 2 and 3). Total nitrogen (TN) levels were highest in Pond 6, and similar for Ponds 1 and 4 which were elevated above Ponds 2, 3 and 5. There were high levels of Nitrate-Nitrite ($NO_3$-$NO_2$) in Pond 1 (Fig. 3.9). The water in this pond is pumped to a small "top" pool and flows back down to Pond 1 greatly increasing the potential for concentration of nutrient levels. Nitrite and Nitrate-Nitrite showed similar seasonal patterns gradually increasing through summer (December 2004 – March 2005), autumn and winter then decreasing again in spring (Fig. 3.10). The ammonia ($NH_4$) level was highest in autumn and similar throughout the rest of the sampling period. Ammonia levels were very high in the inflow, which drains a neighbouring deer farm and flushes through to the wetlands. Levels were measurably lower by the time the water had passed through the Pond 5 (wetlands) and left via the outflow pond (Pond 6).

Table 3.1. Median, minimum and maximum values for physical-chemical parameters measured in six ponds at the Hamilton Zoo. Pond numbers refer to Fig. 2.1.

| | | pH | Temp. (°C) | DO (%) | DO (mg/L) | Sp. Cond. (mS.cm$^{-1}$) | Secchi (cm) | Chl*a* (µg/L) | Sus. Solids (mg/L) | Zoopl. (Ind/L) | Coliform (cells/mL) | *E.coli* (cells/mL) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Pond 1 | Median | 7.38 | 14.09 | 81.40 | 9.06 | 213.00 | 44.50 | 45.94 | 0.028 | 7.48 | 51.54 | 24.88 |
| | Min | 6.82 | 8.00 | 57.40 | 7.10 | 168.40 | 34.00 | 3.03 | 0.005 | 1.07 | 1.00 | 5.00 |
| | Max | 8.01 | 22.20 | 112.47 | 10.60 | 276.45 | 72.10 | 697.49 | 0.172 | 32.74 | 157.00 | 56.00 |
| Pond 2 | Median | 6.98 | 16.38 | 61.50 | 5.96 | 191.53 | 48.90 | 473.82 | 0.024 | 553.31 | 52.19 | 35.15 |
| | Min | 6.55 | 9.20 | 32.10 | 3.28 | 148.53 | 22.30 | 12.75 | 0.002 | 19.88 | 4.00 | 4.00 |
| | Max | 8.29 | 24.50 | 161.47 | 13.95 | 211.93 | 77.00 | 1871.76 | 0.060 | 1361.19 | 118.50 | 79.00 |
| Pond 3 | Median | 7.27 | 16.96 | 84.52 | 8.13 | 195.52 | 46.50 | 1350.00 | 0.032 | 719.89 | 45.27 | 21.15 |
| | Min | 6.56 | 9.45 | 57.40 | 4.90 | 171.53 | 16.80 | 9.16 | 0.019 | 50.83 | 4.00 | 1.00 |
| | Max | 8.88 | 25.10 | 197.97 | 18.21 | 211.63 | 84.60 | 8414.27 | 0.050 | 2639.29 | 278.50 | 68.50 |
| Pond 4 | Median | 6.36 | 16.86 | 35.22 | 3.35 | 196.61 | 37.90 | 51.99 | 0.030 | 496.91 | 22.31 | 23.85 |
| | Min | 5.97 | 10.50 | 10.80 | 1.08 | 135.40 | 16.50 | 2.48 | 0.002 | 3.00 | 1.50 | 0.00 |
| | Max | 6.88 | 25.00 | 91.60 | 8.37 | 290.30 | 69.00 | 242.22 | 0.115 | 1536.00 | 80.50 | 81.00 |
| Pond 5 | Median | 6.53 | 16.78 | 52.55 | 4.95 | 191.08 | 75.00 | 146.87 | 0.017 | 531.08 | 20.73 | 7.92 |
| | Min | 6.03 | 10.70 | 20.30 | 2.08 | 167.80 | 21.00 | 5.41 | 0.001 | 65.48 | 1.00 | 0.50 |
| | Max | 7.40 | 25.00 | 165.75 | 13.86 | 241.50 | 130.00 | 1023.59 | 0.039 | 1494.29 | 98.50 | 24.00 |
| Pond 6 | Median | 6.65 | 15.81 | 76.52 | 5.71 | 192.19 | 49.00 | 532.70 | 0.029 | 932.56 | 31.46 | 21.50 |
| | Min | 6.16 | 10.50 | 33.30 | 2.11 | 147.00 | 25.00 | 4.22 | 0.002 | 66.20 | 1.50 | 1.00 |
| | Max | 7.84 | 22.90 | 111.20 | 9.23 | 217.80 | 121.00 | 8798.59 | 0.081 | 3299.00 | 72.50 | 143.50 |

Table 3.2. Minimum, maximum and range of temperatures found among all ponds (Fig. 2.1) at each sampling date.

| | Temp.(°C) | | |
|---|---|---|---|
| Sampling Date | Min | Max | Range |
| 3/11/2004 | 14.7 | 18.8 | 4.1 |
| 24/11/2004 | 13.4 | 20.3 | 6.9 |
| 8/12/2004 | 16.9 | 23.9 | 7.0 |
| 20/12/2004 | 13.2 | 19.6 | 6.4 |
| 5/01/2005 | 16.8 | 20.3 | 3.5 |
| 19/01/2005 | 17.6 | 23.0 | 5.4 |
| 4/02/2005 | 22.2 | 25.1 | 2.9 |
| 18/02/2005 | 22.2 | 25.1 | 2.9 |
| 4/03/2005 | 17.9 | 22.1 | 4.2 |
| 18/03/2005 | 20.1 | 24.1 | 4.0 |
| 1/04/2005 | 18.1 | 21.1 | 3.0 |
| 22/04/2005 | 16.1 | 19.7 | 3.6 |
| 6/05/2005 | 11.5 | 15.2 | 3.8 |
| 20/05/2005 | 12.8 | 14.9 | 2.1 |
| 3/06/2005 | 14.5 | 15.7 | 1.2 |
| 24/06/2005 | 11.4 | 15.1 | 3.8 |
| 8/07/2005 | 11.0 | 12.5 | 1.5 |
| 22/07/2005 | 11.7 | 13.5 | 1.8 |
| 12/08/2005 | 10.3 | 12.3 | 2.0 |
| 25/08/2005 | 10.9 | 13.2 | 2.3 |
| 9/09/2005 | 10.9 | 13.2 | 2.4 |
| 23/09/2005 | 11.4 | 14.1 | 2.7 |
| 7/10/2005 | 14.2 | 16.4 | 2.2 |
| 21/10/2005 | 14.6 | 17.6 | 3.0 |
| 4/11/2005 | 10.6 | 12.0 | 1.4 |

Table 3.3 Fish and waterfowl taxa observed based on 25 observation periods (November 2004 to November 2005) at each pond. Pond numbers refer to Fig. 2.1.

| Pond | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| Gambusia | | | | * | * | |
| Koi Carp | | * | * | | | * |
| Gold Fish | | * | * | | | |
| Eel | | * | | | | |
| Ducks | * | * | * | * | * | * |
| Black swan | | | * | * | | |
| White swan | | * | | | | |
| Geese | | * | | | | |
| Pukeko | | * | | | | |

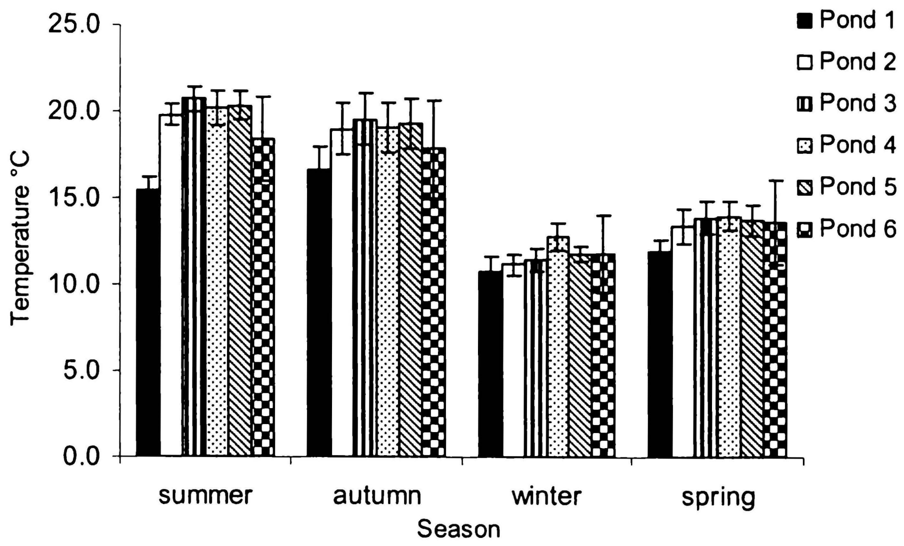



Fig. 3.1. Average temperature fluctuations among the six ponds at Hamilton Zoo (Fig. 2.1) in each austral season (+/- 1s.e.).

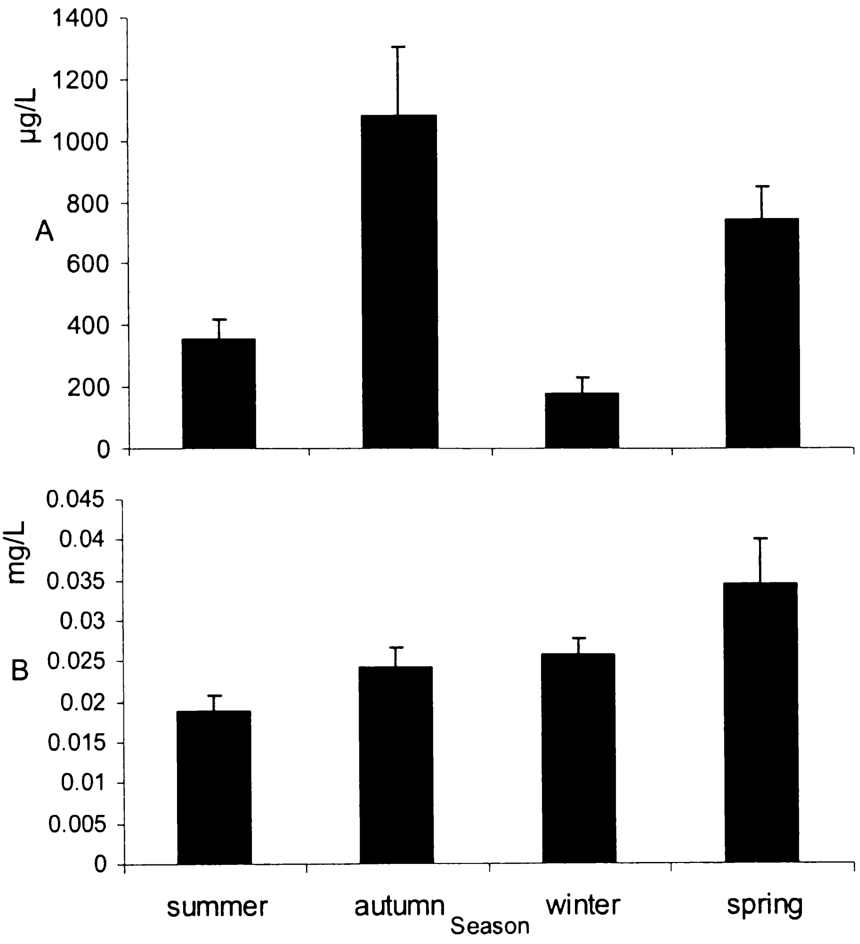



Fig. 3.2. Average concentrations of (A) chlorophyll *a* (µg/L) and (B) suspended solids (mg/L) (+/- 1s.e.) from the six ponds at Hamilton Zoo for each austral season.

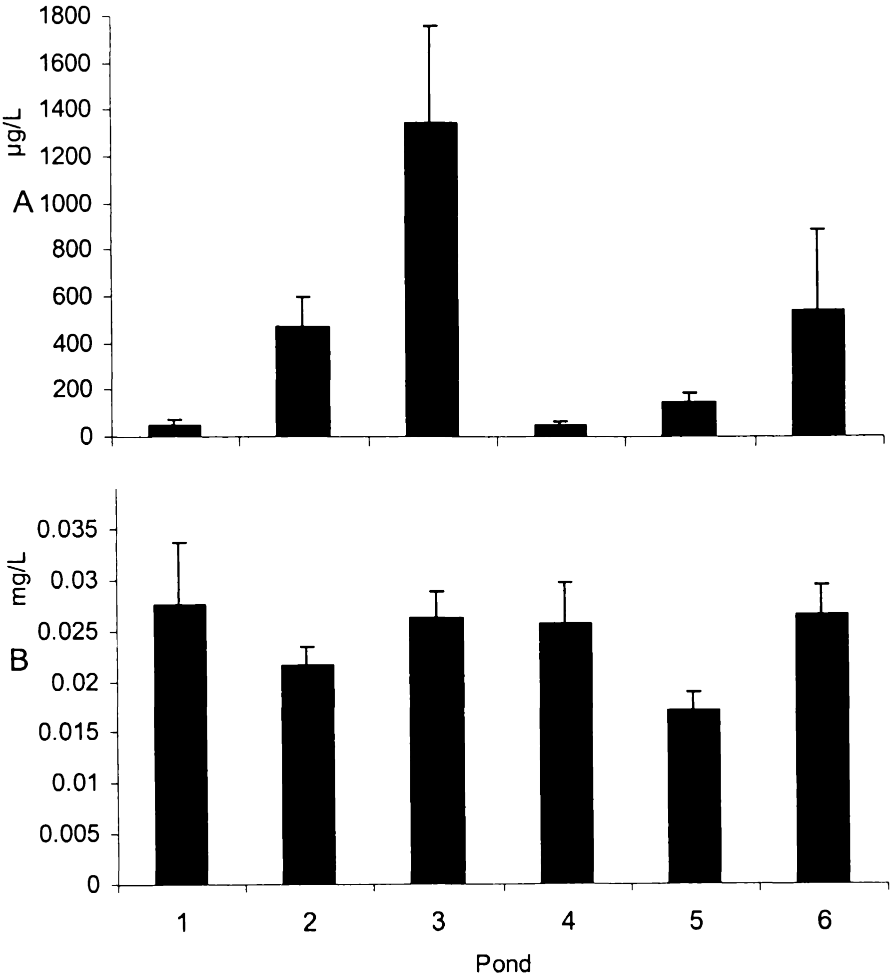



Fig. 3.3. Average annual concentrations of (A) chlorophyll *a* (μg/L) and (B) Suspended solids (mg/L) (+/- 1s.e.) in each pond. Pond numbers refer to Fig. 2.1.

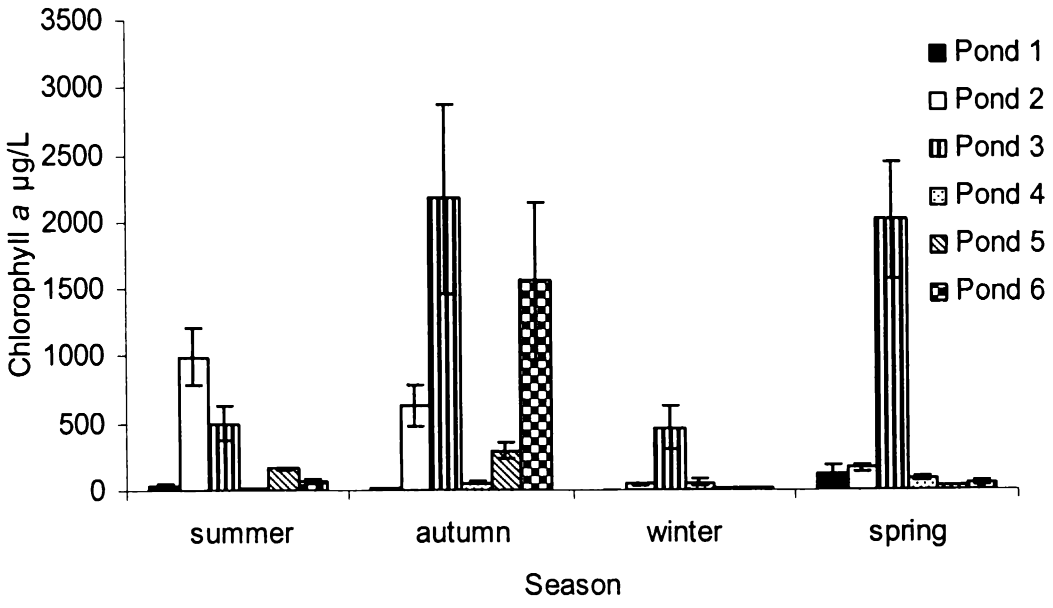



Fig. 3.4. Average austral seasonal concentrations of chlorophyll *a* (+/- 1s.e.) in each pond. Pond numbers refer to Fig. 2.1.

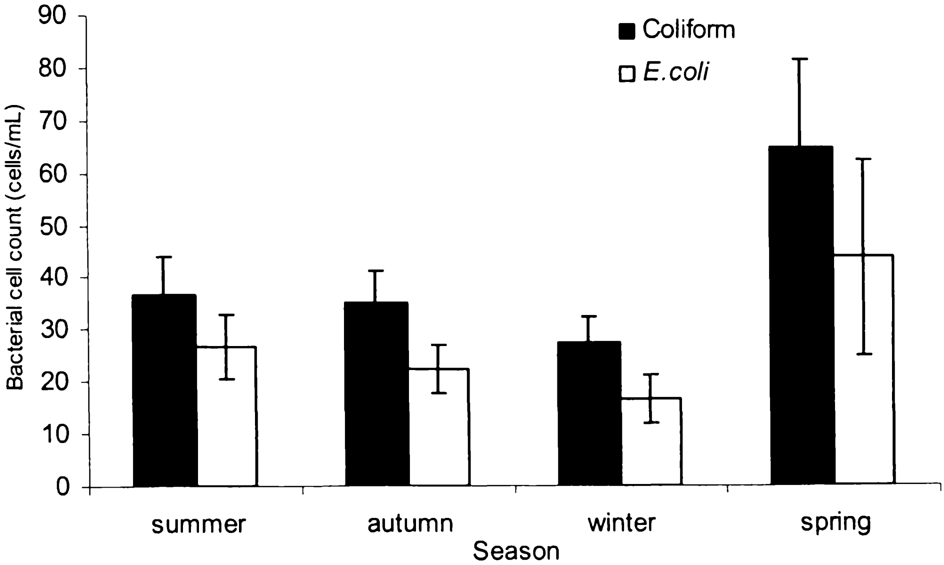



Fig. 3.5. Average concentrations of total coliform and *E.coli* cells (+/- 1s.e.) from six ponds at Hamilton Zoo present in each austral season.

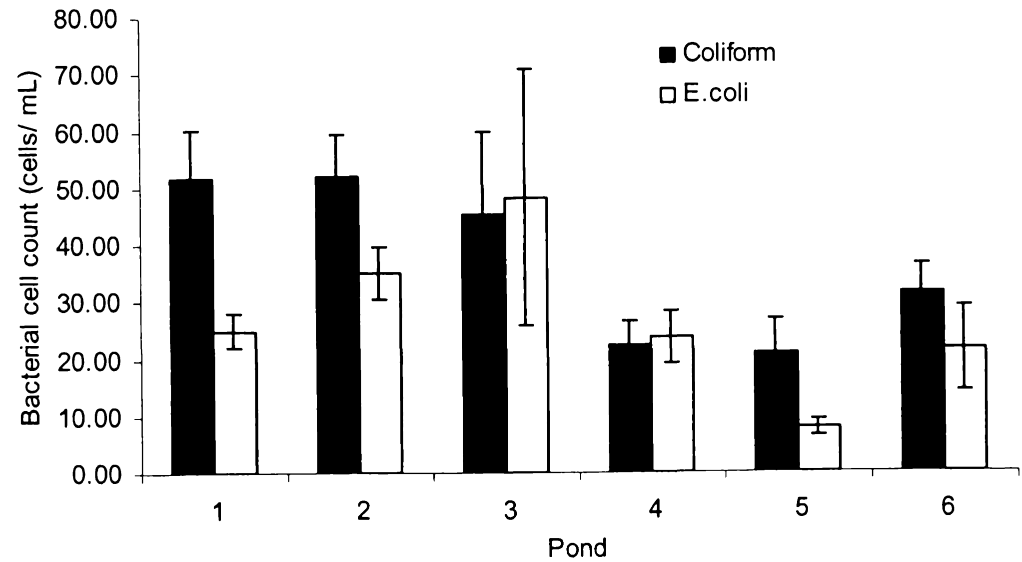



Fig. 3.6. Average annual concentrations of total coliform and *E.coli* cells present in each pond (+/- 1s.e.). Pond numbers refer to Fig. 2.1.

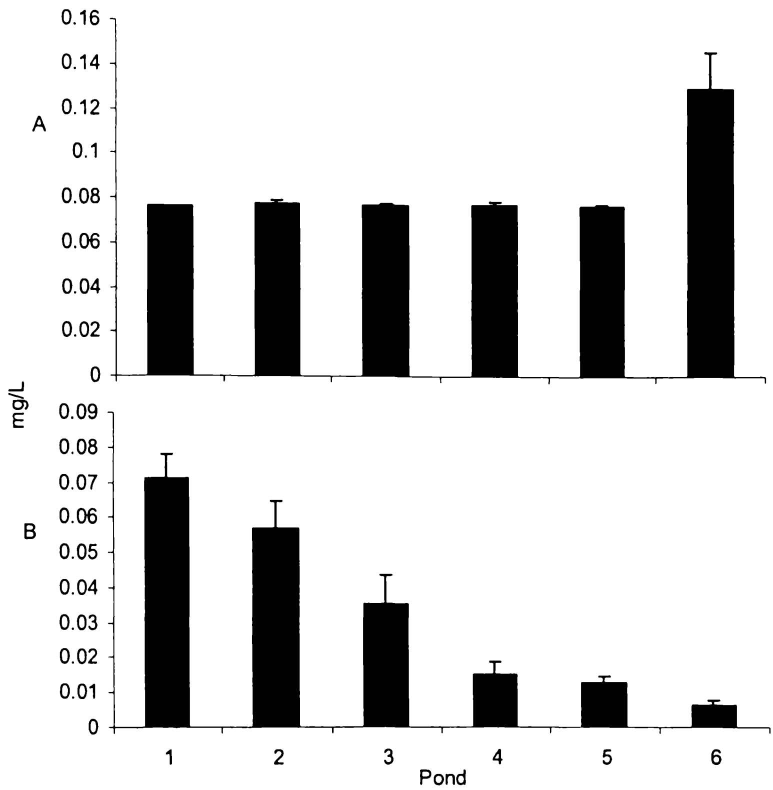



Fig. 3.7. (A) Total phosphorus (TP) (mg/L) and (B) Dissolved reactive phosphorus concentrations (DRP) (mg/L) (+/- 1s.e.) in each of the 6 ponds (see Fig. 2.1).

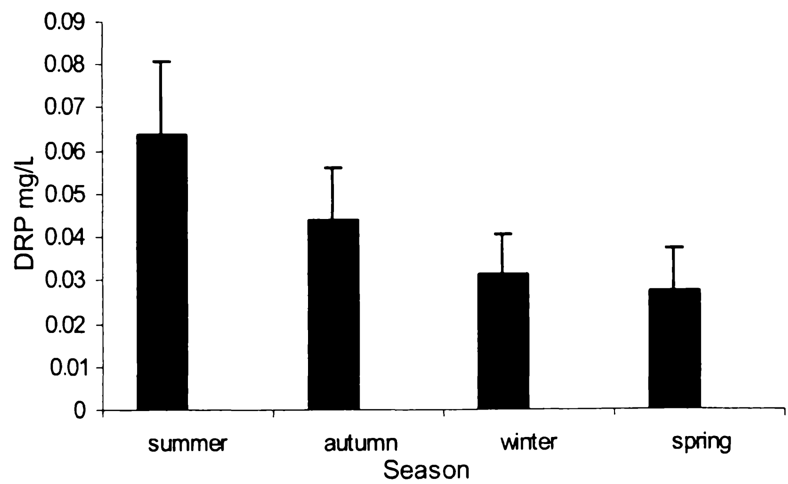



Fig. 3.8. Average dissolved reactive phosphorus (DRP) present in each austral season (+/- 1s.e.) from six ponds at Hamilton Zoo.

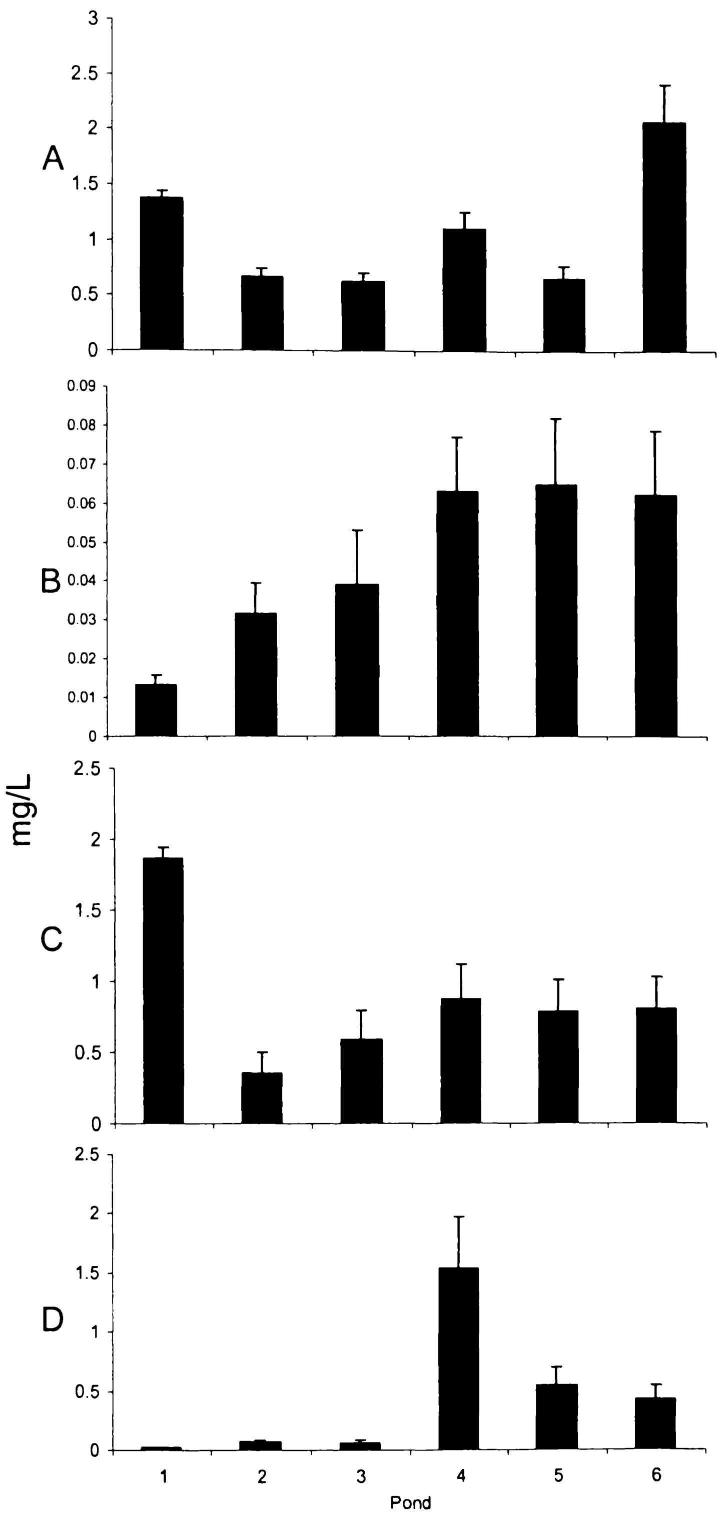



Fig. 3.9. (A) Average total nitrogen (TN) (mg/L), (B) average total Nitrite ($NO_2$) mg/L, (C) average total Nitrate-Nitrite ($NO_3$- $NO_2$) (mg/L), and (D) average total Ammonia ($NH_4$) concentrations (mg/L). (+/- 1s.e.) for six ponds at Hamilton Zoo (Fig. 2.1).

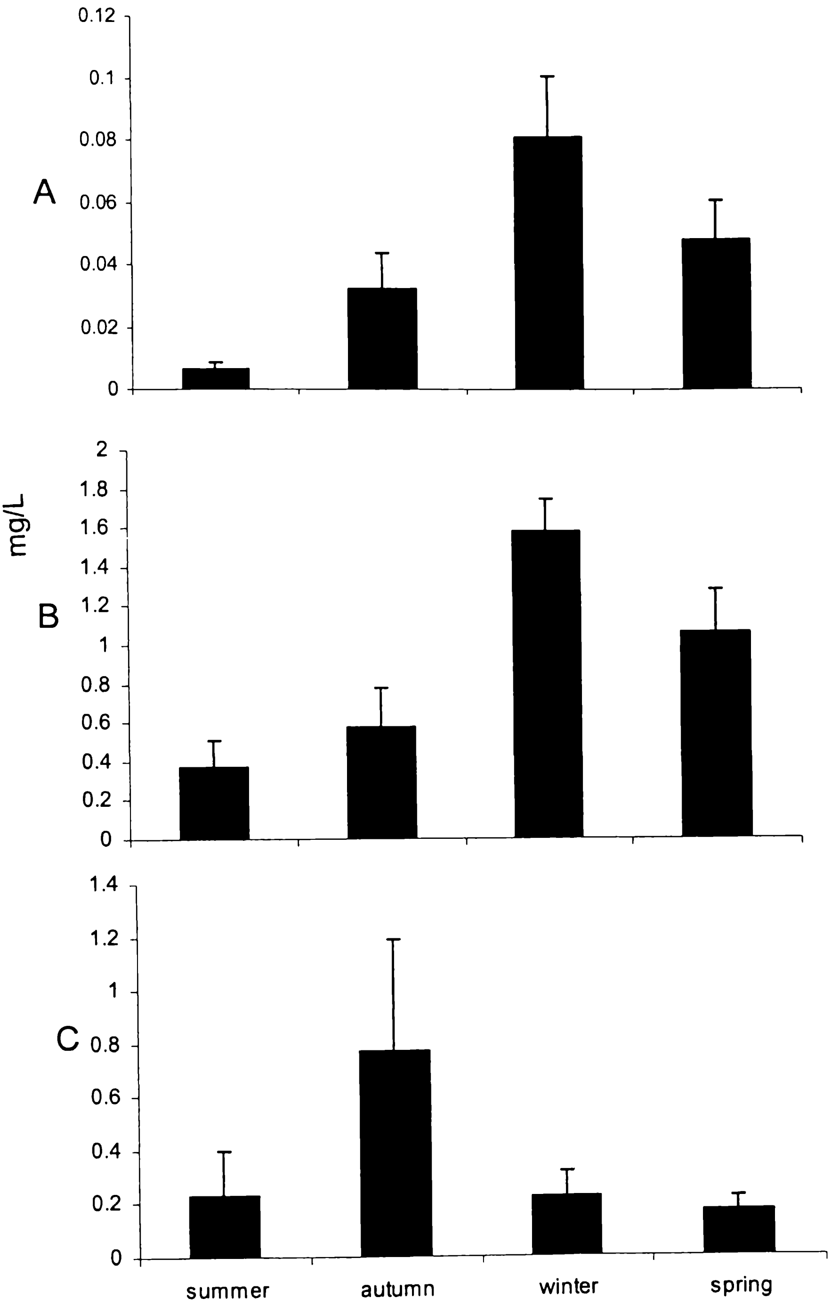



Fig. 3.10. Average concentrations of (A) Ammonia ($NH_4$) (mg/L), (B) Average concentrations of Nitrite ($NO_2$) (mg/L), and (C) Nitrate-Nitrite ($NO_{3\text{-}2}$) (mg/L) in an austral season for six ponds at Hamilton Zoo (Fig. 2.1) (+/- 1s.e.).

### 3.2 Zooplankton abundance and composition

Thirty-eight rotifer, five cladoceran, three copepod and one ostracod species were recorded (Table 3.4). The highest species richness was found in Pond 2 with 37 different species found. Pond 3 was similar with 36 taxa. The lowest species richness was in Ponds 1 and 4 with 30 species each (Table 3.4). Highest species richness of rotifers was also found in Pond 2 with 29 species, Pond 3 had 27, and Pond 1 was had the lowest rotifer species richness with 20 species (Table 3.4).

Variation in zooplankton community composition among ponds is shown in the multi dimensional scaling (MDS) plot (Fig. 3.11), where 3 major groupings can be distinguished. Data were grouped together by pond and not by date. Data from Pond 1 were grouped together on the left of the plot and were quite distinct from the other ponds. The second grouping consists of Ponds 2 and 3 which are loosely placed together in the top right of the plot. The third group comprising of Ponds 4, 5 and 6 are placed close together at the bottom of the ordination.

Zooplankton abundances were highest in autumn (February-May 2005) and lowest in winter (June-August 2005); (Fig. 3.12). Pond 3 had the highest zooplankton abundances (average of 719.89 individuals/L) followed by Pond 2 (553.20 individuals/L) (Fig. 3.13). Pond 1 had the lowest average abundances of zooplankton (7.48 individuals/L) Ponds 4, 5 and 6 had similar average zooplankton numbers (496.91, 531.05 and 531.08 individuals/L, respectively) (Fig. 3.14).

Rotifers were the most abundant total zooplankton taxon in Ponds 2 and 3 (Fig. 3.15), where higher chlorophyll *a* and bacteria levels were also found. Total crustacean taxa (cladocerans, ostracods, copepods) were more abundant in Ponds 1, 4 and 5 (Fig. 3.15).

Both rotifer and crustacean averages were the highest in autumn at similar abundances (Fig. 3.16). Pond 3 had few crustacean taxa, yet had the highest number of rotifer taxa in all seasons when compared with other ponds (Fig. 3.16). Average crustacean densities in Pond 5 reached their peak densities in summer but numbers dramatically decreased in all other seasons (Fig. 3.16). In contrast, all other ponds had highest densities in autumn (Fig. 3.16). Ponds 1 and 6 had considerably fewer rotifers (Fig. 3.16).

The "Shade" diagram (Fig. 3.17) also shows a similar pattern. Nauplii, cyclopoid copepods, *Daphnia* sp. and *Keratella procurva* were found in all ponds the majority of the time sampled. *Ilyocryptus sordidus* was only found in Pond 1, Ostracod sp., *Chydorus* sp. and the calanoid copepod species were primarily found in Pond 1. Ponds 2 and 3 were dominated by the rotifers *Brachionus caliciflorus*, *Synchaeta pectinata, Polyarthtra dolichoptera* and *Filinia longiseta* for most of the year. *Polyarthtra dolichoptera* and *Filinia longiseta* were found in low numbers in other ponds, but were in high abundance in Ponds 2 and 3. *Daphnia* sp. were found in all ponds but were predominately found in Ponds 4, 5 and 6 during all sampling periods. *Trichocera similis* was found in Ponds 4, 5 and 6 throughout the year and was rarely found in other ponds. ANOSIM indicated that species composition was significantly different among ponds, with the exception of Pond 2 from 3 and Pond 5 from 6 (Table 3.5).

Table 3.4. Zooplankton species found and their distribution in the ponds (1-6) (Fig. 2.1) as indicated by asterisks.

| | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|
| **Rotifera** | | | | | | |
| *Anuraeopsis* sp. | | * | * | | * | * |
| *Asplanchna brightwelli* | * | * | * | * | | * |
| *Asplanchna priodonta* | * | * | | * | | * |
| *Asplanchna sieboldi* | | * | * | | * | |
| *Brachionus budapestinensis* | | * | * | | | |
| *Brachionus caliciflorus* | * | * | * | * | * | * |
| *Brachionus lyratus* | | * | * | * | | * |
| *Brachionus quadridentatus* | | * | * | | * | * |
| *Brachionus urceolaris* | * | * | * | * | * | * |
| *Cephalodala sterea* | * | | | * | * | |
| *Cephaladela catellina* | | * | * | | | |
| *Cephaladela ventripes* | * | | | | | |
| *Dicranophoroides caudatus* | | * | * | * | | * |
| *Epiphanes macrourus* | | * | * | | | |
| *Euchlanis dilatata* | * | * | * | * | * | |
| *Euchlanis meneta* | | | | | * | |
| *Euchlanis pyriformis* | * | * | | | * | * |
| *Filinia longiseta* | | * | * | | | |
| *Filinia peleri* | | | | * | * | * |
| *Gastropus hyptopus* | * | * | * | * | * | * |
| *Hexarthra intermedia* | * | * | * | * | * | |
| *Keratella procurva* | * | * | * | * | * | * |
| *Keratella slacki* | * | * | * | * | * | |
| *Keratella cochlearis* | * | * | * | * | * | * |
| *Lecane bulla* | | | | | * | * |
| *Lecane lepadella* | | | | | | * |
| *Lecane lunaris* | * | * | * | * | * | * |
| *Lecane ovalis* | | * | | | | * |
| *Platyais quadricornis* | * | * | | * | * | * |
| *Polyarthra dolichoptera* | * | * | * | * | * | * |
| *Pompholyx complanata* | | * | | * | * | * |
| *Proales* sp. | * | | * | * | * | * |
| *Squatinella mutica* | | * | * | * | * | * |
| *Synchaeta pectinata* | * | * | * | * | * | * |
| *Testudinella patina* | * | * | * | | | * |
| *Trichocerca pusilla* | | | * | | | |
| *Trichocerca similis* | * | * | * | * | * | * |
| unidentified bdelliod | * | * | * | * | * | * |
| **Cladocera** | | | | | | |
| *Bosmina* sp. | * | * | * | | * | * |
| *Chydorus* sp. | * | * | * | * | * | * |
| *Daphnia* sp. | * | * | * | * | * | * |
| *Ilyocryptus sordidus* | * | | * | | | |
| *Simocephalus* sp. | * | * | * | * | | * |
| **Crustacea** | | | | | | |
| unidentified calanoid | * | | * | * | | * |
| unidentified cyclopoid | * | * | * | * | * | * |
| unidentified harpacticoid | * | * | | * | | * |
| unidentified ostracod | * | * | * | * | * | * |
| unidentified nauplii | * | * | * | * | * | * |

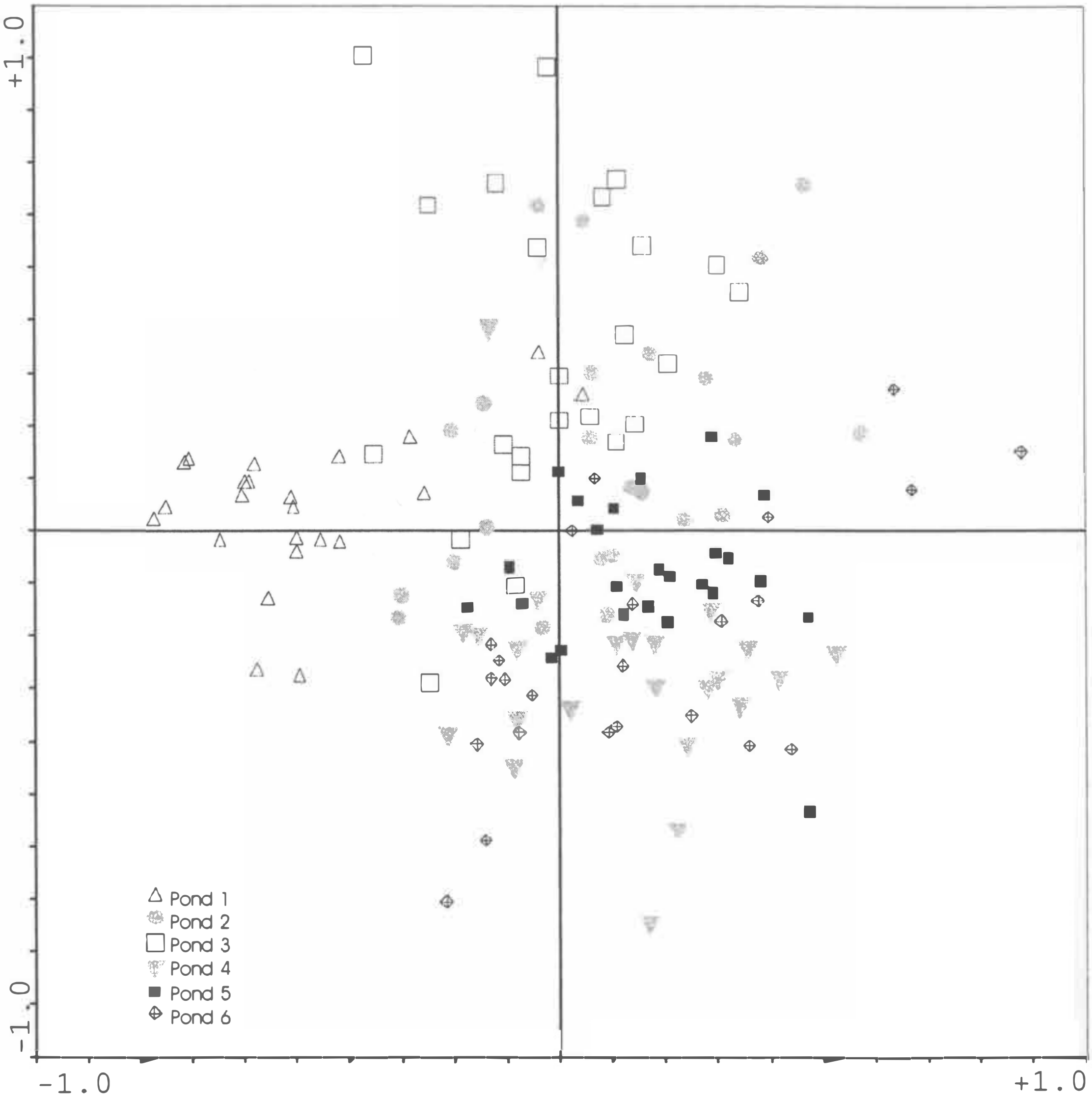



Fig. 3.11. Multidimensional scaling (MDS) plot of zooplankton in the six ponds at Hamilton Zoo (Fig. 2.1). Stress value indicates how well the map fits, zero being perfect.

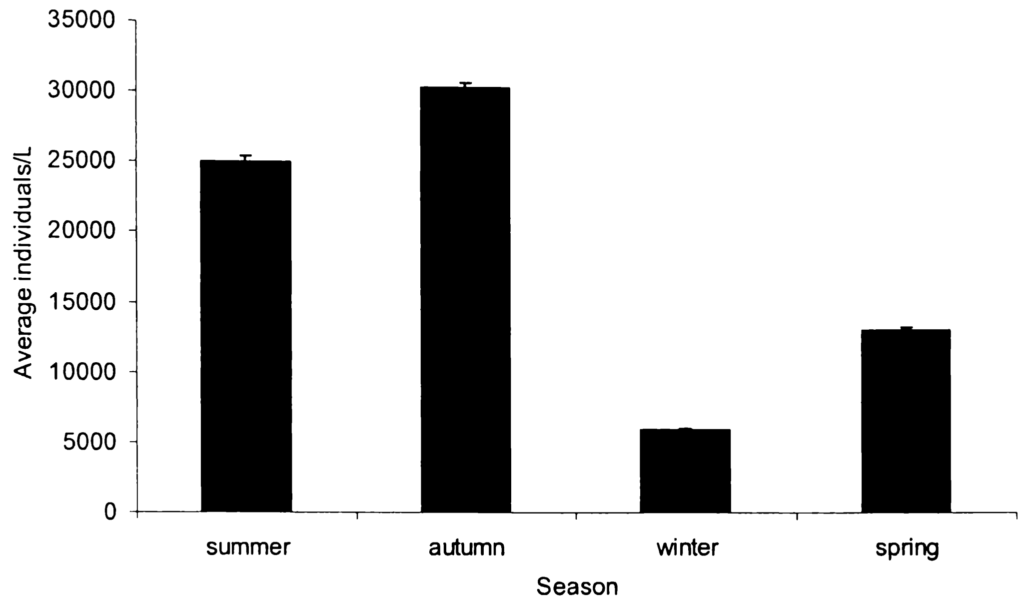



Fig. 3.12. Average abundance of total zooplankton (+/- 1s.e.) in an austral season for the six ponds at the Hamilton Zoo seen in Fig. 2.1.

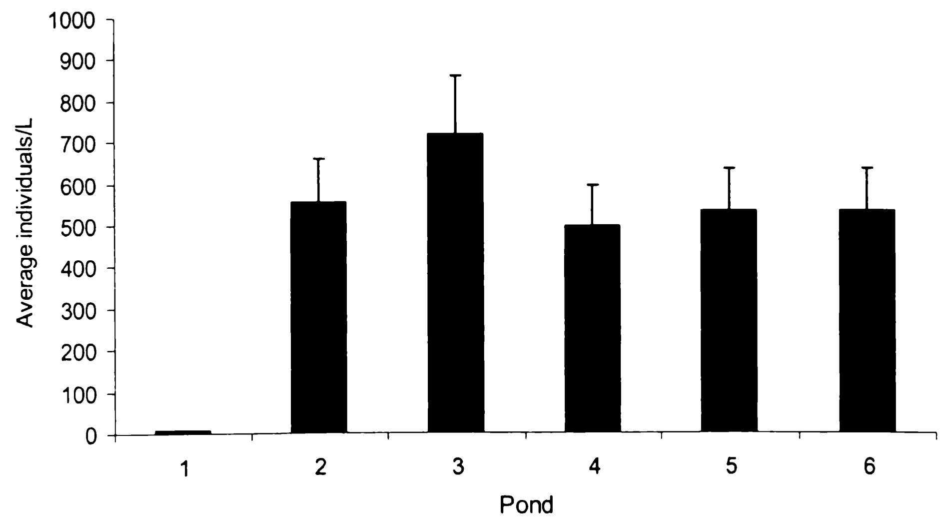



Fig. 3.13. Average total zooplankton abundance (+/- 1s.e.) and their distribution among the six ponds in the Hamilton Zoo (Fig. 2.1).

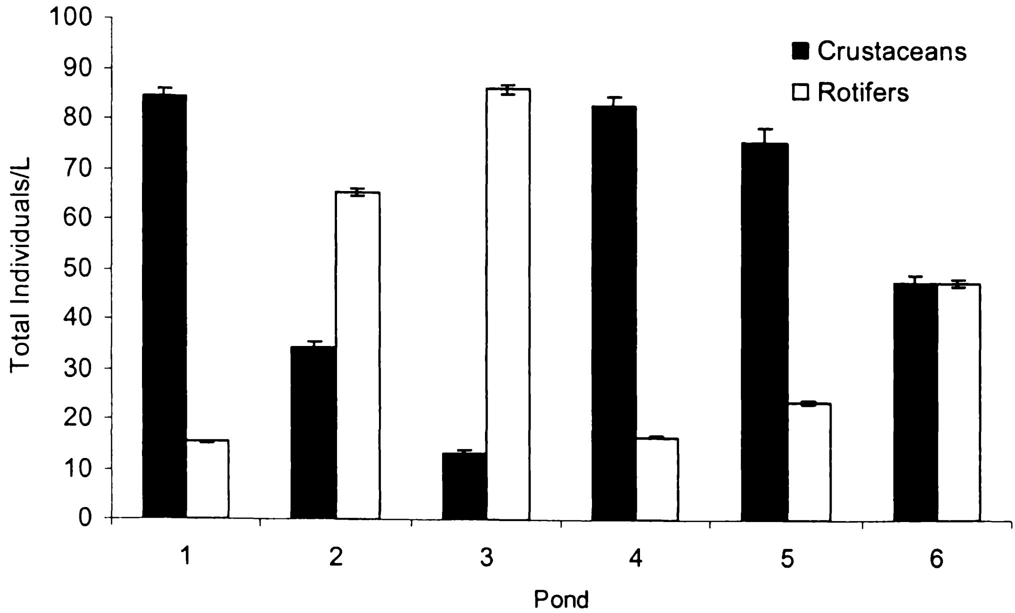



Fig. 3.14. Abundance and distribution (+/- 1s.e.) of rotifers and crustaceans among the six ponds at Hamilton Zoo (Fig. 2.1).

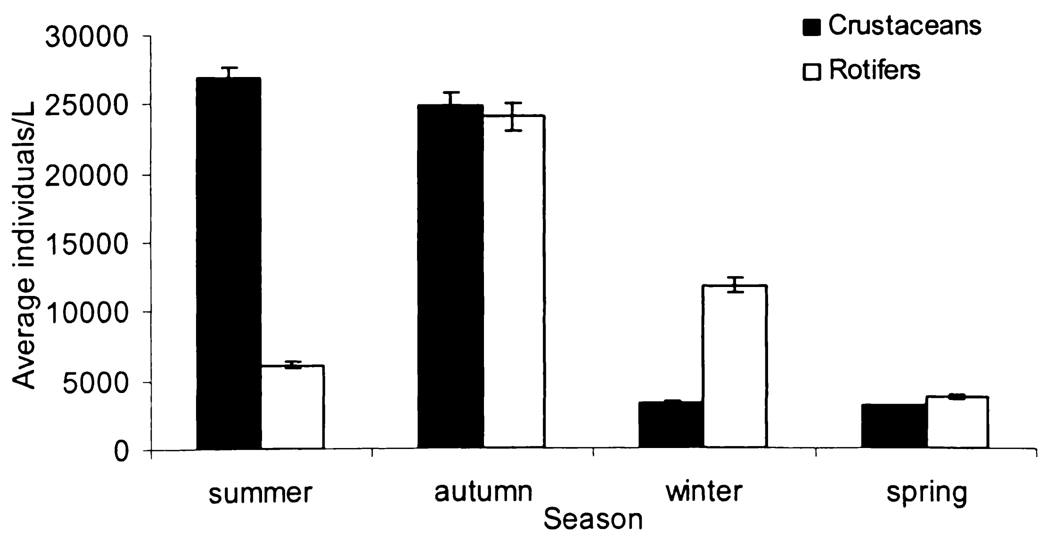



Fig. 3.15. Seasonal abundance (+/- 1s.e.) of rotifers and crustacean for each austral season in the six ponds at Hamilton Zoo (Fig. 2.1).

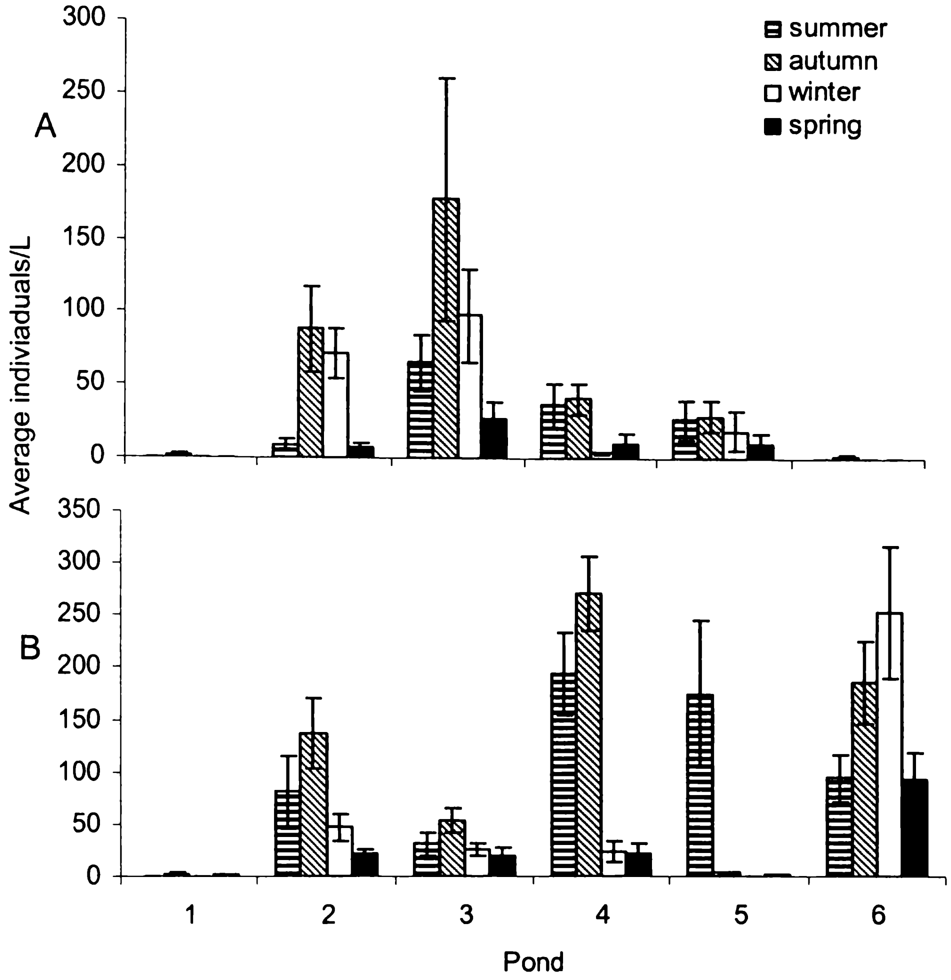



Fig. 3.16. Average austral season variation and abundance (+/- 1s.e.) of (A) rotifers (individuals/L) and (B) crustacean (individuals/L) among six ponds at Hamilton Zoo (Fig. 2.1).

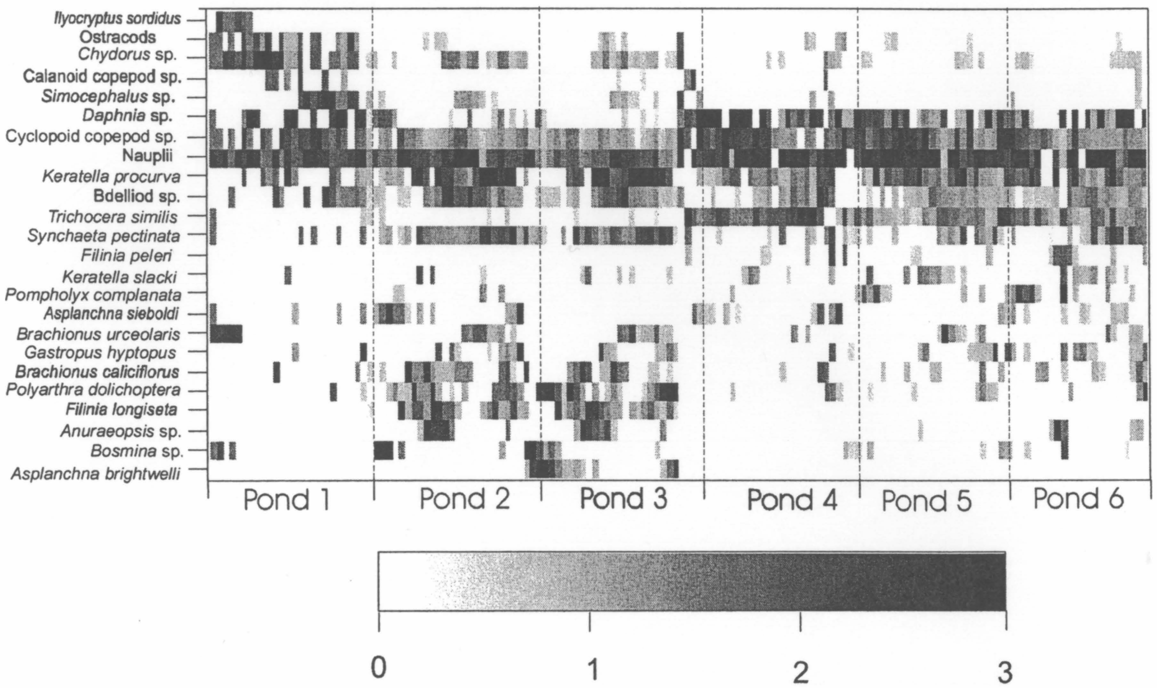



Fig. 3.17. Shade diagram for zooplankton community composition over time by pond number (Fig. 2.1). Darker boxes represent more animals in the sample. Rows are ordered based on similarity from cluster analysis and MDS distributions of species.

### *3.3 Water quality versus zooplankton distribution*

The eigenvalues for Axis 1 and 2 of the CCA (Fig. 3. 18) are shown in Table 3.6. The spread of sample scores correspond to the groups in the MDS ordination plot (Fig 3.11). Pond 1 is negatively associated with Axis 1. Pond 2 is generally weakly positively associated with Axis 1. Pond 3 has a general positive association with Axis 2. Ponds 4 and 6 are positively associated with Axis 1, and negatively with Axis 2 (Fig 3.18).

*Ilycryptus sordidus*, *Simocephalus* sp. calanoid copepods, and *Brachionus urceolaris* and are negatively associated with Axis 1, and are therefore associated with Pond 1. *Asplanchna brightwelli, Anuraeopsis* sp., *Filinia longiseta, Brachionus caliciflorus, Synchaeta pectinata* and the cladoceran *Bosmina* sp. are weakly positively associated to Axis 2, and are therefore associated with Ponds 2 and 3. *Asplanchna sieboldi, Pompholyx complanata, Filinia peleri, Gastropus hyptopus, Keratella procurva, Keratella slacki*, copepods and *Daphnia* have a positive association with Axis 1 and a weak negative association with Axis 2, and are therefore associated with Pond 4, 5 and 6 (Fig 3.18).

The results of the Monte Carlo permututation tests of the significance of the environmental variables are presented in Table 3.7. The Lambda-1 values give the amount of variation the environmental variable has alone, if it were the only one used in the test. The Lamba-A values list each environmental variable as they were used the CCA ordination graph (Fig. 3.18), the additional variance each explains, and its significance at this time indicated by the *P* value ($P<0.05$). Each

Lambda-A value accounts for the amount of variation not accounted for by the previous variable. Axis 1 will be most strongly constrained by the first Lambda-A variable and Axis 2 by the second, unrelated, variable (ter Braak and Smilaeur 1998).

Chlorophyll *a*, pH and temperature were the most significant determinants of zooplankton composition (Table 6) accounting for 12% and 11% and 10% respectively, when considered alone. Other significant variables, indicated by the *P* values are total coliform bacteria, conductivity, total nitrogen and dissolved oxygen (mg /L) and oxygen (% saturation).

Chlorophyll *a* and temperature are strongly positively associated with Axis 1, TN is strongly negatively related. pH, $O_2$% and $O_2$ (mg /L) are strongly positively associated with Axis 2 and TP is strongly negatively related.

Comparing the zooplankton groupings with the ordinations of physical and chemical variables, zooplankton species associated with Pond 1 (*Simocephalus, Chydorus,* cyclopoid copepods, and *Brachionus urceolaris* are associated with low temperature and low chlorophyll *a*, (Fig. 3.18). Zooplankton species associated with Ponds 2 and 3 (*Asplanchna brightwelli, Anuraeopsis* sp., *Filinia longiseta, Brachionus caliciflorus, Synchaeta pectinata* and *Bosmina* sp.) are associated with high chlorophyll *a,* high pH and low TP. The zooplankton species associated with pond 4, 5 and 6 (*Asplanchna sieboldi, Pompholyx complanata, Filinia peleri, Gastropus hyptopus, Keratella procurva, Keratella slackii,* cyclopoid copepods and *Daphnia*) correspond to high TP, low oxygen and pH.

Table 3.5. Summary of r values for zooplankton species composition among ponds. No significant difference found by *P* value ($P < 0.05$) indicated by *.

| | Pond 1 | Pond 2 | Pond 3 | Pond 4 | Pond 5 | Pond 6 |
|---|---|---|---|---|---|---|
| Pond 1 | | | | | | |
| Pond 2 | 0.597 | | | | | |
| Pond 3 | 0.687 | 0.075* | | | | |
| Pond 4 | 0.607 | 0.620 | 0.739 | | | |
| Pond 5 | 0.679 | 0.574 | 0.660 | 0.123 | | |
| Pond 6 | 0.676 | 0.421 | 0.571 | 0.135 | 0.047* | |

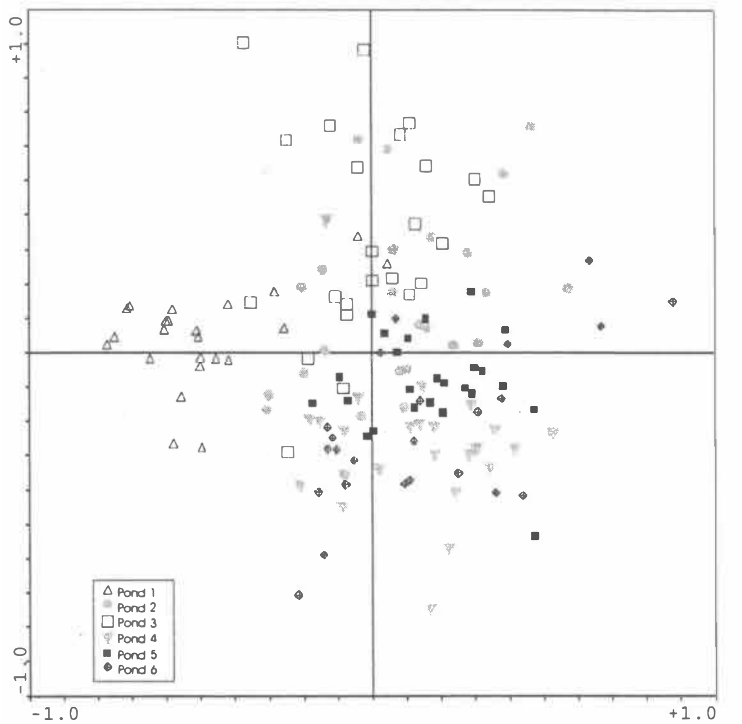
Table 3.6. Eigenvalues of axis for Canonical correspondence analysis (CCA).

| Axis | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Eigen values | 0.1628 | 0.1397 | 0.0769 | 0.0482 |

Table 3.7. Results of Monte Carlo permutation test.

| | Marginal Effects | Conditional Effects | | |
|---|---|---|---|---|
| Variable | Lambda 1 | LambdaA | P | F |
| Chlorophyll *a* | 0.12 | 0.12 | 0.005 | 9.35 |
| pH | 0.11 | 0.12 | 0.005 | 9.50 |
| Temperature | 0.10 | 0.08 | 0.005 | 7.26 |
| Conductivity | 0.04 | 0.04 | 0.005 | 2.84 |
| Total nitrogen | 0.05 | 0.03 | 0.005 | 2.69 |
| DO (mg/L) | 0.09 | 0.02 | 0.035 | 2.07 |
| DO saturation (%) | 0.06 | 0.02 | 0.055 | 1.81 |
| Total coliform | 0.02 | 0.02 | 0.025 | 1.82 |
| Total phosphorus | 0.04 | 0.02 | 0.140 | 1.41 |
| Specific conductance | 0.04 | 0.02 | 0.175 | 1.46 |
| Suspended solids | 0.01 | 0.01 | 0.520 | 0.96 |
| Secchi depth | 0.01 | 0.01 | 0.535 | 0.91 |

A




B

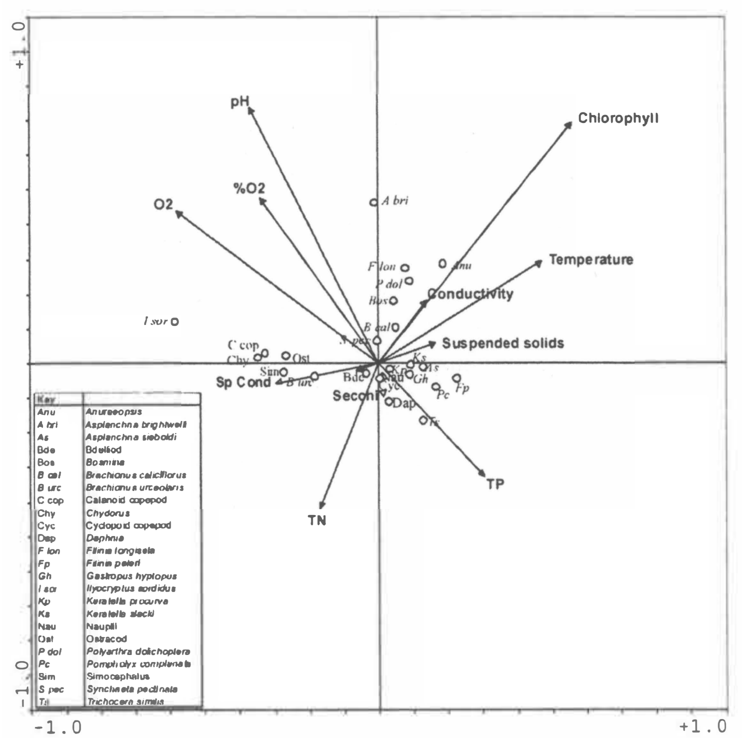



Fig. 3.18. Ordination diagrams based on canonical correspondence analysis (CCA) of zooplankton species in respect to site (pond number) and environmental variables (scaled to fit). Coliform bacteria and *E.coli* have been omitted for clarity.

# Chapter 4: Discussion

## *4.1 Water Quality*

Water temperatures showed considerable spatial and temporal variability. Temperature differences among ponds were highest in summer and lowest in winter, where more exposed ponds (2, 3 and 4) heated up faster than ponds with marginal vegetation (1, 5 and 6). Temperature changes in shallow ponds are generally more frequent and more extreme than in deeper lakes (Martin 1972). Seasonal temperature ranges (STR) were greater (maximum range 16.5°C) than that found for larger North Island lakes (13.0 ± 3.1°C), because of the shallowness of ponds and their high surface area to volume ratios (Martin 1972, Green *et al.* 1987). However, ponds had similar summer temperature ranges to other studies of shallow Waikato lakes (Boswell *et al.* 1985, Miller 2002, Bryant 2003).

Pond 1 has a high loading of organic matter from effluent sources (suggested by the coliform and nutrient data) would be expected to have low dissolved oxygen concentration (e.g. Jarvie *et al.* 2003). However, Pond 1's fairly stable oxygen concentrations in Pond 1 can be attributed an artificial waterfall where water is pumped to an "upper" pool and recirculated back to the pond. Ponds 2 and 3 both had high dissolved oxygen levels and high chlorophyll *a*, levels suggesting high algal productivity. Pond 4 had comparatively lower dissolved oxygen levels than the other ponds, likely attributable to decomposition of effluent from a neighbouring deer farm which flowed into Pond 4. Oxygen depletion was more intense because of lower algal productivity (indicated by the chlorophyll *a* levels) to regenerate oxygen in the water, as indicated by the chlorophyll *a* levels. Dissolved oxygen levels were similar to those of other shallow eutrophic New Zealand ponds (Bryant 2003).

Conductivity levels in all the ponds ranged from 135-290 $mS.cm^{-1}$@ 25°C. Similar findings for these ponds were made by Maseyk (1994) in a three month study conducted twelve years earlier. This suggests that some physical features of ponds may remain relatively consistent between years. Pond 4 had the greatest range of specific conductivity measurements (135.4-290.3 $mS.cm^{-1}$ @ 25°C). Pond 1 had the highest specific conductivities likely due to the re-circulating nature of the pond which would serve to concentrate any dissolved ions. In comparison to water bodies in the Waikato Region, the Waikato River has conductivity of around 150 $mS.cm^{-1}$ (Lam 1981). Water from the zoo ultimately flows into Lake Rotokauri, which has been recorded to have conductivity of 120-140 $mS.cm^{-1}$ (Town 1980). These values are similar to the minimum values of the zoo ponds (135-171 $mS.cm^{-1}$). Similarly high conductivity measurements have also been observed small shallow ponds in the Waikato region (140-250 $mS.cm^{-1}$) (Bryant 2003).

pH did not change greatly within ponds over the year. Measurements were within the range reported by Boswell *et al.* (1985) for shallow lakes in the Waikato regions (6.2-12.3). Ponds 1 and 3 had noticeably higher average values than the other ponds, and Pond 4 had lower values. The pH increase in Pond 3 could be attributed to photosynthetic activities from the high algal abundance found in this pond. As $CO_2$ is taken up during photosynthesis there is a decrease in carbonic acid which increases the pH (Cole 1975). The lower pH in Pond 4 is most likely attributed to acidic untreated effluent entering the pond from outside the system (Karim & Rafi 2002). pH ranges in the Zoo are similar to those measured in Lake Rotokauri (Town 1980).

Fluctuating chlorophyll *a* is common in temperate regions (Baily-Watts 1982, Bennion & Smith 2000). Annual seasonal changes in chlorophyll *a* can be attributed to the availability of light and nutrients for growth, losses by respiration, consumption, flushing and sedimentation (Reynolds 1984, Kasprzak *et al.* 1999, Viner & White 1987). Chlorophyll *a* had an autumn peaks which is consistent with polymictic Lake Rotorua (Viner & White 1987). However, the summer low in chlorophyll *a* contrasts with what is seen in New Zealand lakes (Schwartz & Howard-Williams 1993). One possible explanation for this is that surface blooms were shading (and hence limiting) algal growth below (e.g. Ponds 2 and 3). Wind-induced resuspension of sediments is common in shallow exposed lakes (Schallenberg & Burns 2004) and results in increased nutrient availability and decreased light penetration (Hamilton & Mitchell 1996, Schallenberg & Burns 2004). Decreased penetration of light available for photosynthesis (Hellström 1991, Scheffer 1998) could be attributed to low chlorophyll *a* levels in Ponds 1 and 4. Conversely, chlorophyll *a* has been found to increase with sediment resuspension in nutrient limited waters (Hamilton & Mitchell 1996, Oglivie & Mitchell 1998), which was found in Lake Waihola (Schallenberg & Burns 2004).

All ponds had high numbers of both total coliforms and *E.coli,* and were much higher to what had previously been measured in the downstream Lake Rotokauri (Town 1980) and in the Zoo ponds (Maseyk 1994). Pond 5 had much lower bacterial counts relative to any of the upstream ponds. Wetland ponds such as Pond 5 have been found effective in removing bacteria (among other variables) from the water column (Lau & Chu 2000, Decamp & Warren 2002, Coveney *et al.* 2002, Vacca *et al.* 2005).

Ammonia levels in Pond 4 where up to 1.3 mg/L higher than in other ponds and may have been the result of drainage from a neighbouring deer farm. Maseyk (1994) found that there was considerable variation in nitrogen, and came to this conclusion also. Livestock present in pond catchments have been shown to cause a large export of nitrogen and phosphorus (Ruggiero *et al.* 2003). During the sampling period there were no trees and little grass around Pond 4, and it contained no macrophytes. Accordingly, there was little to remove ammonia from the water column or the immediate catchment. Oxygen depletion in the sediments could also be a cause for high ammonia levels in Pond 4.

$NO_3$-$NO_2$ in Pond 1 was up to 1.5 mg/L higher than in the other ponds and again could be due to water being recycled and nutrient build up. Other nutrients measured (such as ammonia) may have been taken up by plants or have settled out to the sediment. Pond 1 had a much higher proportion of canopy cover than the other ponds contributing detritus to the water. It was also housed within an aviary with birds contributing faecal matter directly and indirectly to the water. Although there were more waterfowl present in Ponds 2, 3, and 5 than in Pond 1, these ponds did not recirculate water.

Dissolved reactive phosphorus (DRP) levels decreased progressively through the ponds system, and in the outflow pond (Pond 6) levels of DRP were low. However, Pond 6 also showed high levels of total phosphorus (TP), indicating that the DRP may have flocculated. Pond 6 also had periods of low dissolved oxygen which would result in the release of minerals that were previously bound to sediment (e.g. Correll 1999).

### 4.2 Zooplankton abundance and composition

A total of 38 species of rotifer was found in the Hamilton Zoo ponds. This is similar to the species richness found in single, deeper, New Zealand lakes, which range from 38-44 species when studied intensively (Duggan *et al.* 2002). This is comparable also to northern temperate lakes (Berner-Frankhauser 1983, Duggan *et al.* 2002). Species richness in the Hamilton Zoo ponds is lower than what would be expected for a series of ponds that differ in water quality parameters, as several small ponds are generally thought to have higher species richness than one large lake (Gee *et al.* 1997). Possible reasons for the lowered richness is the age of the ponds, species richness has been noted to increase with age to about 18 years (Ejsmont-Karabin 1995), or that there was little seasonal variation in species composition.

When comparing species composition among ponds, Pond 1 had the lowest number of rotifer species (20 species) and these were in low abundance. This could be due to the age of the pond, as it is the most recently created (constructed in 1996). Alternatively, the physical parameters (e.g. temperature) were comparatively stable, and this may have contributed to the lower species richness (sensu Duggan *et al.* 2002). In contrast, the nearby Pond 2 had the highest rotifer species richness (29 species), which demonstrates that spatial variation was occurring on a small scale. Pond 2 and 3 had high chlorophyll *a* and high bacterial counts, which could have influenced rotifer abundance and composition. Zooplankton species such as *Filinia* and *Brachionus* that are able to utilise bacterial cells may have an advantage over other species (Pejler 1983, Oom-Wilms *et al.* 1995).

The MDS plot and underlying similarity matrix showed that zooplankton were grouped by pond rather than by date, meaning that changes in composition found over time were relatively insignificant compared with differences among ponds. Temporal differences are usually attributed to seasonal temperature changes (Romare *et al.* 2005), although zooplankton communities in New Zealand are generally thought to show less seasonal variation than other areas of the world due to the temperate climate allowing year round growth and reproduction. This often means that the quality and quantity of food are often the determining factors in zooplankton distribution and abundance (Chapman & Green 1987).

The MDS results showed that the 6 ponds can be placed into 3 main group based on community compositions: a) Pond 1, b) Ponds 2 and 3; and c) Ponds 4, 5 and 6. The differences can primarily be attributed to the connectivity and flow of the ponds (Jenkins & Buikema Jnr 1998). Accordingly, ponds that are not directly connected to each other, do not share water, and therefore do not have similar community composition because of the dispersal ability of zooplankton and differences in internal and external factors influencing zooplankton at each individual pond (Cottenie *et al.* 2001).

The Hamilton Zoo ponds were found to be similar to some of the interconnected ponds studied by Cottenie *et al.* (2001), who noted that ponds in turbid state were characterised by the dominance of the rotifer species *Asplanchna* sp., *Polyarthra* sp., *Brachionus* sp. and *Keratella* sp. All of these taxa were found in large numbers in Ponds 2 and 3, but also in the rest of the ponds at some stage of the year. Rotifer communities in urban ponds have been thought to have a more similar composition to temporary ponds than lake systems (Ejsmont-Karabin and Kuczynska-Kippen 2001). However, the drying out of temporary ponds contributes to disrupted colonisation and low species richness (Holland & Jenkins 1998). Temporary ponds and zoo ponds possessed similar rotifer species, although more crustacean species were generally found in temporary ponds than in the Zoo ponds (Fahd *et al.* 2000, Serrano & Fahd 2005, Tavernini *et al.* 2005).

The rotifer species composition was similar to what has been found in North Island lakes by Duggan (2002), with the addition of *Brachionus lyratus* which was found in Ponds 2, 3 and 4. Previous recordings of this species have been rare. Shiel and Green (1996) compiled a list of rotifers that have been found in New Zealand which included a mention of *B. lyratus* in their own unpublished collections. This species has also been found in large numbers (150 Individuals/$L^{-1}$) in Weavers Lake (S. Balvert, University of Waikato pers. comm.).

The large omnivorous rotifers *Asplanchna brightwelli* and *A. sieboldi* were predominantly found in Ponds 2 and 3 which contained the highest rotifer numbers and highest levels of chlorophyll *a* among the ponds. *Asplanchna* spp. are commonly known to feed on other rotifers and phytoplankton (Kappes *et al.* 2000), and this could have restricted *Asplanchna* abundance to Pond 2 and 3. Restriction in species distribution was also seen in the other ponds. For example *Trichocera similus* was rarely found in Ponds 1, 2 and 3 but was found in large numbers in Ponds 4, 5 and 6. *Ilyocryptus sordidus* was only found in Pond 1.

Seasonal variation of zooplankton communities was not as pronounced as the differences in species composition among ponds. However, crustaceans were found to be more abundant in the warmer summer to autumn months (November 2004-May 2005). Stout (1975) also found that crustacean copepods were more abundant in the warmer months. Pond 6 had higher densities of crustaceans. Rotifer numbers could have been lower in this pond due to competition with the crustacean species present (Christoffersen *et al.* 1993).

Peak rotifer abundance was found in autumn which is similar to rotifer studies by Forsyth & McCallum (1980) and Jolly & Chapman (1980), who also found peak rotifer abundance in winter. Rotifers dominated during winter and spring which is similar to a study of Lake Grasmere, a small South Island lake (Stout, 1975).

### *4.3 Zooplankton versus water quality parameters*

Chlorophyll *a* was found to be the most important environmental variable affecting the distribution of zooplankton among ponds, this has been previously observed in several other studies (Beaver *et al.* 1998, Bini *et al.* 2001, Norlin *et al.* 2005). Zooplankton densities were higher in Ponds 2 and 3, where chlorophyll *a* and bacteria levels were higher than the other ponds. Pond 1 had low chlorophyll *a* levels and low zooplankton abundance. This is a likely result of zooplankton using algae as a food source (sensu Lubzens 1987, Schlüter *et al.* 1987, Devetter & Sed'a 2003) with the potential to regulate chlorophyll *a* and bacteria biomass (Mitchell & Wass 1996, Perrow *et al.* 1999). They are therefore likely to be sensitive to the quantity and quality of food that the water is providing, and subsequently be influenced by changes in trophic state. Three groupings were found amongst the ponds, the type of food available, (algae and / or bacteria) and palatability of food for zooplankton in each group must be considerably different to influence community composition (Duggan *et al.* 2002).

Chlorophyll *a* concentrations have been found to influence rotifer populations more so than crustaceans (Beaver & Havens 1996) and to relate also to the fecundity of rotifers (Devetter & Sed'a 2003). Rotifers have been noted to have an extremely fast population growth rate and a shortened developmental stage when there are favourable conditions (Andrew & Fitzsimons 1992, Thouvenot *et al.* 2000, Castro *et al.* 2005) which explains the difference in high rotifer numbers in ponds such as Pond 2 and 3 that had higher chlorophyll *a* levels, and low rotifer numbers in Pond 1 which had low chlorophyll *a* levels.

pH was also an important variable determining zooplankton composition and abundance in this study. Highest pH was observed in Pond 1 and 3, and the lowest in Pond 4. pH is commonly found to influence zooplankton community composition (Bērziņš & Pejler 1987, Arnott & Vanni 1993, Duggan *et al.* 1998) biomass and productivity (Havens 1992). The amount of chlorophyll *a* in Pond 3 has had an effect on pH, where more photosynthesis leads to higher a pH.

Temperature was also a determining factor influencing zooplankton composition in this study. Pond 1 was consistently the coldest, had the highest pH and lowest chlorophyll, which had an effect on the amount of zooplankton found. When compared with the other ponds which had higher temperatures and higher chlorophyll *a*, Pond 1 had lower densities of total zooplankton throughout the year and fewer species present. Ponds 2 and 3 were warmer and more exposed and had similar richness with 37 and 36 species respectively, the highest found in the study. Seasonal changes in temperature are usually important in influencing zooplankton abundance, with the exception of this study. Temperature influences seasonal succession, where in winter there are less zooplankton (Wolfinbarger 1999, Swadling *et al.* 2000, Cardoso & Marques 2004). The seasonal temperature range was high compared with other lakes, but ponds that contained few species (e.g. Pond 1) therefore had few interactions among species, reducing the effects seasonality usually has on zooplankton.

# Chapter 5: Conclusion

## 5.1 General conclusions

All ponds showed considerable spatial and temporal variability in physical and chemical parameters. In contrast, zooplankton showed spatial variability yet only limited temporal variability. This differs to what has been found in lakes which show more temporal variability than spatial variability.

Zooplankton community composition in the ponds was mostly determined by chlorophyll *a*, pH and temperatures of the ponds. For example, Pond 1 had low chlorophyll a, low temperatures and high pH year-round and had comparatively few zooplankton and low species richness. Ponds 2 and 3 had high chlorophyll *a* and bacteria levels, which may not be desirable from water quality point of view. However, they were also highest in densities and species richness of zooplankton when compared with all other ponds and even contained the rarely recorded species *Brachionus lyratus*, making the environment of the ponds potentially important in terms of biodiversity and conservation.

Numerically dominant taxa differed between ponds. For example, Ponds 2 and 3 were dominated by rotifer species and Ponds 1, 4, 5 and 6 were dominated by crustacean taxa. Some species were found to be primarily limited to one pond (e.g. *Ilyocryptus sordidus* was found only in Pond 1). This indicates that small scale spatial diversity is occurring in the Hamilton Zoo ponds.

## 5.2 Management Recommendations for the Hamilton Zoo

On the basis of our study carried out over a 12 month period, we conclude that the major water quality issues facing the Hamilton Zoo ponds are the result of nutrient inputs and associated algal productivity. In order to enhance water quality and/or public perception of water quality, we provide the following three recommendations:

1) Nutrient Diversion: Nutrients from animal enclosures (particularly the tapir enclosure) should be diverted away from the ponds and perhaps into the Hamilton City sewerage system if possible. The gravel filter system downstream of Pond 1 was effective in removing a majority of bacteria. However, this had a minimal effect on the nutrient content. For example, the levels of nitrate-nitrite decreased, although levels of phosphate were actually higher after being discharged from the filter. The ammonia level in Pond 4 was significantly higher than that found in the other ponds. This was likely the result of effluent reaching this pond from the neighbouring deer farm (see also pond colour in Fig. 2.1). This effluent should ideally be controlled and/or diverted if possible.

2) Public Safety: Total coliforms and faecal coliforms (indicated by *E.coli*) were well above acceptable guidelines for even secondary recreational use. Accordingly, it would be prudent to check for any on-site maintenance issues (e.g. malfunctioning septic tanks) and to maintain present fencing arrangements to restrict public access to the ponds.

3) Planting: Planting of native trees, shrubs and flaxes around ponds should be continued. Pond 5 demonstrated the success of the wetland system for improving water quality by reducing total nitrogen, ammonia, bacteria, suspended solids and having a high secchi depth.

4) Education: The importance of conservation of small ponds and their resident biota (e.g. phytoplankton, zooplankton) should be made available to the public (e.g. via information display boards etc). Catchy titles such as “Beautiful Scum” could capture the public’s imagination when discussing algal productivity. However, the “take-home message” is that the ponds are an integral part of biodiversity in New Zealand even though they may not look “pristine”.

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