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# **Trophic manipulation in freshwater plankton communities**

A thesis submitted in partial fulfilment  
of the requirements for the degree of  
Doctor of Philosophy  
in Biological Sciences

by

**Nick B. Edgar**

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## ABSTRACT

The effects of zooplankton herbivory on natural phytoplankton communities in two urban mesotrophic lakes in the North Island of New Zealand were studied over the course of one year. Lakes Rotoroa and Pupuke have zooplankton assemblages typical of most New Zealand lakes, in having a low species diversity, being dominated by calanoid copepods, and lacking *Daphnia*.

*In situ* enclosure (limnocorral) experiments were conducted in each season of the year in each lake using 1 m<sup>3</sup> (1000 litre) volume plastic bags. The enclosures were initially filled with lake water filtered through an 80 µm mesh plankton net to remove the majority of the zooplankton. Subsequently, a gradient of zooplankton biomass was established in eight enclosures by adding crustacean zooplankton collected from the epilimnion. Four densities (each duplicated) were established: enclosure (no zooplankton added), 1X, 2X, and 4X ambient zooplankton biomass. Experiments were conducted for 10 days with physico-chemical and biological sampling made on Days 0, 3, 6, and 10. Their aim was to investigate the role of zooplankton grazing on total algal biomass, the dynamics of population level responses of the phytoplankters, feeding selectivities of the herbivores and any changes in nutrient dynamics mediated by zooplankton grazing.

In Lake Rotoroa zooplankton grazing had no significant effect on total algal biomass in autumn. In winter, spring and summer there were significant reductions in phytoplankton biomass particularly in the size fraction  $\leq 80$  µm. In Lake Pupuke grazing caused no change in algal biomass in autumn and winter, but in spring it was significantly reduced. However, in summer algal biomass was positively associated with zooplankton biomass possibly indicating that nutrient regeneration by zooplankters was important in this season.

At the population level, algal species-specific response to herbivory varied between grazing suppression, a lack of response, increased abundance or in some cases, a unimodal response. The majority of phytoplankters in Lake Rotoroa were 'decreasers'. In Lake Pupuke most algae were 'unresponsive' to grazing.

Most 'decreasers' were of smaller size  $\leq 30 \mu\text{m}$  in Greatest Axial Linear Dimension (GALD). 'Unresponsive' algae and 'increasers' were usually  $>30 \mu\text{m}$  in GALD. Relationships with algal biovolume were less consistent, but there was an upper limit to the volume of suppressed algae ( $\sim 6,000 \mu\text{m}^3$ ) above which no species were significantly grazed.

In Lake Rotoroa the presence of herbivores increased the availability of nitrogen ( $\text{NH}_4$  and DON) in spring and of phosphorus (DRP and DOP) in summer. In Lake Pupuke zooplankton altered nutrient concentrations little during spring but increased the availability of both organic N and P during the summer experiment.

The results suggest that integration of the ecological forces of grazing and nutrient limitation are required to explain patterns of planktonic seasonal succession, rather than depicting the two control processes as mutually exclusive.



## ACKNOWLEDGEMENTS

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## ERRATA

- pg.iii Funding agencies should include a research grant from The World Wide Fund for Nature (NZ) 1992.
- pg.5 metereological should be meteorological
- pg.6 *meriodionalis* should be *meridionalis*  
*Tench* should be *tench*  
*Tincatinca* should be *Tinca tinca*
- pg.20 Zooplankton counting followed the method of Greenwood (1987)  
GREENWOOD, T.L. 1987: Comparative ecological studies on three New Zealand planktonic Cladocera. M.Sc. thesis, University of Waikato, Hamilton. 157p.  
hydrozine should be hydrazine
- pg.72 Solid bars indicate should be The height of each bar indicates
- pg.115 *Achanthes* should be *Achnanthes*
- pg.117 *Achanthes* should be *Achnanthes*
- pg.130-137 All points on each figure should be considered a '.'
- pg.144 phytoplankters should be phytoplankter`s
- pg.156 De Mott should be DeMott
- pg.182 regenration should be regeneration
- pg.186-202 All references are ordered primarily by alphabetic sequence and secondarily by chronological order of the first author.
- pg.221 *Synachaeta* should be *Synchaeta*

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## CHAPTER ONE

### INTRODUCTION

#### 1.1 General Introduction

The view of zooplankton as regulators of functional and structural components of the phytoplankton community has been supported by both theoretical, experimental and empirical studies (Sterner 1989). The relationship is not one-directional however, as properties of the phytoplankton community are important for distribution and abundance of zooplankton as well (Gliwicz 1980).

Zooplankton may affect phytoplankton *via* two different processes. One of these is direct selective grazing which causes selective mortality among phytoplankton. Grazing is based on size, shape and taste of the algae and it may be adjusted in relation to the abundance of the food objects (Svensson and Stenson 1991). The second aspect of the grazers' impact, recycling of nutrients, adds further complexity to these interactions since it may selectively affect different phytoplankton species according to their demands and abilities to compete for these nutrients (Sommer 1989). The fact that zooplankton may supply a considerable amount or even the majority of the algal phosphorus demand to the epilimnion demonstrates the importance of the process (Lehman 1980).

Both the selective grazing and the nutrient recycling processes are operating simultaneously in nature, making their effects hard to separate. The highly co-evolved relationship between the ever-present zooplankton and their food makes it still more difficult to analyse this complexity of interactions (Porter 1977). Recent studies of the role of growth and loss processes in phytoplankton dynamics have taken advantage of significantly improved methodologies, but because of wide confidence intervals definitive conclusions are still difficult to make (Sterner 1989).

For the time being, it seems difficult to make reasonable and precise predictions of how, for example, a specific phytoplankton community will respond to changes in zooplankton community structure. This lack of predictive ability is exemplified in the modelling strategies of Scheffer (1991) who has linked planktonic dynamics to chaos theory.

A number of recent studies have concluded that loss processes in phytoplankton in general, and grazing losses in particular, are important in seasonal succession (Reynolds 1984). However, critical tests of the seasonal variation in grazing and nutrient limitation, and the mechanisms accounting for this variation, are lacking (Vanni & Temte 1990). Evaluation of these influences should help refine models of plankton succession and aid in development of conceptual models that integrate grazing and nutrient limitation, rather than depicting the two control processes as mutually exclusive.

The purpose of this study was to investigate the net effect of seasonal variations in zooplankton biomass on total algal biomass in two meso-eutrophic lakes and to relate this to underlying species-specific responses of phytoplankton populations. Assessment was also made of variation in patterns of grazing selectivity and the potential role of zooplankton in altering nutrient regimes. An experimental approach was taken, using field enclosures or limnocorrals to allow manipulation of grazer biomass and replicability. An attempt was made to synthesise the results and to present them in the context of current theories designed to elucidate causal mechanisms in phytoplankton-zooplankton interactions.

New Zealand zooplankton communities are characterised by a low number of species, by few species that prey on them, and by indications that they tend to be food-limited (Malthus and Mitchell 1990). There is little regional or ecological differentiation among the crustacean communities in different lakes and they are frequently dominated by calanoid copepods (Chapman and Green 1987). Lakes in New Zealand are all warm



monomictic or polymictic and only a few small lakes are known to freeze over in winter. If treated as a group, the lakes can be distinguished from lakes in similar latitudes elsewhere by their reduced annual temperature range, enlarged depth of epilimnia and increased potential to mix (Green *et al.* 1987). I am unaware of any other enclosure-based study which has examined a similar calanoid dominated zooplankton community and its potential influence on two different algal assemblages over the full seasonal cycle. The chosen lakes are both located in urban settings and have been influenced by accelerated eutrophication providing the opportunity to examine potential applications of trophic manipulation to lake restoration.

## 1.2 Study Sites

### 1.2.1 Lake Rotoroa

Lake Rotoroa or Hamilton Lake (37°48' S, 175°16'30" E) is situated in the Waikato Basin on the western side of Hamilton city. The lake was formed in an embayment dammed along its western margin by alluvial levee deposits of the palaeo-Waikato River, overlain by shallow peat (McCraw 1971). Presence of Rerewhakaaitu Ash within lake sediments that overlie Hinuera Formation muds suggest the lake was formed between 15,500 and 17,500 years BP (Green and Lowe 1992). The lake covers an area of 54 ha and has a maximum depth of 6m with two main basins linked by a central shallow area. The lake has a maximum length of 1.3 km and a maximum width of 0.5 km. Over 54% of the lake area is less than 2m deep and 25% less than 1 m deep (Tanner *et al.* 1990).

The lake surface comprises 40% of the catchment area, residential housing 25% and recreational reserve 35%. Drainage water enters the lake via 10 major inlet pipes around the lake margin. A makeshift weir at the single outlet maintains a relatively constant water level. The estimated turnover time of the lake is approximately 2.4 years assuming a lake volume of  $1.3 \times 10^6 \text{m}^3$ , an annual net precipitation of 203 mm on the

lake surface and a mean annual discharge of 16 litres s<sup>-1</sup>km<sup>-2</sup> from the surrounding catchment (Tanner *et al.* 1990).

The surface water temperature ranges from 9 - 25°C. The lake is polymictic, with weak thermal stratification common over the summer period (Tanner *et al.* 1987). Davenport (1981) and Boswell *et al.* (1985) described Lake Rotoroa as mesotrophic on the basis of its moderate transparency, absence of oxygen deficit in bottom waters, low chlorophyll concentrations and absence of algal blooms. However, other studies (e.g. Tanner *et al.* 1987; 1990) have shown that marked deoxygenation occurs in the bottom water of the lake over the summer period and that while the chlorophyll *a* concentrations in the lake are indicative of eutrophic conditions the total phosphorus concentrations are more characteristic of mesotrophic conditions.

A regular water quality sampling programme for Lake Rotoroa was recommended by Tanner *et al.* (1987) in order to provide baseline data to interpret water quality changes in the future and identify critical factors in the lake's ecology. A monthly water sampling programme was initiated in November 1987 and the data obtained indicate adverse changes in the condition of Lake Rotoroa in recent years (de Winton *et al.* 1991).

Secchi depth data show an overall trend of decreasing water clarity. Secchi depths have varied between 0.58m and 1.56m since November 1987. The previous minimum Secchi depth record was 1m recorded in 1982 (de Winton *et al.* 1991). Mean monthly total suspended solids have increased significantly with the organic fraction generally forming the predominant component, ranging from 43% to 89%, and fluctuating in unison with chlorophyll *a* concentration. Concomitant with increasing chlorophyll *a* abundance there has been a trend towards increased levels of both total phosphorus and nitrogen. Submerged vegetation has not been recorded in Lake Rotoroa since late 1990 following a steady decline in plant abundance over the previous two years.

The water quality decline could be partially attributable to the loss of beneficial influences of submerged vegetation, which may have played a role in phytoplankton suppression, sediment settling and stabilisation, and nutrient buffering (de Winton *et al.* 1991). It is difficult to assess the causes of the submerged vegetation decline in Lake Rotoroa, though reductions in water clarity have been suggested to account for the loss. There are unusually high concentrations of heavy metals (Zn, Cu, Pb) in lake sediment near stormwater outflows, and sodium arsenite herbicide application to Lake Rotoroa in 1959 has resulted in the persistence of potentially toxic arsenic (Tanner and Clayton 1990). Such pollutants in concert with plant disease, grazing by herbivorous fish such as rudd, and meteorological events (such as higher than normal rainfall) may have provided additional stress that contributed to the collapse of submerged vegetation. In the absence of competitive suppression from submerged macrophytes, it has been predicted that increased water clarity could result in phytoplankton becoming an increasingly important component of the lake ecosystem (de Winton *et al.* 1991).

Etheredge (1987) recorded monthly variations in phytoplankton species and abundance in Lake Rotoroa over an annual period (1983/84). In terms of abundance, the phytoplankton community was dominated by the Euchlorophyceae (58%), and Chrysophyceae (22%). All other classes were relatively unimportant. However, despite comparatively low densities, the Dinophyceae (5%) was the major taxon in terms of biomass (78%). The Chrysophyceae, Euglenophyceae and Euchlorophyceae all contributed 6% each to total algal biomass. *Tetrastrum triangulare*, *Dinobryon cylindricum* and *Cyclotella stelligera* were the most abundant species but, because of their relatively small biovolumes, none was dominant in terms of biomass. Instead *Peridinium* species made up 69% of the mean total biomass (Etheredge 1987). Cyanobacteria have not been a significant component of the phytoplankton community, and in recent years it has been dominated by Chlorophyceae (*Botryococcus braunii*), Euchlorophytes (*Trachelomonas* sp.), and Diatoms (*Cyclotella* sp.). Buoyant

*Botryococcus braunii* was dominant during late 1990 and early 1991 and formed scums in sheltered bays on windward shores in December 1990 (de Winton *et al.* 1991).

The zooplankton assemblage of Lake Rotoroa is very similar to that of Lake Pupuke. Lake Rotoroa contains populations of both *Ceriodaphnia pulchella* and *C. dubia*. Greenwood *et al.* (1991) record five co-occurrences, not only in Waikato lakes. Two to three other instances have been recorded since, and they probably co-occur frequently. *Calamoecia lucasi* is the only calanoid copepod and *Bosmina meridionalis* and the cyclopoid cf. *Mesocyclops leuckarti* are also present.

The fish fauna of Hamilton lake consists mainly of introduced species. These are perch (*Perca fluviatilis*), rudd (*Scardinius erythrophthalmus*), brown bullhead catfish (*Ictalurus nebulosus*), mosquitofish (*Gambusia affinis*), goldfish (*Carassius auratus*) and Tench (*Tinca tinca*). The short-finned eel, (*Anguilla australis*) and the common bully (*Gobiomorphus cotidianus*) are native to New Zealand. Eels gain access to the lake probably via the Waikato river and the Waitewhiriwhiri stream and are thought to be one of the major predators of fish in the lake (Wise 1990).

The distribution and abundance of aquatic macrophytes in Lake Rotoroa were studied in six SCUBA surveys between 1977 and 1986 (Tanner *et al.* 1990). At the end of 1986 macrophytes were present over approximately 80% of the lake bed. *Egeria densa* was the dominant vascular plant making up 35% of the lake's vegetation, whereas *Lagarosiphon major* and *Elodea canadensis* which had dominated the submerged vascular plant community in 1977 had become less abundant. Extensive beds of charophytes (*Chara corallina*, *Nitella hookeri* and *N. pseudoflabellata*) made up an estimated 52% of the vegetation in 1986. Emergent macrophytes, particularly *Baumea articulata*, *Iris pseudacorus*, *Eleocharis sphacelata*, *Typha orientalis* and floating-leaved *Nymphaea* were recorded around approximately 50% of the lake shore. Currently, emergent macrophytes are still present but, as discussed previously, submerged plant

species were last recorded from the lake in July 1990 (de Winton 1991). Ten out of fifteen major Waikato lakes have now experienced loss of oxygen weed dominated aquatic vegetation in the past 15 years. A likely common denominator in all these lakes could be a gradual decline in water quality and clarity.

Lake Rotoroa and its surrounding area is designated as a Recreational Reserve and wildlife refuge. The lake is the focus of much recreational activity, due mainly to its location within reach of many people, but also to relatively high water quality (Davenport 1981; Boswell *et al.* 1985). The recent deterioration of water quality may adversely affect this pattern of lake usage.

### ***1.2.2 Lake Pupuke***

Lake Pupuke (36°47' S, 174°46' E) lies in a maar, (a basin formed by volcanic explosions at depth below the land surface) in an urban area (North Shore City) of the Auckland region.

The rock type is basalt (Searle 1959) and the lake is within 200m of the sea with the surface approximately 5m above sea level. Searle (1964) believes that a number of volcanic eruptions within a comparatively short time in the North Shore area formed Lake Pupuke. <sup>14</sup>C datings on wood and kauri gum found in peat lying immediately below Pupuke flow suggest a minimum age for Pupuke of not less than 42,000 years (Searle 1959). Recent thermoluminescence dates suggest a considerably older age (I.E.M. Smith, pers. comm). Other explosion craters nearby once held lakes but only Pupuke has escaped the eroding effect of the sea, because the surrounding lava field, whilst allowing fresh water to escape by way of its joints, has acted as a barrier. Although small in area, 1.1 km<sup>2</sup> or 110 ha, the lake is relatively deep, with a maximum depth of ~58m, and mean depth 29m. The lake volume is 2.9 x 10<sup>7</sup>m<sup>3</sup>, maximum width is 1.3km and shoreline length is 4.3km (Coffey and Clayton 1987).

The hydrology of the lake is complex : there are no major surface inflows, and the outflow is also subsurface. The hydraulic residence time is relatively long (approximately 30 years) and the land catchment has an area of 0.8 km<sup>2</sup>. Rates of rainfall and of evaporation from the lake are 1240 and 870 mm yr<sup>-1</sup> respectively (Vant and Pridmore 1990). Natural water levels in Lake Pupuke appear to be controlled by a balance between the inputs of rain falling directly onto the surface of the lake, plus about 70% of the rain that falls on land in the surrounding catchment, and the outputs of evaporation from the lake surface and the underground outflow of water which enters the sea on the Takapuna coastline at ~~Herne~~ Bay (Coffey 1990).

Thorne's

Despite its proximity to Auckland city the lake was almost unknown biologically until 1964 (Green 1967). Lists of the phytoplankton species found in the open waters of Lake Pupuke since 1966 show that the same species have been recorded each year and a consistent seasonal pattern of species dominance has been observed (Vant and Pridmore 1990). Typically, the winter assemblage has been dominated by the blue-green alga *Microcystis aeruginosa*, the desmids *Closterium aciculare* and *Staurastrum* spp, the pennate diatom *Fragilaria crotonensis*, and several species of the dinoflagellate *Peridinium*. During the late winter and spring the diatoms *Aulacosira granulata* and *A. g. var. angustissima* proliferate. The summer assemblage has typically resembled that observed in winter with the addition of various *Cosmarium* species, *Oocystis*, and in the past occasional blooms of *Anabaena* (Vant and Pridmore 1990).

Most of the phytoplankton in Lake Pupuke appears to be confined to the upper 20m of the water column throughout the year. This distribution corresponds roughly with the depth of the upper mixed layer (15-20m) during the summer and, in general with the depth of the euphotic zone (Green 1967; Cassie 1989; Vant and Pridmore 1990).

Several changes in water quality have occurred between 1966-67 and the present. Though a continuous record of water quality since 1966 does not exist the lake was

studied intensively in 1966-67 and again in 1984-86. During 1976-1990 water quality was generally monitored at quarterly intervals. Phytoplankton abundance has decreased with the average concentration of chlorophyll *a* in near surface waters falling from 22mg m<sup>-3</sup> in 1966 - 67 to less than a third of this in 1982-90, when the average was 5.7 mg m<sup>-3</sup>. In accord with this decline in chlorophyll *a* water clarity has increased. Secchi disc transparency has increased from 2.4m (1966-67) to 3.5m (1976-1990) (Vant and Pridmore 1990). Along with the observed decline in phytoplankton biomass the rate at which dissolved oxygen is consumed in the bottom water in summer has decreased. During 1984-86 the rate of oxygen depletion in the 20-30m stratum was 0.027 - 0.03 gm<sup>-3</sup>d<sup>-1</sup> compared with a value of 0.073 gm<sup>-3</sup>d<sup>-1</sup> in 1966-67 (Vant and Pridmore 1990).

These changes in water quality may reflect changes in the catchment nutrient loads entering Lake Pupuke. In the 1930s domestic and agricultural wastewaters were uncontrolled and nuisance outbreaks of phytoplankton occurred (Vant and Pridmore 1990). Since this time it has become recognised that sewage disposal is detrimental to water quality and there are indications that stopping sewage disposal in Lake Pupuke may have caused plant nutrient concentrations to decline. Nitrate and ammonia concentrations were apparently 3-12 times higher in 1966-67 than 1976-90 (Vant and Pridmore 1990). Taken together these changes indicate that the lake is now less eutrophic than it was in 1966-67 but the lake waters are still moderately fertile: meso-eutrophic.

The zooplankton assemblage of Lake Pupuke is mainly composed of crustaceans and rotifers (Green 1967). In general the most abundant crustacean taxa are *Calamoecia lucasi* together with *Ceriodaphnia* cf. *pulchella* and *C. dubia*, *Bosmina meridionalis* and cf. *Mesocyclops leuckarti*. Rotifer communities are often comprised of *Keratella* species, *Asplanchna brightwelli*, *Hexarthra*, *Filinia* and *Synchaeta* (Chapman and Green 1987).

Fish species known to be in Lake Pupuke are rudd (*Scardinius erythrophthalmus*), perch (*Perca fluviatilis*), eel (*Anguilla* spp); tench (*Tinca tinca*); goldfish (*Carassius auratus*), bully (*Gobiomorphus* sp.); catfish (*Ictalurus nebulosus*), mosquito fish (*Gambusia affinis*) and rainbow trout (*Oncorhynchus mykiss*). Except for the eels and bullies all species are exotic and have been introduced into New Zealand. All species are self-sustaining except the rainbow trout which require artificial stocking (ARWB 1979). Initial (pre-1967) trout stocks in Lake Pupuke were good but since this time the trout population has declined. This change has been attributed in part to the introduction of new fish species into the lake and subsequent competition for food (ARWB 1979).

Lake Pupuke is unique in New Zealand in that all four obligate submerged members of the adventive Hydrocharitaceae, *Vallisneria gigantea* and the oxygen weeds *Lagarosiphon major*, *Elodea canadensis* and *Egeria densa*, co-exist there. Dense stands of *Vallisneria*, up to 5m tall, dominated the mid-littoral zone through to 1985. *Egeria* was first recorded in Lake Pupuke in 1980. It occurred in the mid-littoral zone and in 1982 was estimated to occupy 2% of the total macrophyte volume. By 1983 this had increased to 10% and in 1985 to 25%. This trend suggests that *Egeria* is the potential dominant of this community (Coffey and Clayton 1987).

In Lake Pupuke the catchment is a mixture of residential (46%), commercial - including a major hospital, with large car parks and grassed area, and also schools (28%), recreational parks (16%), roads (8%) and industrial - a disused quarry (2%). Although in the past the lake was used for water supply, a fall in the level due to over-extraction in 1914, and a deterioration in the quality from 1921, led to abandonment of the extraction in 1941. Currently, the lake is used only for recreation (Hoare 1990).



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## CHAPTER TWO

### DATA COLLECTION AND ANALYSES

#### 2.1 Introduction

A one year seasonal experimental programme was conducted in each study lake. In Lake Rotoroa the first deployment of limnocorrals was at the beginning of June 1990, corresponding to late autumn, and was followed by experiments in July/August 1990 (winter), October 1990 (spring) and February 1991 (summer). In Lake Pupuke deployment was in late May 1991 - corresponding again to autumn and in July/August 1991 (winter), October 1991 (spring) and February 1992 (summer). Each experiment lasted for a period of ten days with physico-chemical and biological sampling being conducted on Days 0, 3, 6, and 10.

#### 2.2 Field methodology

##### 2.2.1 *Enclosure design*

The design of the limnetic enclosures closely resembled that used during the International Forum on Cyanobacterial Dominance (McAllister 1987; Lean *et al.* 1987; Mitchell 1989; White *et al.* 1989) and previous studies of zooplankton - phytoplankton interactions (Edgar 1989), though some additional modifications were incorporated.

Each bag was made from 125  $\mu\text{m}$  clear polythene tubing with an inner diameter of approximately 600 mm. A 100 m roll of tubing was heat sealed by machine and cut into 25 four metre long individual bags. Two additional heat seals were made at 2 cm and 4 cm above the bottom seal of each bag as an added precaution against the bags bursting while being filled with lake water. These additional seals were made by pressing a hot soldering iron against the bags (Porter, 1972; Etheredge, 1987). Aluminium foil placed between the bags and the tip of the soldering iron prevented the plastic from being burnt. A 10mm diameter metal grommet was attached at the centre of

each bag just below the bottom heat seal, and a 20cm length of chain was then connected to it by a small galvanised shackle. The chain added extra weight to the base of the bags helping them to sink vertically (see Fig. 2).

The bags were attached at their top ends to floats. These floats were made from 22 gauge galvanised iron sheeting between which were two 800mm x 800mm sheets of polystyrene foam, both 75mm thick. The polythene bags passed through a 600 mm galvanised iron ring in the float and were attached to the outer surface of this ring using a *Scru-Seal Bandit Band*<sup>®</sup> metal ring which was tightened around the plastic using a screwdriver. The floats were attached in series using lengths of 5mm stainless steel cable. Adjacent rings were linked with shark clips (Fig. 2).

Protective covers were made using 1.0m diameter stainless steel hoops covered with transparent 5mm perspex. The cover was mounted above the opening in the iron ring of each float using three equidistant stainless steel tubes (10mm in diameter) rivetted to the upper surface of the floats. Three pins on the cover hoops were aligned with the rods on the float and the cover was lowered into place and secured with metal clips. There was a gap between the perspex face and the iron ring of the floats so that air flow over the water surface was not impeded. The cover was used to prevent airborne contaminants such as bird droppings or leaves from falling into the enclosures (Edgar 1989) and also to prevent fish from jumping into the enclosures (Schoenberg and Carlson 1984). During pilot-tests of the equipment in April-May 1990 it was discovered that quite severe wave action developed on Lake Rotoroa at times. Waves were high enough to enter the bags with or without plastic covers, which filled above the level of the surrounding lake and burst or ripped away from their attachments. By increasing the height of the iron rings and using metal hoops and perspex instead of the previous plastic hoops and polythene bag coverings used by Edgar (1989) the problem of water entering the bags was solved.

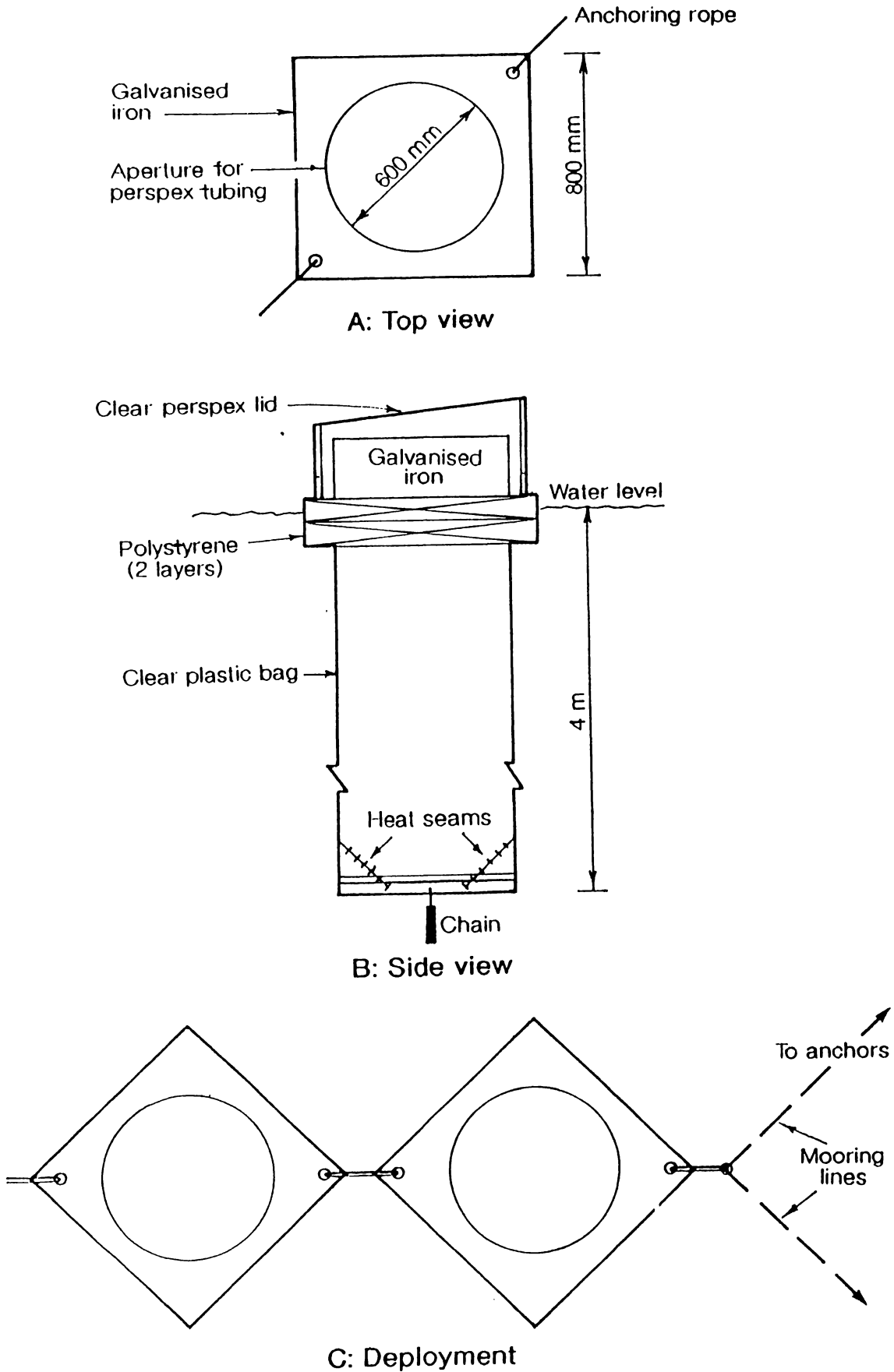


Figure 2: Basic design of enclosure bag and float

### 2.2.2 Deployment

For each experiment eight limnocorrals were set out in a row on the lake using two pairs of block anchors attached at both ends of the row (see Fig. 2). The bags were rolled up initially and contained no air and as they were filled with lake water they gradually unrolled and sank through the water column with the aid of the metal chain attached at their sealed ends.

The bags were filled using a submersible Daishin centrifugal sludge pump that delivered 150ℓ per minute. The intake hose of the pump was positioned approximately one metre below the water surface (Lampert *et al.* 1986; Vanni 1986b). In order to establish the volume of the limnocorrals the time taken to fill a number of limnocorrals was determined and this was related to the time taken to fill a standard (50 litre) plastic barrel. The volume of each limnocorral was approximately 1000 litres, in agreement with previous estimates using this equipment. Edgar (1989) and Mitchell (1989) calculated volumes of 1160 litres and 1m<sup>3</sup> respectively. A dinghy was used to travel along the row of enclosures filling each enclosure in turn. After each bag was filled approximately 20 litres of water was removed to reduce tension in the bags. McAllister (1987) found that this reduced the occurrence of bursts along the heat seals during turbulent surface conditions.

Water was pumped into each enclosure through an 80µm mesh plankton net to remove the majority of the zooplankton before subsequent zooplankton manipulations were performed. During preliminary investigations a range of mesh sizes was used to establish which removed most zooplankters from the bags whilst retaining as many species as possible of the natural phytoplankton assemblage of each lake. Mesh sizes larger than 80 µm allowed copepodites, and especially juvenile stages of *Bosmina* species to enter the bags. This was offset by gains in the upper size range of phytoplankton species capable of passing through the net (see Appendix V). The chosen mesh size struck a balance between efficiency of zooplankton removal (although

small numbers of rotifers and copepod nauplii did pass through the net (see Tables 5.1 - 5.8)) and the need to include large phytoplankters in the initial algal complement of each enclosure (Bergquist *et al.* 1985; Bergquist and Carpenter 1986; Lampert *et al.* 1986).

Eight limnocorrals were filled in this manner. Two bags were chosen to act as controls, that is zooplankton enclosures, while the other six were to undergo subsequent zooplankton manipulations. The aim of the zooplankton manipulations was to introduce a gradient of zooplankton density and therefore biomass into the remaining six enclosures. Three biomass treatments with two replicates were chosen. Two bags received zooplankton biomass similar to that in the surface water (i.e. 0 - 4m) of the lake, that is, at ambient (1X) surface water biomass. Two bags received zooplankton additions approximately twice (2X) the natural surface biomass, and the final two bags received zooplankton additions of approximately four times (4X) ambient surface water biomass. The designations of 1X, 2X and 4X zooplankton biomass were regarded as guidelines only. The actual biomass ( $\text{mg.m}^{-3}$  dry weight) was determined by samples of zooplankton taken from each bag on Day 0 (see below).

Before introducing zooplankton to the limnocorrals, zooplankton biomass in the lake was determined by sampling the water column with a PAR electric peristaltic pump at 0.5 or 1.0m intervals to a depth of 4.0m. The pump had a delivery rate of 40 litres per minute and was run for one minute at half or one metre depth intervals. Zooplankton were collected in an 80  $\mu\text{m}$  mesh net and preserved in 4% formalin for subsequent identification and enumeration.

The results of the zooplankton counts were plotted as total crustacean biomass per  $\text{m}^3$  versus depth and the mean biomass of zooplankton  $\text{m}^{-2}$  calculated by integrating the area under the graph (see Appendix I). A similar technique was employed by

Bergquist *et al.* (1985) and Bergquist and Carpenter (1986). The conversion of zooplankton counts to biomass is explained in Section 2.4.1

Zooplankton were collected for introduction into the zooplankton enclosures by hauling an 80 $\mu$ m mesh 39cm diameter plankton net from a depth of 4m to the surface and then the contents were slowly washed into each bag. To calculate the retention efficiency of the net used to collect zooplankton for addition to the enclosures a number of additional hauls using the 80 $\mu$ m plankton net from a depth of 4m to the surface were made and the contents of each haul collected and preserved in 4% formalin for subsequent identification and enumeration. The zooplankton biomass per m<sup>3</sup> was calculated from the dimensions of the net and the length of the haul and compared to the value obtained from the integrated depth series (see Appendix I).

A dinghy was used to travel along the length of the limnocorral series filling each of the six zooplankton enclosures with the appropriate number of net hauls. Once all the zooplankton introductions had been made each bag was carefully but thoroughly mixed using a weighted 20 diameter Secchi disc suspended on a 5m rope which was lowered and then pulled slowly up through the water column of the bag a number of times.

### **2.2.3 Sampling**

Each experiment was conducted over a period of ten days. The bags were sampled for phytoplankton immediately after filling on Day 0, then on Day 3, Day 6 and finally Day 10. Water samples for phytoplankton analyses were collected with a 10 mm (I.D.) rubber tube sampler four metres in length (Lund 1949; Lund and Talling 1957; Lewis 1978; Thompson *et al.* 1982). In order to increase the sampling efficiency of the tube sampler the mass of the basal weight was reduced to the minimum necessary to straighten the tube, and streamlined to minimise bow-wave effects (Zohary and Ashton 1985). Two integrated samples from each bag were pooled in a well rinsed container from which two 100ml sample bottles were filled and immediately preserved with

approximately 2ml of Lugol's iodine (Etheredge 1985). Similar samples were also taken from the lake adjacent to the deployment site.

Zooplankton samples were taken from each bag at the beginning of the experiment (Day 0) and at the completion (Day 10). On Day 0 the bags were thoroughly mixed by repeated lowering and raising of the Secchi disc. Samples were obtained by slowly lowering and raising the intake hose of a PAR peristaltic pump through the length of the bag and pumping water from the outlet through a 47 $\mu$ m mesh plankton net. 40 $\ell$  (approximately 4% of the limnocorral volume) was filtered. At the beginning of the experiment these samples were visually checked in an effort to establish zooplankton survival. Survival appeared to be very high with only a small number of injured or dead individuals per sample. Samples were preserved in 4% formalin for subsequent identification and enumeration.

On Day 10 the bags were mixed as described above and a 47 $\mu$ m mesh, Nansen-type plankton net with a mouth diameter of 215mm was raised from the bottom of each bag to the surface to obtain one integrated sample per bag. Each sample was then preserved in 4% formalin. Samples were enumerated and checks were again made to determine survival of the animals. No less than 80% of the zooplankton appeared viable.

On Day 10, water temperature, dissolved oxygen concentrations, and scalar irradiance were measured at 1 m intervals from the surface to the bottom of a minimum of three limnocorrals and compared with profiles in the lake, using a YSI model 4 oxygen meter and a Licor light meter with a 4 $\pi$  sensor. Secchi disc measurements were made on all eight bags and a number of lake sites in proximity to the bags.

During the spring and summer experiments on both lakes water samples were collected for dissolved nutrient analysis. Two 100 ml samples were taken from each limnocorral

and the lake at approximately 20cm below the surface and kept in the dark until returned to the laboratory. Samples were taken on Days 0, 3, 6 and 10.

## **2.3 Laboratory Methodology**

### **2.3.1 *Phytoplankton enumeration***

Phytoplankton were counted using the sedimentation technique (Utermöhl 1958) which is the preferred method for the determination of phytoplankton population dynamics and community structure (Lund *et al.* 1958; Hasle, 1978; Wetzel and Likens 1979; Rott 1981). Two samples from each bag on each sampling date were gently but thoroughly shaken prior to the removal of an aliquot (25 to 50 ml) from each for sedimentation. A settling time of 48 hours was allowed (Lund *et al.* 1958; Rott 1981; Etheredge 1985). The counts were made using a model M2 Olympus inverted microscope.

It was decided at the beginning of the experiments to count only the dominant phytoplankton species using random fields of view from both central and peripheral regions of each basal plate. Experience of phytoplankton counts in the NLU (the National Swedish Environment Protection Board, Limnological Survey) has shown that about six species usually represent more than 90% or more of the total phytoplankton volume in nutrient rich waters (Willén 1976). This approach has been endorsed by Hobro and Willén (1977), whose phytoplankton intercalibrations recognised the value of enumerating only the most important species. In general, ten to twenty species were counted per sample. In addition a record was kept of all rarer algal species found in the course of each seasonal experiment in each lake.

To achieve 20% counting accuracy, an acceptable level for phytoplankton analyses (Utermöhl 1958, Hobro and Willén 1977; Northcote *et al.* 1990), counting continued until each major species had been recorded at least 100 times (Lund *et al.* 1958). In cases where numbers of dominant taxa were reduced by loss processes during the course of an experiment, a minimum of 100 fields of view per magnification per sample



was employed. Counts were performed at three magnifications. For Lake Rotoroa samples 150X, 300X and 945X magnifications were employed. For Lake Pupuke samples 200X, 400X and 800X magnifications were used. Empty cells, scales, thecae or “dead cells” were not counted. A cell was considered “dead” if it contained less than one half of the usual cellular content for that species (Etheredge 1985). Coenobial species were counted as independent units or plankton units to allow meaningful comparisons between experimental treatments (Chandler 1940; Lewis 1978).

The total numbers for each species per aliquot were calculated by multiplying the ratio of the chamber area to the area covered by the number of fields of view counted. This value was converted to numbers per ml by dividing by the volume of the aliquot sedimented. Values of plankton units per ml for each species were then summed to give the total number of plankton units per ml for the most dominant species.

### ***2.3.2 Phytoplankton Identification***

The general taxonomic texts consulted for identification were Huber-Pestalozzi (1938, 1941, 1942, 1955, 1961, 1968); Huber-Pestalozzi and Fott (1968); Prescott (1962) and Bourelly (1966, 1968, 1970). The taxonomic arrangement to the familial level follows Bourelly (1966, 1968, 1970). The method used to remove organic material from diatoms involved a mild cleaning treatment. The subsample to be identified was mixed with H<sub>2</sub>O<sub>2</sub> (30% v/v) and allowed to stand at room temperature for 24 h (Barber and Haworth 1981). Water mounts were subsequently prepared.

### ***2.3.3 Zooplankton Enumeration***

For counting, the entire plankton sample from each limnocorral was searched and species occurring in low densities (fewer than 50 individuals per sample) were recorded. In most cases however, samples were too dense to enumerate entirely and subsampling was necessary. The sample was made up to a known volume in an appropriately sized graduated pyrex beaker. The beaker values were checked for

accuracy and the same beakers were used throughout. The sample was stirred in a figure-of-eight motion and a 5ml subsample withdrawn, using a wide mouth pipette. The subsample was transferred to a rectangular, perspex counting tray, mounted on the movable stage of a Zeiss stereomicroscope. Counts were made at X32 magnification and recorded on a Denominator Counter. Stage V calanoid copepodites and adults (Stage VI) were enumerated as a group. Stage I - IV calanoid copepodites were also enumerated as a group. This procedure was also performed with cyclopoid copepods. Naupliar stages of both calanoids and cyclopoids were enumerated together. Numbers of juvenile and adult *Bosmina* and *Ceriodaphnia*, and genera of the rotifers, were also recorded. The wide variation in the abundance of different species and stages meant that different dilutions were usually required for the enumeration of one sample. Generally, 30 - 200 individuals from each taxon were counted per subsample. Replicate subsamples were enumerated until there was close agreement between subsamples.

#### **2.3.4 Zooplankton Identification**

The general taxonomic texts consulted were Koste (1978); Chapman and Lewis (1976); and Greenwood *et al.* (1991).

#### **2.3.5 Nutrient analyses**

Nutrient samples were autoanalysed by the National Institute of Water and Atmospheric Research Ltd (NIWAR). The concentration of dissolved reactive phosphorus (DRP) was determined by a variation of the molybdenum blue method (Downes 1978(a)). Nitrate ( $\text{NO}_3$ ) underwent hydrozine reduction to nitrite ( $\text{NO}_2$ ) and was measured as the sum of both (Downes 1978 (b)). Ammonia-N ( $\text{NH}_4$ ) concentration was determined by the Berthelot reaction which results in the formation of indophenol blue dye (Crooke and Simpson 1971). Dissolved organic phosphorus (DOP) was determined by breaking organic P down to orthophosphate by exposing it to a powerful UV lamp in the presence of an oxidant (10% Na perchlorate, pH 1). Organic P is then the

difference between total dissolved P measured and DRP determined by Downes (1978(a)) above. Dissolved organic nitrogen (DON) was determined by the oxidation of organic N and ammonia-N ( $\text{NH}_4$ ) to ( $\text{NO}_3\text{-N} + \text{NO}_2\text{-N}$ ) using the same UV lamp and a potassium/tetraborate oxidant in alkaline conditions (pH 9). Measured as for nitrate ( $\text{NO}_3$ ) above, with DON established by difference.

## **2.4 Methodology for Data Analysis**

### **2.4.1. Mean Cell Biovolume and Biomass**

The biovolumes of a minimum of 25-30 specimens of the dominant phytoplankton species, selected throughout the course of an experiment, were used to calculate a mean cell/colony/filament biovolume for each lake. Linear measurements (excluding spines and gelatinous material) were made with an ocular micrometer at 800X. Biovolume was calculated using the stereometric formula which most closely approximated the shape or composite shapes. The final biovolume represents the mean of the volume of each of the measured cells, colonies or filaments (Smayda 1978; Sommer 1988). These biovolumes were then converted to biomass expressed as wet weight ( $\text{mg m}^{-3}$ ), assuming that the specific gravity of phytoplankton is unity (Willén 1959; Reuter 1979; Holmgren 1984). Total algal biomass was calculated by summing the product of species density and mean biovolume across all algal taxa.

The biomass of a zooplankton taxon was calculated from the product of the mean individual biomass of the species and species density. Individual biomasses were taken from the literature, the sources for which are presented in Appendix II. Total zooplankton biomass is the sum of all species biomasses (Lampert *et al.* 1986; Drenner *et al.* 1989; Bloesch *et al.* 1988; Vanni 1988; Malthus and Mitchell 1990; Vanni and Findlay 1990; Elser and Goldman 1991).

### 2.4.2 *Greatest Axial Linear Dimensions*

The mean GALD (greatest axial linear dimension (Lewis 1976)) was calculated for each of the most dominant species in each experiment in both lakes. Measurements were obtained from a minimum of 25-30 individuals selected during the course of an experiment. For a cylindrical species it was the length of the cylinder, for a spherical species, the diameter, and for an ellipsoidal species the longest axis of rotation. However, for irregular colonies, the GALD was taken as the longest line connecting any two surfaces, despite the fact that this line could not pass through an axis of symmetry (Lewis and Riehl 1982). The SGALD (second greatest axial linear dimension (Lewis 1978)) was also recorded for a minimum of 25-30 individuals of each species.

### 2.4.3 *Algal Growth Rates*

Species specific algal growth rates ( $r$ ,  $d^{-1}$ ) in the limnocorrals were calculated as:

$$r = \frac{[\ln (F/I)]}{D}$$

where F and I are the final and initial concentrations (plankton units  $ml^{-1}$ ) of that species respectively and D is the duration of the incubation in days (6 days). Justification for the use of this time interval is given in Chapter Three.

### 2.4.4 *Statistical Analyses*

The effects of zooplankton on total phytoplankton biomass were assessed by considering final total phytoplankton biomass (calculated as the sum of species-specific abundance multiplied by species-specific biomass) as the dependent variable and regressing this against total zooplankton biomass. Linear and quadratic regressions were conducted for total phytoplankton biomass. Significant ( $P < 0.05$ ) regressions were considered evidence of zooplankton effects (Lehman and Sandgren 1985; Vanni and Temte 1990). A one-way analysis of variance (ANOVA) was also used to

compare differences in total algal biomass between treatments over the course of each experiment.

To assess taxon-specific responses of phytoplankton, regression analysis was again adopted, except that growth rate ( $r$ ) was used as the dependent variable in the regressions (Lehman and Sandgren 1985; Vanni and Temte 1990). Earlier studies have shown that species-specific algal growth rates ( $r$ ) can be a unimodal function of zooplankton biomass, that is,  $r$  exhibits a maximum value at an intermediate level of zooplankton biomass (Elser *et al.* 1987). Therefore both quadratic and linear regression models for  $r$  were used to determine which model yielded the best fit. Linear and quadratic regressions were performed with both untransformed and log-transformed zooplankton biomass, because previous studies have shown that the growth rate of some algal species exhibits a better fit to log-transformed zooplankton biomass (Elser *et al.* 1987). Phytoplankton taxa were classified into one of four categories based on their responses to zooplankton density (Lehman and Sandgren 1985; Elser *et al.* 1987; Vanni and Temte 1990): decreasing growth rate -  $r$  displaying a significant negative slope with increasing zooplankton biomass; increasing -  $r$  exhibiting a positive slope; unimodal -  $r$  maximum at intermediate zooplankton biomass, and no response - no relationship between  $r$  and increasing zooplankton biomass.

Graphs of log biovolume versus GALD or SGALD were plotted for each experiment for each taxon (according to response to grazing pressure) to determine whether a relationship existed between size (as measured by GALD, SGALD and biovolume) and response to zooplankton presence (Merrick and Ganf 1988).

The potential for zooplankton grazing to alter concentrations of dissolved nutrients was assessed by regression of nutrient concentration against the gradient in zooplankton biomass. SYSTAT (Wilkinson 1992) was used for all statistical analyses.

## CHAPTER THREE

### ASSESSMENT OF METHODOLOGIES

#### 3.1 Introduction

The limnocorral technique (Uehlinger *et al.* 1984) is an experimental method well suited for many purposes, including testing for limiting nutrients and toxic substances. Experiments of the cause-effect type result in net changes of the biological system but do not elucidate single pathways of the complex community or ecological network. On the other hand, limnocorrals can be used for biomanipulation studies to investigate ecologically relevant fluxes such as nutrient regeneration, zooplankton grazing, sedimentation, and their interrelationships. As in any other method, this technique has advantages and disadvantages which have been thoroughly debated (see Bloesch *et al.* 1988 for a review). The aims of this chapter are to examine specific problems that were associated with my investigation, to describe attempts to ameliorate negative effects and to compare these findings with those of others using similar methodologies. There are three main topics to consider: problems associated with the field methodology (limnocorral size, time scales, sampling frequency, screening of zooplankton/phytoplankton, zooplankton additions, and phytoplankton survival in the bags), laboratory methodology (principally related to phytoplankton counting), and justification of the statistical tests used to account for significant responses.

#### 3.2. Methodologies

Table 3 summarises a number of recent investigations using similar methodologies to those of this study. Instances where experiments were performed over the course of one year are virtually absent. Only one investigation (Scheda and Cowell 1988) used experimental runs in all four seasons. Most of the studies were conducted during the Northern Hemisphere summer which suggests extrapolation to annual scales may be unwarranted.

Table 3 Screening procedures for zooplankton-phytoplankton manipulations

| Seasonality | Exclusion of Zooplankton      | Zooplankton Additions        | Impact of Zooplankton Exclusion or Addition on Phytoplankton       | Zooplankton Densities                                                       | Reference                    |
|-------------|-------------------------------|------------------------------|--------------------------------------------------------------------|-----------------------------------------------------------------------------|------------------------------|
| None        | Filtered by 75µm net          | Vertical hauls of 80µm net   | Taxa collected in zooplankton hauls excluded from further analysis | 3.9 - 4.3 X epilimnetic density<br><br>4.8 - 5.2 X ambient lakewide density | Bergquist <i>et al.</i> 1985 |
| None        | Filtered by 75µm net          | Vertical hauls of 80µm net   | Taxa collected in zooplankton hauls excluded from further analysis | 0.5 - 9 X ambient lakewide density                                          | Bergquist and Carpenter 1986 |
| None        | Filtered by 95µm net          | Unfiltered treatment         | Screening affected net phytoplankton biomass in 3 of 8 experiments | Unknown relative to lake values                                             | Bloesch and Burgi 1989       |
| None        | Filtered by 45µm net          | Animals retained in 45µm net | Not determined                                                     | 1 - 2 X Lake densities at 5m depth                                          | Carrillo <i>et al.</i> 1990  |
| None        | Filtered by 125µm net         | Vertical hauls of 80µm net   | Considered zero or insubstantial                                   | 0.25 - 8 X ambient density from 0-5m                                        | Elser <i>et al.</i> 1987     |
| None        | Filtered by 125µm mesh screen | Vertical hauls of 80µm net   | Removed <15% of the algae                                          | 0.25 - 8 X ambient density                                                  | Elser <i>et al.</i> 1988     |

|                            |                               |                                         |                                                                                                                                                                       |                                                                                                   |                            |
|----------------------------|-------------------------------|-----------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------|----------------------------|
| None                       | Filtered by 125µm net         | Schindler trap with 75µm mesh           | During screening <3% of total Chla was removed in two lakes studied. ~10% of total Chla was removed from the third lake due to presence of large colonial blue-greens | 0.5 - 8 X average (day-night) mixed layer abundance or average (day) whole water column abundance | Elser and Goldman 1991     |
| None                       | Killed by CO <sub>2</sub>     | Unfiltered treatment                    | Species affected by CO <sub>2</sub> omitted from analysis                                                                                                             | Lake Density at 1.5m depth                                                                        | Etheredge 1987             |
| Spring<br>Summer<br>Autumn | Not excluded                  | Vertical net hauls of 45µm net          | Not determined                                                                                                                                                        | Epilimnetic densities                                                                             | Faafeng <i>et al.</i> 1990 |
| None                       | Filtered by 100µm net         | Vertical net hauls of 58µm net          | Not determined                                                                                                                                                        | Lake densities at 0-1m depth                                                                      | Havens and Decosta 1985    |
| None                       | Filtered by 80µm or 200µm net | Unfiltered treatment                    | Not determined                                                                                                                                                        | Lake densities at 0-2m depth                                                                      | Henry 1985                 |
| None                       | Filtered (?) by 150µm net     | Schindler - Patalas trap with 150µm net | Not determined                                                                                                                                                        | Gradient of biomass from animals collected at 6m                                                  | James and Forsyth 1990     |
| None                       | Filtered by 280µm net         | Enriched with 280µm net                 | Not determined                                                                                                                                                        | Lake densities 0-3m depth or selectively enriched                                                 | Kerfoot <i>et al.</i> 1988 |
| None                       | Filtered by 100µm net         | Vertical hauls of 100µm net             | Not determined                                                                                                                                                        | Lake densities at 1m depth                                                                        | Lampert <i>et al.</i> 1986 |



|          |                                                 |                                  |                                                                                                                            |                                         |                          |
|----------|-------------------------------------------------|----------------------------------|----------------------------------------------------------------------------------------------------------------------------|-----------------------------------------|--------------------------|
| None     | Filtered by 130µm net                           | Van Dorn sampler                 | Large algae and colonies were absent implying little effect                                                                | Multiples of lake density at 1.5m depth | Lehman and Sandren 1985  |
| None     | Filtered by 120µm net                           | Vertical hauls of 120µm net      | Unknown                                                                                                                    | Ambient lakewide densities              | Liebold 1991             |
| None     | Filtered by 64µm net                            | Unfiltered treatment             | Large algae were removed by filtering                                                                                      | Lake density at <1m depth               | Lynch 1978               |
| None     | Net hauls in enclosures - 135µm net             | Unfiltered treatment             | Large blue-greens were retained by the net                                                                                 | Ambient lakewide densities              | McCauley and Briand 1979 |
| None     | Filtered by 40µm screen                         | Schindler trap                   | Large colonies of phytoplankton were removed or broken up by the screen                                                    | Unknown relative to lake values         | Merrick and Ganf 1988    |
| None     | Filtered by 125µm net                           | Unfiltered treatment             | Not determined                                                                                                             | Lake density at < 2m depth              | Porter 1972              |
| None     | Filtered by 100µm net                           | Self-acting trap                 | Collected zooplankton passed through a 125µm screen to reduce contribution of large algae. Not tested to determine success | Lake density at 3m depth (day or night) | Redfield 1980            |
| Complete | Filtered by 28µm net and subsequently 158µm net | Schindler-Patalas trap 28µm mesh | Concentrated large algae                                                                                                   | 1-8 X ambient surface lake density      | Scheda and Cowell 1988   |

|                  |                                 |                                                        |                                                                           |                                                                           |                              |
|------------------|---------------------------------|--------------------------------------------------------|---------------------------------------------------------------------------|---------------------------------------------------------------------------|------------------------------|
| None             | Killed by CO <sub>2</sub>       | From laboratory stocks                                 | Complete alteration of dominant phytoplankton                             | Unknown relative to lake values                                           | Schoenberg and Carlson, 1984 |
| None             | Filtered by 110µm net           | Vertical hauls of 110µm(?) net                         | Not determined                                                            | Areal lake density or surface water densities                             | Schoenberg 1990              |
| None             | Killed by rotenone              | Non-rotenone treatment                                 | Not determined                                                            | Lake surface water densities                                              | Svensson and Stenson 1991    |
| None             | Filtered by 40µm or 100µm mesh  | Zooplankton >850µm added by unknown method             | 40µm mesh prevented a dominant blue-green from introduction to enclosures | Lake surface water densities                                              | Vyhnalek 1983                |
| Spring<br>Summer | Filtered by 130µm or 350µm mesh | Plastic buckets fitted with either 130µm or 350µm mesh | No more than 5% of Chla was removed by either screening process           | Gradient of zooplankton biomass bracketing lake values (of unknown) depth | Vanni and Temte 1990         |

Exclusion of zooplankton from limnocorrals is usually done by filtering lake surface water (0 - 2m depth) through varying size mesh nets or screens, or by vertical hauls of plankton nets within filled enclosures. Zooplankton additions are generally made from either vertical net hauls, trap samples or from unfiltered treatments, that is, lake water pumped into the limnocorrals without further manipulation. There is a wide variation in the mesh sizes used to screen or add zooplankton to limnocorral investigations, and generally little justification given for the chosen mesh size. Additionally, most authors fail to indicate the impact of manipulations on the initial algal complement of the limnocorrals. Concomitant with varying zooplankton exclusion/addition methodologies there is a wide variety of resulting zooplankton densities and biomass gradients.

### **3.3. Discussion**

As Table 3 shows there has been wide variation in the techniques for limnocorral research. Enclosures range in size from less than one litre (e.g. Knisely and Geller 1986) to 18,500 m<sup>3</sup> (Lund and Reynolds 1982), and from completely closed (e.g. Porter 1972; Henry 1985; Lehman and Sandgren 1985) to open at the surface to allow gaseous exchange but sealed at the bottom (Lynch and Shapiro 1981; McCauley and Briand 1979; Reinersten *et al.* 1986; Edgar 1989), or open at both ends to the surface and sediments (Lund and Reynolds 1982; Schoenberg and Carlson 1984). Fish have been introduced to some enclosures and excluded from others (Lynch and Shapiro 1981; Reinersten *et al.* 1986; Mazumder *et al.* 1990(a)); nutrients have been added to the enclosures in some studies and not in others (Lehman and Sandgren 1985; Bergquist and Carpenter 1986; Elser and Goldman 1991). An important problem which has not been satisfactorily resolved is the size of the limnocorral and its relationship to the purpose of the investigation.

Increasing the size of the enclosure decreases the surface area to volume ratio which should lessen the influence of wall effects (reduced mixing and light, increased sedimentation rates, build up of periphyton). However, increasing size may create greater heterogeneity (Gamble and Davies 1982). Heterogeneity of phytoplankton and zooplankton assemblages was considered insignificant in my study, as is discussed in Section 5.3 pg 65. Bloesch *et al.* (1988) increased the diameter and hence volume of their limnocorrals to counter wall effects but found the behaviour of their enclosed mesocosms was still seriously affected by the reduction of turbulence. Applying criteria of similarity used in hydraulics (see Bloesch *et al.* 1988), the size of an appropriate epilimnetic limnocorral would imply a diameter in the order of the typical eddies occurring in the lake where they are exposed. However, since the spectrum of horizontal eddies extends over the size of the lake basin down to the smallest turbulent structures limited by the energy dissipation of friction, any limnocorral will change the mixing pattern. Thus it is impossible to avoid changes in turbulence inside limnocorrals.

It has been suggested that artificially-induced water turbulence may ameliorate this loss of mixing in small enclosures (~1800 litres) (Kotak and Robinson 1991). However, using pumps placed inside the limnocorrals these researchers introduced additional problems of elevated suspended particulate concentration (but lower organic content), higher turbidity and lower oxygen levels relative to the adjacent Delta Marsh and control enclosures without pumps (Kotak and Robinson 1991). The use of open water enclosures rather than the littoral enclosures used in the above study may reduce these adverse effects. Bloesch *et al.* (1988) recommend the use of large limnocorrals for ecological studies although technical and financial problems may occur. In the present investigation the limnocorrals were approximately 1,000 litres in volume. Therefore they lie on the border between classification as a mesocosm (<1m<sup>3</sup> in volume) and a macrocosm (> 1m<sup>3</sup> in volume). For investigating species-specific responses of algae

to a gradient of zooplankton biomass my limnocorrals used in this study are an order of magnitude larger than most of those used elsewhere.

Another important problem with limnocorral investigations is the choice of method for excluding zooplankton from the initial planktonic assemblage before subsequent zooplankton manipulations (i.e. additions) are performed. Table 3 indicates that in most cases nets or screens between 75-130µm mesh size are used. Of twenty-three such studies 13 did not include any analysis of the effects of this screening process on the composition of the algal communities in the limnocorrals. Of the remaining 11 studies 10 reported instances where large phytoplankton were removed or broken up by the screening process and/or in which a reduction in Chl *a* in the limnocorrals occurred relative to unfiltered lake water. In the study of Lehman and Sandgren (1985) large algae and colonies were absent implying filtering had little impact.

In my study a mesh size of 80 µm was chosen in order to remove as much of the zooplankton biomass as possible whilst retaining a phytoplankton assemblage similar to that in unfiltered samples. In general, zooplankton are of larger average body size in Northern Hemisphere lakes than in New Zealand (Chapman and Green 1987). Therefore a larger mesh size for filtering zooplankton in a number of Northern Hemisphere investigations is a natural consequence of larger average zooplankton size (Table 3). Even with 80 µm mesh, rotifers, nauplii and younger stages of copepod copepodites were not always excluded (see Chapter Five). However, only two phytoplankton species, *Dinobryon cylindricum* and *Botryococcus braunii*, were retained by this mesh in the Lake Rotoroa experiments, and only four species, *Aulacosira granulata*, *Mougeotia* sp., *Closterium aciculare* and *Ceratium hirundinella* were retained in the Lake Pupuke experiments (see Appendix V).

The abundances of these taxa were considered to be artificially reduced below natural levels in exclosures and artificially elevated in zooplankton enclosures due to the “inoculation” effect of adding net hauls of zooplankton to these enclosures so they were excluded from further analysis, as were algal species occurring in the mesh nets of Bergquist *et al.* (1985) and Bergquist and Carpenter (1986). The abundances of the retained algae in Lakes Rotoroa and Pupuke are presented in Appendix V, but they were not considered part of the total algal biomass described in Chapter Six and presented in Appendix IV.

The ramifications of this decision must be kept in mind when interpreting the results of Chapter Six. Despite the fact that only two species were not included in the total phytoplankton biomass in the Lake Rotoroa experiments, one in particular - *Botryococcus braunii* - despite low abundance, contained a massive amount of biomass. As can be seen in Appendix VIII these net phytoplankton formed over 84% of total algal biomass (Experiment 1 (Autumn)). In Experiment 2 (Winter) only *Botryococcus* was present and accounted for nearly 87% of total algal abundance. Rough estimates made in conjunction with counts of other algae during Experiments 3 (Winter) and 4 (Summer) indicated that *Botryococcus* occurred at similar abundances to Experiments 1 and 2.

Appendix VIII indicates the % contribution made by the retained species to total phytoplankton biomass in Lake Pupuke. At no time did these species contribute more than about 8% to total algal biomass. These values agree well with those of Elser *et al.* (1988); Vanni and Temte (1990) and Elser and Goldman (1991) (see Table 3). As a consequence total algal biomass for Lake Rotoroa is equivalent to total algal biomass in the fraction <80 µm. For Pupuke this is also the case, although the phytoplankton fraction < 80 µm is almost synonymous with total phytoplankton biomass.

Having established a series of limnocorrals with an algal complement as similar as possible to the lake the next step is to choose how to manipulate or add zooplankton to some of the enclosures in order to create contrasting grazer treatments. I used vertical net hauls of an 80  $\mu\text{m}$  mesh plankton net from four metres to the surface - approximately the length of the limnocorrals. The aim was to use the same number of hauls (two for a 1X biomass, four for a 2X biomass and eight for a 4X biomass designation respectively) at the start of each experiment. Ideally the zooplankton biomass of the enclosures should vary in the same fashion as the zooplankton biomass in the lake (surface waters). This methodology has been used by a number of workers (Lampert *et al.* 1986; Merrick and Ganf 1988). In order for this type of manipulation to be appropriate the resulting zooplankton biomass gradient should “bracket” lake biomass so as to achieve realistic biomasses of grazers. This topic is discussed in more depth in Section 5.3. As will be reiterated in Chapter Five, the designations 1X, 2X and 4X lake biomass are guidelines only. The actual gradients are described in Chapter Five with possible explanations for discrepancies. These discrepancies more likely reflect the large inherent variability associated with biological parameters rather than methodological and/or analytical errors (Bloesch *et al.* 1988).

In some studies the development of phytoplankton populations in undisturbed enclosures is significantly different from that in the lake (e.g. Lund 1972; Bloesch *et al.* 1988). A possible explanation for such effects is a decrease in natural turbulence and eddy diffusion due to the enclosure walls acting as a mechanical barrier - leading to alterations in phytoplankton sedimentation rates and nutrient circulation. In the present study there appeared to be few instances where algal species abundance declined markedly in the limnocorrals relative to lake levels (see Appendix IV). Uehlinger *et al.* (1984) noted the loss of diatoms from suspension in the water column of limnocorrals as one of the major disadvantages of the technique. However, this was not true of all the diatoms of this study and the genera *Cyclotella*, *Fragilaria*, *Achnanthes*,

*Asterionella* and *Aulacosira* were unaffected by containment. Any limnocorral effects on phytoplankton species were, if detectable, generally positive. As has been noted previously (Etheredge 1987; Edgar 1989), desmids often respond positively to containment. Presumably, containment provided conditions especially suitable for these species (e.g. *Staurostrum leptocladum* var. *insigne* and *Closterium acutum* var. *variabile*) thus promoting an increased growth rate relative to lake populations. For example, these non-motile phytoplankters when confined to the upper 4m of the lake may experience a more favourable light regime than when randomly distributed within the whole lake water column. Despite such responses, in general the abundances of phytoplankton species in the lake fell within the range of abundances for those species within the limnocorrals. In those algal species that show positive growth during containment, a significant depression by grazers during the experiments must be a conservative estimate of true grazing pressure.

The frequency and duration of sampling necessary for a particular investigation are controlled by its overall objectives. Periods of a few days can encompass changes in algal species growth and loss rates in lakes (Lehman and Sandgren 1985; Bergquist *et al.* 1985), yet are shorter than the intervals over which grazing rates change significantly (Harris 1980; Carpenter and Kitchell 1984). Time-course experiments have confirmed that changes in density of algal species and size classes plateau in a few days, while zooplankton biomass can be held essentially constant and enclosure effects appear minimal (Lehman 1979; Lehman and Sandgren 1985; Bergquist and Carpenter 1986; Pace and Funke 1991).

In the present study enclosures were sampled on Days 0, 3, 6 and 10. The impact of zooplankton grazing on total algal biomass and the species-specific responses of the phytoplankton was examined for the period from Day 0 to Day 6. This experimental time scale allows for a potential response of several generations of the phytoplankton,



depending on growth rates, while limiting the ability of zooplankton to change substantially from initial biomasses (Pace and Funke 1991). Similar studies in the Northern Hemisphere have ranged from three to seven days duration. It was assumed that a six day experimental period (rather than ten days) for New Zealand zooplankton would also limit the change in zooplankton biomass. In the majority of seasonal experiments the temperatures would be cooler (implying slower generation times) than in summer experiments conducted in the Northern Hemisphere. In addition, the dominant zooplankton in both Lakes Rotoroa and Pupuke are cyclopoid and calanoid copepods (Tables 5.1 - 5.8) which have much slower generation times than cladocerans (Chapman and Green 1987).

The number of sampling stations needed to yield data representative of the planktonic systems of relatively small lakes is uncertain. The importance of horizontal patchiness in marine environments is unquestionable (Riley 1965; 1976) but, in lakes where distance scales are smaller, its significance is still unclear. Lewis (1978), for example, considered that horizontal heterogeneity was not important in Lake Lanao, despite the fact that it was statistically detectable, and concluded that significant patchiness occurred only at scales considerably greater than 1 km. In the present study, it was assumed that phytoplankton samples taken from enclosures at a single station were adequate to describe the major seasonal trends. In the case of Lake Rotoroa the experimental deployment was conducted over the deepest area of the lake. In Lake Pupuke, because of its much greater depth, deployment over the deepest area would have involved considerable mechanical difficulties and it was decided to deploy the enclosures closer to shore. Vant and Pridmore (1990) suggest that samples taken from a very small distance away from the Lake Pupuke shoreline are representative of the water body as a whole. Both lakes are relatively small, display marked vertical mixing and no obstructions (such as islands) are present. Also, phytoplankton species

composition tends to vary more vertically than horizontally (Richerson *et al.* 1970, 1975).

Assessment of laboratory methodology focusses on the problems associated with estimates of phytoplankton abundance and biomass. The Utermöhl technique is the preferred method for the determination of phytoplankton community structure and population dynamics (Lund *et al.* 1958; Hasle 1978; Wetzel and Likens 1979; Rott 1981; Etheredge 1985). Although Willén (1976) rejected the technique as too time-consuming, there is no quicker method that could replace it and at the same time provide accurate quantitative information. Unfortunately there are disadvantages in the technique. It may lead to inaccuracies in biomass estimation and thus false conclusions about planktonic interactions because of the difficulties in determining cell viability, particularly of armoured species. Paerl (1978) compared phytoplankton counts using Utermöhl and autoradiographic techniques and found significant discrepancies between the two methods due to the inability in the former to distinguish between functional intracellular material and decomposing cellular contents. In particular the counts of diatom species in the experiments may indicate higher percentages of viability than is in fact the case.

Another source of error lies in the difficulty of establishing accurate estimates of phytoplankton biomass (Hobro and Willén 1977; Hallegraeff 1977; Smayda 1978). The sources of error in biovolume estimations based on species composition, number and individual estimated biovolumes are: (1) lack of accuracy in measuring and calculating the biovolumes of irregularly shaped taxa; (2) varying ratios of metabolising cytoplasm or plasma volume (Smayda 1978) and vacuolar "dead" volume and resistant wall materials; (3) influences of the physiological state of a cell on volumes of cytoplasmic constituents (Sicko-Goad *et al.* 1977).

The distribution of phytoplankton on the basal plate of the sedimentation chamber was tested using Fisher's Index of Dispersion (Fisher 1948), as defined by Lund *et al.* (1958):

$$\chi^2 = \frac{\sum (x - \bar{x})^2}{\bar{x}}$$

Where  $x$  = number of plankton units  $\text{ml}^{-1}$ .

Counts were made of common taxa recorded as dominants during experiments on both lakes. Seven chamber transects were counted on each occasion. All taxa were distributed randomly upon the basal plate (see Appendix III).

Fisher's Index of Dispersion was used to determine whether aliquots were randomly drawn from a particular sample. 300 ml samples from both lakes were gently but thoroughly shaken and six 50 ml aliquots were removed using a pipette. After settling counts were made of the most abundant taxa in each aliquot (see Appendix III). A random distribution amongst the subsamples was found.

Etheredge (1987) used material from Lake Mangahia, which like Lake Rotorua lies in the central Waikato region, to determine the time required to obtain complete sedimentation of 25 ml aliquots of phytoplankton. Her results indicated a minimum of 24 hours was adequate for sedimentation. This period was doubled to 48 hours in my experiments to allow for the slightly larger volumes of the aliquots being settled (50 ml). The same 48 hour settling period was also used for the Lake Pupuke samples. This is in agreement with the methods suggested by Willén (1976) who recommended a sedimentation time of 48 hours for 50 ml and 100 ml chambers.

The statistical tests used for investigating significant grazing responses by the zooplankton essentially were one way ANOVAs across treatments, combined with linear or quadratic regressions of total phytoplankton biomass against zooplankton biomass. Similar regression analyses were used for species-specific responses and the

examination of the influence of grazer biomass on altering nutrient regimes within the limnocorrals.

Both statistical procedures require that the samples come from a normal distribution and have homogeneity of variances. All phytoplankton and zooplankton data were investigated for normality and homoscedasticity. The data (phytoplankton and zooplankton abundance and biomass) displayed normality when plotted as stem-and-leaf diagrams and in probability plots of cumulative relative frequency (Zar 1984). The shape of pooled data was normal when Lilefors test was applied. Homogeneity of variance was examined using Bartlett's test - an approximation to the chi-square distribution. Testing indicated variances in proportion to means and this is supported by an examination of coefficients of variation (see sections 5.3 and 6.3) across replicates. The low inter-replicate variability of means within treatments compared with those across a range of treatments leads to confidence in the power of these statistical procedures.

Zar (1984) suggests the analysis of variance is robust, operating well even with considerable heterogeneity of variances as long as sample sizes are equal (which is the case for the present investigation). It is also robust with respect to the assumption of the underlying population's normality. The validity of the analysis is affected only slightly by considerable deviations from normality (in skewness and/or kurtosis). Thus the analysis of variance may be depended upon unless the data deviate severely from the underlying assumptions. In the latter case, non-parametric tests are required. I also performed non-parametric one-way ANOVA (Kruskal-Wallis test with ranked data) and found significant effects (at the 0.05 significance level) identical to those for parametric ANOVA tests.

In the case of regression analyses, for both total phytoplankton biomass and species-specific algal growth rates the residuals were tested to satisfy the associated assumptions of the general linear model. Probability plots were constructed for the residuals of all significant linear and quadratic regressions and in all cases the errors appeared normally distributed. Plotting studentized residuals against estimated values showed that in the majority of cases homogeneity of variance was observed. That is, the errors had constant variance. Only seven regression equations proved to have one single outlier each. In these instances the outlier was removed and the regression re-run. Plotting studentized residuals against estimated values indicated that the errors were independent of each other. This was confirmed by testing the residuals for serial correlation. Autocorrelation plots revealed no instances for any regressions where one residual could be predicted from the preceding one. That all the members of the population were described by the same linear model was confirmed by plotting Cook's distance against the estimated values. This measures the influence of each sample observation on the co-efficient estimates. For no regression was the absolute value of Cook's distance above 2 implying there were no particularly large residuals influencing the calculation of the regression coefficients.

Despite the technical difficulties and associated methodological problems of limnocorral experiments they are still of considerable value. Unfortunately the benefit of the limnocorral technique is at the same time its crux, because the system, while close to nature, is very complex and therefore not easy to understand. There are difficulties and dangers in attempting to generalise from the results of limnocorral studies (Burns 1987) and the author supports the view of Bloesch *et al.* (1988) who believe results from such enclosure work should be interpreted in a qualitative rather than a quantitative manner.

## CHAPTER FOUR

### TEMPERATURE, OXYGEN AND LIGHT PROFILES

#### 4.1 Introduction

At the completion (day 10) of each experiment on both lakes, measurements of temperature, oxygen and light were made at 1 metre intervals from the surface (0m) to near the bottom of the limnocorrals. Such profiles were recorded from a minimum of three randomly chosen limnocorrals and their mean values compared with mean profiles determined from three randomly chosen lake sites adjacent to the limnocorrals. In addition, Secchi depths were recorded for limnocorrals and lake stations.

#### 4.2 Results

##### *4.2.1 Lake Rotoroa*

At the completion of Experiment 1 (Autumn), there were no differences in temperature profiles between the limnocorrals and the lake (Table 4.1). However, oxygen recordings were consistently higher for each depth in the limnocorrals than the lake, with a maximum difference of  $1.65 \text{ mg l}^{-1}$  at the surface. The differences were relatively small and may reflect higher total phytoplankton biomass, particularly in the enclosures, resulting in a marginally higher photosynthetic production of  $\text{O}_2$ . Light profiles in the limnocorrals and the lake were very similar below the surface (0m) (Table 4.1). Surface values were much higher for the lake and probably indicate shading at the surface of the limnocorrals by the iron rings of the flotation units. The light profiles were taken in direct sunlight, when shading by the limnocorral is likely to be more obvious. Secchi depth profiles were quite similar between limnocorral treatments with the (1x) enclosure treatment showing the closest similarity to the lake values.

Temperature and oxygen profiles on day 10 of Experiment 2 (Winter) were again very similar between the limnocorrals and the lake. Maximum differences were  $0.3^\circ\text{C}$  at 2m depth and  $0.71 \text{ mg l}^{-1}$  of  $\text{O}_2$  at 3m depth (see Table 4.2). Light profiles were also

similar between the limnocorrals and the lake. As in Experiment 1, there was indication of shading by the limnocorrals at the surface, but recording in diffuse sunlight reduced this (Table 4.2). Secchi disc depths were similar in all limnocorrals. Lake Secchi depths were closest to those in the 1x - 2x enclosure treatments.

At the completion of Experiment 3 (Spring), there were very slight differences between both temperature and oxygen profiles in the limnocorrals and the lake (Table 4.3). Maximum differences (0.8°C) in temperature occurred at the surface. Lake oxygen values were slightly above the limnocorral values from 0-2 metres depth. This could possibly result from reduced mixing at the atmosphere-water interface of the limnocorrals caused by the mechanical barrier of the aluminium hood. However, differences of this magnitude were not observed in Experiments 1 or 2 when the differences were marginal. Light profiles were similar between the lake and the limnocorrals (Table 4.3). Shading by the limnocorrals appeared to occur principally at 1m depth.

Temperature profiles on day 10 of Experiment 4 (Summer) were identical between the limnocorrals and the lake. Oxygen profiles were again slightly higher for the limnocorrals than the lake and probably reflect higher total algal biomass in the limnocorrals and/or the influence of deoxygenated bottom waters in the lake. Maximum differences were only 1.41 mg l<sup>-1</sup> O<sub>2</sub> (Table 4.4). There was close agreement in light profiles and Secchi disc depths between the limnocorrals and the lake (Table 4.4).

#### **4.2.2 Lake Pupuke**

In Experiment 5 (Autumn) there was little difference between temperature, light and oxygen profiles in the limnocorrals and the lake (Table 4.5). Shading by the limnocorrals was evident at the surface (0m) with a difference of 230 mξm<sup>-2</sup> s<sup>-1</sup> between the lake and limnocorrals. Secchi disc depth was 6.5m for the lake (Table 4.5) and in all limnocorrals was greater than the depth of the bottom of the bags.

Temperature, light and oxygen profiles on day 10 Experiment 6 (Winter) were similar between the lake and the limnocorrals (Table 4.6). Secchi disc depth again exceeded the bottom of the bags.

There was good agreement between the limnocorrals and the lake for temperature and oxygen profiles of Experiment 7 (Spring) (Table 4.7). This was generally true for the light profiles as well (Table 4.14) although shading was again apparent at the surface of the limnocorrals.

At the completion of Experiment 8 (Summer) there was close agreement in temperature, oxygen and light profiles for the limnocorrals and the lake (Tables 4.8). However, the  $4\pi$  sensor used on all previous experiments was unavailable and profiles of downwelling and upwelling radiation were recorded with a  $2\pi$  sensor.

### 4.3 Discussion

The temperature profiles which developed in the limnocorrals of each experiment were virtually identical to those of adjacent lake sites. On no occasion was the difference in temperature for any depth greater than  $0.8^{\circ}\text{C}$  and in most cases it was  $\leq 0.1^{\circ}\text{C}$ . Similar agreement between temperature profiles for experimental limnocorrals and lake values has been found in many investigations (e.g. Boyce 1974; Takahasi and Whitney 1977; Spencer 1988). All profiles from both limnocorrals and the lakes in my investigation were homogeneous and there was no indication of stratification. There is evidence, however, that despite the rapidity with which temperature profiles become similar to that of the surrounding lake, a reduction in circulation occurs within the limnocorrals with time (Steele *et al.* 1977). This could lead to increased rates of phytoplankton sedimentation (particularly significant for diatoms) and also alter the vertical mixing patterns of important nutrients.



**Table 4.1** Comparison of temperature, oxygen and light profiles between the limnocorrals and Lake Rotoroa in Experiment 1, Day 10 (11.6.90). Secchi depths ( $Z_{SD}$ ) are also indicated. Light profiles were recorded in direct sunlight.

| Depth (m) | Temperature ( $^{\circ}\text{C}$ ) (n=3) |      | Oxygen ( $\text{gm}^3$ ) (n=3) |      |
|-----------|------------------------------------------|------|--------------------------------|------|
|           | Limnocorral                              | Lake | Limnocorral                    | Lake |
| 0         | 10.0                                     | 10.0 | 9.50                           | 7.85 |
| 1         | 10.0                                     | 10.0 | 9.47                           | 7.85 |
| 2         | 10.0                                     | 10.0 | 9.40                           | 7.85 |
| 3         | 10.0                                     | 10.0 | 9.37                           | 7.85 |
| 3.5       | 10.0                                     | 10.0 | 9.33                           | 7.80 |

| Depth (m) | Quanta ( $\text{m}\xi \text{ m}^{-2}\text{s}^{-1}$ ) (n=3) |       | Secchi depth ( $Z_{SD}$ ) (n=2) |      |
|-----------|------------------------------------------------------------|-------|---------------------------------|------|
|           | Limnocorral                                                | Lake  |                                 |      |
| 0         | 140.0                                                      | 460.0 | Exclosures                      | 1.52 |
| 1         | 160.5                                                      | 140.0 | Enclosures (1X)                 | 1.37 |
| 2         | 40.0                                                       | 38.0  | Enclosures (2X)                 | 1.50 |
| 3         | 9.5                                                        | 10.0  | Enclosures (4X)                 | 1.58 |
| 3.5       | 2.5                                                        | 5.8   | Lake                            | 1.16 |

**Table 4.2** Comparison of temperature, oxygen and light profiles between the limnocorrals and Lake Rotoroa in Experiment 2, Day 10 (6.8.90). Secchi depths ( $Z_{SD}$ ) are also indicated. Light profiles were recorded in diffuse sunlight.

| Depth (m) | Temperature ( $^{\circ}\text{C}$ ) (n=3) |      | Oxygen ( $\text{gm}^3$ ) (n=3) |       |
|-----------|------------------------------------------|------|--------------------------------|-------|
|           | Limnocorral                              | Lake | Limnocorral                    | Lake  |
| 0         | 11.8                                     | 11.9 | 11.2                           | 10.59 |
| 1         | 11.5                                     | 11.7 | 11.1                           | 10.45 |
| 2         | 11.3                                     | 11.6 | 11.1                           | 10.40 |
| 3         | 11.3                                     | 11.5 | 11.1                           | 10.39 |
| 3.5       | 11.3                                     | 11.5 | 10.9                           | 10.35 |

| Depth (m) | Quanta ( $\text{m}\xi\text{ m}^{-2}\text{s}^{-1}$ ) (n=3) |       | Secchi depth ( $Z_{SD}$ ) (n=2) |      |
|-----------|-----------------------------------------------------------|-------|---------------------------------|------|
|           | Limnocorral                                               | Lake  |                                 |      |
| 0         | 205.0                                                     | 320.0 | Exclosures                      | 1.30 |
| 1         | 78.0                                                      | 62.0  | Enclosures (1X)                 | 1.32 |
| 2         | 18.5                                                      | 16.0  | Enclosures (2X)                 | 1.32 |
| 3         | 4.4                                                       | 3.4   | Enclosures (4X)                 | 1.21 |
| 3.5       | 2.6                                                       | 1.4   | Lake                            | 1.41 |

**Table 4.3** Comparison of temperature, oxygen and light profiles between the limnocorrals and Lake Rotoroa in Experiment 3, Day 10 (22.10.90). Secchi depths ( $Z_{SD}$ ) are also indicated. Light profiles were recorded in diffuse sunlight.

| Depth (m) | Temperature ( $^{\circ}\text{C}$ ) (n=3) |      | Oxygen ( $\text{gm}^3$ ) (n=3) |       |
|-----------|------------------------------------------|------|--------------------------------|-------|
|           | Limnocorral                              | Lake | Limnocorral                    | Lake  |
| 0         | 19.2                                     | 20.0 | 9.91                           | 10.21 |
| 1         | 18.7                                     | 18.8 | 9.87                           | 10.20 |
| 2         | 18.4                                     | 18.5 | 9.74                           | 9.80  |
| 3         | 18.2                                     | 18.1 | 9.35                           | 8.80  |
| 3.5       | 18.1                                     | 17.8 | 9.21                           | 7.83  |

| Depth (m) | Quanta ( $\text{m}\xi \text{ m}^{-2}\text{s}^{-1}$ ) (n=3) |         | Secchi depth ( $Z_{SD}$ ) (n=2) |      |
|-----------|------------------------------------------------------------|---------|---------------------------------|------|
|           | Limnocorral                                                | Lake    |                                 |      |
| 0         | 2,145.0                                                    | 2,410.0 | Exclosures                      | 1.55 |
| 1         | 265.0                                                      | 640.0   | Enclosures (1X)                 | 1.88 |
| 2         | 107.5                                                      | 193.0   | Enclosures (2X)                 | 1.66 |
| 3         | 45.0                                                       | 64.8    | Enclosures (4X)                 | 0.73 |
| 3.5       | 1.4                                                        | 3.1     | Lake                            | 1.40 |

**Table 4.4** Comparison of temperature, oxygen and light profiles between the limnocorrals and Lake Rotoroa in Experiment 4, Day 10 (15.2.91). Secchi depths ( $Z_{SD}$ ) are also indicated. Light profiles were recorded in diffuse sunlight.

| Depth (m) | Temperature (oC) (n=4) |      | Oxygen (gm <sup>3</sup> ) (n=4) |      |
|-----------|------------------------|------|---------------------------------|------|
|           | Limnocorral            | Lake | Limnocorral                     | Lake |
| 0         | 25                     | 25   | 8.41                            | 7.00 |
| 1         | 25                     | 25   | 8.36                            | 6.95 |
| 2         | 25                     | 25   | 8.31                            | 6.90 |
| 3         | 25                     | 25   | 8.11                            | 6.85 |
| 3.5       | 25                     | 25   | 7.98                            | 6.85 |

| Depth (m) | Quanta (m $\xi$ m <sup>-2</sup> s <sup>-1</sup> ) (n=3) |       | Secchi depth ( $Z_{SD}$ ) (n=2) |      |
|-----------|---------------------------------------------------------|-------|---------------------------------|------|
|           | Limnocorral                                             | Lake  |                                 |      |
| 0         | 420.0                                                   | 490.0 | Exclosures                      | 0.78 |
| 1         | 28.0                                                    | 40.0  | Enclosures (1X)                 | 0.72 |
| 2         | 11.5                                                    | 11.2  | Enclosures (2X)                 | 0.68 |
| 3         | 1.5                                                     | 1.3   | Enclosures (4X)                 | 0.73 |
| 3.5       | 0.9                                                     | 0.8   | Lake                            | 0.74 |

**Table 4.5** Comparison of temperature, oxygen and light profiles between the limnocorrals and Lake Pupuke in Experiment 5, Day 10 (31.5.91). Secchi depths ( $Z_{SD}$ ) are also indicated. Light profiles were recorded in direct sunlight.

| Depth (m) | Temperature ( $^{\circ}\text{C}$ ) (n=3) |      | Oxygen ( $\text{gm}^3$ ) (n=3) |      |
|-----------|------------------------------------------|------|--------------------------------|------|
|           | Limnocorral                              | Lake | Limnocorral                    | Lake |
| 0         | 13.8                                     | 13.8 | 9.57                           | 9.23 |
| 1         | 13.8                                     | 13.9 | 9.58                           | 9.23 |
| 2         | 13.8                                     | 13.8 | 9.59                           | 9.23 |
| 3         | 13.8                                     | 13.8 | 9.62                           | 9.23 |
| 3.5       | 13.8                                     | 13.8 | 9.63                           | 9.23 |

| Depth (m) | Quanta ( $\text{m}\xi \text{ m}^{-2}\text{s}^{-1}$ ) (n=3) |       | Secchi depth ( $Z_{SD}$ ) (n=2) |       |
|-----------|------------------------------------------------------------|-------|---------------------------------|-------|
|           | Limnocorral                                                | Lake  |                                 |       |
| 0         | 275.0                                                      | 505.0 | Exclosures                      | >3.50 |
| 1         | 175.0                                                      | 140.0 | Enclosures (1X)                 | >3.50 |
| 2         | 202.0                                                      | 248.0 | Enclosures (2X)                 | >3.50 |
| 3         | 232.0                                                      | 287.0 | Enclosures (4X)                 | >3.50 |
| 3.5       | 288.5                                                      | 250.0 | Lake                            | 6.48  |

**Table 4.6** Comparison of temperature, oxygen and light profiles between the limnocorrals and Lake Pupuke in Experiment 6, Day 10 (2.8.91). Secchi depths ( $Z_{SD}$ ) are also indicated. Light profiles were recorded in diffuse sunlight.

| Depth (m) | Temperature ( $^{\circ}\text{C}$ ) (n=3) |      | Oxygen ( $\text{gm}^3$ ) (n=3) |      |
|-----------|------------------------------------------|------|--------------------------------|------|
|           | Limnocorral                              | Lake | Limnocorral                    | Lake |
| 0         | 10.8                                     | 11.0 | 8.54                           | 7.90 |
| 1         | 10.8                                     | 10.9 | 8.52                           | 7.90 |
| 2         | 10.8                                     | 10.8 | 8.47                           | 7.90 |
| 3         | 10.8                                     | 10.8 | 8.47                           | 7.90 |
| 3.5       | 10.8                                     | 10.8 | 8.47                           | 7.90 |

| Depth (m) | Quanta ( $\text{m}\xi \text{ m}^{-2}\text{s}^{-1}$ ) (n=3) |       | Secchi depth ( $Z_{SD}$ ) (n=2) |       |
|-----------|------------------------------------------------------------|-------|---------------------------------|-------|
|           | Limnocorral                                                | Lake  |                                 |       |
| 0         | 390.0                                                      | 518.5 | Exclosures                      | >3.50 |
| 1         | 230.0                                                      | 240.0 | Enclosures (1X)                 | >3.50 |
| 2         | 231.0                                                      | 239.5 | Enclosures (2X)                 | >3.50 |
| 3         | 91.4                                                       | 88.7  | Enclosures (4X)                 | >3.50 |
| 3.5       | 61.2                                                       | 50.5  | Lake                            | 4.53  |

**Table 4.7** Comparison of temperature, oxygen and light profiles between the limnocorrals and Lake Pupuke in Experiment 7, Day 10 (18.10.91). Secchi depths ( $Z_{SD}$ ) are also indicated. Light profiles were recorded in diffuse sunlight.

| Depth (m) | Temperature (oC) (n=3) |      | Oxygen (gm <sup>3</sup> ) (n=3) |       |
|-----------|------------------------|------|---------------------------------|-------|
|           | Limnocorral            | Lake | Limnocorral                     | Lake  |
| 0         | 13.9                   | 13.9 | 13.25                           | 13.00 |
| 1         | 13.8                   | 13.9 | 13.30                           | 13.00 |
| 2         | 13.9                   | 13.9 | 13.35                           | 13.00 |
| 3         | 13.8                   | 13.8 | 13.32                           | 13.00 |
| 3.5       | 13.8                   | 13.8 | 13.33                           | 13.00 |

| Depth (m) | Quanta (mξ m <sup>-2</sup> s <sup>-1</sup> ) (n=3) |       | Secchi depth ( $Z_{SD}$ ) (n=2) |      |
|-----------|----------------------------------------------------|-------|---------------------------------|------|
|           | Limnocorral                                        | Lake  |                                 |      |
| 0         | 73.3                                               | 180.0 | Enclosures                      | >3.5 |
| 1         | 66.7                                               | 90.0  | Enclosures (1X)                 | >3.5 |
| 2         | 55.3                                               | 60.0  | Enclosures (2X)                 | >3.5 |
| 3         | 41.3                                               | 41.0  | Enclosures (4X)                 | >3.5 |
| 3.5       | 36.2                                               | 30.1  | Lake                            | 5.40 |

**Table 4.8** Comparison of temperature, oxygen and light profiles between the limnocorrals and Lake Pupuke in Experiment 8, Day 10 (14.2.92). Secchi depths (ZSD) are also indicated. Light profiles were recorded in diffuse sunlight.

| Depth (m) | Temperature (°C) (n=3) |      | Oxygen (gm <sup>-3</sup> ) (n=3) |      |
|-----------|------------------------|------|----------------------------------|------|
|           | Limnocorral            | Lake | Limnocorral                      | Lake |
| 0         | 22.8                   | 22.8 | 7.84                             | 7.78 |
| 1         | 22.8                   | 22.8 | 7.86                             | 7.82 |
| 2         | 22.8                   | 22.8 | 7.84                             | 7.71 |
| 3         | 22.8                   | 22.7 | 7.85                             | 7.73 |
| 3.5       | 22.8                   | 22.6 | 7.82                             | 7.69 |

| Depth (m)<br>(n=2) | Quanta (mξ m <sup>-2</sup> s <sup>-1</sup> ) (n=3) |               | Secchi depth (ZSD) |       |
|--------------------|----------------------------------------------------|---------------|--------------------|-------|
|                    | Limnocorral                                        | Lake          |                    |       |
| 0                  | 2.66 / 100.00                                      | 3.03 / 195.00 | Exclosures         | >3.50 |
| 1                  | 3.05 / 69.25                                       | 2.35 / 99.25  | Enclosures (1X)    | >3.50 |
| 2                  | 2.90 / 55.00                                       | 1.50 / 57.25  | Enclosures (2X)    | >3.50 |
| 3                  | 2.15 / 46.00                                       | 1.00 / 54.60  | Enclosures (4X)    | >3.50 |
| 3.5                | 2.73 / 45.00                                       | 0.61 / 51.05  | Lake               | 4.33  |

upwelling / downwelling



That some circulation does occur in limnocorrals of this size and type has been established previously (Edgar 1989). Dye tests revealed mixing throughout much of the limnocorral water column (4 metres) and this mixing developed in considerably less than 24 hours.

Such mixing is unlikely to be directly wind induced because of the small area and protected nature of the water surface in the limnocorrals. Penetrative convection caused by heating and cooling at the surface (Imberger, 1985) may have been important. It is possible that flexible enclosures, such as those used in this study, allow momentum from horizontal pulsations in the lake to be transmitted, albeit attenuated, to the interior of an enclosure. Vertical motions, however, must set up shear forces in the plane of the barrier (limnocorral wall) which are resisted by the weight of the bag and so cannot be transmitted into the interior (Boyce 1974). Evidence of transmission of horizontal pulsations to the limnocorrals was observed during Experiment 8 when I inspected the limnocorrals under water using SCUBA. Water currents in the surface of Lake Pupuke caused considerable bag movement and presumably internal water mixing. In addition, Steele *et al.* (1977) believe that thermal forcing also generates vertical motion in the bags. Thermal forcing results from changes in the thermal structure outside the limnocorral (due to wind mixing or internal waves) which can produce appreciable gradients across the enclosure wall; subsequently, conduction of heat through the wall may induce convection within the bag resulting in mixing.

The oxygen profiles which developed in the limnocorrals of Experiments 1 - 8 were either almost identical to adjacent lake sites or were slightly elevated (by  $\approx 1\text{mg l}^{-1} \text{O}_2$ ). A similar result was noted in a previous investigation (Edgar, 1989). The slightly higher  $\text{O}_2$  values in the limnocorrals probably reflect higher total algal biomass and photosynthetically derived  $\text{O}_2$  production, increased availability of light due to a shorter

water column (4m) and the lack of mixing in the bags with the deeper more deoxygenated waters of the adjacent lake.

Light profiles and Secchi disc depth showed good agreement on most occasions between limnocorral treatments and lake values. Takahasi and Whitney (1977) found that on sunny days, in direct sunlight, solar energy was reduced by 50% in enclosed water columns (CEPEX), except in unshaded surface waters. These values were obtained from significantly larger enclosures than those used in the present study and may reflect extensive shading due to enclosure design. Generally, surface waters (0m) showed the largest differences which, as indicated previously, probably reflects shading by the aluminium hoods and iron rings of the flotation collars. Similar results have been recorded previously with similar flotation equipment (Spencer 1988; Edgar 1989).

Another problem is that periphyton growth on the plastic sheeting of enclosures may alter the light regime of the bags relative to the lake (Uehlinger *et al.* 1984) thus altering the physical, chemical and biological properties inside the enclosures (Bloesch *et al.* 1988). By keeping the length of the experiments short the effect of the periphyton was kept to a minimum. In both Lake Pupuke and Lake Rotoroa limnocorrals lacked obvious films of periphyton after ten days of deployment. Preliminary testing of the equipment showed that periphyton build-up became noticeable after fifteen days on Lake Rotoroa and therefore all experimental investigations were kept to a ten day period.

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## CHAPTER FIVE

### ZOOPLANKTON

#### 5.1 Introduction

As noted earlier, the designations of 1X, 2X and 4X ambient surface lake biomass are only guidelines to the actual biomass present. In order to establish the actual zooplankton biomass in the enclosures and adjacent lake sites zooplankton were sampled at the beginning (Day 0) of each experiment in both lakes. The samples were enumerated and the biomass of both individual taxa and total zooplankton determined. The results of enumeration of samples taken on Day 0 are presented for individual taxa as well as for total zooplankton biomass across treatments.

#### 5.2 Results

##### 5.2.1 Lake Rotoroa

The zooplankton of Experiment 1 (Autumn) was numerically dominated by *Bosmina meridionalis* followed by *Ceriodaphnia* species, *Calamoecia lucasi* adults and combined copepod nauplii (Table 5.1). Rotifers occurred in low numbers and composed approximately 10% of total zooplankton biomass in the enclosure treatment but decreased to 1% in the 4X treatment (Table 5.1). The treatments encompassed a 29 fold gradient in total zooplankton biomass. The discrete sample series for Day 0 indicated an ambient surface (0-4m) lake biomass of approximately 121.5 mg m<sup>-3</sup>. This agreed well with the (1X) treatment and the actual treatment designations for enclosures, (1X) enclosures (2X) enclosures and 4X enclosures were 0.12X, 1.05X, 2.19X and 3.53X ambient surface lake biomass respectively.

In Experiment 2 (Winter) the zooplankton composition was quite similar to that of Experiment 1. The same species were numerically dominant but slightly lower numbers of *Bosmina* and *Ceriodaphnia* species were present (Table 5.2). Conversely, *Calamoecia lucasi* copepodites occurred in higher densities. Total zooplankton biomass

in the lake on Day 0 ( $119.4 \text{ mg m}^{-3}$ ) was almost the same as that for Experiment 1. The actual zooplankton biomasses for exclosures, (1X) enclosures, (2X) enclosures and (4X) enclosures were 0.03X, 0.40X, 1.47X and 2.87X ambient lake surface biomass respectively. Reasons for these discrepancies are discussed below. Again crustaceans dominated the total zooplankton biomass, frequently contributing more than 95% (Table 5.2).

The zooplankton composition of Experiment 3 (Spring) was similar to that in the previous experiments. Rotifers again dominated numerically. Total zooplankton biomass in the surface lake waters ( $90.2 \text{ mg m}^{-3}$ ) was lower than in Experiments 1 and 2. The actual zooplankton biomasses for exclosures, (1X) enclosures, (2X) enclosures and (4X) enclosures were 0.17X, 0.90X, 1.49X and 2.95X ambient lake surface water values respectively. There was a 17 fold range in zooplankton biomass across treatments.

The summer experiment (Experiment 4) had the highest biomass of zooplankton ( $281.1 \text{ mg m}^{-3}$ ) for all experiments on both Lake Rotoroa and Lake Pupuke (Table 5.4). The actual zooplankton biomasses for exclosures, (1X) enclosures, (2X) enclosures and (4X) enclosures were 0.47X, 0.82X, 1.16X and 1.47X ambient lake surface biomass respectively. *Bosmina* and *Ceriodaphnia* were again very abundant but the contributions of cf. *Mesocyclops leuckarti* copepodites and adults were higher than for any other experiment in Lake Rotoroa. The rotifer *Keratella cochlearis* was the numerical dominant and *Asplanchna* was absent (Table 5.4). Again crustacean biomass dominated total zooplankton biomass across all treatments. There was a 3-fold range in zooplankton biomass across treatments reflecting increased *Mesocyclops* copepodite and rotifer abundances in the controls (exclosures).

### 5.2.2 Lake Pupuke

In Lake Pupuke total zooplankton biomass in the lake surface (0-4m depth) was lower than that for Lake Rotoroa in all four experiments. In fact the highest zooplankton biomass (Experiment 8 - Summer) for Lake Pupuke was less than one half of the lowest zooplankton biomass for Lake Rotoroa (Experiment 3 - Spring). There was a close similarity in zooplankton composition between Lake Pupuke and Lake Rotoroa in all experiments. Both lakes have the same crustacean species and in most cases rotifer genera.

The zooplankton in Experiment 5 (Autumn) was numerically dominated by *Calamoecia lucasi* adults, combined copepod nauplii, *Ceriodaphnia* species and *Asplanchna* (Table 5.5). The dominance of *Calamoecia* was reflected in the greater than 90% contribution of crustaceans to total zooplankton biomass across all treatments. Total zooplankton biomass in lake surface waters was  $27.1 \text{ mg m}^{-3}$ . The actual zooplankton biomasses for exclosures, (1X) enclosures, (2X) enclosures and 4X enclosures were 0.09X, 0.77X, 0.98X and 2.51X ambient lake surface biomass respectively.

Experiment 6 (Winter) yielded the lowest ambient lake total zooplankton biomass of all eight seasonal experiments ( $17.5 \text{ mg m}^{-3}$ ). The actual zooplankton biomasses for exclosures, (1X) enclosures, (2X) enclosures and (4X) enclosures were 0.04X, 1.57X, 2.40X and 3.15X ambient lake biomass respectively. Again crustaceans dominated total zooplankton biomasses across treatments, particularly in the enclosure treatments (Table 5.6). Copepod nauplii dominated numerically followed in decreasing order by *Calamoecia lucasi* adults and copepodites (Table 5.6).

**Table 5.1** Densities (numbers per litre) of zooplankton from limnocorrals in Lake Rotoroa on Day 0, Experiment 1 (1.6.90) (n = 4). Standard deviations are indicated in parentheses. Lake surface water biomass ( $\text{mg.m}^{-3}$ ) = 121.5.

| Taxon                                                                   | Mean Density<br>Zooplankton<br>Enclosures | Mean Density<br>Zooplankton<br>Enclosures (IX) | Mean Density<br>Zooplankton<br>Enclosures (2X) | Mean Density<br>Zooplankton<br>Enclosures (4X) |
|-------------------------------------------------------------------------|-------------------------------------------|------------------------------------------------|------------------------------------------------|------------------------------------------------|
| <b>Calanoida</b>                                                        |                                           |                                                |                                                |                                                |
| <i>Calamoecia</i><br>(V + adults)                                       | 2.36 (1.36)                               | 16.79 (5.49)                                   | 32.60 (3.55)                                   | 58.13 (12.47)                                  |
| <i>Calamoecia</i><br>(I-IV)                                             | 0.57 (0.19)                               | 1.47 (1.11)                                    | 0.27 (0.54)                                    | 0.54 (1.09)                                    |
| <b>Cyclopoida</b>                                                       |                                           |                                                |                                                |                                                |
| <i>Mesocyclops</i><br>(Adults)                                          | 0.08 (0.16)                               | 0.16 (0.33)                                    | 0.27 (0.54)                                    | 1.63 (2.08)                                    |
| <i>Mesocyclops</i><br>(Copepodites)                                     | 0.68 (0.33)                               | 3.59 (0.84)                                    | 4.35 (0.89)                                    | 12.50 (2.73)                                   |
| Total Nauplii                                                           | 12.66 (2.79)                              | 35.04 (1.87)                                   | 38.85 (7.75)                                   | 47.81 (6.40)                                   |
| <b>Cladocera</b>                                                        |                                           |                                                |                                                |                                                |
| <i>Bosmina meridionalis</i>                                             | 2.28 (0.87)                               | 55.42 (15.38)                                  | 129.58 (16.84)                                 | 195.05 (15.71)                                 |
| <i>Ceriodaphnia</i> cf. <i>pulchella</i><br><i>C. dubia</i>             | 3.34 (1.45)                               | 29.18 (3.55)                                   | 65.20 (9.60)                                   | 110.29 (14.24)                                 |
| <b>Rotifera</b>                                                         |                                           |                                                |                                                |                                                |
| <i>Ascomorpha</i>                                                       | 12.05 (3.72)                              | 17.44 (4.19)                                   | 21.167 (2.35)                                  | 15.07 (1.21)                                   |
| <i>Asplanchna</i>                                                       | 0.32 (0.40)                               | 0.49 (0.62)                                    | 1.09 (2.17)                                    | 0.54 (1.09)                                    |
| <i>Conochilus</i>                                                       | 9.92 (1.18)                               | 13.80 (2.65)                                   | 14.81 (6.96)                                   | 20.92 (6.91)                                   |
| <i>Filinia</i>                                                          | 0.58 (0.26)                               | 1.69 (0.74)                                    | 4.21 (2.52)                                    | 4.89 (2.31)                                    |
| <i>Trichocerca</i>                                                      | 0.48 (0.31)                               | 1.03 (0.67)                                    | 0.95 (0.52)                                    | 0.41 (0.52)                                    |
| Total numbers ( $\text{L}^{-1}$ )                                       | 43.317 (4.827)                            | 175.922 (19.448)                               | 313.326 (36.965)                               | 467.778 (5.783)                                |
| Total biomass ( $\text{mg.m}^{-3}$ )                                    | 14.571 (1.58)                             | 127.647 (18.622)                               | 265.999 (27.333)                               | 428.383 (9.753)                                |
| % contribution of crustacean<br>biomass to total zooplankton<br>biomass | 89.86                                     | 98.05                                          | 98.57                                          | 99.00                                          |

**Table 5.2** Densities (numbers per litre) of zooplankton from limnocorrals in Lake Rotoroa on Day 0, Experiment 2 (27.7.90) (n = 4). Standard deviations are indicated in parentheses. Lake surface water biomass ( $\text{mg.m}^{-3}$ ) = 119.37.

| Taxon                                                                   | Mean Density<br>Zooplankton<br>Exclosures | Mean Density<br>Zooplankton<br>Enclosures (IX) | Mean Density<br>Zooplankton<br>Enclosures (2X) | Mean Density<br>Zooplankton<br>Enclosures (4X) |
|-------------------------------------------------------------------------|-------------------------------------------|------------------------------------------------|------------------------------------------------|------------------------------------------------|
| Calanoida                                                               |                                           |                                                |                                                |                                                |
| <i>Calamoecia</i><br>(V + adults)                                       | 0.0 (0.0)                                 | 6.57 (2.91)                                    | 18.74 (2.06)                                   | 48.08 (6.17)                                   |
| <i>Calamoecia</i><br>(I-IV)                                             | 0.27 (0.14)                               | 5.92 (0.84)                                    | 20.65 (5.68)                                   | 33.69 (8.18)                                   |
| Cyclopoida                                                              |                                           |                                                |                                                |                                                |
| <i>Mesocyclops</i><br>(Adults)                                          | 0.0 (0.0)                                 | 0.38 (0.11)                                    | 1.35 (1.04)                                    | 2.99 (1.86)                                    |
| <i>Mesocyclops</i><br>(Copepodites)                                     | 0.06 (0.06)                               | 0.27 (0.21)                                    | 1.36 (2.06)                                    | 2.72 (2.88)                                    |
| Total Nauplii                                                           | 7.06 (1.02)                               | 23.04 (2.87)                                   | 40.75 (2.59)                                   | 51.07 (6.08)                                   |
| Cladocera                                                               |                                           |                                                |                                                |                                                |
| <i>Bosmina meridionalis</i>                                             | 0.27 (0.26)                               | 14.56 (5.79)                                   | 76.33 (5.57)                                   | 150.50 (27.22)                                 |
| <i>Ceriodaphnia</i> cf. <i>pulchella</i><br><i>C. dubia</i>             | 0.06 (0.06)                               | 10.81 (2.42)                                   | 41.02 (9.86)                                   | 69.81 (1.63)                                   |
| Rotifera                                                                |                                           |                                                |                                                |                                                |
| <i>Ascomorpha</i>                                                       | 3.59 (0.76)                               | 8.10 (2.23)                                    | 11.41 (3.49)                                   | 8.23 (3.11)                                    |
| <i>Asplanchna</i>                                                       | 0.16 (0.21)                               | 2.39 (0.40)                                    | 5.98 (0.63)                                    | 9.24 (2.88)                                    |
| <i>Conochilus</i>                                                       | 4.24 (0.42)                               | 7.39 (1.19)                                    | 10.65 (0.73)                                   | 15.48 (3.79)                                   |
| <i>Filinia</i>                                                          | 0.65 (0.36)                               | 0.54 (0.28)                                    | 2.12 (1.55)                                    | 2.20 (1.08)                                    |
| <i>Keratella</i>                                                        | 0.33 (0.38)                               | 0.44 (0.62)                                    | 0.33 (0.52)                                    | 1.06 (0.90)                                    |
| <i>Polyarthra</i>                                                       | 1.14 (0.27)                               | 1.63 (0.45)                                    | 1.03 (0.37)                                    | 0.25 (0.31)                                    |
| <i>Trichocerca</i>                                                      | 8.15 (0.72)                               | 12.01 (1.70)                                   | 15.21 (7.35)                                   | 9.54 (0.90)                                    |
| Total numbers ( $\ell^{-1}$ )                                           | 25.969 (1.636)                            | 94.046 (11.888)                                | 246.930 (20.908)                               | 404.841 (29.678)                               |
| Total biomass ( $\text{mg.m}^{-3}$ )                                    | 3.989 (0.070)                             | 47.143 (12.621)                                | 175.821 (10.105)                               | 342.510 (28.348)                               |
| % contribution of crustacean<br>biomass to total zooplankton<br>biomass | 58.96                                     | 94.43                                          | 97.56                                          | 98.72                                          |

**Table 5.3** Densities (numbers per litre) of zooplankton from limnocorrals in Lake Rotoroa on Day 0, Experiment 3 (12.10.90) (n = 4). Standard deviations are indicated in parentheses. Lake surface water biomass (mg.m<sup>-3</sup>) = 90.16.

| Taxon                                                                       | Mean Density<br>Zooplankton<br>Exclosures | Mean Density<br>Zooplankton<br>Enclosures (IX) | Mean Density<br>Zooplankton<br>Enclosures (2X) | Mean Density<br>Zooplankton<br>Enclosures (4X) |
|-----------------------------------------------------------------------------|-------------------------------------------|------------------------------------------------|------------------------------------------------|------------------------------------------------|
| <b>Calanoida</b>                                                            |                                           |                                                |                                                |                                                |
| <i>Calamoecia</i><br>(V + adults)                                           | 0.0 (0.0)                                 | 8.42 (2.61)                                    | 9.75 (1.21)                                    | 13.57 (1.02)                                   |
| <i>Calamoecia</i><br>(I-IV)                                                 | 5.76 (0.38)                               | 1.22 (0.93)                                    | 1.78 (0.68)                                    | 4.16 (1.10)                                    |
| <b>Cyclopoida</b>                                                           |                                           |                                                |                                                |                                                |
| <i>Mesocyclops</i><br>(Adults)                                              | 0.0 (0.0)                                 | 0.68 (0.52)                                    | 2.33 (0.93)                                    | 3.04 (1.41)                                    |
| <i>Mesocyclops</i><br>(Copepodites)                                         | 4.18 (1.46)                               | 2.72 (1.93)                                    | 6.17 (1.20)                                    | 13.06 (3.02)                                   |
| Total Nauplii                                                               | 2.45 (2.00)                               | 19.70 (4.49)                                   | 8.77 (0.91)                                    | 10.51 (1.75)                                   |
| <b>Cladocera</b>                                                            |                                           |                                                |                                                |                                                |
| <i>Bosmina meridionalis</i>                                                 | 0.49 (0.11)                               | 13.04 (3.20)                                   | 46.53 (4.22)                                   | 85.51 (12.16)                                  |
| <i>Ceriodaphnia</i> cf. <i>pulchella</i><br><i>C. dubia</i>                 | 0.27 (0.21)                               | 62.62 (6.81)                                   | 74.73 (20.32)                                  | 178.73 (12.78)                                 |
| <b>Rotifera</b>                                                             |                                           |                                                |                                                |                                                |
| <i>Ascomorpha</i>                                                           | 40.179 (11.652)                           | 17.66 (10.66)                                  | 8.92 (1.15)                                    | 22.72 (2.41)                                   |
| <i>Asplanchna</i>                                                           | 5.71 (2.24)                               | 0.27 (0.544)                                   | 0.0 (0.0)                                      | 0.27 (0.54)                                    |
| <i>Keratella</i>                                                            | 1.90 (2.41)                               | 0.68 (0.82)                                    | 0.27 (0.32)                                    | 0.55 (0.64)                                    |
| <i>Polyarthra</i>                                                           | 6.79 (2.72)                               | 0.0 (0.0)                                      | 0.14 (0.28)                                    | 0.27 (0.54)                                    |
| <i>Trichocerca</i>                                                          | 30.70 (7.28)                              | 13.18 (1.80)                                   | 5.06 (1.46)                                    | 13.32 (4.15)                                   |
| <br>Total numbers (ℓ <sup>-1</sup> )                                        | <br>98.421 (10.987)                       | <br>140.172 (18.626)                           | <br>164.443 (19.589)                           | <br>345.714 (9.657)                            |
| Total biomass (mg.m <sup>-3</sup> )                                         | 15.263 (1.647)                            | 81.049 (6.447)                                 | 134.302 (10.632)                               | 266.151 (10.672)                               |
| <br>% contribution of crustacean<br>biomass to total zooplankton<br>biomass | <br>64.89                                 | <br>97.64                                      | <br>99.41                                      | <br>99.22                                      |



**Table 5.4** Densities (numbers per litre) of zooplankton from limnocorrals in Lake Rotoroa on Day 0, Experiment 4 (5.2.91) (n = 4). Standard deviations are indicated in parentheses. Lake surface water biomass (mg.m<sup>-3</sup>) = 281.12.

| Taxon                                                                   | Mean Density<br>Zooplankton<br>Enclosures | Mean Density<br>Zooplankton<br>Enclosures (IX) | Mean Density<br>Zooplankton<br>Enclosures (2X) | Mean Density<br>Zooplankton<br>Enclosures (4X) |
|-------------------------------------------------------------------------|-------------------------------------------|------------------------------------------------|------------------------------------------------|------------------------------------------------|
| <b>Calanoida</b>                                                        |                                           |                                                |                                                |                                                |
| <i>Calamoecia</i><br>(V + adults)                                       | 2.17 (1.77)                               | 3.53 (3.48)                                    | 6.25 (3.25)                                    | 23.63 (7.95)                                   |
| <i>Calamoecia</i><br>(I-IV)                                             | 1.90 (1.63)                               | 5.70 (2.06)                                    | 8.92 (2.06)                                    | 10.59 (6.36)                                   |
| <b>Cyclopoida</b>                                                       |                                           |                                                |                                                |                                                |
| <i>Mesocyclops</i><br>(Adults)                                          | 2.72 (2.08)                               | 7.61 (2.66)                                    | 10.05 (1.37)                                   | 18.20 (2.41)                                   |
| <i>Mesocyclops</i><br>(Copepodites)                                     | 35.59 (10.70)                             | 18.74 (1.04)                                   | 28.80 (3.60)                                   | 36.94 (6.70)                                   |
| Total Nauplii                                                           | 10.32 (1.40)                              | 95.62 (15.95)                                  | 59.76 (15.99)                                  | 75.52 (11.17)                                  |
| <b>Cladocera</b>                                                        |                                           |                                                |                                                |                                                |
| <i>Bosmina meridionalis</i>                                             | 24.99 (2.94)                              | 85.30 (5.51)                                   | 128.49 (15.95)                                 | 151.04 (6.21)                                  |
| <i>Ceriodaphnia</i> cf. <i>pulchella</i><br><i>C. dubia</i>             | 31.24 (9.28)                              | 66.83 (6.24)                                   | 117.35 (30.24)                                 | 126.32 (12.93)                                 |
| <b>Rotifera</b>                                                         |                                           |                                                |                                                |                                                |
| <i>Filinia</i>                                                          | 12.166 (2.240)                            | 7.06 (3.26)                                    | 2.17 (1.77)                                    | 2.17 (1.77)                                    |
| <i>Hexarthra</i>                                                        | 23.909 (4.458)                            | 6.52 (4.70)                                    | 1.63 (2.08)                                    | 0.54 (1.09)                                    |
| <i>Keratella</i>                                                        | 298.073 (87.147)                          | 236.88 (2.51)                                  | 242.86 (85.20)                                 | 189.61 (23.96)                                 |
| <i>Synchaeta</i>                                                        | 11.95 (7.42)                              | 1.63 (2.08)                                    | 1.09 (1.26)                                    | 1.63 (2.08)                                    |
| Total numbers (L <sup>-1</sup> )                                        | 455.031 (70.153)                          | 535.423 (13.495)                               | 606.866 (111.733)                              | 636.206 (21.190)                               |
| Total biomass (mg.m <sup>-3</sup> )                                     | 131.291 (22.052)                          | 229.849 (8.178)                                | 325.040 (37.585)                               | 412.539 (9.528)                                |
| % contribution of crustacean<br>biomass to total zooplankton<br>biomass | 82.03                                     | 93.20                                          | 95.90                                          | 97.43                                          |

**Table 5.5** Densities (numbers per litre) of zooplankton from limnocorrals in Lake Pupuke on Day 0, Experiment 5 (21.5.91) (n = 4). Standard deviations are indicated in parentheses. Lake surface water biomass (mg.m<sup>-3</sup>) = 27.07.

| Taxon                                                                   | Mean Density<br>Zooplankton<br>Exclosures | Mean Density<br>Zooplankton<br>Enclosures (IX) | Mean Density<br>Zooplankton<br>Enclosures (2X) | Mean Density<br>Zooplankton<br>Enclosures (4X) |
|-------------------------------------------------------------------------|-------------------------------------------|------------------------------------------------|------------------------------------------------|------------------------------------------------|
| <b>Calanoida</b>                                                        |                                           |                                                |                                                |                                                |
| <i>Calamoecia</i><br>(V + adults)                                       | 0.87 (0.89)                               | 8.20 (0.54)                                    | 11.30 (1.76)                                   | 33.90 (13.45)                                  |
| <i>Calamoecia</i><br>(I-IV)                                             | 0.08 (0.06)                               | 1.66 (0.42)                                    | 3.10 (0.84)                                    | 3.04 (1.28)                                    |
| <b>Cyclopoida</b>                                                       |                                           |                                                |                                                |                                                |
| <i>Mesocyclops</i><br>(Adults)                                          | 0.03 (0.06)                               | 0.60 (0.14)                                    | 0.27 (0.21)                                    | 0.65 (0.56)                                    |
| <i>Mesocyclops</i><br>(Copepodites)                                     | 0.03 (0.06)                               | 0.65 (0.24)                                    | 0.71 (0.45)                                    | 0.65 (1.04)                                    |
| Total Nauplii                                                           | 2.20 (0.29)                               | 10.60 (2.03)                                   | 6.03 (1.91)                                    | 14.02 (5.45)                                   |
| <b>Cladocera</b>                                                        |                                           |                                                |                                                |                                                |
| <i>Bosmina meridionalis</i>                                             | 0.08 (1.04)                               | 0.14 (0.10)                                    | 0.54 (0.13)                                    | 0.76 (0.22)                                    |
| <i>Ceriodaphnia</i> cf. <i>pulchella</i><br><i>C. dubia</i>             | 0.16 (0.19)                               | 2.53 (0.35)                                    | 4.02 (0.38)                                    | 8.15 (5.91)                                    |
| <b>Rotifera</b>                                                         |                                           |                                                |                                                |                                                |
| <i>Ascomorpha</i>                                                       | 0.11 (0.09)                               | 0.11 (0.13)                                    | 0.11 (0.22)                                    | 0.00 (0.00)                                    |
| <i>Asplanchna</i>                                                       | 0.03 (0.06)                               | 1.55 (0.27)                                    | 4.62 (0.54)                                    | 7.28 (2.17)                                    |
| <i>Keratella</i>                                                        | 0.11 (0.09)                               | 0.16 (0.11)                                    | 0.38 (0.27)                                    | 0.38 (0.51)                                    |
| <i>Pompholyx</i>                                                        | 0.27 (0.11)                               | 0.60 (0.27)                                    | 0.82 (0.27)                                    | 0.76 (1.03)                                    |
| <i>Trichocerca</i>                                                      | 1.69 (0.23)                               | 2.50 (0.65)                                    | 2.01 (0.21)                                    | 3.21 (0.74)                                    |
| Total numbers ( $\times 10^3$ )                                         | 5.652 (1.158)                             | 29.283 (2.741)                                 | 33.902 (0.812)                                 | 72.802 (10.55)                                 |
| Total biomass (mg.m <sup>-3</sup> )                                     | 2.464 (1.576)                             | 20.702 (1.319)                                 | 26.438 (2.757)                                 | 68.027 (18.464)                                |
| % contribution of crustacean<br>biomass to total zooplankton<br>biomass | 91.60                                     | 97.69                                          | 97.06                                          | 98.30                                          |

**Table 5.6** Densities (numbers per litre) of zooplankton from limnocorrals in Lake Pupuke on Day 0, Experiment 6 (23.7.91) (n = 4). Standard deviations are indicated in parentheses. Lake surface water biomass (mg.m<sup>-3</sup>) = 17.54.

| Taxon                                                                   | Mean Density<br>Zooplankton<br>Enclosures | Mean Density<br>Zooplankton<br>Enclosures (IX) | Mean Density<br>Zooplankton<br>Enclosures (2X) | Mean Density<br>Zooplankton<br>Enclosures (4X) |
|-------------------------------------------------------------------------|-------------------------------------------|------------------------------------------------|------------------------------------------------|------------------------------------------------|
| <b>Calanoida</b>                                                        |                                           |                                                |                                                |                                                |
| <i>Calamoecia</i><br>(V + adults)                                       | 0.01 (0.03)                               | 10.11 (1.13)                                   | 15.59 (2.72)                                   | 23.58 (3.81)                                   |
| <i>Calamoecia</i><br>(I-IV)                                             | 0.07 (1.03)                               | 6.25 (0.63)                                    | 9.02 (1.68)                                    | 9.45 (1.40)                                    |
| <b>Cyclopoida</b>                                                       |                                           |                                                |                                                |                                                |
| <i>Mesocyclops</i><br>(Adults)                                          | 0.00 (0.0)                                | 0.27 (0.11)                                    | 0.38 (0.27)                                    | 0.27 (0.21)                                    |
| <i>Mesocyclops</i><br>(Copepodites)                                     | 0.00 (0.0)                                | 0.16 (0.26)                                    | 0.05 (0.11)                                    | 0.00 (0.0)                                     |
| Total Nauplii                                                           | 0.98 (0.28)                               | 24.69 (1.90)                                   | 40.15 (3.93)                                   | 40.36 (4.04)                                   |
| <b>Cladocera</b>                                                        |                                           |                                                |                                                |                                                |
| <i>Bosmina meridionalis</i>                                             | 0.07 (0.05)                               | 0.08 (0.10)                                    | 0.11 (0.13)                                    | 0.22 (0.31)                                    |
| <i>Ceriodaphnia</i> cf. <i>pulchella</i><br><i>C. dubia</i>             | 0.00 (0.0)                                | 0.52 (0.10)                                    | 0.98 (0.13)                                    | 1.25 (0.45)                                    |
| <b>Rotifera</b>                                                         |                                           |                                                |                                                |                                                |
| <i>Ascomorpha</i>                                                       | 0.25 (0.10)                               | 0.63 (0.35)                                    | 0.60 (0.37)                                    | 1.13 (0.60)                                    |
| <i>Asplanchna</i>                                                       | 0.04 (0.05)                               | 1.63 (0.15)                                    | 1.47 (0.62)                                    | 1.79 (0.27)                                    |
| <i>Filinia</i>                                                          | 0.15 (0.09)                               | 0.57 (0.31)                                    | 1.30 (0.47)                                    | 1.11 (0.57)                                    |
| <i>Keratella</i>                                                        | 0.05 (0.08)                               | 0.33 (0.15)                                    | 0.38 (0.21)                                    | 0.23 (0.46)                                    |
| <i>Pompholyx</i>                                                        | 1.32 (0.16)                               | 2.36 (0.52)                                    | 2.34 (0.60)                                    | 3.55 (1.27)                                    |
| <i>Trichocerca</i>                                                      | 0.25 (0.11)                               | 0.90 (0.24)                                    | 0.60 (0.21)                                    | 0.56 (0.24)                                    |
| Total numbers ( $\times 10^3$ )                                         | 3.178 (0.410)                             | 48.490 (2.806)                                 | 72.966 (2.254)                                 | 83.500 (3.123)                                 |
| Total biomass (mg.m <sup>-3</sup> )                                     | 0.618 (0.146)                             | 27.445 (1.939)                                 | 42.143 (3.381)                                 | 55.164 (4.673)                                 |
| % contribution of crustacean<br>biomass to total zooplankton<br>biomass | 62.14                                     | 97.205                                         | 97.56                                          | 98.00                                          |

**Table 5.7** Densities (numbers per litre) of zooplankton from limnocorrals in Lake Pupuke on Day 0, Experiment 7 (8.10.91) (n = 4). Standard deviations are indicated in parentheses. Lake surface water biomass (mg.m<sup>-3</sup>) = 25.73.

| Taxon                                                                   | Mean Density<br>Zooplankton<br>Enclosures | Mean Density<br>Zooplankton<br>Enclosures (IX) | Mean Density<br>Zooplankton<br>Enclosures (2X) | Mean Density<br>Zooplankton<br>Enclosures (4X) |
|-------------------------------------------------------------------------|-------------------------------------------|------------------------------------------------|------------------------------------------------|------------------------------------------------|
| <b>Calanoida</b>                                                        |                                           |                                                |                                                |                                                |
| <i>Calamoecia</i><br>(V + adults)                                       | 0.00 (0.0)                                | 2.55 (0.48)                                    | 10.16 (1.92)                                   | 16.73 (3.63)                                   |
| <i>Calamoecia</i><br>(I-IV)                                             | 0.38 (0.37)                               | 0.65 (0.18)                                    | 1.20 (0.90)                                    | 2.39 (0.83)                                    |
| <b>Cyclopoida</b>                                                       |                                           |                                                |                                                |                                                |
| <i>Mesocyclops</i><br>(Adults)                                          | 0.05 (0.11)                               | 1.09 (0.47)                                    | 2.34 (0.74)                                    | 3.15 (1.14)                                    |
| <i>Mesocyclops</i><br>(Copepodites)                                     | 0.00 (0.0)                                | 1.14 (0.27)                                    | 2.83 (0.77)                                    | 6.09 (1.07)                                    |
| Total Nauplii                                                           | 3.59 (0.74)                               | 16.71 (1.36)                                   | 25.67 (4.42)                                   | 28.80 (5.87)                                   |
| <b>Cladocera</b>                                                        |                                           |                                                |                                                |                                                |
| <i>Bosmina meridionalis</i>                                             | 0.33 (0.28)                               | 2.77 (1.51)                                    | 3.59 (1.29)                                    | 7.72 (1.99)                                    |
| <i>Ceriodaphnia</i> cf. <i>pulchella</i><br><i>C. dubia</i>             | 0.05 (0.11)                               | 5.92 (1.60)                                    | 17.33 (3.39)                                   | 28.03 (4.40)                                   |
| <b>Rotifera</b>                                                         |                                           |                                                |                                                |                                                |
| <i>Asplanchna</i>                                                       | 0.11 (0.13)                               | 1.20 (0.13)                                    | 0.72 (0.27)                                    | 1.85 (0.96)                                    |
| <i>Keratella</i>                                                        | 1.63 (0.77)                               | 2.58 (0.93)                                    | 0.82 (0.70)                                    | 0.54 (0.44)                                    |
| <i>Polyarthra</i>                                                       | 18.06 (2.32)                              | 6.52 (4.44)                                    | 3.53 (0.94)                                    | 2.85 (0.27)                                    |
| <i>Pompholyx</i>                                                        | 56.78 (3.59)                              | 51.75 (5.55)                                   | 49.17 (4.27)                                   | 38.98 (3.95)                                   |
| <i>Trichocerca</i>                                                      | 23.77 (3.95)                              | 29.07 (2.10)                                   | 31.65 (3.33)                                   | 27.44 (4.03)                                   |
| Total numbers (L <sup>-1</sup> )                                        | 104.748 (8.753)                           | 121.944 (10.125)                               | 148.974 (13.196)                               | 164.566 (5.152)                                |
| Total biomass (mg.m <sup>-3</sup> )                                     | 10.856 (1.241)                            | 27.818 (1.475)                                 | 54.772 (4.987)                                 | 82.638 (3.366)                                 |
| % contribution of crustacean<br>biomass to total zooplankton<br>biomass | 14.97                                     | 68.64                                          | 84.65                                          | 91.49                                          |

**Table 5.8** Densities (numbers per litre) of zooplankton from limnocorrals in Lake Pupuke on Day 0, Experiment 8 (4.2.92) (n = 4). Standard deviations are indicated in parentheses. Lake surface water biomass ( $\text{mg.m}^{-3}$ ) = 37.3.

| Taxon                                                                   | Mean Density<br>Zooplankton<br>Exclosures | Mean Density<br>Zooplankton<br>Enclosures (IX) | Mean Density<br>Zooplankton<br>Enclosures (2X) | Mean Density<br>Zooplankton<br>Enclosures (4X) |
|-------------------------------------------------------------------------|-------------------------------------------|------------------------------------------------|------------------------------------------------|------------------------------------------------|
| <b>Calanoida</b>                                                        |                                           |                                                |                                                |                                                |
| <i>Calamoecia</i><br>(V + adults)                                       | 1.85 (0.28)                               | 3.37 (1.14)                                    | 5.00 (1.09)                                    | 3.04 (1.12)                                    |
| <i>Calamoecia</i><br>(I-IV)                                             | 2.23 (0.57)                               | 1.41 (0.38)                                    | 3.48 (0.71)                                    | 2.39 (1.09)                                    |
| <b>Cyclopoida</b>                                                       |                                           |                                                |                                                |                                                |
| <i>Mesocyclops</i><br>(Adults)                                          | 0.65 (0.18)                               | 1.52 (0.64)                                    | 2.39 (0.44)                                    | 2.39 (0.44)                                    |
| <i>Mesocyclops</i><br>(Copepodites)                                     | 1.03 (0.67)                               | 1.41 (0.56)                                    | 1.74 (0.71)                                    | 2.61 (0.0)                                     |
| Total Nauplii                                                           | 4.67 (1.79)                               | 14.04 (2.44)                                   | 27.38 (7.12)                                   | 41.73 (6.77)                                   |
| <b>Cladocera</b>                                                        |                                           |                                                |                                                |                                                |
| <i>Bosmina meridionalis</i>                                             | 0.38 (0.21)                               | 0.92 (0.27)                                    | 3.04 (1.12)                                    | 8.69 (1.59)                                    |
| <i>Ceriodaphnia</i> cf. <i>pulchella</i><br><i>C. dubia</i>             | 1.79 (1.25)                               | 24.07 (5.36)                                   | 42.16 (6.04)                                   | 49.98 (6.90)                                   |
| <b>Rotifera</b>                                                         |                                           |                                                |                                                |                                                |
| <i>Asplanchna</i>                                                       | 1.09 (0.47)                               | 0.16 (0.21)                                    | 0.44 (0.50)                                    | 0.65 (0.83)                                    |
| <i>Hexarthra</i>                                                        | 7.72 (8.64)                               | 1.14 (0.78)                                    | 0.65 (0.44)                                    | 0.22 (0.44)                                    |
| <i>Pompholyx</i>                                                        | 4.67 (0.74)                               | 3.99 (1.23)                                    | 2.83 (1.30)                                    | 3.91 (1.12)                                    |
| <i>Synchaeta</i>                                                        | 1.41 (0.74)                               | 1.01 (0.78)                                    | 2.39 (1.69)                                    | 1.09 (0.83)                                    |
| <i>Trichocerca</i>                                                      | 21.84 (5.04)                              | 19.80 (7.31)                                   | 24.34 (12.31)                                  | 21.30 (7.60)                                   |
| Total numbers ( $\text{L}^{-1}$ )                                       | 49.332 (9.753)                            | 72.857 (10.665)                                | 115.832 (12.998)                               | 137.999 (23.014)                               |
| Total biomass ( $\text{mg.m}^{-3}$ )                                    | 13.081 (1.417)                            | 33.301 (4.295)                                 | 56.870 (8.231)                                 | 69.267 (9.906)                                 |
| % contribution of crustacean<br>biomass to total zooplankton<br>biomass | 71.91                                     | 92.16                                          | 94.61                                          | 96.08                                          |

The rotifer *Pompholyx* numerically dominated the zooplankton of Experiment 7 (Spring), followed closely by *Trichocerca*, and then *Ceriodaphnia*, combined nauplii and *Calamoecia lucasi* adults (Table 5.7). Total zooplankton biomass in the lake was  $25.7 \text{ mg m}^{-3}$ , the second lowest value for all eight seasonal experiments. The actual zooplankton biomasses for the exclosures, (1X) enclosures, (2X) enclosures and (4X) enclosures were 0.42X, 1.0X, 2.13X and 3.21X lake biomass respectively. Crustacean biomass dominated total zooplankton biomass in all enclosure treatments, but not for the exclosures (Table 5.7) reflecting the large contribution made by the rotifers to this particular treatment. There was a 7.6 fold range of total zooplankton biomass.

*Ceriodaphnia* were numerically dominant on Day 0 (4/2/92) of Experiment 8 (Summer) followed in decreasing order of importance by combined copepod nauplii, the rotifer *Trichocerca*, and *Bosmina meridionalis* (Table 5.8). Total zooplankton biomass in the lake surface waters was  $37.3 \text{ mg m}^{-3}$ , the highest found in Lake Pupuke. The actual zooplankton biomasses for exclosures, (1X) enclosures, (2X) enclosures and (4X) enclosures were 0.35X, 0.89X, 1.53X and 1.86X lake biomass respectively. Consequently there was a 5.3 fold range of zooplankton biomass across treatments, again with Crustacea dominating zooplankton biomass (Table 5.8).

### 5.2.3 Independence of Treatments

To determine whether each individual treatment designation was independent from the other treatment designations of each experiment, I performed a one-way ANOVA on total zooplankton biomass across treatments for all eight seasonal experiments and checked the probability of similarity between treatment means with a Tukey HSD matrix of pairwise multiple comparisons. Only in Experiment 5 (Autumn) on Lake Pupuke was there an overlap in treatment means. At a significance level of 0.05 it was not possible to say the exclosure treatment was different than the (1X) enclosure treatment nor that the (1X) enclosure treatment was different from the (2X) enclosure treatment. However, the exclosure treatment was different from the (2X) and (4X) enclosure treatments. The

(2X) enclosure treatment was different from the (4X) treatment and the (4X) enclosure treatment was different from all other treatments. Therefore when interpreting the results of Experiment 5 (Autumn) in Chapter Six this must be taken into account. The actual zooplankton biomasses for these treatments were in fact 0.09X, 0.77X, 0.98X and 2.51X lake biomass for the enclosure, (1X) enclosure, (2X) enclosure and (4X) enclosure respectively. It is obvious that there is little separating the (1X) and (2X) treatment designations. However the probability that the enclosure and (1X) enclosure are from the same population was 0.07, implying that at a significance level of 0.10 often used in these analyses (Vanni and Temte 1990; Elser and Goldman 1991) the two treatments would be considered different.

It may be argued that such a parametric test is unusable if the data are not normally distributed and do not have homogeneous variances. Probability plots and Lilefors tests suggested the data were normal. Bartlett's test for homogeneity of variances yielded probability values  $< 0.05$  on most occasions. However an analysis of coefficients of variation across treatments indicated that 50% of CVs were  $\leq 0.10$  for all treatment means and 87.5% of all treatments had CVs  $\leq 0.25$ . Duplicated estimates of total zooplankton biomass within a particular bag indicated that 84.38% of CVs were  $\leq 0.10$  and that 100% of CVs were  $\leq 0.25$ . Despite such indications that variances were proportional to mean values, I re-tested the zooplankton biomasses by treatment using the non-parametric one way analyses of ranked means, the Kruskal-Wallis test. All treatment means were separable at a probability level  $\leq 0.003$  confirming the results of the ANOVA.

### 5.3 Discussion

As with any experimental method the use of limnocorrals has both advantages and disadvantages. It has been suggested that large enclosures may develop patchy distribution patterns of planktonic species which may lead to increased sampling variability. Stephenson *et al.* (1984) investigated the spatial distribution of both

phytoplankton and zooplankton in enclosures of three different sizes: small (20m<sup>3</sup>), medium (125m<sup>3</sup>) and large (1,000 m<sup>3</sup>). There was no defined edge zone in any enclosure with respect to phytoplankton density or biomass. Zooplankton population estimates from samples collected from the edge to the centre in the small and medium enclosures varied slightly but no consistent pattern of distribution was present. However, the large enclosure showed a distinct edge zone that extended about 1m from the walls where macrozooplankton appeared in higher proportions than microzooplankton. In the present investigation the volume of the limnocorrals was approximately 1m<sup>3</sup> (1,000 litres). This is considerably smaller than the smallest used by Stephenson *et al.* (1984) and implies that both phytoplankton and zooplankton heterogeneity may have been insignificant.

Zooplankton heterogeneity in both Lakes Rotoroa and Pupuke however cannot be assumed insignificant and may explain the discrepancies between the putative designations of 1X, 2X and 4X ambient lake biomass and the actual values obtained from direct counts of limnocorral samples on Day 0 of each experiment. Actual treatment means for total zooplankton biomass were close to the designations 1X, 2X and 4X on a number of occasions, for example, Experiments 1,3,6 and 7. In others the 2X and 4X designations were closer to 1X or 1.5X and 2X lake biomasses respectively. These biomass treatments are similar to the concentrations of zooplankton aggregated in patches in both lakes (see Appendix I) and are a feature of similarly designed limnocorral experiments (Bergquist *et al.* 1985; Bergquist and Carpenter 1986). The purpose of creating this range or gradient in zooplankton biomass was to examine the response of the phytoplankton to different levels of grazing pressure - a grazing pressure which should ideally "bracket" natural lake values (Vanni and Temte 1990). This occurred in all eight experiments of this investigation. For a fuller discussion of this feature of the work refer to Chapter Three.



It may be argued that inefficiencies in the plankton net used to create the zooplankton manipulations could account for some of this variation. Appendix I summarises parallel checks of net hauls using the same 80  $\mu\text{m}$  net (used to add the zooplankton to the bags) with the discrete depth series created using the pump. In three experiments the net was less efficient than the pump series (assuming the integrated pump series is 100% efficient at estimating total zooplankton biomass from the surface to four metres depth). However, in five experiments the efficiency of the net was greater than 100% making it difficult to assume that inefficiencies in the 80 $\mu\text{m}$  net can account for the lower than (4X) ambient lake biomass that occurred in the majority of the bags for the (4X) designation. The ability of a net to collect more efficiently when compared to discrete depth data has been noted previously (de Vries and Stein 1991).

As well as producing realistic biomasses of grazers, the 80 $\mu\text{m}$  mesh net harvested largely crustaceans and kept the contribution of rotifers to total zooplankton biomass to less than 10% across the majority of enclosure treatments. Rotifers contributed proportionately more biomass in the enclosure treatments - a consequence of compromising between a smaller mesh size to exclude them and ensuring as much as possible of the phytoplankton assemblage was added to each limnocorral at the beginning of each experiment. The choice of 80 $\mu\text{m}$  mesh was discussed in more detail in Chapter Three.

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## CHAPTER SIX

### THE RESPONSE OF TOTAL ALGAL BIOMASS TO ZOOPLANKTON GRAZING

#### 6.1 Introduction

This chapter describes the response of total algal biomass in the fraction  $\leq 80 \mu\text{m}$  to the range of zooplankton manipulations discussed in Chapter Five. Each seasonal experiment on Lakes Rotoroa and Pupuke will be examined individually to determine the response of the phytoplankton community to herbivory. Both ANOVA and regression analyses have been applied to the data and the results of all eight seasonal experiments will be compared to similar enclosure based research.

#### 6.2 Results

##### 6.2.1 Lake Rotoroa

On Day 0 (1/6/90) of Experiment 1 (Autumn) there were no significant differences in total algal biomass between zooplankton treatment combinations and the lake adjacent to the site of limnocorral deployment (see Fig. 6.1). Despite higher mean algal biomass in the enclosure treatment variance was large and mean values were not separable. On Day 3 (4/6/90) there were also no statistically significant differences between grazer treatments and the lake (see Fig. 6.2) however, total algal biomass in the enclosure treatment had declined from  $3,470 \text{ mg m}^{-3}$  on Day 0 to  $1,980 \text{ mg m}^{-3}$ . All enclosure treatments changed only marginally but the lake phytoplankton biomass also declined from a value of  $1,325 \text{ mg m}^{-3}$  on Day 0 to  $895 \text{ mg m}^{-3}$ . Again, on Day 6 (7/6/90) variance across treatment means was high and no differences were statistically significant (Fig. 6.3). Regressing total algal biomass against the gradient of zooplankton biomass (Fig. 6.33) on Day 6 yielded a similar lack of response. Despite using a six-day interval (Day 0 to Day 6) to investigate the influence of grazing on total algal biomass (for reasons discussed in Chapter Three) it was decided to analyse the results on Day 10 of each seasonal experiment to determine whether trends established on Day 6 were also apparent at the completion (Day 10) of each experiment. The underlying assumption of

unchanging zooplankton biomass over a ten-day interval is speculative and therefore the results of the Day 10 analyses need to be viewed with some caution. By Day 10 (11/6/90) within-treatment variance had declined markedly and all enclosures containing zooplankton had statistically significant reductions in phytoplankton biomass compared with the enclosure treatment (Fig. 6.4). There was a significant relationship between zooplankton biomass and total algal biomass (Table 6.2).

On Day 0 (27/7/90) of Experiment 2 (Winter) there were no significant differences in total algal biomass between enclosure and enclosure treatments (Fig. 6.5), but lake values were significantly lower than in the limnocorrals. By Day 3 (30/7/90) phytoplankton biomass was significantly lower in both the 2x and 4x zooplankton treatments compared to enclosure levels. However, algal biomass in the lake had increased (Fig. 6.6). This trend of increasing lake phytoplankton biomass continued to the end of the experiment. Algal biomass in the enclosures was similar on Day 6 to previous sampling dates (Fig. 6.7) however in all enclosure treatments there were considerable reductions. Phytoplankton biomass was also significantly ( $p < 0.01$ ) reduced in the 4x enclosure treatment relative to the 1x enclosure treatment and 2x enclosure treatment. There was a significant negative regression between total algal biomass and zooplankton biomass (see Fig. 6.34). This relationship was also apparent on Day 10 (Fig. 6.8) although the percentage of variance explained was slightly reduced (Table 6.2).

In Experiment 3 (Spring) total algal biomass was not significantly different across limnocorral treatments or the lake on Day 0 (12/10/90) (Fig. 6.9). However, by Day 3 (15/10/90) significant reductions in algal biomass were apparent between the enclosure treatment and all zooplankton enclosures (Fig. 6.10). There were no differences amongst zooplankton enclosure treatments or the lake. The pattern established on Day 3 was even more marked by Day 6 (18/10/90) (Fig. 6.11). There was a significant regression of total algal biomass on zooplankton biomass. This trend toward decreasing

phytoplankton biomass with increasing zooplankton biomass was also apparent on Day 10 (Fig. 6.12), although the relationship was slightly weaker than on day 6 (Table 6.2).

On Day 0 (5/2/91) of Experiment 4 (Summer) there were again no significant differences in total algal biomass across limnocorral treatments and the lake (Fig. 6.13). This pattern was also apparent on Day 3 (8/2/91), however there was a significant reduction in algal biomass between the enclosure and the (1x) enclosure treatment (Fig. 6.14). By Day 6 (11/2/91) the biomass reduction between the enclosure and the (1x) enclosure treatment still existed but was only significant at 0.10 significance level (Fig. 6.15). However, there was a marked reduction in algal biomass between the enclosure and the (4x) enclosure treatments. All other pairwise comparisons of treatment means were not significant. There was a significant negative regression between total algal biomass and zooplankton biomass (Fig. 6.36). This relationship was also apparent on Day 10 (15/2/92) of Experiment 4 (Fig. 6.16) but was weaker and was significant only at a  $p$  value  $< 0.10$  (see Table 6.2).

### **6.2.2 Lake Pupuke**

The first seasonal experiment performed on this lake was Experiment 5 (Autumn). On Day 0 (21/5/91) there was a high degree of overlap between phytoplankton biomass in treatment combinations and the lake (Fig. 6.17). ANOVA indicated no significant differences between treatments. This was also the case on Day 3 (24/5/91) however, total algal biomass in the lake was significantly lower than in the enclosure and (2x) enclosure treatments (Fig. 6.18). By Day 6 (27/5/91) significant reductions in phytoplankton biomass existed between the enclosure and the (2x) and (4x) enclosure treatments and in the surrounding lake. Conversely, the (1x) enclosure treatment had significantly higher mean algal biomass than the enclosure treatment, the other enclosure treatments and in the lake (Fig. 6.19). Regression of total algal biomass against zooplankton biomass on Day 6 yielded a significant negative relationship (Fig. 6.37). By Day 10 (31/5/91) total algal biomass in the (1x) enclosure treatment had dropped

markedly and there were significantly reduced levels of phytoplankton biomass in all enclosure treatments and in the lake relative to the exclosures (Fig. 6.20). On Day 10 there was no significant relationship between total algal biomass and zooplankton biomass. However, log transformation of zooplankton biomass produced a significant negative relationship (Table 6.2).

On Day 0 (23/7/91) of Experiment 6 ANOVA indicated no significant differences in total algal biomass across all limnocorral treatments and the lake (Fig. 6.21). Algal biomass had increased in all limnocorrals and the lake by Day 3 (26/7/91) but high overlap between treatments suggested no significant differences between treatment means (see Fig. 6.22). This situation continued to Day 6 (29/7/91) (Fig. 6.23). Regression of total algal biomass against zooplankton biomass on Day 6 yielded a negative relationship ( $p < 0.10$ ) (Fig. 6.38). By Day 10 (2/8/91) this negative relationship between algal biomass and grazer biomass was stronger (Fig. 6.24 : Table 6.2).

In Experiment 7 (Spring) there were no significant differences in total algal biomass across all limnocorral treatments and the lake (Fig. 6.25). However, if a significance level of 0.10 is used then there was a significant reduction in algal biomass between the enclosure and the (2X) enclosure treatment on Day 0. By Day 3 (11/10/91) phytoplankton biomass in the exclosures was significantly higher than that in the (1X) enclosure. Interestingly, the differences between the enclosure and (2X) enclosure treatments observed on Day 0 were no longer apparent. However, at a significance level of 0.10 there were also reductions in algal biomass between the exclosures and the 4X enclosures and the lake (Fig. 6.26). By Day 6 (14/10/91) algal biomass was significantly reduced in the (2X) and (4X) enclosure treatments relative to the exclosures (Fig. 6.27) and there was a significant negative regression between total algal biomass and zooplankton biomass (Fig. 6.39 : Table 6.2). This situation was also observed on Day 10 (18/10/91). Lake algal biomass remained consistently lower than limnocorral values during Experiment 7 and this is particularly noticeable on Day 10 (Fig. 6.28).

**Figure 6.1**

Total algal biomass ( $\leq 80\mu\text{m}$ ) in all experimental treatments and in the lake at a site adjacent to the area of limnocoaral deployment on Day 0 (1/6/90) of Experiment 1 (Autumn) in Lake Rotoroa. Solid bars indicate the mean biomass per treatment calculated from two samples taken from two limnocoarals ( $n = 4$ ). Lake values were calculated from two samples ( $n = 2$ ). Error bars indicate one standard deviation. Ex = exclosure treatment; En (1X) = 1X ambient zooplankton biomass; En (2X) = 2X ambient zooplankton biomass; En (4X) = 4X ambient zooplankton biomass. In conjunction with each preceding figure caption a matrix of pairwise absolute mean differences across treatments is presented. Probabilities associated with these differences are also shown. The matrix key is 1 = exclosure treatment; 2 = (1X) ambient zooplankton biomass treatment; 3 = (2X) ambient zooplankton biomass treatment; 4 = (4X) ambient zooplankton biomass and 5 = lake values. Units for total algal biomass are  $\text{mg m}^{-3}$  (freshweight).

Matrix of pairwise absolute mean differences.

|   | 1        | 2       | 3       | 4       | 5     |
|---|----------|---------|---------|---------|-------|
| 1 | 0.000    |         |         |         |       |
| 2 | 1509.827 | 0.000   |         |         |       |
| 3 | 1653.075 | 143.248 | 0.000   |         |       |
| 4 | 1763.665 | 253.838 | 110.590 | 0.000   |       |
| 5 | 2144.491 | 634.665 | 491.417 | 380.827 | 0.000 |

Tukey HSD matrix of pairwise comparison probabilities.

|   | 1     | 2     | 3     | 4     | 5     |
|---|-------|-------|-------|-------|-------|
| 1 | 1.000 |       |       |       |       |
| 2 | 0.778 | 1.000 |       |       |       |
| 3 | 0.725 | 1.000 | 1.000 |       |       |
| 4 | 0.683 | 1.000 | 1.000 | 1.000 |       |
| 5 | 0.539 | 0.986 | 0.995 | 0.998 | 1.000 |

**Figure 6.2**

Total algal biomass in all experimental treatments and in the lake on Day 3 (4/6/90) of Experiment 1 (Autumn) in Lake Rotoroa. See Figure 6.1 for definitions of symbols and associated matrices.

Matrix of pairwise absolute mean differences.

|   | 1        | 2        | 3        | 4       | 5     |
|---|----------|----------|----------|---------|-------|
| 1 | 0.000    |          |          |         |       |
| 2 | 76.226   | 0.000    |          |         |       |
| 3 | 250.846  | 174.620  | 0.000    |         |       |
| 4 | 374.952  | 451.178  | 625.798  | 0.000   |       |
| 5 | 1087.722 | 1163.949 | 1338.568 | 712.771 | 0.000 |

Tukey HSD matrix of pairwise comparison probabilities.

|   | 1     | 2     | 3     | 4     | 5     |
|---|-------|-------|-------|-------|-------|
| 1 | 1.000 |       |       |       |       |
| 2 | 1.000 | 1.000 |       |       |       |
| 3 | 0.976 | 0.994 | 1.000 |       |       |
| 4 | 0.909 | 0.844 | 0.656 | 1.000 |       |
| 5 | 0.247 | 0.207 | 0.138 | 0.560 | 1.000 |

FIG. 6.1.

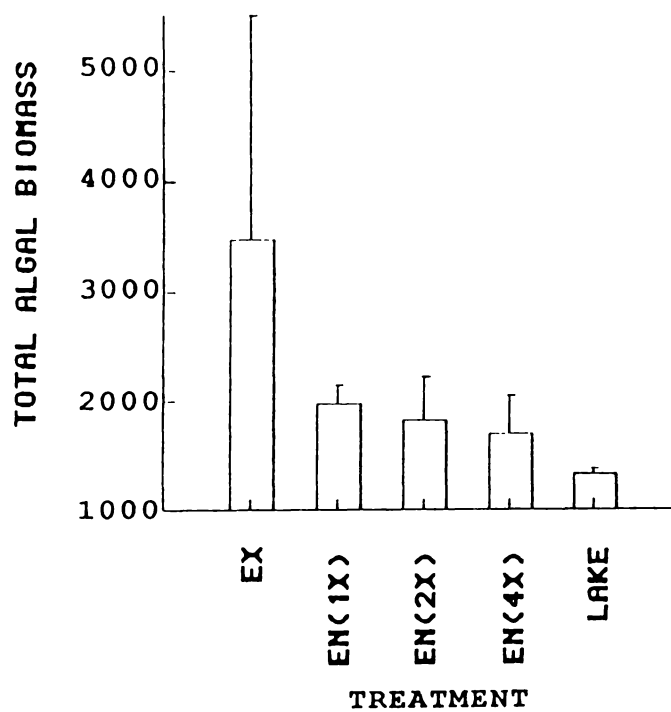


FIG. 6.2.

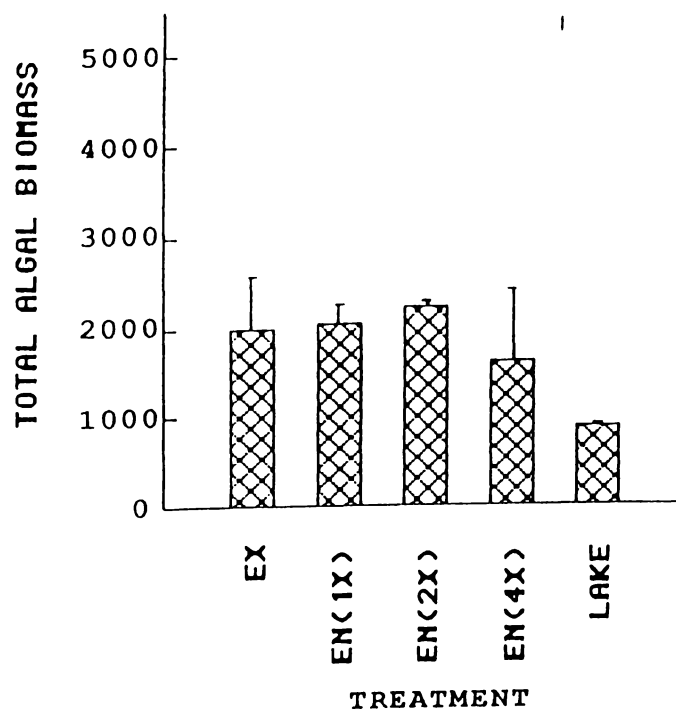


**Figure 6.3**

Total algal biomass in all experimental treatments and in the lake on Day 6 (7/6/90) of Experiment 1 (Autumn) in Lake Rotoroa. See Figure 6.1 for definitions of symbols and associated matrices.

Matrix of pairwise absolute mean differences.

|   | 1       | 2       | 3       | 4       | 5     |
|---|---------|---------|---------|---------|-------|
| 1 | 0.000   |         |         |         |       |
| 2 | 376.941 | 0.000   |         |         |       |
| 3 | 66.197  | 443.138 | 0.000   |         |       |
| 4 | 369.771 | 7.170   | 435.968 | 0.000   |       |
| 5 | 27.610  | 404.551 | 38.587  | 397.381 | 0.000 |

Tukey HSD matrix of pairwise comparison probabilities.

|   | 1     | 2     | 3     | 4     | 5     |
|---|-------|-------|-------|-------|-------|
| 1 | 1.000 |       |       |       |       |
| 2 | 0.562 | 1.000 |       |       |       |
| 3 | 0.998 | 0.436 | 1.000 |       |       |
| 4 | 0.577 | 1.000 | 0.449 | 1.000 |       |
| 5 | 1.000 | 0.507 | 1.000 | 0.521 | 1.000 |

**Figure 6.4**

Total algal biomass in all experimental treatments and in the lake on Day 10 (11/6/90) of Experiment 1 (Autumn) in Lake Rotoroa. See Figure 6.1 for definitions of symbols and associated matrices.

Matrix of pairwise absolute mean differences.

|   | 1        | 2       | 3       | 4       | 5     |
|---|----------|---------|---------|---------|-------|
| 1 | 0.000    |         |         |         |       |
| 2 | 922.008  | 0.000   |         |         |       |
| 3 | 775.127  | 146.881 | 0.000   |         |       |
| 4 | 1036.603 | 114.595 | 261.476 | 0.000   |       |
| 5 | 908.216  | 13.791  | 133.090 | 128.386 | 0.000 |

Tukey HSD matrix of pairwise comparison probabilities.

|   | 1     | 2     | 3     | 4     | 5     |
|---|-------|-------|-------|-------|-------|
| 1 | 1.000 |       |       |       |       |
| 2 | 0.009 | 1.000 |       |       |       |
| 3 | 0.018 | 0.854 | 1.000 |       |       |
| 4 | 0.005 | 0.931 | 0.485 | 1.000 |       |
| 5 | 0.000 | 1.000 | 0.890 | 0.901 | 1.000 |



FIG. 6.3.

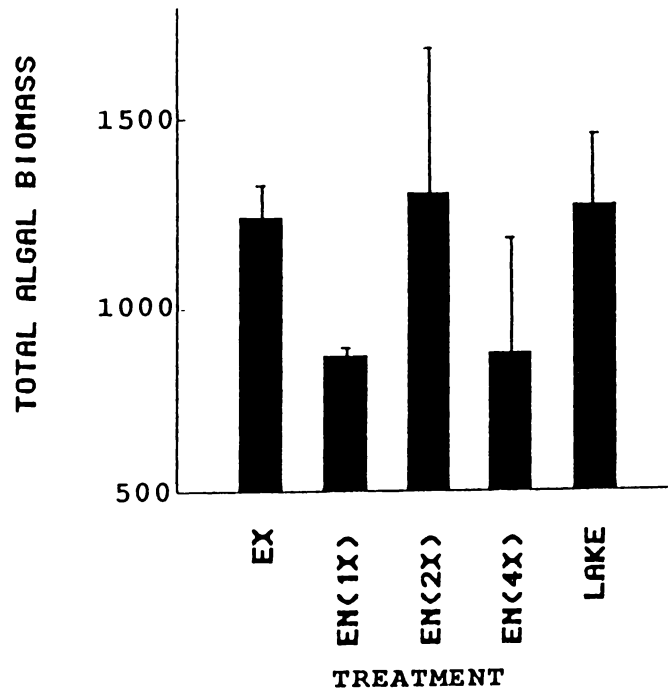


FIG. 6.4.

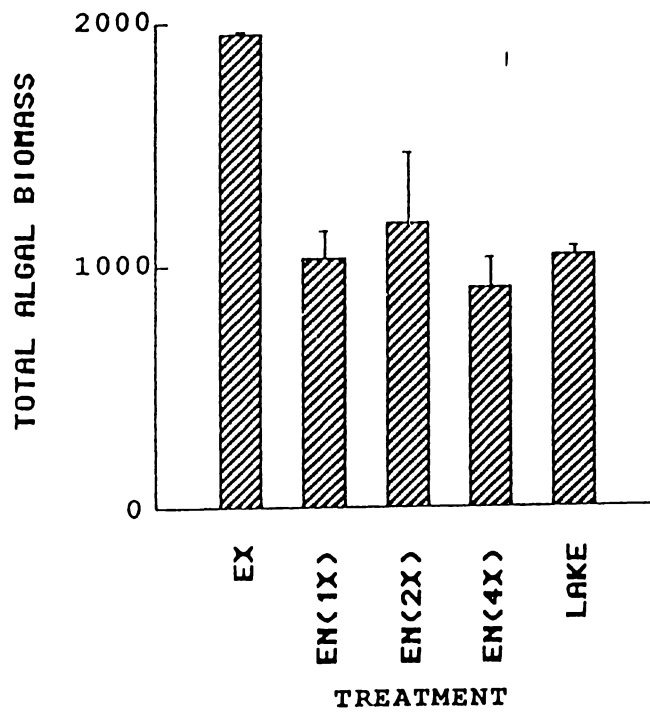


**Figure 6.5**

Total algal biomass in all experimental treatments and in the lake on Day 0 (27/7/90) of Experiment 2 (Winter) in Lake Rotoroa. See Figure 6.1 for definitions of symbols and associated matrices.

Matrix of pairwise absolute mean differences.

|   | 1       | 2        | 3       | 4       | 5     |
|---|---------|----------|---------|---------|-------|
| 1 | 0.000   |          |         |         |       |
| 2 | 48.348  | 0.000    |         |         |       |
| 3 | 76.620  | 124.967  | 0.000   |         |       |
| 4 | 64.586  | 112.933  | 12.034  | 0.000   |       |
| 5 | 961.754 | 1010.102 | 885.135 | 897.169 | 0.000 |

Tukey HSD matrix of pairwise comparison probabilities.

|   | 1     | 2     | 3     | 4     | 5     |
|---|-------|-------|-------|-------|-------|
| 1 | 1.000 |       |       |       |       |
| 2 | 0.992 | 1.000 |       |       |       |
| 3 | 0.959 | 0.806 | 1.000 |       |       |
| 4 | 0.978 | 0.855 | 1.000 | 1.000 |       |
| 5 | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 |

**Figure 6.6**

Total algal biomass in all experimental treatments and in the lake on Day 3 (30/7/90) of Experiment 2 (Winter) in Lake Rotoroa. See Figure 6.1 for definitions of symbols and associated matrices.

Matrix of pairwise absolute mean differences.

|   | 1        | 2       | 3       | 4       | 5     |
|---|----------|---------|---------|---------|-------|
| 1 | 0.000    |         |         |         |       |
| 2 | 485.316  | 0.000   |         |         |       |
| 3 | 1098.498 | 613.182 | 0.000   |         |       |
| 4 | 1198.434 | 713.119 | 99.936  | 0.000   |       |
| 5 | 435.305  | 50.011  | 663.193 | 763.130 | 0.000 |

Tukey HSD matrix of pairwise comparison probabilities.

|   | 1     | 2     | 3     | 4     | 5     |
|---|-------|-------|-------|-------|-------|
| 1 | 1.000 |       |       |       |       |
| 2 | 0.382 | 1.000 |       |       |       |
| 3 | 0.007 | 0.189 | 1.000 |       |       |
| 4 | 0.004 | 0.101 | 0.995 | 1.000 |       |
| 5 | 0.659 | 1.000 | 0.285 | 0.178 | 1.000 |

FIG. 6.5.

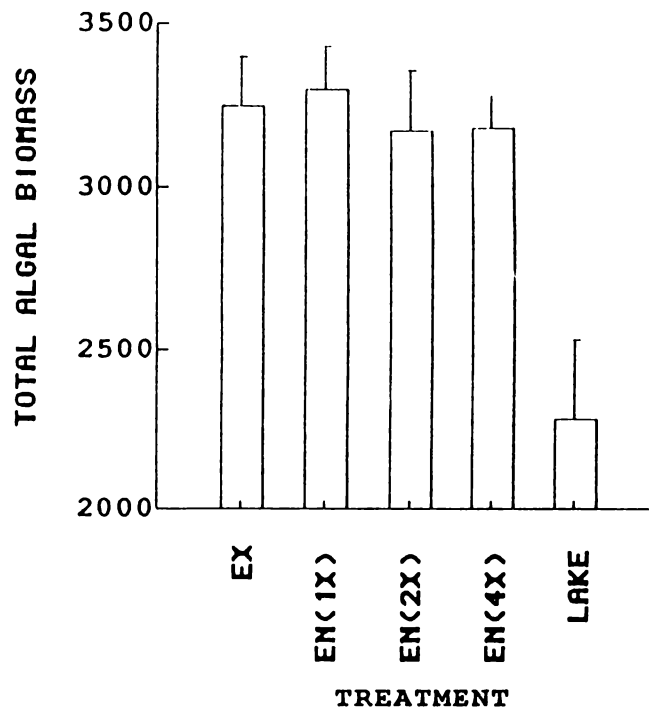


FIG. 6.6.

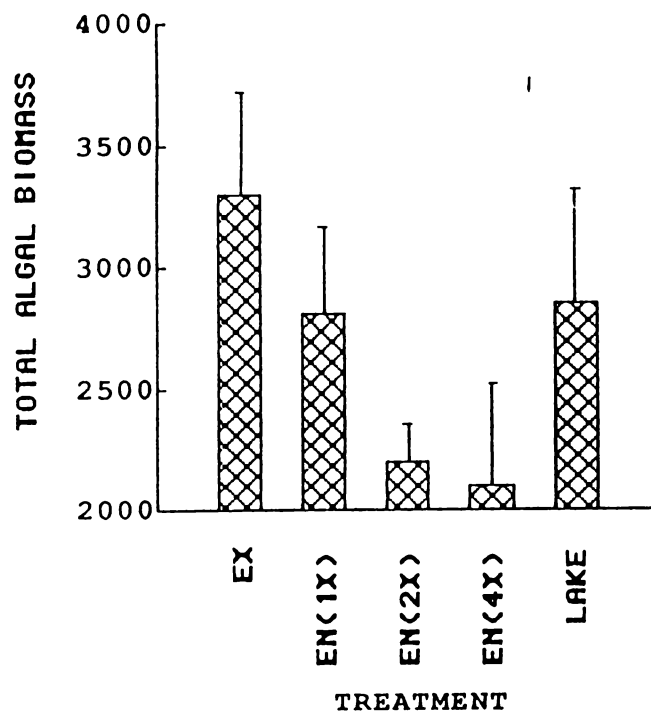


**Figure 6.7**

Total algal biomass in all experimental treatments and in the lake on Day 6 (2/8/90) of Experiment 2 (Winter) in Lake Rotoroa. See Figure 6.1 for definitions of symbols and associated matrices.

Matrix of pairwise absolute mean differences.

|   | 1        | 2        | 3       | 4        | 5     |
|---|----------|----------|---------|----------|-------|
| 1 | 0.000    |          |         |          |       |
| 2 | 944.210  | 0.000    |         |          |       |
| 3 | 1373.718 | 429.507  | 0.000   |          |       |
| 4 | 2076.263 | 1132.052 | 702.545 | 0.000    |       |
| 5 | 423.047  | 521.163  | 950.670 | 1653.215 | 0.000 |

Tukey HSD matrix of pairwise comparison probabilities.

|   | 1     | 2     | 3     | 4     | 5     |
|---|-------|-------|-------|-------|-------|
| 1 | 1.000 |       |       |       |       |
| 2 | 0.016 | 1.000 |       |       |       |
| 3 | 0.001 | 0.452 | 1.000 |       |       |
| 4 | 0.000 | 0.004 | 0.088 | 1.000 |       |
| 5 | 0.645 | 0.461 | 0.053 | 0.001 | 1.000 |

**Figure 6.8**

Total algal biomass in all experimental treatments and in the lake on Day 10 (6/8/90) of Experiment 2 (Winter) in Lake Rotoroa. See Figure 6.1 for definitions of symbols and associated matrices.

Matrix of pairwise absolute mean differences.

|   | 1        | 2        | 3        | 4        | 5     |
|---|----------|----------|----------|----------|-------|
| 1 | 0.000    |          |          |          |       |
| 2 | 893.830  | 0.000    |          |          |       |
| 3 | 889.071  | 4.759    | 0.000    |          |       |
| 4 | 1885.526 | 991.697  | 996.456  | 0.000    |       |
| 5 | 576.978  | 1470.808 | 1466.049 | 2462.504 | 0.000 |

Tukey HSD matrix of pairwise comparison probabilities.

|   | 1     | 2     | 3     | 4     | 5     |
|---|-------|-------|-------|-------|-------|
| 1 | 1.000 |       |       |       |       |
| 2 | 0.007 | 1.000 |       |       |       |
| 3 | 0.008 | 1.000 | 1.000 |       |       |
| 4 | 0.000 | 0.003 | 0.003 | 1.000 |       |
| 5 | 0.231 | 0.001 | 0.001 | 0.000 | 1.000 |

FIG. 6.7.

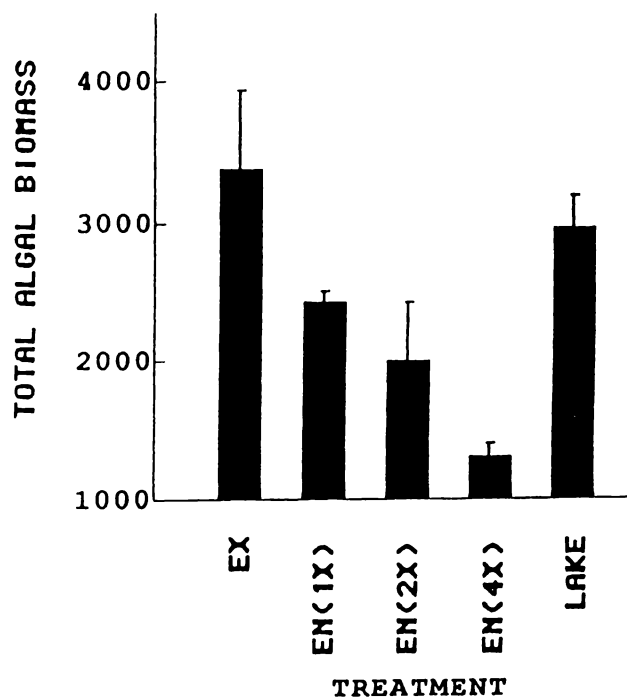


FIG. 6.8.

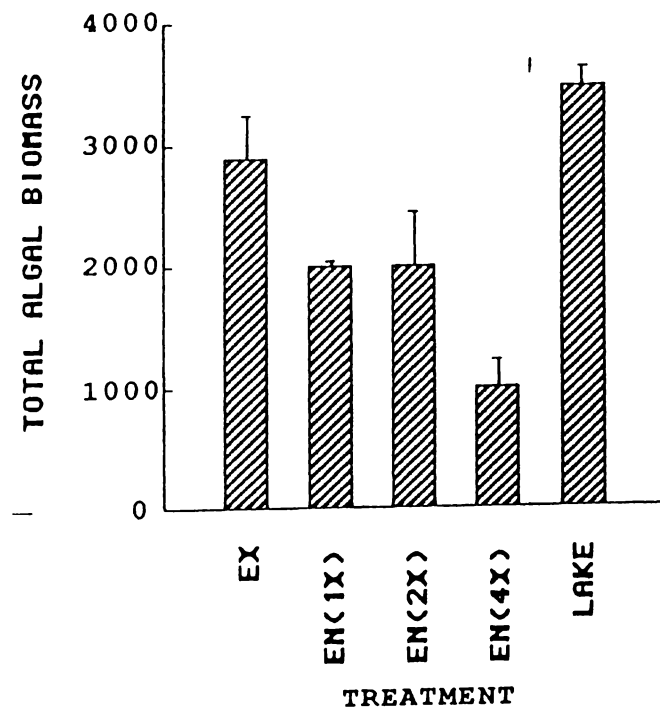


**Figure 6.9**

Total algal biomass in all experimental treatments and in the lake on Day 0 (12/10/90) of Experiment 3 (Spring) in Lake Rotoroa. See Figure 6.1 for definitions of symbols and associated matrices.

Matrix of pairwise absolute mean differences.

|   | 1      | 2      | 3      | 4      | 5     |
|---|--------|--------|--------|--------|-------|
| 1 | 0.000  |        |        |        |       |
| 2 | 91.356 | 0.000  |        |        |       |
| 3 | 87.460 | 3.896  | 0.000  |        |       |
| 4 | 60.766 | 30.591 | 26.694 | 0.000  |       |
| 5 | 4.399  | 86.957 | 83.060 | 56.366 | 0.000 |

Tukey HSD matrix of pairwise comparison probabilities.

|   | 1     | 2     | 3     | 4     | 5     |
|---|-------|-------|-------|-------|-------|
| 1 | 1.000 |       |       |       |       |
| 2 | 0.403 | 1.000 |       |       |       |
| 3 | 0.443 | 1.000 | 1.000 |       |       |
| 4 | 0.745 | 0.971 | 0.982 | 1.000 |       |
| 5 | 1.000 | 0.629 | 0.666 | 0.885 | 1.000 |

**Figure 6.10**

Total algal biomass in all experimental treatments and in the lake on Day 3 (15/10/90) of Experiment 3 (Spring) in Lake Rotoroa. See Figure 6.1 for definitions of symbols and associated matrices.

Matrix of pairwise absolute mean differences.

|   | 1       | 2      | 3       | 4       | 5     |
|---|---------|--------|---------|---------|-------|
| 1 | 0.000   |        |         |         |       |
| 2 | 200.612 | 0.000  |         |         |       |
| 3 | 218.166 | 17.554 | 0.000   |         |       |
| 4 | 234.456 | 33.844 | 16.290  | 0.000   |       |
| 5 | 115.945 | 84.667 | 102.221 | 118.511 | 0.000 |

Tukey HSD matrix of pairwise comparison probabilities.

|   | 1     | 2     | 3     | 4     | 5     |
|---|-------|-------|-------|-------|-------|
| 1 | 1.000 |       |       |       |       |
| 2 | 0.028 | 1.000 |       |       |       |
| 3 | 0.017 | 0.998 | 1.000 |       |       |
| 4 | 0.036 | 0.986 | 0.999 | 1.000 |       |
| 5 | 0.474 | 0.730 | 0.585 | 0.582 | 1.000 |

FIG. 6.9.

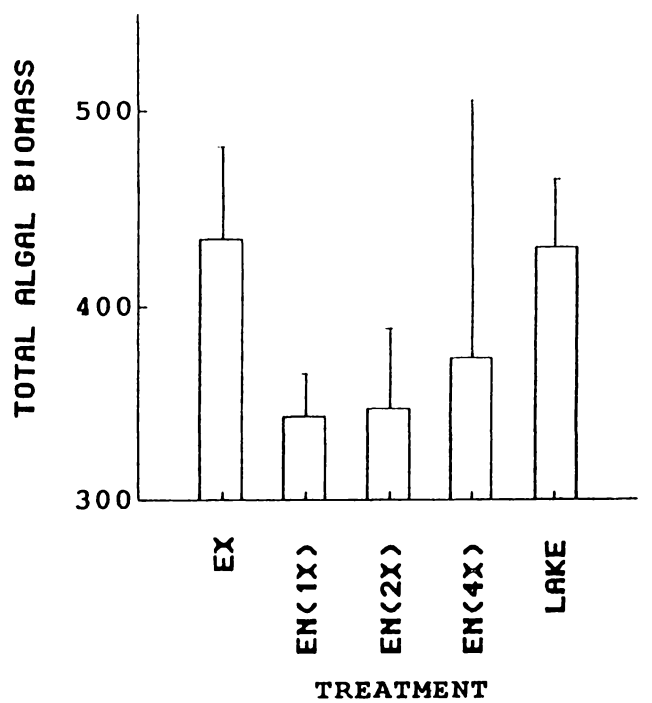


FIG. 6.10.

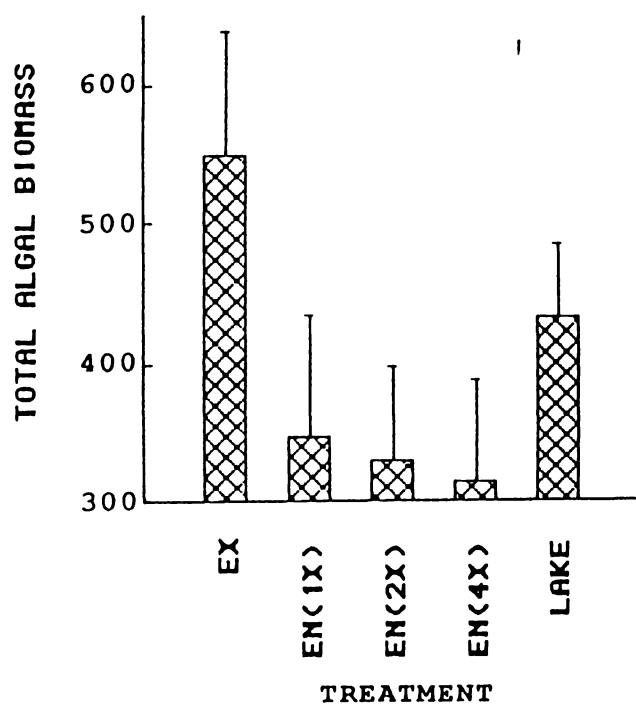


**Figure 6.11**

Total algal biomass in all experimental treatments and in the lake on Day 6 (18/10/90) of Experiment 3 (Spring) in Lake Rotoroa. See Figure 6.1 for definitions of symbols and associated matrices.

Matrix of pairwise absolute mean differences.

|   | 1       | 2      | 3      | 4       | 5     |
|---|---------|--------|--------|---------|-------|
| 1 | 0.000   |        |        |         |       |
| 2 | 389.502 | 0.000  |        |         |       |
| 3 | 452.877 | 63.375 | 0.000  |         |       |
| 4 | 485.189 | 95.687 | 32.313 | 0.000   |       |
| 5 | 362.037 | 27.465 | 90.840 | 123.152 | 0.000 |

Tukey HSD matrix of pairwise comparison probabilities.

|   | 1     | 2     | 3     | 4     | 5     |
|---|-------|-------|-------|-------|-------|
| 1 | 1.000 |       |       |       |       |
| 2 | 0.000 | 1.000 |       |       |       |
| 3 | 0.000 | 0.597 | 1.000 |       |       |
| 4 | 0.000 | 0.232 | 0.940 | 1.000 |       |
| 5 | 0.000 | 0.984 | 0.455 | 0.195 | 1.000 |

**Figure 6.12**

Total algal biomass in all experimental treatments and in the lake on Day 10 (22/10/90) of Experiment 3 (Spring) in Lake Rotoroa. See Figure 6.1 for definitions of symbols and associated matrices.

Matrix of pairwise absolute mean differences.

|   | 1       | 2      | 3       | 4      | 5     |
|---|---------|--------|---------|--------|-------|
| 1 | 0.000   |        |         |        |       |
| 2 | 825.184 | 0.000  |         |        |       |
| 3 | 842.820 | 17.636 | 0.000   |        |       |
| 4 | 807.646 | 17.538 | 35.174  | 0.000  |       |
| 5 | 740.799 | 84.385 | 102.021 | 66.847 | 0.000 |

Tukey HSD matrix of pairwise comparison probabilities.

|   | 1     | 2     | 3     | 4     | 5     |
|---|-------|-------|-------|-------|-------|
| 1 | 1.000 |       |       |       |       |
| 2 | 0.000 | 1.000 |       |       |       |
| 3 | 0.000 | 0.997 | 1.000 |       |       |
| 4 | 0.000 | 0.997 | 0.961 | 1.000 |       |
| 5 | 0.000 | 0.697 | 0.539 | 0.838 | 1.000 |



FIG. 6.11.

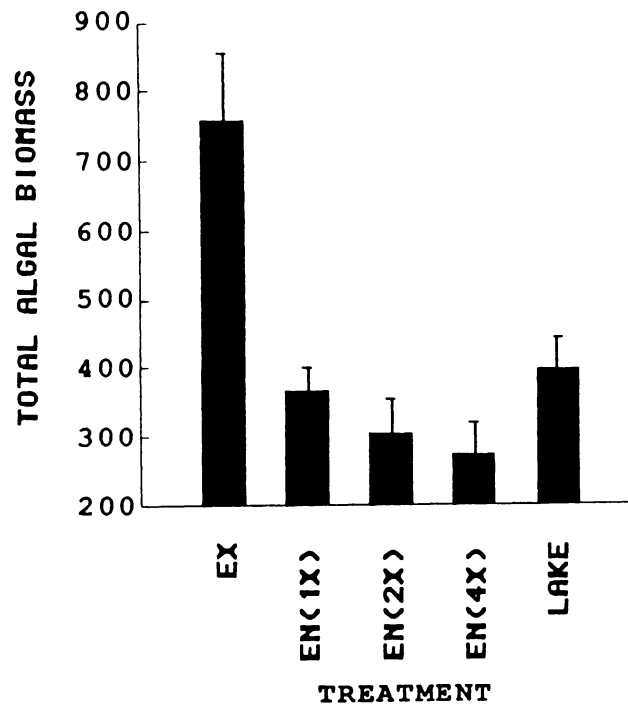


FIG. 6.12.

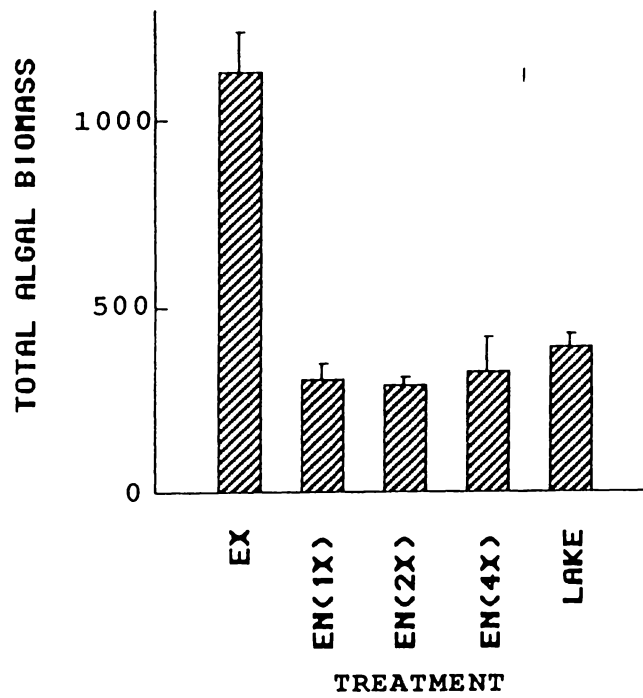


**Figure 6.13**

Total algal biomass in all experimental treatments and in the lake on Day 0 (5/2/91) of Experiment 4 (Summer) in Lake Rotoroa. See Figure 6.1 for definitions of symbols and associated matrices.

Matrix of pairwise absolute mean differences.

|   | 1       | 2       | 3       | 4       | 5     |
|---|---------|---------|---------|---------|-------|
| 1 | 0.000   |         |         |         |       |
| 2 | 330.264 | 0.000   |         |         |       |
| 3 | 328.508 | 1.756   | 0.000   |         |       |
| 4 | 550.081 | 219.817 | 221.572 | 0.000   |       |
| 5 | 299.872 | 30.392  | 28.636  | 250.208 | 0.000 |

Tukey HSD matrix of pairwise comparison probabilities.

|   | 1     | 2     | 3     | 4     | 5     |
|---|-------|-------|-------|-------|-------|
| 1 | 1.000 |       |       |       |       |
| 2 | 0.957 | 1.000 |       |       |       |
| 3 | 0.958 | 1.000 | 1.000 |       |       |
| 4 | 0.786 | 0.990 | 0.990 | 1.000 |       |
| 5 | 0.985 | 1.000 | 1.000 | 0.993 | 1.000 |

**Figure 6.14**

Total algal biomass in all experimental treatments and in the lake on Day 3 (8/2/91) of Experiment 4 (Summer) in Lake Rotoroa. See Figure 6.1 for definitions of symbols and associated matrices.

Matrix of pairwise absolute mean differences.

|   | 1        | 2        | 3       | 4       | 5     |
|---|----------|----------|---------|---------|-------|
| 1 | 0.000    |          |         |         |       |
| 2 | 1772.424 | 0.000    |         |         |       |
| 3 | 923.043  | 849.381  | 0.000   |         |       |
| 4 | 1299.806 | 472.618  | 376.763 | 0.000   |       |
| 5 | 679.158  | 1093.266 | 243.884 | 620.647 | 0.000 |

Tukey HSD matrix of pairwise comparison probabilities.

|   | 1     | 2     | 3     | 4     | 5     |
|---|-------|-------|-------|-------|-------|
| 1 | 1.000 |       |       |       |       |
| 2 | 0.034 | 1.000 |       |       |       |
| 3 | 0.436 | 0.513 | 1.000 |       |       |
| 4 | 0.157 | 0.892 | 0.949 | 1.000 |       |
| 5 | 0.825 | 0.467 | 0.995 | 0.866 | 1.000 |

FIG. 6.13.

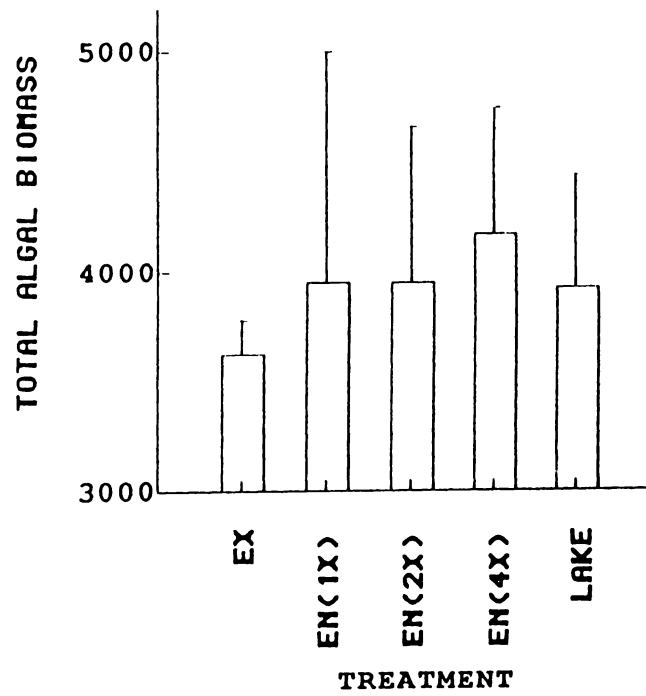


FIG. 6.14.

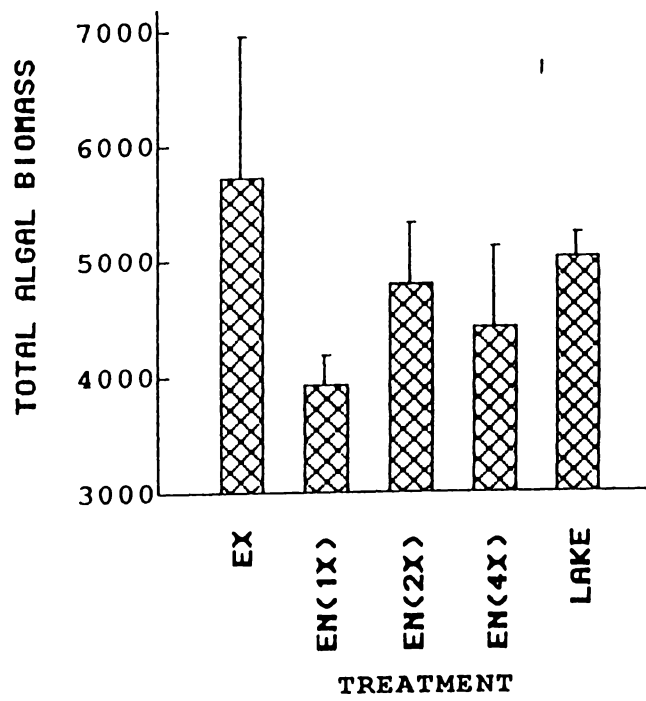


**Figure 6.15**

Total algal biomass in all experimental treatments and in the lake on Day 6 (11/2/91) of Experiment 4 (Summer) in Lake Rotoroa. See Figure 6.1 for definitions of symbols and associated matrices.

Matrix of pairwise absolute mean differences.

|   | 1        | 2        | 3        | 4        | 5     |
|---|----------|----------|----------|----------|-------|
| 1 | 0.000    |          |          |          |       |
| 2 | 1843.153 | 0.000    |          |          |       |
| 3 | 1643.990 | 199.163  | 0.000    |          |       |
| 4 | 2904.103 | 1060.950 | 1260.113 | 0.000    |       |
| 5 | 1631.486 | 211.668  | 12.505   | 1272.618 | 0.000 |

Tukey HSD matrix of pairwise comparison probabilities.

|   | 1     | 2     | 3     | 4     | 5     |
|---|-------|-------|-------|-------|-------|
| 1 | 1.000 |       |       |       |       |
| 2 | 0.082 | 1.000 |       |       |       |
| 3 | 0.137 | 0.998 | 1.000 |       |       |
| 4 | 0.004 | 0.494 | 0.336 | 1.000 |       |
| 5 | 0.288 | 0.999 | 1.000 | 0.513 | 1.000 |

**Figure 6.16**

Total algal biomass in all experimental treatments and in the lake on Day 10 (15/2/91) of Experiment 4 (Summer) in Lake Rotoroa. See Figure 6.1 for definitions of symbols and associated matrices.

Matrix of pairwise absolute mean differences.

|   | 1        | 2        | 3        | 4        | 5     |
|---|----------|----------|----------|----------|-------|
| 1 | 0.000    |          |          |          |       |
| 2 | 1842.955 | 0.000    |          |          |       |
| 3 | 1122.845 | 720.110  | 0.000    |          |       |
| 4 | 1839.285 | 3.670    | 716.440  | 0.000    |       |
| 5 | 3094.643 | 1251.688 | 1971.798 | 1255.359 | 0.000 |

Tukey HSD matrix of pairwise comparison probabilities.

|   | 1     | 2     | 3     | 4     | 5     |
|---|-------|-------|-------|-------|-------|
| 1 | 1.000 |       |       |       |       |
| 2 | 0.022 | 1.000 |       |       |       |
| 3 | 0.238 | 0.631 | 1.000 |       |       |
| 4 | 0.022 | 1.000 | 0.635 | 1.000 |       |
| 5 | 0.002 | 0.316 | 0.049 | 0.314 | 1.000 |

FIG. 6.15.

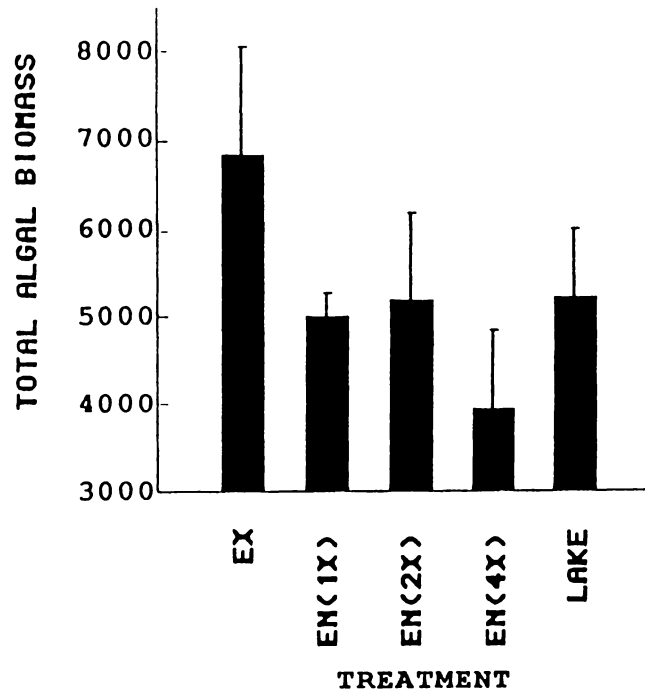


FIG. 6.16.

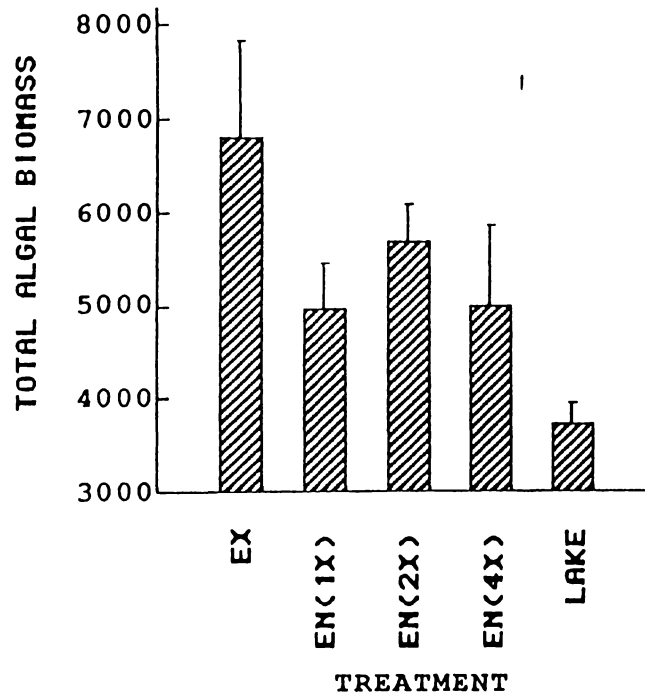


**Figure 6.17**

Total algal biomass across all experimental treatments and in the lake on Day 0 (21/5/91) of Experiment 5 (Autumn) in Lake Pupuke. See Figure 6.1 for definitions of symbols and associated matrices.

Matrix of pairwise absolute mean differences.

|   | 1       | 2        | 3       | 4       | 5     |
|---|---------|----------|---------|---------|-------|
| 1 | 0.000   |          |         |         |       |
| 2 | 589.912 | 0.000    |         |         |       |
| 3 | 599.997 | 1189.909 | 0.000   |         |       |
| 4 | 741.470 | 1331.382 | 141.473 | 0.000   |       |
| 5 | 957.186 | 1547.098 | 357.189 | 215.716 | 0.000 |

Tukey HSD matrix of pairwise comparison probabilities.

|   | 1     | 2     | 3     | 4     | 5     |
|---|-------|-------|-------|-------|-------|
| 1 | 1.000 |       |       |       |       |
| 2 | 0.815 | 1.000 |       |       |       |
| 3 | 0.806 | 0.249 | 1.000 |       |       |
| 4 | 0.665 | 0.168 | 0.999 | 1.000 |       |
| 5 | 0.622 | 0.203 | 0.982 | 0.997 | 1.000 |

**Figure 6.18**

Total algal biomass across all experimental treatments and in the lake on Day 3 (24/5/91) of Experiment 5 (Autumn) in Lake Pupuke. See Figure 6.1 for definitions of symbols and associated matrices.

Matrix of pairwise absolute mean differences.

|   | 1        | 2        | 3        | 4        | 5     |
|---|----------|----------|----------|----------|-------|
| 1 | 0.000    |          |          |          |       |
| 2 | 926.654  | 0.000    |          |          |       |
| 3 | 41.897   | 968.551  | 0.000    |          |       |
| 4 | 782.925  | 143.729  | 824.822  | 0.000    |       |
| 5 | 2152.032 | 1225.378 | 2193.929 | 1369.107 | 0.000 |

Tukey HSD matrix of pairwise comparison probabilities.

|   | 1     | 2     | 3     | 4     | 5     |
|---|-------|-------|-------|-------|-------|
| 1 | 1.000 |       |       |       |       |
| 2 | 0.354 | 1.000 |       |       |       |
| 3 | 1.000 | 0.314 | 1.000 |       |       |
| 4 | 0.509 | 0.998 | 0.461 | 1.000 |       |
| 5 | 0.021 | 0.287 | 0.018 | 0.200 | 1.000 |

FIG. 6.17.

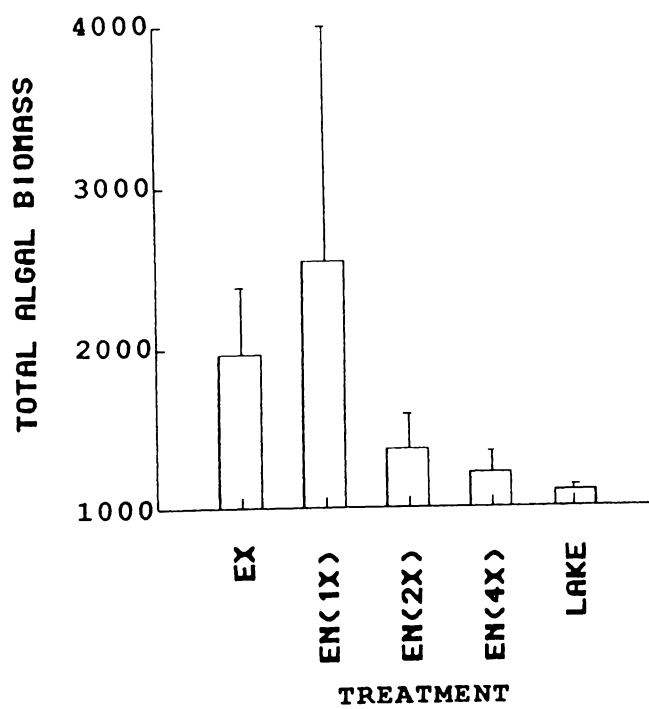


FIG. 6.18.

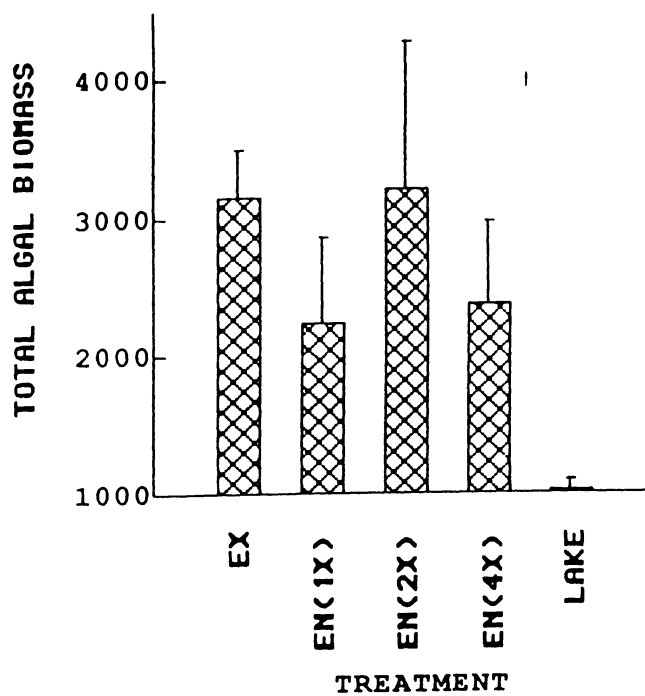


**Figure 6.19**

Total algal biomass in all experimental treatments and in the lake on Day 6 (27/5/91) of Experiment 5 (Autumn) in Lake Pupuke. See Figure 6.1 for definitions of symbols and associated matrices.

Matrix of pairwise absolute mean differences.

|   | 1        | 2        | 3       | 4       | 5     |
|---|----------|----------|---------|---------|-------|
| 1 | 0.000    |          |         |         |       |
| 2 | 986.046  | 0.000    |         |         |       |
| 3 | 889.415  | 1875.461 | 0.000   |         |       |
| 4 | 1252.324 | 2238.370 | 362.909 | 0.000   |       |
| 5 | 1611.597 | 2597.643 | 722.182 | 359.273 | 0.000 |

Tukey HSD matrix of pairwise comparison probabilities.

|   | 1     | 2     | 3     | 4     | 5     |
|---|-------|-------|-------|-------|-------|
| 1 | 1.000 |       |       |       |       |
| 2 | 0.007 | 1.000 |       |       |       |
| 3 | 0.015 | 0.000 | 1.000 |       |       |
| 4 | 0.001 | 0.000 | 0.545 | 1.000 |       |
| 5 | 0.001 | 0.000 | 0.142 | 0.718 | 1.000 |

**Figure 6.20**

Total algal biomass in all experimental treatments and in the lake on Day 10 (31/5/91) of Experiment 5 (Autumn) in Lake Pupuke. See Figure 6.1 for definitions of symbols and associated matrices.

Matrix of pairwise absolute mean differences.

|   | 1        | 2        | 3        | 4       | 5     |
|---|----------|----------|----------|---------|-------|
| 1 | 0.000    |          |          |         |       |
| 2 | 2144.368 | 0.000    |          |         |       |
| 3 | 922.604  | 1221.764 | 0.000    |         |       |
| 4 | 1639.689 | 504.678  | 717.086  | 0.000   |       |
| 5 | 2327.436 | 183.069  | 1404.833 | 687.747 | 0.000 |

Tukey HSD matrix of pairwise comparison probabilities.

|   | 1     | 2     | 3     | 4     | 5     |
|---|-------|-------|-------|-------|-------|
| 1 | 1.000 |       |       |       |       |
| 2 | 0.000 | 1.000 |       |       |       |
| 3 | 0.065 | 0.012 | 1.000 |       |       |
| 4 | 0.001 | 0.499 | 0.196 | 1.000 |       |
| 5 | 0.000 | 0.987 | 0.018 | 0.401 | 1.000 |



FIG. 6.19.

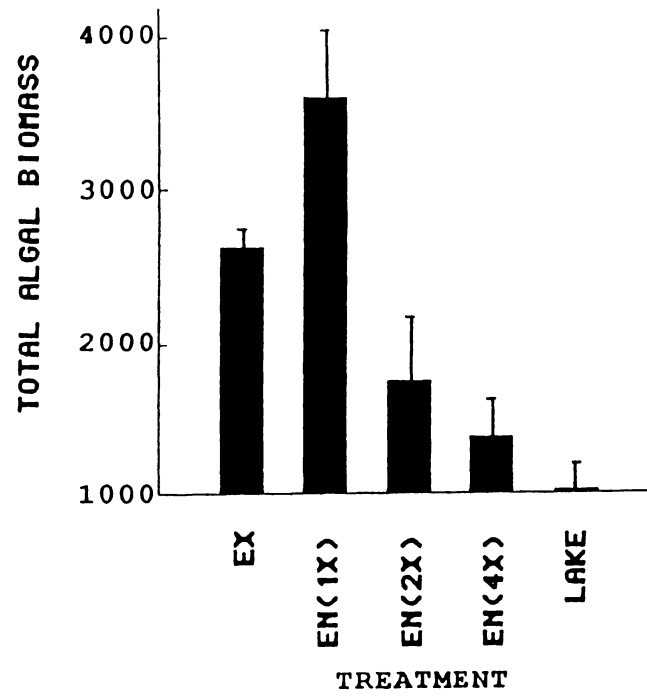


FIG. 6.20.

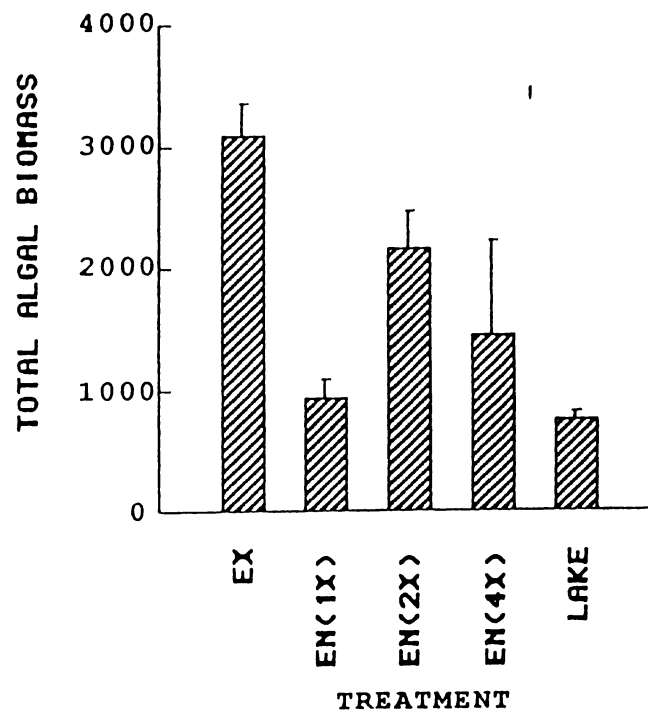


**Figure 6.21**

Total algal biomass in all experimental treatments and in the lake on Day 0 (23/7/91) of Experiment 6 (Winter) in Lake Pupuke. See Figure 6.1 for definitions of symbols and associated matrices.

Matrix of pairwise absolute mean differences.

|   | 1      | 2      | 3      | 4      | 5     |
|---|--------|--------|--------|--------|-------|
| 1 | 0.000  |        |        |        |       |
| 2 | 16.024 | 0.000  |        |        |       |
| 3 | 5.367  | 10.658 | 0.000  |        |       |
| 4 | 36.698 | 52.723 | 42.065 | 0.000  |       |
| 5 | 35.437 | 19.412 | 30.070 | 72.135 | 0.000 |

Tukey HSD matrix of pairwise comparison probabilities.

|   | 1     | 2     | 3     | 4     | 5     |
|---|-------|-------|-------|-------|-------|
| 1 | 1.000 |       |       |       |       |
| 2 | 0.962 | 1.000 |       |       |       |
| 3 | 0.999 | 0.992 | 1.000 |       |       |
| 4 | 0.578 | 0.254 | 0.454 | 1.000 |       |
| 5 | 0.760 | 0.964 | 0.848 | 0.173 | 1.000 |

**Figure 6.22**

Total algal biomass in all experimental treatments and in the lake on Day 3 (26/7/91) of Experiment 6 (Winter) in Lake Pupuke. See Figure 6.1 for definitions of symbols and associated matrices.

Matrix of pairwise absolute mean differences.

|   | 1       | 2       | 3       | 4       | 5     |
|---|---------|---------|---------|---------|-------|
| 1 | 0.000   |         |         |         |       |
| 2 | 396.359 | 0.000   |         |         |       |
| 3 | 346.799 | 49.559  | 0.000   |         |       |
| 4 | 781.751 | 385.392 | 434.952 | 0.000   |       |
| 5 | 596.214 | 199.855 | 249.414 | 185.537 | 0.000 |

Tukey HSD matrix of pairwise comparison probabilities.

|   | 1     | 2     | 3     | 4     | 5     |
|---|-------|-------|-------|-------|-------|
| 1 | 1.000 |       |       |       |       |
| 2 | 0.750 | 1.000 |       |       |       |
| 3 | 0.827 | 1.000 | 1.000 |       |       |
| 4 | 0.184 | 0.768 | 0.685 | 1.000 |       |
| 5 | 0.594 | 0.986 | 0.970 | 0.990 | 1.000 |

FIG. 6.21.

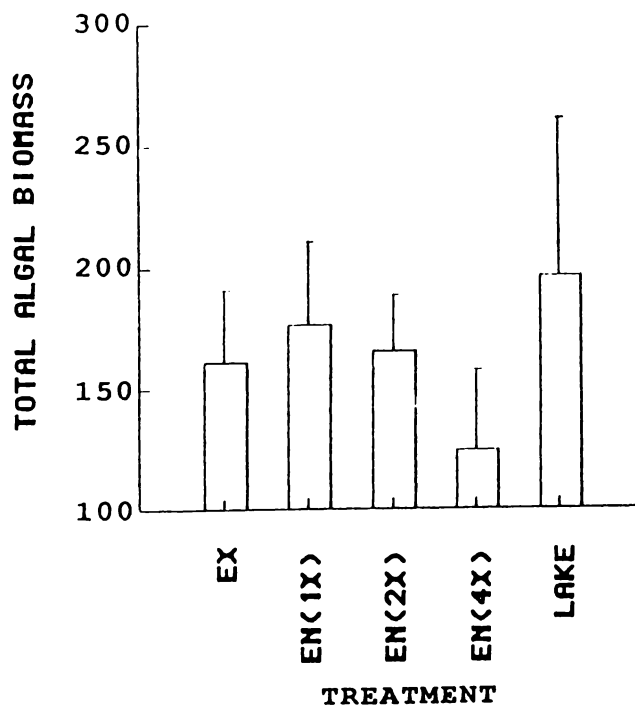


FIG. 6.22.

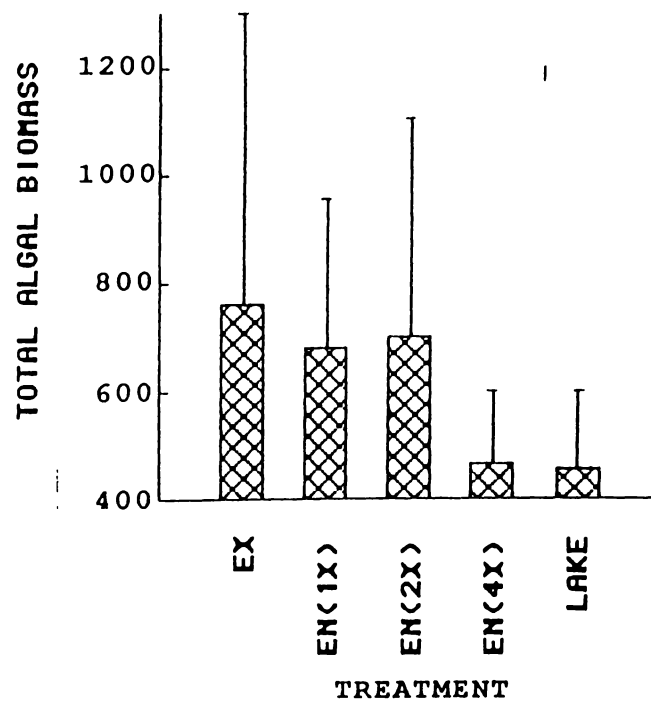


**Figure 6.23**

Total algal biomass in all experimental treatments and in the lake on Day 6 (29/7/91) of Experiment 6 (Winter) in Lake Pupuke. See Figure 6.1 for definitions of symbols and associated matrices.

Matrix of pairwise absolute mean differences.

|   | 1       | 2       | 3       | 4      | 5     |
|---|---------|---------|---------|--------|-------|
| 1 | 0.000   |         |         |        |       |
| 2 | 396.359 | 0.000   |         |        |       |
| 3 | 346.799 | 49.559  | 0.000   |        |       |
| 4 | 781.751 | 385.392 | 434.952 | 0.000  |       |
| 5 | 830.627 | 434.268 | 483.827 | 48.876 | 0.000 |

Tukey HSD matrix of pairwise comparison probabilities.

|   | 1     | 2     | 3     | 4     | 5     |
|---|-------|-------|-------|-------|-------|
| 1 | 1.000 |       |       |       |       |
| 2 | 0.748 | 1.000 |       |       |       |
| 3 | 0.825 | 1.000 | 1.000 |       |       |
| 4 | 0.182 | 0.766 | 0.682 | 1.000 |       |
| 5 | 0.291 | 0.814 | 0.750 | 1.000 | 1.000 |

**Figure 6.24**

Total algal biomass in all experimental treatments and in the lake on Day 10 (2/8/91) of Experiment 6 (Winter) in Lake Pupuke. See Figure 6.1 for definitions of symbols and associated matrices.

Matrix of pairwise absolute mean differences.

|   | 1        | 2        | 3        | 4        | 5     |
|---|----------|----------|----------|----------|-------|
| 1 | 0.000    |          |          |          |       |
| 2 | 1581.802 | 0.000    |          |          |       |
| 3 | 3130.286 | 1548.484 | 0.000    |          |       |
| 4 | 2531.340 | 949.538  | 598.946  | 0.000    |       |
| 5 | 4288.563 | 2706.761 | 1158.277 | 1757.223 | 0.000 |

Tukey HSD matrix of pairwise comparison probabilities.

|   | 1     | 2     | 3     | 4     | 5     |
|---|-------|-------|-------|-------|-------|
| 1 | 1.000 |       |       |       |       |
| 2 | 0.201 | 1.000 |       |       |       |
| 3 | 0.004 | 0.216 | 1.000 |       |       |
| 4 | 0.019 | 0.644 | 0.900 | 1.000 |       |
| 5 | 0.002 | 0.043 | 0.647 | 0.277 | 1.000 |

FIG. 6.23.

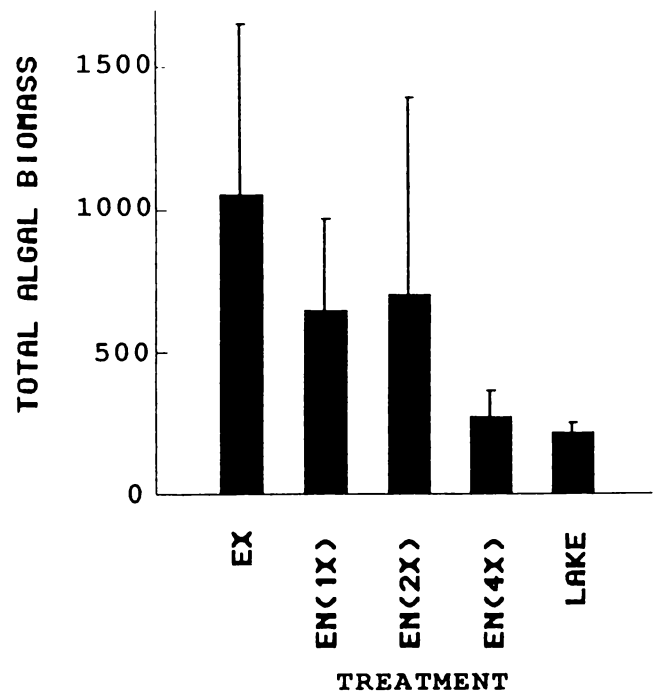


FIG. 6.24.

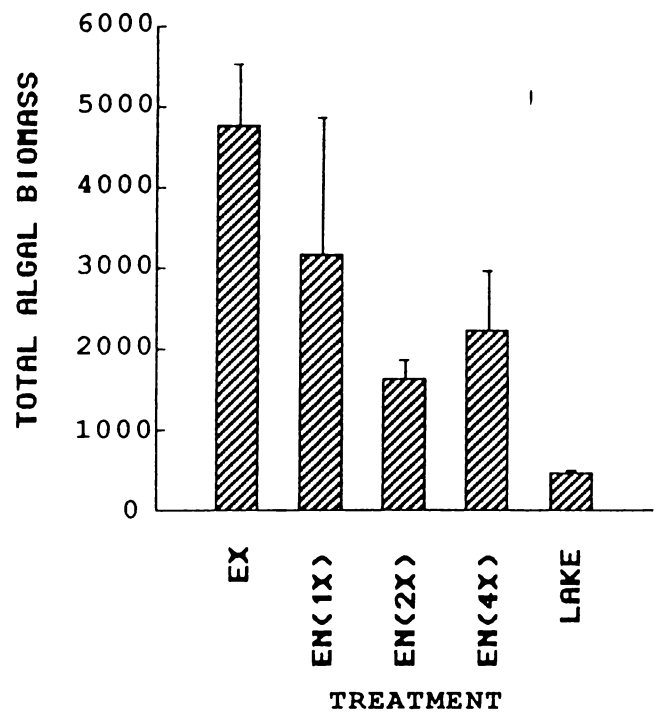


**Figure 6.25**

Total algal biomass in all experimental treatments and in the lake on Day 0 (8/10/91) of Experiment 7 (Spring) in Lake Pupuke. See Figure 6.1 for definitions of symbols and associated matrices.

Matrix of pairwise absolute mean differences.

|   | 1       | 2       | 3       | 4       | 5     |
|---|---------|---------|---------|---------|-------|
| 1 | 0.000   |         |         |         |       |
| 2 | 302.554 | 0.000   |         |         |       |
| 3 | 404.473 | 101.919 | 0.000   |         |       |
| 4 | 118.138 | 184.416 | 286.335 | 0.000   |       |
| 5 | 334.685 | 32.131  | 69.788  | 216.547 | 0.000 |

Tukey HSD matrix of pairwise comparison probabilities.

|   | 1     | 2     | 3     | 4     | 5     |
|---|-------|-------|-------|-------|-------|
| 1 | 1.000 |       |       |       |       |
| 2 | 0.271 | 1.000 |       |       |       |
| 3 | 0.087 | 0.950 | 1.000 |       |       |
| 4 | 0.918 | 0.702 | 0.318 | 1.000 |       |
| 5 | 0.359 | 1.000 | 0.994 | 0.732 | 1.000 |

**Figure 6.26**

Total algal biomass in all experimental treatments and in the lake on Day 3 (11/10/91) of Experiment 7 (Spring) in Lake Pupuke. See Figure 6.1 for definitions of symbols and associated matrices.

Matrix of pairwise absolute mean differences.

|   | 1        | 2       | 3       | 4       | 5     |
|---|----------|---------|---------|---------|-------|
| 1 | 0.000    |         |         |         |       |
| 2 | 1004.517 | 0.000   |         |         |       |
| 3 | 741.964  | 262.554 | 0.000   |         |       |
| 4 | 815.451  | 189.066 | 73.488  | 0.000   |       |
| 5 | 1057.744 | 53.226  | 315.780 | 242.293 | 0.000 |

Tukey HSD matrix of pairwise comparison probabilities.

|   | 1     | 2     | 3     | 4     | 5     |
|---|-------|-------|-------|-------|-------|
| 1 | 1.000 |       |       |       |       |
| 2 | 0.028 | 1.000 |       |       |       |
| 3 | 0.133 | 0.888 | 1.000 |       |       |
| 4 | 0.087 | 0.962 | 0.999 | 1.000 |       |
| 5 | 0.065 | 1.000 | 0.894 | 0.956 | 1.000 |

FIG. 6.25.

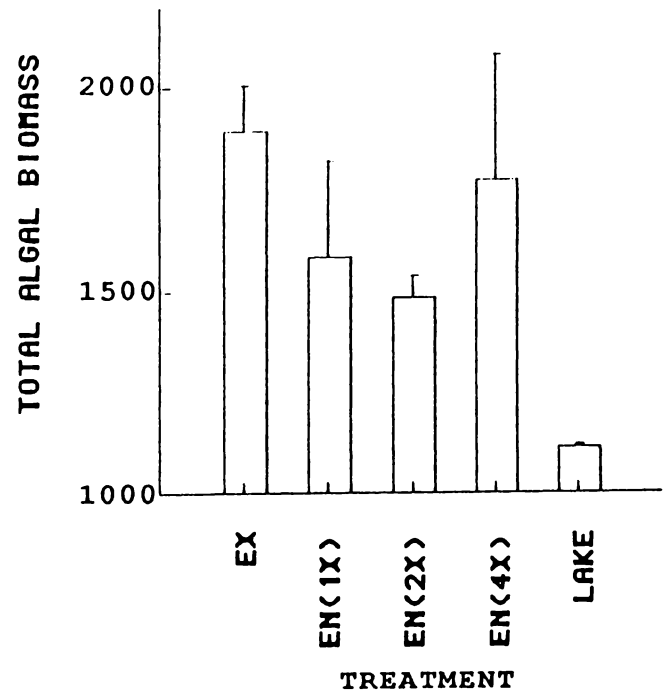


FIG. 6.26.

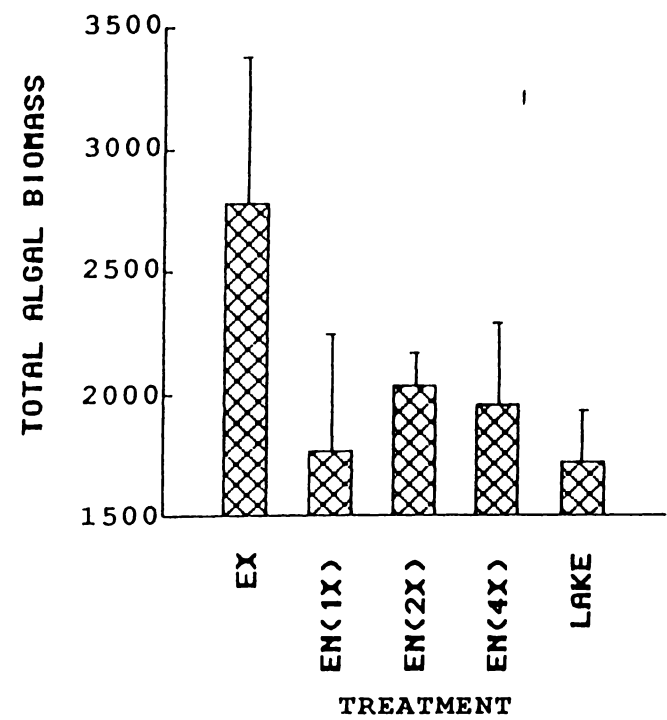


**Figure 6.27**

Total algal biomass in all experimental treatments and in the lake on Day6 (14/10/91) of Experiment 7 (Spring) in Lake Pupuke. See Figure 6.1 for definitions of symbols and associated matrices.

Matrix of pairwise absolute mean differences.

|   | 1        | 2        | 3       | 4       | 5     |
|---|----------|----------|---------|---------|-------|
| 1 | 0.000    |          |         |         |       |
| 2 | 495.613  | 0.000    |         |         |       |
| 3 | 1204.084 | 708.472  | 0.000   |         |       |
| 4 | 1184.559 | 688.947  | 19.525  | 0.000   |       |
| 5 | 1927.129 | 1431.517 | 723.045 | 742.570 | 0.000 |

Tukey HSD matrix of pairwise comparison probabilities.

|   | 1     | 2     | 3     | 4     | 5     |
|---|-------|-------|-------|-------|-------|
| 1 | 1.000 |       |       |       |       |
| 2 | 0.520 | 1.000 |       |       |       |
| 3 | 0.013 | 0.208 | 1.000 |       |       |
| 4 | 0.015 | 0.228 | 1.000 | 1.000 |       |
| 5 | 0.002 | 0.016 | 0.359 | 0.335 | 1.000 |

**Figure 6.28**

Total algal biomass in all experimental treatments and in the lake on Day 10 (18/10/91) of Experiment 7 (Spring) in Lake Pupuke. See Figure 6.1 for definitions of symbols and associated matrices.

Matrix of pairwise absolute mean differences.

|   | 1        | 2        | 3       | 4        | 5     |
|---|----------|----------|---------|----------|-------|
| 1 | 0.000    |          |         |          |       |
| 2 | 1013.872 | 0.000    |         |          |       |
| 3 | 1116.750 | 102.878  | 0.000   |          |       |
| 4 | 1032.690 | 18.818   | 84.061  | 0.000    |       |
| 5 | 2059.989 | 1046.117 | 943.239 | 1027.299 | 0.000 |

Tukey HSD matrix of pairwise comparison probabilities.

|   | 1     | 2     | 3     | 4     | 5     |
|---|-------|-------|-------|-------|-------|
| 1 | 1.000 |       |       |       |       |
| 2 | 0.021 | 1.000 |       |       |       |
| 3 | 0.011 | 0.996 | 1.000 |       |       |
| 4 | 0.019 | 1.000 | 0.998 | 1.000 |       |
| 5 | 0.000 | 0.058 | 0.098 | 0.064 | 1.000 |



FIG. 6.27.

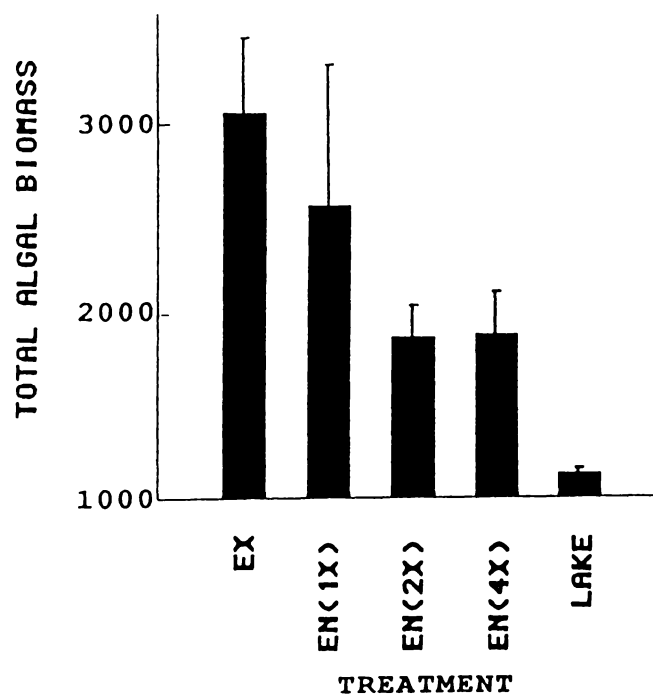


FIG. 6.28.

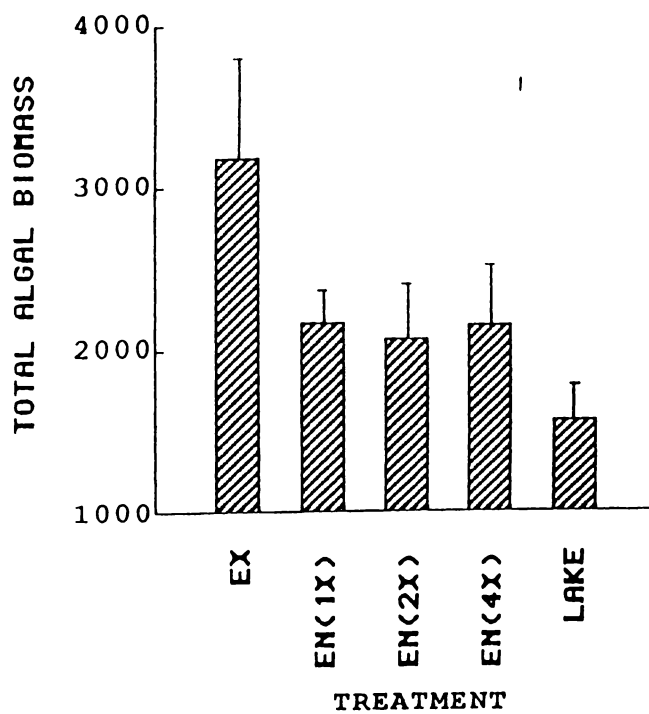


**Figure 6.29**

Total algal biomass in all experimental treatments and in the lake on Day 0 (4/2/92) of Experiment 8 (Summer) in Lake Pupuke. See Figure 6.1 for definitions of symbols and associated matrices.

Matrix of pairwise absolute mean differences.

|   | 1        | 2        | 3        | 4       | 5     |
|---|----------|----------|----------|---------|-------|
| 1 | 0.000    |          |          |         |       |
| 2 | 2015.697 | 0.000    |          |         |       |
| 3 | 2191.929 | 176.232  | 0.000    |         |       |
| 4 | 3684.402 | 1668.704 | 1492.473 | 0.000   |       |
| 5 | 4209.514 | 2193.817 | 2017.585 | 525.113 | 0.000 |

Tukey HSD matrix of pairwise comparison probabilities.

|   | 1     | 2     | 3     | 4     | 5     |
|---|-------|-------|-------|-------|-------|
| 1 | 1.000 |       |       |       |       |
| 2 | 0.590 | 1.000 |       |       |       |
| 3 | 0.516 | 1.000 | 1.000 |       |       |
| 4 | 0.107 | 0.737 | 0.805 | 1.000 |       |
| 5 | 0.144 | 0.686 | 0.745 | 0.998 | 1.000 |

**Figure 6.30**

Total algal biomass in all experimental treatments and in the lake on Day 3 (7/2/92) of Experiment 8 (Summer) in Lake Pupuke. See Figure 6.1 for definitions of symbols and associated matrices.

Matrix of pairwise absolute mean differences.

|   | 1       | 2       | 3        | 4        | 5     |
|---|---------|---------|----------|----------|-------|
| 1 | 0.000   |         |          |          |       |
| 2 | 98.729  | 0.000   |          |          |       |
| 3 | 538.640 | 637.370 | 0.000    |          |       |
| 4 | 855.834 | 954.563 | 317.194  | 0.000    |       |
| 5 | 497.183 | 398.454 | 1035.824 | 1353.017 | 0.000 |

Tukey HSD matrix of pairwise comparison probabilities.

|   | 1     | 2     | 3     | 4     | 5     |
|---|-------|-------|-------|-------|-------|
| 1 | 1.000 |       |       |       |       |
| 2 | 0.999 | 1.000 |       |       |       |
| 3 | 0.588 | 0.436 | 1.000 |       |       |
| 4 | 0.187 | 0.121 | 0.901 | 1.000 |       |
| 5 | 0.794 | 0.893 | 0.196 | 0.060 | 1.000 |

FIG. 6.29.

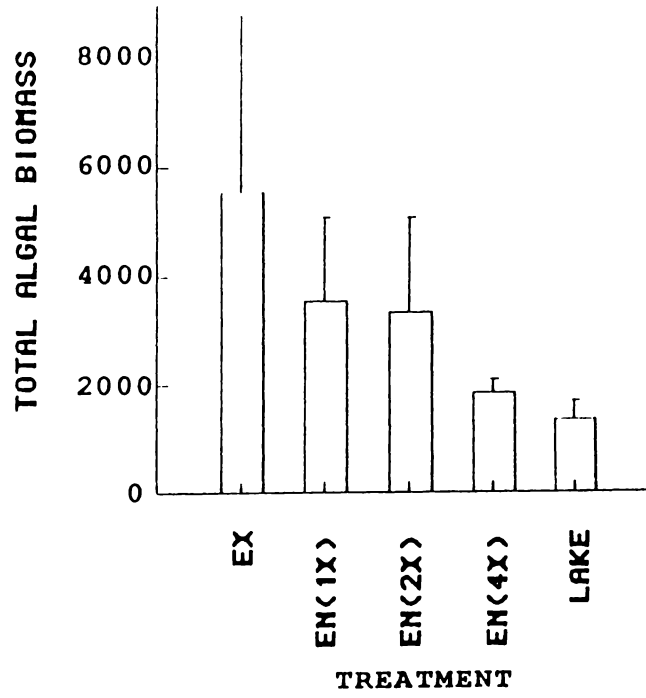


FIG. 6.30.

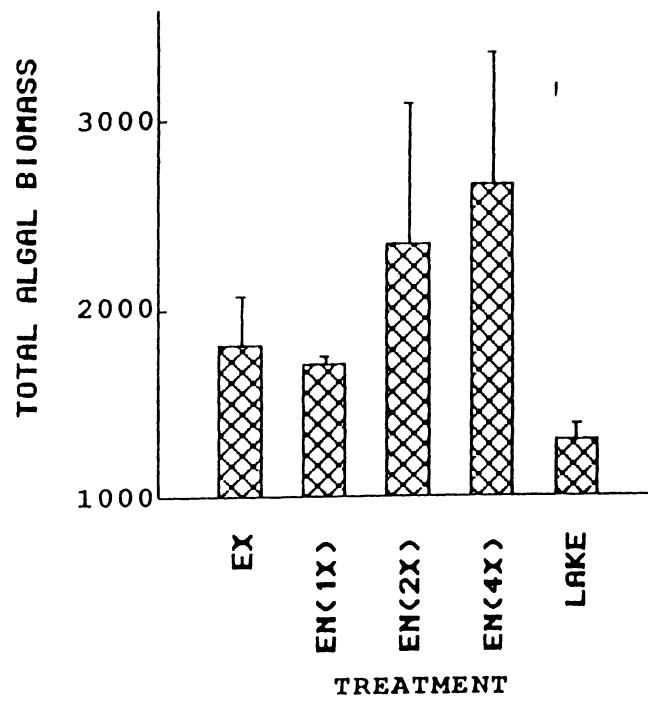


**Figure 6.31**

Total algal biomass in all experimental treatments and in the lake on Day 6 (10/2/92) of Experiment 8 (Summer) in Lake Pupuke. See Figure 6.1 for definitions of symbols and associated matrices.

Matrix of pairwise absolute mean differences.

|   | 1       | 2       | 3       | 4        | 5     |
|---|---------|---------|---------|----------|-------|
| 1 | 0.000   |         |         |          |       |
| 2 | 5.163   | 0.000   |         |          |       |
| 3 | 404.050 | 409.213 | 0.000   |          |       |
| 4 | 822.578 | 827.741 | 418.528 | 0.000    |       |
| 5 | 445.411 | 440.248 | 849.462 | 1267.989 | 0.000 |

Tukey HSD matrix of pairwise comparison probabilities.

|   | 1     | 2     | 3     | 4     | 5     |
|---|-------|-------|-------|-------|-------|
| 1 | 1.000 |       |       |       |       |
| 2 | 1.000 | 1.000 |       |       |       |
| 3 | 0.446 | 0.434 | 1.000 |       |       |
| 4 | 0.025 | 0.024 | 0.413 | 1.000 |       |
| 5 | 0.542 | 0.553 | 0.067 | 0.005 | 1.000 |

**Figure 6.32**

Total algal biomass in all experimental treatments and in the lake on Day 10 (14/2/92) of Experiment 8 (Summer) in Lake Pupuke. See Figure 6.1 for definitions of symbols and associated matrices.

Matrix of pairwise absolute mean differences.

|   | 1       | 2       | 3       | 4       | 5     |
|---|---------|---------|---------|---------|-------|
| 1 | 0.000   |         |         |         |       |
| 2 | 526.407 | 0.000   |         |         |       |
| 3 | 778.488 | 252.082 | 0.000   |         |       |
| 4 | 801.755 | 275.349 | 23.267  | 0.000   |       |
| 5 | 73.411  | 599.818 | 851.899 | 875.166 | 0.000 |

Tukey HSD matrix of pairwise comparison probabilities.

|   | 1     | 2     | 3     | 4     | 5     |
|---|-------|-------|-------|-------|-------|
| 1 | 1.000 |       |       |       |       |
| 2 | 0.458 | 1.000 |       |       |       |
| 3 | 0.141 | 0.919 | 1.000 |       |       |
| 4 | 0.125 | 0.893 | 1.000 | 1.000 |       |
| 5 | 1.000 | 0.524 | 0.216 | 0.196 | 1.000 |

FIG. 6.31.

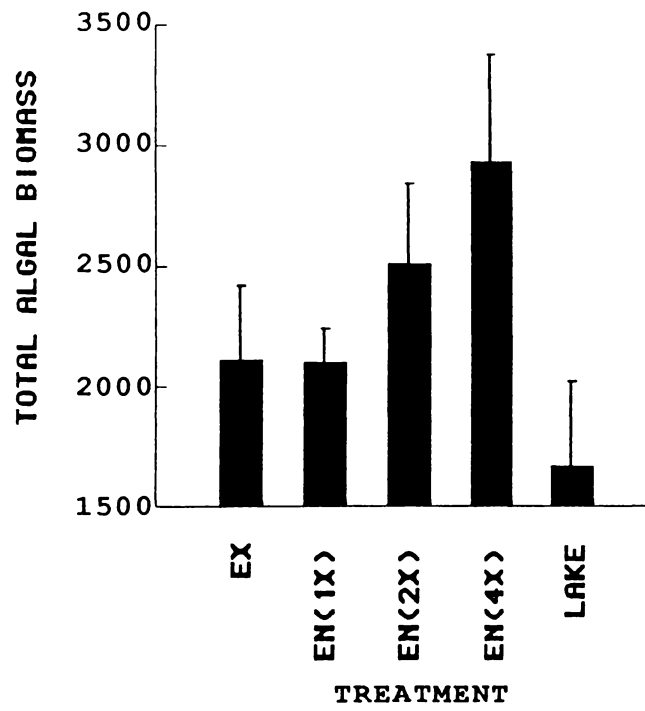


FIG. 6.32.

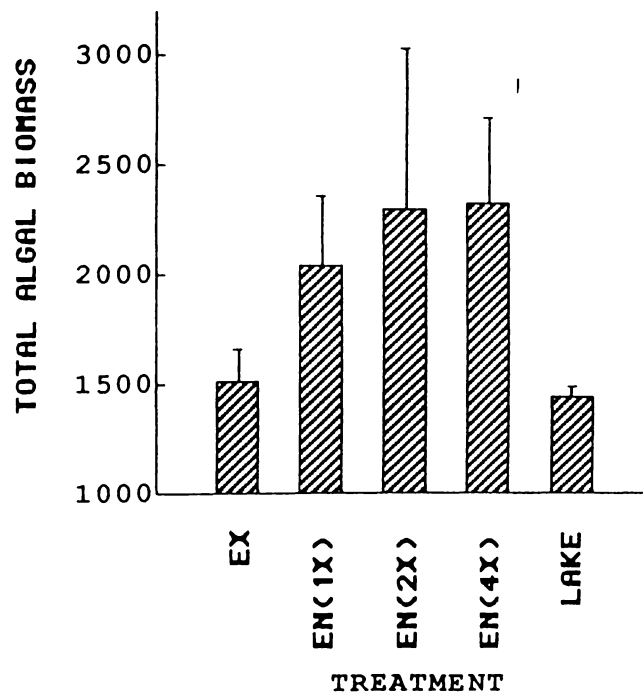


**Figure 6.33**

Regression of total algal biomass ( $\leq 80\mu\text{m}$ ) against the gradient of zooplankton biomass on Day 6 (7/6/90) of Experiment 1 (Autumn) in Lake Rotoroa. Both total algal biomass (freshweight) and Zooplankton biomass (dry weight) have units of  $\text{mg m}^{-3}$ . 95% confidence intervals are displayed for all linear regressions. For a complete statistical analysis  $r^2 = 0.085$ ;  $p = 0.484$  see Tale 6.2, pg 100.

**Figure 6.34**

Regression of total algal biomass against zooplankton biomass on Day 6 (2/8/90) of Experiment 2 (Winter) in Lake Rotoroa. See Figure 6.33 for axes definitions and associated statistical analysis.  $r^2 = 0.856$ ;  $p = 0.001$ .

**Figure 6.35**

Regression of total algal biomass against zooplankton biomass on Day 6 (18/10/90) of Experiment 3 (Spring) in Lake Rotoroa. See Figure 6.33 for axes definitions and associated statistical analysis.  $r^2 = 0.907$ ;  $p = 0.000$ .

FIG. 6.33.

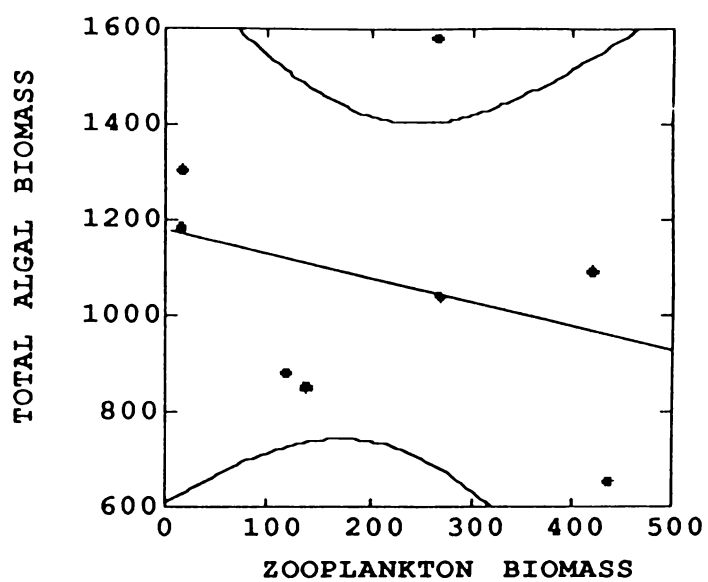


FIG. 6.34.

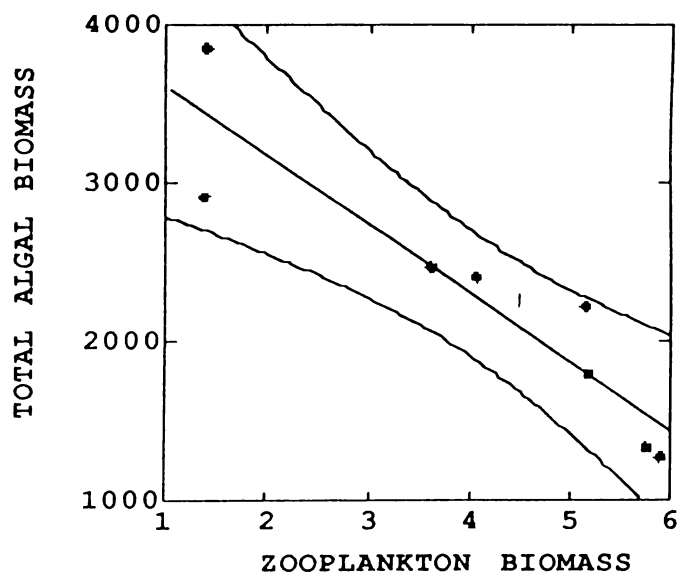


FIG. 6.35.

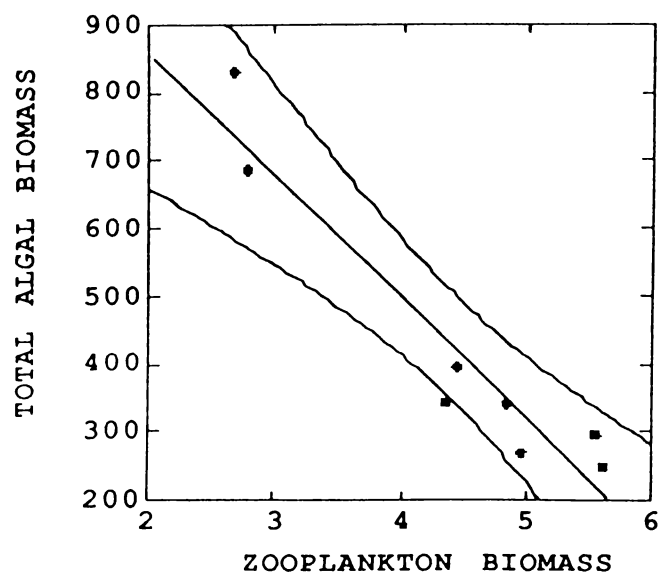


**Figure 6.36**

Regression of total algal biomass against zooplankton biomass on Day 6 (11/2/91) of Experiment 4 (Summer) in Lake Rotoroa. See Figure 6.33 for axes definitions and associated statistical analysis.  $r^2 = 0.707$ ;  $p = 0.009$ .

**Figure 6.37**

Regression of total algal biomass against zooplankton biomass on Day 6 (27/5/91) of Experiment 5 (Autumn) in Lake Pupuke. See Figure 6.33 for axes definitions and associated statistical analysis.  $r^2 = 0.418$ ;  $p = 0.083$ .

**Figure 6.38**

Regression of total algal biomass against zooplankton biomass on Day 6 (29/7/91) of Experiment 6 (Winter) in Lake Pupuke. See Figure 6.33 for axes definitions and associated statistical analysis.  $r^2 = 0.476$ ;  $p = 0.058$ .



FIG. 6.36.

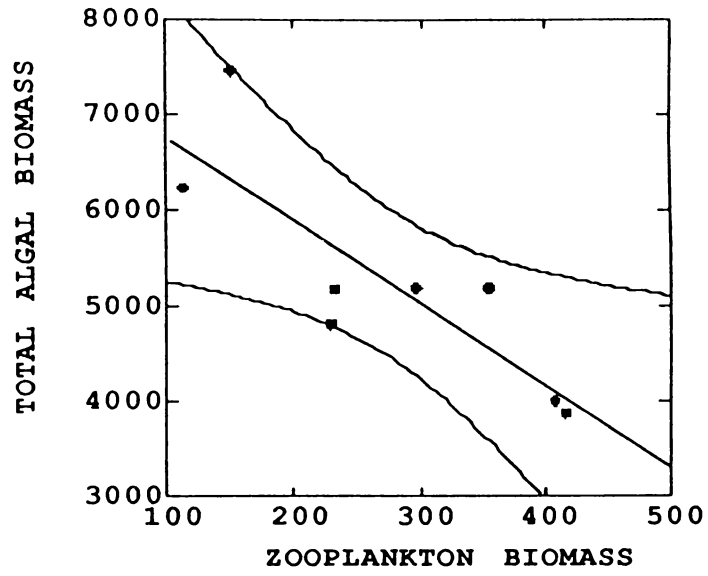


FIG. 6.37.

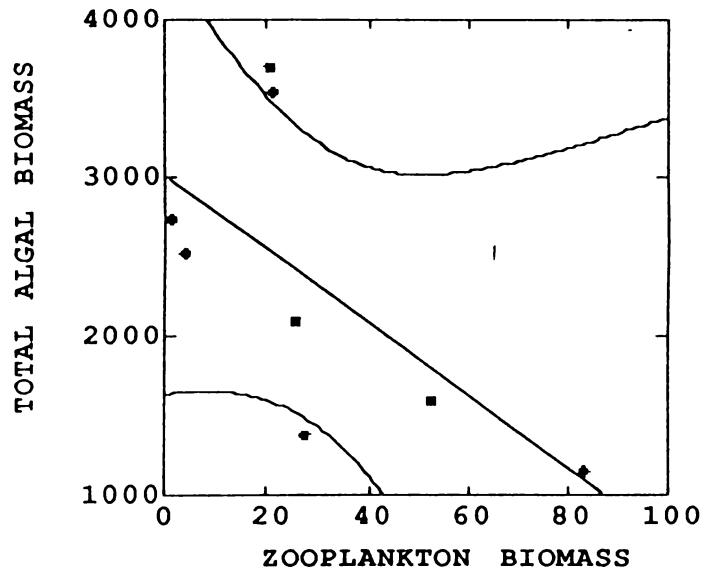


FIG. 6.38.

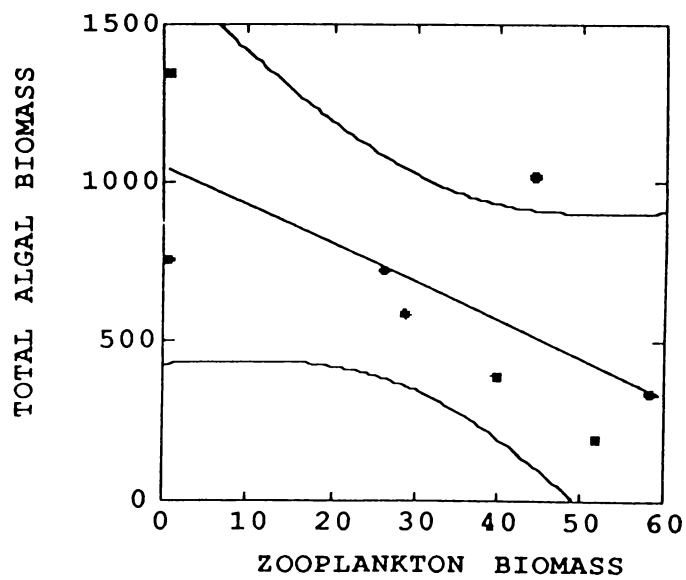


**Figure 6.39**

Regression of total algal biomass against zooplankton biomass on Day 6 (14/10/91) of Experiment 7 (Spring) in Lake Pupuke. See Figure 6.33 for axes definitions and associated statistical analysis.  $r^2 = 0.622$ ;  $p = 0.020$ .

**Figure 6.40**

Regression of total algal biomass against zooplankton biomass on Day 6 (10/2/92) of Experiment 8 (Summer) in Lake Pupuke. See Figure 6.33 for axes definitions and associated statistical analysis.  $r^2 = 0.657$ ;  $p = 0.015$ .

FIG. 6.39.

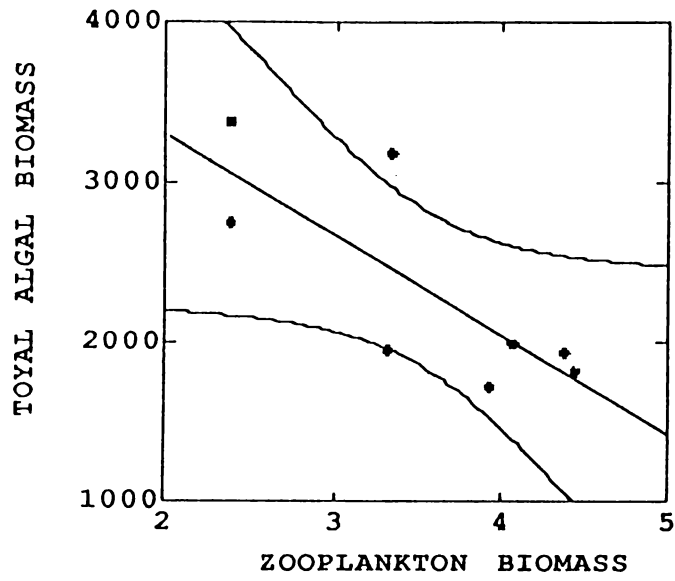


FIG. 6.40.

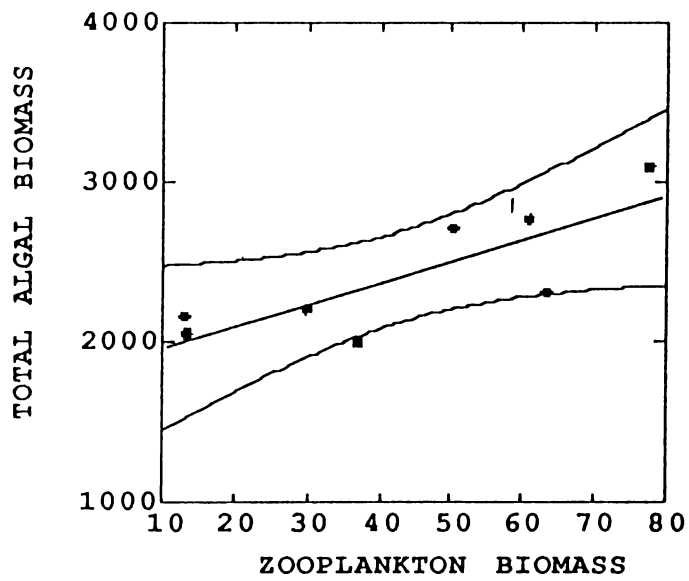


**Table 6.1** : Review of recent limnocorral experiments investigating phytoplankton - zooplankton interactions

| Lake                        | Trophic/Nutrient Status                    | Enclosure Size*   | Zooplankton Composition                                                                                                                                                                                    | Zooplankton Densities                                      | Response of Phytoplankton Biomass to Grazing                                                            | Nutrient Regeneration due to Grazing                                                                                                                                                                  | Reference                                |
|-----------------------------|--------------------------------------------|-------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------|---------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------|
| Trummen and Bysjön (Sweden) | Eutrophic                                  | 15 m <sup>3</sup> | Rotifers and cyclopoid copepodites<br><i>Daphnia longispina</i> + <i>D. cucullata</i><br><i>Bosmina longirostris</i> (Trummen)<br><i>Daphnia magna</i><br><i>D. pulex</i><br><i>D. longispina</i> (Bysjön) | -                                                          | Considerable reduction in both lakes                                                                    | Confounded by fish introductions                                                                                                                                                                      | Andersson, G. <i>et al.</i> 1978         |
| Peter (U.S.A)               | Infertile                                  | 120 ℓ             | <i>Daphnia pulex</i><br><i>Diaptomus oregonensis</i><br><i>Holopedium gibberum</i>                                                                                                                         | 0.5 - 9 X Lakewide concentration                           | Increasing zooplankton concentration resulted in increased Chl a concentration                          | Alkaline phosphatase activity decreased with increasing zooplankton concentration. Specific primary productivity increased significantly with with zooplankton concentration in enriched limnocorrals | Bergquist, A.M. and Carpenter, S.R. 1986 |
| Lucerne (Switzerland)       | Mesotrophic                                | 70 m <sup>3</sup> | -                                                                                                                                                                                                          | Ambient lake concentrations                                | Reduction in standing crops                                                                             | Carbon and phosphorus regeneration were not significantly affected                                                                                                                                    | Bloesch, J. <i>et al.</i> 1988           |
| La Caldera (Spain)          | Phytoplankton is strongly nutrient limited | 15 ℓ and 350 ℓ    | <i>Mixodiaptomus laciniatus</i><br><i>Hexarthra bulgarica</i>                                                                                                                                              | A gradient (0, 1, 2X) of natural zooplankton concentration | Increasing zooplankton density resulted in increased phytoplankton growth rates and higher Chl a values | This net, positive impact of zooplankton on phytoplankton was considered to be "almost certainly mediated by nutrient regeneration".                                                                  | Carrillo, P. <i>et al.</i> 1990          |

\**In situ* unless otherwise stated. - Designates an unknown or non-investigated parameter

|                                      |                     |                           |                                                                                                                                                                                                                                  |                                                                                                                                                      |                                                                                                                                                                                                                                                                                                          |                                                                                                                                                                                        |                                            |
|--------------------------------------|---------------------|---------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------|
| Ros<br>(Poland)                      | Mesotrophic         | 3 m <sup>3</sup>          | <i>Daphnia galeata</i><br><i>D. hyalina</i><br><i>D. cucullata</i><br><i>D. cristata</i><br><i>Bosmina</i> spp<br>or with additional<br><i>Daphnia magna</i>                                                                     | Enclosures were<br>filled with lake<br>water with natural<br>zooplankton or had<br><i>Daphnia magna</i> in<br>addition to the<br>natural zooplankton | In enclosures with natural lake<br>zooplankton phytoplankton<br>biomass (Chl a) increased<br>whereas enclosures which also<br>had <i>Daphnia magna</i> present<br>showed a decrease in Chl a.                                                                                                            | -                                                                                                                                                                                      | Dawidowicz, P.<br>1990                     |
| Flathead<br>(U.S.A.)                 | Oligotrophic        | 1,570 ℓ                   | -                                                                                                                                                                                                                                | Ambient near-<br>surface<br>concentrations                                                                                                           | -                                                                                                                                                                                                                                                                                                        | NO <sub>3</sub> <sup>-</sup> and NO <sub>4</sub> <sup>+</sup><br>regeneration from zoo-<br>plankton grazing was<br>sufficient to meet phyto-<br>plankton nitrogen<br>requirements      | Dodds, W.K.<br>and<br>Priscu, J.C.<br>1990 |
| Texoma<br>(U.S.A.)                   | Eutrophic           | 7,000 ℓ<br>(Outdoor tank) | <i>Bosmina</i><br><i>Ceriodaphnia</i><br><i>Daphnia</i><br><i>Cyclops</i> and<br><i>Keratella</i>                                                                                                                                | -                                                                                                                                                    | Fish suppression of<br>cladocerans resulted in<br>a significant enhancement<br>of Chl a                                                                                                                                                                                                                  | -                                                                                                                                                                                      | Drenner, R.W.<br><i>et al.</i> 1989        |
| Peter<br>Paul<br>Tuesday<br>(U.S.A.) | Nutrient<br>limited | 36 ℓ                      | <i>Daphnia pulex</i><br><i>D. rosea</i><br><i>Holopedium</i><br><i>gibberum</i><br><br><i>D. pulex</i><br><i>H. gibberum</i><br><i>Diaptomus</i><br><i>oregonensis</i><br><br><i>Tropocyclops</i><br><i>prasinus</i><br>rotifers | 0.25 - 8X<br>Ambient<br>lakewide<br>density                                                                                                          | In Peter lake algal biovolume<br>consistently increased slightly<br>at intermediate zooplankton<br>densities above which it<br>declined.<br>Paul and Tuesday lakes<br>exhibited three different<br>responses in three experiments.<br>Biovolume was constant,<br>increased or decreased<br>exponentially | Frequent unimodal and<br>increasing responses of<br>algal taxa to zooplankton<br>biomass demonstrated<br>clearly the positive<br>effects of grazing<br>reducing nutrient<br>limitation | Elser, J.J.<br><i>et al.</i> 1987          |
| Peter<br>Paul<br>Tuesday<br>(U.S.A.) | Nutrient<br>limited | 45 ℓ                      | <i>Daphnia pulex</i><br><i>D. rosea</i><br><i>Holopedium</i><br><i>gibberum</i>                                                                                                                                                  | 0.25 - 8X<br>Ambient<br>lakewide<br>density                                                                                                          | Chlorophyll declined<br>significantly with increasing<br>zooplankton biomass in all<br>three lakes. However the<br>overall change in<br>Chlorophyll was not large                                                                                                                                        | Phosphorus limitation<br>tended to increase with<br>increasing zooplankton<br>biomass and size the<br>reverse situation<br>occurred with nitrogen                                      | Elser, J.J.<br><i>et al.</i> 1988          |

|                                                   |                                  |                      |                                                                                                                                                                                  |                                                                                                                                                  |                                                                                                                                                                                      |                                                                                                                                                                                       |                                          |
|---------------------------------------------------|----------------------------------|----------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------|
| Tahoe                                             | Ultra-oligotrophic               | 20ℓ                  | <i>Diaptomus tyrelli</i><br><i>Epischura</i> sp or<br><i>Daphnia schodleri</i>                                                                                                   | Gradient in both<br>ambient zooplankton<br>densities<br>1/2, 1, 2, 4 or 8X                                                                       | Lake Tahoe phytoplankton were<br>unaffected by all levels of<br>ambient zooplankton but phyto-<br>plankton biomass decreased<br>with <i>Daphnia</i> additions                        | NH <sub>4</sub> <sup>+</sup> concentration<br>increased with increasing<br>zooplankton biomass in<br>Lake Tahoe as did P<br>uptake.                                                   | Elser, J.J. and<br>Goldman, C.R.<br>1991 |
| Castle                                            | Meso-oligotrophic                | 10ℓ                  | <i>Daphnia rosea</i><br><i>Holopedium</i><br><i>gibberum</i><br><i>Diaptomus</i> sp<br>or<br><i>Daphnia pulex</i>                                                                | and a separate group<br>of experiments using<br>a gradient in<br><i>Daphnia</i> sp density<br>1, 2, 4, 8 or 16<br>animals ℓ <sup>-1</sup>        | Castle Lake total biovolume<br>decreased with both<br>increasing levels of ambient<br>zooplankton and <i>Daphnia</i>                                                                 | In Castle Lake NH <sub>4</sub> <sup>+</sup> also<br>increased with higher<br>grazer biomass but P uptake<br>declined implying there was<br>a decline in the degree of P<br>deficiency |                                          |
| Clear<br>(U.S.A.)                                 | Strongly eutrophic               | 10ℓ                  | <i>Daphnia pulex</i><br><i>D. galeata</i><br><i>Diaptomus</i> sp<br><i>Mesocyclops</i> sp<br>or <i>Daphnia schodleri</i>                                                         |                                                                                                                                                  | Manipulation of ambient<br>zooplankton in Clear lake<br>produced no significant changes<br>in total algal biovolume. This<br>response also occurred with<br><i>Daphnia</i> additions | No significant responses<br>were recorded for Clear<br>Lake                                                                                                                           |                                          |
| Rotomanuka                                        | Meso-eutrophic                   | 1,200ℓ               | -                                                                                                                                                                                | Absent or lake<br>surface ambient<br>concentrations                                                                                              | Rotomanuka phytoplankton<br>showed marked increases in<br>biomass in the absence of<br>zooplankton.<br>Maratoto phytoplankton were<br>not responsive to zooplankton<br>absence       | -                                                                                                                                                                                     | Etheredge, M.K.<br>1987                  |
| Maratoto<br>(N. Z.)                               | Dystrophic                       |                      |                                                                                                                                                                                  |                                                                                                                                                  |                                                                                                                                                                                      |                                                                                                                                                                                       |                                          |
| Simulated<br>Epilimnetic<br>Community<br>(U.S.A.) | Constant<br>nutrient<br>addition | 200ℓ<br>(steel drum) | <i>Daphnia magna</i>                                                                                                                                                             | 0.25 animals<br>ℓ <sup>-1</sup>                                                                                                                  | Standing stocks of algae<br>were lower in the presence<br>of <i>Daphnia</i>                                                                                                          | -                                                                                                                                                                                     | Elliott, F.T.<br><i>et al.</i> 1983      |
| Gjersjoen<br>(Norway)                             | Meso-eutrophic                   | 7m <sup>3</sup>      | <i>Thermocyclops</i> sp<br><i>Mesocyclops</i><br><i>leuckarti</i><br><i>Bosmina longirostris</i><br><i>Daphnia</i> spp or with<br>additional <i>Daphnia</i><br><i>longispina</i> | Enclosures contained<br>natural lake zooplank-<br>ton at epilimnetic<br>densities with or with-<br>out added <i>Daphnia</i><br><i>longispina</i> | Experiments were performed<br>in spring, summer and autumn.<br>Only in summer did both<br>lake zooplankton with or<br>without <i>Daphnia longispina</i><br>reduce Chl a              | -                                                                                                                                                                                     | Faafeng, B.D.<br><i>et al.</i> 1990      |

|                                            |                         |                           |                                                                                                                                   |                                                                                                          |                                                                                                                                                                                                                          |                                                                                                                                  |                                           |
|--------------------------------------------|-------------------------|---------------------------|-----------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------|
| Green<br>(U.S.A.)                          | -                       | 12m <sup>3</sup>          | <i>Daphnia</i> , <i>Bosmina</i><br>and copepods                                                                                   | -                                                                                                        | Increasing zooplankton<br>concentrations resulted in<br>decreasing phytoplankton<br>concentrations                                                                                                                       | -                                                                                                                                | Goad, J.A.<br>1984                        |
| Cheat<br>(U.S.A.)                          | Acidic<br>oligotrophic  | 1.75m <sup>3</sup>        | <i>Cyclopoid</i> nauplii<br><i>Cyclopoid</i> copepodites<br><i>Bosmina longirostris</i><br><i>Keratella cochlearis</i>            | Approximately<br>mean lake<br>densities                                                                  | Despite marked differences<br>in herbivore abundance<br>total algal volume never<br>differed significantly                                                                                                               | -                                                                                                                                | Havens, K. and<br>de Costa, J.<br>1985    |
| Pond B<br>(Water<br>reservoir)<br>(U.S.A.) | -                       | 1,570ℓ                    | rotifers, small<br>cladocera,<br>copepoda                                                                                         | Lower density<br>and mean length<br>than lake<br>populations                                             | -                                                                                                                                                                                                                        | Decreased body size of<br>zooplankton resulted<br>in an increase in the<br>amount and turnover<br>time of phosphorus             | Henry, R.L.<br>1985                       |
| Rotongaio<br>(N. Z.)                       | Eutrophic               | 4ℓ and<br>20ℓ             | <i>Boeckella propinqua</i><br><i>Ceriodaphnia dubia</i><br><i>Bosmina meridionalis</i>                                            | A gradient of<br>zooplankton<br>biomass                                                                  | Chlorophyll <i>a</i> showed a<br>significant negative linear<br>change with increasing<br>zooplankton biomass                                                                                                            | Phytoplankton growth was<br>not stimulated by addition<br>of nutrients, suggesting<br>nutrient regeneration was<br>not important | James, M R.<br>Forsyth, D J.<br>1990      |
| Mekkojarvi<br>(Finland)                    | Polyhumic               | 500ℓ<br>(outdoor<br>tank) | <i>Daphnia longispina</i>                                                                                                         | With or without<br><i>Daphnia</i> from<br>epilimnetic water                                              | In the presence of <i>Daphnia</i><br>phytoplankton biomass was<br>rapidly depleted                                                                                                                                       | Zooplankton could provide<br>a major contribution to<br>the total P requirements<br>for phytoplankton production                 | James, M.R.<br>and<br>Salonen, K.<br>1991 |
| Mitchell<br>(U.S.A.)                       | Mesotrophic             | 12,000ℓ                   | <i>Daphnia rosea</i><br><i>D. pulicaria</i><br><i>Diaphanosoma</i><br><i>brachyurum</i><br><i>Bosminia</i><br><i>longirostris</i> | Natural surface<br>water assemblages,<br>selectively enriched<br>and selectively<br>lowered<br>densities | Total phytoplankton cell<br>densities persist at<br>comparable levels before<br>and after grazer fluctuations.<br>Reduction in <i>Daphnia</i><br>abundance led to immediate<br>increases in highly edible<br>flagellates | -                                                                                                                                | Kerfoot, W.C.<br><i>et al.</i> 1988       |
| Schohsee<br>(Germany)                      | Moderately<br>eutrophic | 1.7m <sup>3</sup>         | <i>Daphnia galeata</i><br><i>D. hyalina</i><br><i>Eudiaptomus</i><br><i>gracilis</i><br><i>E. graciloides</i>                     | Zooplankton<br>density in the bags<br>changed in the same<br>relative fashion as in<br>the lake          | In all zooplankton-free<br>bags, without exception,<br>Chla in the size fraction<br><35μm was higher at the<br>end of an experiment than<br>in the bags with grazers                                                     | -                                                                                                                                | Lampert, W.<br><i>et al.</i> 1986         |

|                        |                                     |                          |                                                                                                                                                                                                                         |                                                                                                         |                                                                                                                                                                                                 |                                                                                                                                                                                                                   |                                    |
|------------------------|-------------------------------------|--------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------|
| Pleasant Pond (U.S.A.) | Phytoplankton not limited by P or N | 1m diameter<br>1.8m deep | <i>Daphnia pulex</i><br><i>D. siciloides</i><br><i>Ceriodaphnia reticulata</i>                                                                                                                                          | Surface lake populations of zooplankton whose densities declined with addition of zooplanktivorous fish | At even the lowest level of fish predation all <i>Daphnia pulex</i> were removed and total algal biomass increased over control (no fish) densities by more than an order of magnitude          | -                                                                                                                                                                                                                 | Lynch, M. and Shapiro, J. 1981     |
| St George (Canada)     | Meso-eutrophic                      | 750,000 ℓ                | <i>Daphnia</i><br><i>Ceriodaphnia</i><br><i>Bosmina</i><br>rotifers                                                                                                                                                     | Ambient lake densities and treatments with fish added which lowered mean body lengths of zooplankton    | Phytoplankton biomass (Chl <i>a</i> ) was higher in the enclosures with fish where planktivore predation had reduced the abundance of large zooplankton                                         | Phosphate turnover time was significantly faster (i.e. more severe phosphate limitation) in enclosures with fish than in enclosures lacking fish                                                                  | Mazumder, A. <i>et al.</i> 1990(b) |
| Heney (Canada)         | Low-nutrient status                 | 8,000 ℓ                  | <i>Chydorus sphaericus</i><br><i>Bosmina longirostris</i><br><i>Ceriodaphnia reticulata</i><br><i>Daphnia retrocurva</i><br><i>D. galeata</i><br><i>D. longiremis</i><br><i>Diaphanosoma</i> sp<br><i>Holopedium</i> sp | Ambient lake densities and densities reduced by netting                                                 | Total phytoplankton volume was unaffected by reduced herbivore levels relative to controls. However, the relative density of the edible (<50µm) species increased with reduced herbivore levels | -                                                                                                                                                                                                                 | McCauley, E. Briand, F. 1979       |
| Memphremagog (Canada)  | Phytoplankton not limited by P      | 7,000 ℓ                  | -                                                                                                                                                                                                                       | A gradient of crustacean zooplankton biomass from ambient to very low levels                            | -                                                                                                                                                                                               | Only two of seven field experiments provided evidence that reducing zooplankton levels led to an increase in P deficiency. Zooplankton supplied P was of little significance owing to conditions of P sufficiency | McCauley, E. Kalff, J. 1987        |



|                               |                                                |                                   |                                                                                                                                                                            |                                                                                                               |                                                                                                                                                                                   |                                                                                                                                                                      |                                                                |
|-------------------------------|------------------------------------------------|-----------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------|
| Mt Bold Reservoir (Australia) | Phytoplankton growth probably nutrient limited | ~157 <i>l</i>                     | <i>Boeckella triarticulata</i><br><i>Calamoecia ampulla</i><br><i>Daphnia carinata</i><br><i>Ceriodaphnia quadrangula</i><br><i>Diaphanosoma</i> sp<br><i>Moina micura</i> | Limnocoerrals with or without 40µm screened additions of zooplankton                                          | Final Chl <i>a</i> concentrations were lower in grazed treatments. Mean net growth rates of phytoplankton were greater in ungrazed treatments                                     | -                                                                                                                                                                    | Merrick, C.J.<br>Ganf, G G.<br>1988                            |
| Americana Reservoir (Brazil)  | -                                              | ~2,500 <i>l</i>                   | <i>Daphnia</i> spp<br><i>Ceriodaphnia</i><br><i>Bosmina</i><br>rotifers                                                                                                    | Surface (0-2m) concentrations reduced in some treatments by addition of planktivorous fish                    | Phytoplankton cell density and biomass were significantly reduced in the fishless (large <i>Daphnia</i> present) enclosures, particularly in the small cell size fraction (<15µm) | -                                                                                                                                                                    | Northcote, T.G.<br><i>et al.</i> 1990                          |
| Peter and Paul (U.S.A.)       | Oligotrophic                                   | 45 <i>l</i>                       | <i>Daphnia pulex</i><br><i>D. rosea</i>                                                                                                                                    | Very low densities (0.0-0.5 zoo <i>l</i> <sup>-1</sup> ) to higher values (8-18+ zoo <i>l</i> <sup>-1</sup> ) | Additions of <i>Daphnia</i> did not change phytoplankton biomass in three out of four cases. The net effect of zooplankton was considered unimportant                             | Under conditions of high nutrient levels (nutrient addition experiments) <i>Daphnia</i> crops some of the phytoplankton and and nutrient regeneration is unimportant | Pace, M.L.<br>Funke, E.<br>1991                                |
| Texoma                        | -                                              | 900 <i>l</i><br>(outdoor tubs)    | <i>Daphnia</i><br><i>Diaphanosoma</i><br>copepods<br>rotifers<br>nauplii                                                                                                   | Zooplankton additions with 80µm mesh net with or without planktivorous fish present                           | Fish suppressed cladocerans, copepods and nauplii. Algal biomass was enhanced and mean cell size was reduced                                                                      | -                                                                                                                                                                    | Qin, J.<br>Threlkeld, S.T.<br>1990<br>(Exp 2 June 1987)        |
| Texoma (U.S.A.)               | -                                              | 7,000 <i>l</i><br>(outdoor tanks) | <i>Bosmina</i><br><i>Chydorus</i><br>copepods<br>rotifers<br>nauplii                                                                                                       | All tanks were filled with Lake Texoma water with or without planktivorous and benthivorous fish              | Cladocerans were rare and copepods and nauplii were suppressed by fish but phytoplankton were not enhanced                                                                        | -                                                                                                                                                                    | Qin, J.<br>Threlkeld, S.T.<br>1990<br>(Exp 3 July-August 1987) |

|                           |                             |                            |                                                                                      |                                                                                                                 |                                                                                                                                                                                                                                                                      |                                                                                                                                                                                                                                                                                                                                                         |                                           |
|---------------------------|-----------------------------|----------------------------|--------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------|
| Castle<br>(U.S.A.)        | Meso-oligotrophic           | 22ℓ                        | <i>Daphnia rosea</i><br><i>Holopedium gibberum</i><br><i>Diaptomus novamexicanus</i> | Few zooplankton compared to natural day time and night time densities at 3m                                     | During 5 experiments over a three month period in summer the net effect of zooplankton grazing shifted from a positive increase in algal productivity to a negative by the end of summer                                                                             | Analysis of nitrogen transformations in the epilimnion indicates that zooplankton excretion supplies substantial amounts of NH <sub>4</sub> <sup>+</sup> relative to that taken up by phytoplankton. The actively growing algae at the beginning of summer benefitted more from nutrient regeneration than the less productive community of late summer | Redfield, G.W.<br>1980                    |
| Brooker<br>(U.S.A.)       | Eutrophic                   | 2ℓ                         | Rotifers                                                                             | OX = control<br>1 -8 X ambient surface lake density                                                             | Total and chlorophycean nannoplankton decreased at every rotifer density above the control in all four seasonal experiments                                                                                                                                          | -                                                                                                                                                                                                                                                                                                                                                       | Scheda, S.M.<br>Lowell, B.C.<br>1988      |
| Crystal<br>(U.S.A.)       | Hypereutrophic              | 1.4m diameter<br>2.5m deep | <i>Daphnia galeata mendotae</i><br>or<br><i>Bosmina longirostris</i>                 | 0.25 - 0.5 ℓ <sup>-1</sup><br><br>20 ℓ <sup>-1</sup><br>(these densities resulted in equal zooplankton biomass) | <i>Bosmina</i> enclosures preceded from green to blue green dominated phytoplankton with increased algal biomass and productivity. <i>Daphnia</i> enclosures featured periods of low biomass, primary productivity and a reduced proportion of bluegreens            | -                                                                                                                                                                                                                                                                                                                                                       | Schoenberg, S.A.<br>Carlson, R.E.<br>1984 |
| Dean's Pond               | Circumneutral<br>Clear Lake | 250ℓ                       | <i>Diaptomus siciloides</i><br>cyclopoid copepods<br><i>Daphnia laevis</i>           | Natural whole-lake densities or reduced levels                                                                  | Algal biomass (Chl <i>a</i> ) was suppressed in enclosures with ambient grazer levels in six of ten experiments and enhanced in one experiment. Normal grazer biomass enhanced specific algal productivity in only one of ten experiments performed on the two lakes | Despite increased nutrient and organic levels of the dystrophic, acid lake, the algae and bacteria were no less responsive to grazers than in the circumneutral, clear lake implying little influence of grazer mediated nutrient regeneration                                                                                                          | Schoenberg, S.A. 1990                     |
| Buzzard Roost<br>(U.S.A.) | Dystrophic<br>acid lake     |                            | <i>Diaptomus sinuatus</i><br><i>Eubosmina tubicen</i><br>and rotifers                |                                                                                                                 |                                                                                                                                                                                                                                                                      |                                                                                                                                                                                                                                                                                                                                                         |                                           |

|                                                    |                       |                            |                                                                                                                                           |                                                                                                                                  |                                                                                                                                                                                                                                                           |   |                                         |
|----------------------------------------------------|-----------------------|----------------------------|-------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---|-----------------------------------------|
| Lilla<br>(Sweden)                                  | Nutrient-poor         | 250 ℓ                      | <i>Eudiaptomus gracilis</i><br><i>Bosmina longirostris</i>                                                                                | Ambient lake densities<br>or elimination by<br>rotenone application                                                              | Phytoplankton biomass and<br>production were higher in<br>grazer-free enclosures                                                                                                                                                                          | - | Svensson, J. and<br>Stenson, J.<br>1991 |
| Postfelden<br>Reservoir<br>(Germany)               | Eutrophic             | 10m in diameter<br>5m deep | <i>Brachionus calyciflorus</i><br><i>Daphnia cucullata</i>                                                                                | Either natural zoo-<br>plankton or natural<br>zooplankton with<br><i>Daphnia magna</i> at<br>10 ind. ℓ <sup>-1</sup>             | Chl <i>a</i> concentrations were<br>reduced to very low levels<br>and phytoplankton was<br>effectively eliminated in the<br><i>Daphnia</i> enclosures. With<br>natural lake zooplankton Chl <i>a</i><br>and algal densities were<br>reduced to low levels | - | Theiss, J.<br><i>et al.</i> 1990        |
| Dynamite<br>(U.S.A.)                               | Oligo-meso<br>trophic | 1,000 ℓ                    | <i>Bosmina</i><br><i>Ceriodaphnia</i><br><i>Diaphanosoma</i><br><i>Diaptomus</i><br>cyclopoid<br>copepodites                              | Natural densities of<br>zooplankton with<br>or without<br>zooplanktivorous<br>fish                                               | Phytoplankton density was<br>greater in the presence of<br>fish (with lower mean body<br>size of grazing Cladocerans)<br>especially high quality,<br>edible algae                                                                                         | - | Vanni, M. J.<br>1986(a)                 |
| Lake 221<br>Experimental<br>Lakes area<br>(Canada) | Oligotrophic          | 10,000 ℓ                   | <i>Diaptomus minutus</i><br><i>D. oregonensis</i><br><i>Daphnia galeata</i><br><i>Holopedium</i><br><i>gibberum</i><br><i>Bosmina</i> sp. | Natural densities of<br>resident zooplankton<br>with or without<br>added <i>Daphnia</i><br><i>catawba</i> (0.1 ℓ <sup>-1</sup> ) | Grazing by <i>Daphnia</i> did not<br>control phytoplankton<br>biomass in the enclosures                                                                                                                                                                   | - | Vanni, M. J.<br>1988                    |

|                                                             |           |     |                                                                                                                                                                                     |                                                                                                                                         |                                                                                                                                                                                                                                                                                                                                                                                  |                                                                                                                                                                                                                                                                                                              |                                          |
|-------------------------------------------------------------|-----------|-----|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------|
| Mendota<br>(U.S.A.)                                         | Eutrophic | 19ℓ | <i>Diacyclops</i> sp.<br>cyclopoid copepodites<br>—<br><i>Diacyclops</i> sp.<br><i>Daphnia galeata</i><br>—<br><i>Mesocyclops</i> sp.<br><i>Leptodiaptomus</i><br><i>siciloides</i> | Gradient in both ambient zooplankton densities and a separate group of experiments using a gradient in <i>Daphnia pulicaria</i> density | In the first experimental series (during the spring bloom of phytoplankton) both ambient zooplankton and the <i>Daphnia</i> treatments reduced phytoplankton biomass. During the second experimental series (clear-water phase) only the <i>Daphnia</i> gradient reduced algal biomass. In the third series (summer) neither zooplankton gradient reduced phytoplankton biomass. | During the spring bloom experiments phytoplankton biomass was not significantly nutrient limited. This was also true of clear-water phase experiments. In summer algal biomass was strongly nutrient limited and it was suggested that grazing losses may balance the positive effects of nutrient excretion | Vanni, M. J.<br>and<br>Temte, J.<br>1990 |
| Velky Palenec<br>and<br>Smyslov<br>(Fish ponds)<br>(Prague) | Eutrophic | 50ℓ | -                                                                                                                                                                                   | Surface pond levels of natural zooplankton with or without additional <i>Daphnia</i> spp.                                               | Grazing had a positive effect on the growth of net phytoplankton (>40μm). Nanoplankton species (<40μm) were suppressed                                                                                                                                                                                                                                                           | -                                                                                                                                                                                                                                                                                                            | Vyhnaek, V.<br>1983                      |

**Table 6.2** Summary of regression analyses

Regression of total phytoplankton biomass ( $\leq 80\mu\text{m}$ ) against total zooplankton biomass for Lake Rotoroa (Experiments 1-4) and Lake Pupuke (Experiments 5-8) on Day 6. Units for the intercept (constant) are  $\text{mg m}^{-3}$  ( $n=8$ ).

| Experiment       | Equation                  | $r^2$  | p     | Figure |
|------------------|---------------------------|--------|-------|--------|
| 1. (Autumn 1990) | $y = 1179.679 - 0.508x$   | 0.085  | 0.484 | 6.33   |
| 2. (Winter 1990) | $y = 4027.384 - 430.997x$ | 0.856* | 0.001 | 6.34   |
| 3. (Spring 1990) | $y = 1217.062 - 179.788x$ | 0.907* | 0.000 | 6.35   |
| 4. (Summer 1991) | $y = 7604.417 - 8.590x$   | 0.707  | 0.009 | 6.36   |
| 5. (Autumn 1991) | $y = 3009.797 - 22.909x$  | 0.418  | 0.083 | 6.37   |
| 6. (Winter 1991) | $y = 1045.030 - 12.000x$  | 0.476  | 0.058 | 6.38   |
| 7. (Spring 1991) | $y = 4572.005 - 632.015x$ | 0.622* | 0.020 | 6.39   |
| 8. (Summer 1992) | $y = 1833.249 + 13.412x$  | 0.657  | 0.015 | 6.40   |

Regression of total phytoplankton biomass ( $\leq 80\mu\text{m}$ ) against total zooplankton biomass for Lake Rotoroa (Experiments 1-4) and Lake Pupuke (Experiments 5-8) on Day 10. Units for the intercept (constant) are  $\text{mg m}^{-3}$  ( $n = 8$ ).

| Experiment       | Equation                  | $r^2$  | p     |
|------------------|---------------------------|--------|-------|
| 1. (Autumn 1990) | $y = 1695.804 - 2.057x$   | 0.570  | 0.030 |
| 2. (Winter 1990) | $y = 2609.028 - 4.555x$   | 0.746  | 0.006 |
| 3. (Spring 1990) | $y = 829.773 - 2.582x$    | 0.432  | 0.077 |
| 4. (Summer 1991) | $y = 6928.134 - 4.794x$   | 0.417  | 0.084 |
| 5. (Autumn 1991) | $y = 3281.064 - 495.332x$ | 0.566* | 0.031 |
| 6. (Winter 1991) | $y = 4670.672 - 55.464x$  | 0.659  | 0.014 |
| 7. (Spring 1991) | $y = 2899.129 - 11.751x$  | 0.403  | 0.091 |
| 8. (Summer 1992) | $y = 416.958 + 452.685x$  | 0.460* | 0.065 |

Regression of total phytoplankton biomass ( $\leq 80\mu\text{m} + >80\mu\text{m}$  fractions) against total zooplankton biomass for Experiments 1 (Autumn) and 2 (Winter) in Lake Rotoroa on Day 6. Units for the intercept (constant) are  $\text{mg m}^{-3}$  ( $n = 8$ ).

| Experiment       | Equation                   | $r^2$ | p     |
|------------------|----------------------------|-------|-------|
| 1. (Autumn 1990) | $y = 10310.933 + 64.852x$  | 0.547 | 0.036 |
| 2. (Winter 1990) | $y = -3866.768 + 447.123x$ | 0.925 | 0.000 |

\* data had a better fit with log transformed zooplankton biomass

In Experiment 8 (Summer) again there were no significant differences in total algal biomass between limnocorral treatments and the lake on Day 0 (4/2/92) (Fig. 6.29). This situation was also apparent on Day 3 (7/2/92) although there seemed to be a trend towards decreasing phytoplankton biomass particularly amongst the enclosure and (1X) enclosure treatments (Fig. 6.30). By Day 6 (10/2/92) there was significantly higher algal biomass in the (4X) enclosure treatment than in both the enclosures and the (1X) enclosure treatment (Fig. 6.31). A significant positive regression of total algal biomass against zooplankton biomass on Day 6 supported this observation (Fig. 6.40). On Day 10 (14/2/92) there was a significant relationship between phytoplankton biomass and log transformed zooplankton biomass. However the relationship was weaker than on Day 6 and ANOVA performed across treatment combinations revealed no significant differences in total algal biomass (see Fig. 6.32 and Table 6.2)).

### 6.3 Discussion

The intention of all seasonal experiments conducted on both study lakes was to establish the initial algal complement of each limnocorral and to compare these with an adjacent lake site. After a six-day period a re-comparison was conducted to establish potential differences amongst treatments and the lake. A six-day experimental interval was decided on for reasons discussed in Chapter Three. Comparisons were also made on the last date of each experiment (Day 10) and were designed to evaluate whether patterns established at Day 6 continued to Day 10. Using a six-day experimental interval and a significance level of  $p = 0.05$  in the regression of algal biomass against zooplankton, then in Lake Rotorua, Experiment 1 (Autumn) generated a non-significant response and Experiments 2, 3 and 4 all displayed significant reductions in algal biomass with increasing zooplankton biomass. In Lake Pupuke in Experiments 5 (Autumn) and 6 (Winter) there was no algal response to grazing. Experiment 7 (Spring) yielded a significant decline in algal biomass with increasing zooplankton biomass and the reverse situation was apparent in Experiment 8 (Summer). Therefore across all eight

experiments, three were non-significant, four indicated a suppression of algal biomass and one experiment indicated an increase of algal biomass.

At the completion of each experiment - Day 10 - (if assumptions generated for a six-day experimental interval still apply) at a level of significance of 0.10 there were significant reductions in algal biomass in Experiment 1 (Autumn) in Lake Rotoroa and in Experiments 2, 3 and 4. In Lake Pupuke Experiment 5 (Autumn) yielded a significant reduction algal biomass against log-transformed zooplankton biomass and this negative relationship was apparent for Experiments 6 and 7. Experiment 8 (Summer) in Lake Pupuke suggested an increase in algal biomass with grazer abundance. Therefore across all eight experiments - seven indicated a significant suppression of algal biomass and one experiment indicated an enhancement of algal biomass.

It becomes apparent from this summary that there appears to be considerable variation in the impact of zooplankton grazing on total algal biomass. It is also important to realize that total algal biomass in the context of this investigation applies to that fraction of phytoplankton  $\leq 80 \mu\text{m}$  in greatest axial linear dimension (GALD). When I regressed total algal biomass in fractions  $\leq 80 \mu\text{m}$  and  $>80 \mu\text{m}$  together against the gradient in zooplankton biomass for Experiments 1 and 2 on Lake Rotoroa a potential confounding factor in the interpretation of the results emerged. On Days 6 and 10 for both experiments the slope of the regressions became significantly positive, that is to say, total algal biomass ( $\leq 80 \mu\text{m} + >80 \mu\text{m}$ ) increased with increasing zooplankton biomass. The increase in algal biomass in Experiment 1 was caused by a significant increase in the growth rate of *Dinobryon cylindricum* (see Chapter Seven) and a possible increase in the biomass of *Botryococcus braunii*. In Experiment 2 (Winter) in Lake Rotoroa *Botryococcus* may again have been responsible for the increasing algal biomass across the gradient in zooplankton biomass. However, counts of *Botryococcus* were extremely low (generally less than ten colonies across the entire basal plate of a sedimentation chamber) for every experiment making it impossible to accurately describe changes in

algal growth rate due to the associated errors in determining actual numbers (P.U. ml<sup>-1</sup>). As indicated in Chapter Three rough counts of this species were recorded for Experiments 3 and 4 as well, and the patterns suggested for Experiments 1 and 2 also apply. Interestingly, Wilcox and DeCosta (1990) recorded *Botryococcus braunii* and *Dinobryon divergens* in their limnocorral samples and suggested both species demonstrated pronounced “bag effects” by increasing in numbers (and biomass) in all bag treatments while having a lower cell volume in the lake. It would appear that this is also the case for the Lake Rotoroa experiments.

I support the view of Bloesch *et al.* (1988) who consider that the results from limnocorral experiments should be interpreted in a cautious and therefore conservative manner. With this in mind I believe the results of all seasonal experiments should be viewed in the context of the small number of data points available and the potential confounding role of algae greater than 80 µm in GALD. Therefore in Lake Rotoroa, after six days the algal biomass in the fraction ≤ 80 µm was significantly ( $p = 0.05$ ) reduced in 3 experiments but not in one. Total zooplankton biomass (≤ 80 µm + >80 µm) after six days I consider non-responsive to the gradient in algal biomass. In Lake Pupuke algal biomass in the fraction ≤ 80 µm was significantly ( $p = 0.05$ ) reduced in one experiment, was non-responsive in two and increased in one. Total algal biomass (≤ 80 µm + >80 µm) I consider to have followed the same patterns observed for the fraction ≤ 80 µm.

On only one occasion, Experiment 2 (Winter) in Lake Rotoroa, were there statistically significant differences between the limnocorrals and the lake. Generally, on other days differences were most apparent between the enclosure treatment and lake values and much less so for all other enclosure treatments. Initially this makes sense as the enclosure treatment lacks the range of potential zooplankton biomass found throughout the water column of both study lakes (see Appendix I). The expectation that any treatments (exclosures or enclosures) should resemble the lake beyond Day 0 is



questionable (Mazumder *et al.* 1990a). Although enclosed natural populations are referred to as “control” in the context of an experiment, they cannot be compared with the lake because they exclude fish. New Zealand lakes often lack vertebrate predators on zooplankton (Burns 1991) and it could be argued that for this reason fish exert little influence of zooplankton dynamics. However, fish have the potential to indirectly alter nutrient regimes in the water column (see Northcote 1988 for a review) especially in shallow lakes such as Lake Rotoroa. Additionally, the limnocorrals of this investigation allow only limited vertical migration ( $\approx 4\text{m}$ ) of zooplankton, and this may be especially important in a deep lake like Lake Pupuke, where vertical migration of zooplankton has previously been recorded (Chapman and Green 1987). Therefore, the phytoplankton in these enclosures were not spatially segregated from their predators and could potentially be consumed at high rates 24 hours per day.

For these reasons alone I would argue that comparisons with adjacent lake sites are useful in determining whether there were similar initial conditions between the lake and the limnocorrals, i.e. whether the methodologies employed in limnocorral deployment radically altered natural abundances and compositions of the planktonic communities. Such a comparison also makes determination of any “bag effects” on enclosed populations easier to establish so that species of zooplankton and phytoplankton adversely affected by “enclosure” can be eliminated from analyses. In this context, the limnocorrals in this study supported planktonic populations within the range of values encompassed by lake populations and did not appear to adversely effect any species of zooplankton or phytoplankton (see Chapter Three).

Extending the results of Section 6.2 beyond comparisons between the limnocorral treatments and the associated parent lake to the comparison of *in situ* enclosure research in other lake systems requires due caution. Table 6.1 summarises 38 research projects that have a similar focus to the current study. This table represents recent examples of limnocorral based research and is in no way a complete literature review of the study

area. The studies encompass a range of lake types, trophic statuses, experiment lengths, enclosure sizes, and planktonic communities. The principal aim of making comparisons between these studies is to indicate how the results of my work compare with a spectrum of possible responses.

In terms of the response of total algal biomass (or Chl *a*) to zooplankton grazing the studies may be arbitrarily divided into two groups: those which found a reduction in phytoplankton and those where algal biomass was unresponsive or increased in the presence of grazers. 27 of the 38 reported studies fell into the former category, of which two cases reported algal reductions only in the presence of a gradient in *Daphnia* species biomass alone. Of these, there were only four cases in which the lakes were either infertile, (i.e. described as oligotrophic) or where the phytoplankton was suggested to be nutrient limited - these were Elser *et al.* 1987; Elser *et al.* 1988; Merrick and Ganf 1988 and Svensson and Stenson 1991. Both studies conducted by Elser *et al.* (1987; 1988) were in the infertile, nutrient limited lakes Peter, Paul and Tuesday, and the results suggested either that the overall change in chlorophyll *a* was not large or that the response of the phytoplankton communities was often contradictory. Instances where there was either a lack of algal response or exponential increase were also found. Merrick and Ganf (1988) assumed the phytoplankton was probably nutrient limited because the experiments were conducted in summer during thermal stratification. Interestingly, their final experiment, conducted after stratification had broken down, and when nutrient concentrations in the surface waters may have been increasing, generated by far the strongest suppression of Chl *a*. The only study in which there was consistent suppression of algal growth by zooplankton in a nutrient poor environment is that of Svensson and Stenson (1991).

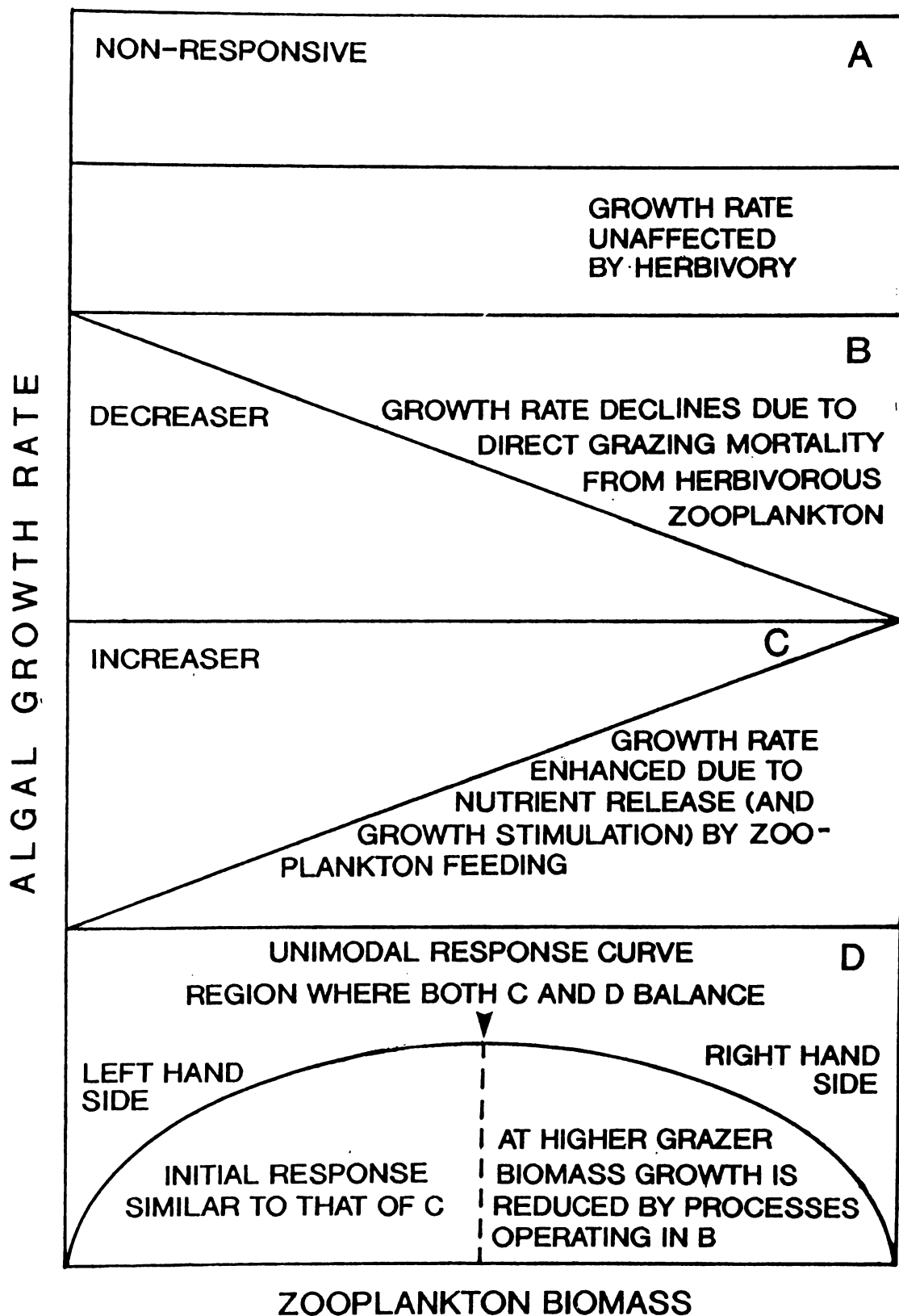
Of the eleven studies reporting either a lack of response, or an enhancement of algal biomass due to grazing, nine investigations were in lakes considered infertile, (i.e. oligotrophic) or in which the phytoplankton was considered to be nutrient limited. Only

two cases reported instances where such responses occurred in more productive lakes. Dawidowicz (1990) suggested that there was an increase in Chl *a* in enclosures containing natural lake zooplankton in mesotrophic Lake Ros, however those to which additional *Daphnia magna* were added showed a decrease in Chl *a*. In Clear Lake, manipulation of ambient zooplankton and a gradient of *Daphnia* biomass had no impact on total algal biovolume (Elser and Goldman 1991). These workers argued that the majority of algal biomass was unavailable to zooplankton grazers due to its large size and inedibility.

The results of the present study span the range of possible responses of total algal biomass to increase in zooplankton biomass, i.e. from suppression, through no change, to an increase. The results could be interpreted as supporting views that either zooplankton grazing has positive correlations with Chl *a* concentration, little or no effect on primary productivity, or can depress primary production (see Sterner 1989 for a review). Such conflicting results suggest that there is a unimodal response of primary productivity to zooplankton grazing, and that conflicting data may represent opposite sides of the response curve (Bergquist and Carpenter 1986) (Fig. 6.41). The unimodal response results from an initial increase in primary productivity due to zooplankton grazing releasing nutrients into the water column available for phytoplankton uptake and growth. Above a certain level of herbivore biomass algal productivity declines as the loss of phytoplankton cells to ingestion is higher than the gains made from nutrient uptake.

This concept was supported by Elser *et al.* (1987) who also highlighted the reports of both negative and positive correlations between zooplankton abundance and algal biomass and productivity. They argued that apparently conflicting results probably reflect the compensatory processes of nutrient regeneration and grazing loss, through their effects on algal nutrient status and size distribution.

**Figure 6.41: Responses of Phytoplankton Growth Rate to Zooplankton Grazing**



The only occasion in my study where phytoplankton biomass responded positively to grazer biomass was Experiment 8 (Summer) on Lake Pupuke. In this experiment the surface waters were cut off from the sediments due to stratification, and nutrient levels were the lowest recorded from either Lake Pupuke or Lake Rotoroa (see Chapter Nine). This experiment would suggest the phytoplankton response fell on the left-hand side of a unimodal response curve. The majority of the other experiments indicated a lack of algal response, (in Lake Rotoroa only in the fraction  $\leq 80 \mu\text{m}$ ), and may represent instances where the experimental response lies at the top part of the unimodal response curve. The only instance where total algal biomass was significantly reduced (by Day 6) was Experiment 7 (Spring) in Lake Pupuke, conducted during turnover when nutrient levels were elevated. This example may illustrate a response lying on the right-hand side of the curve. This view of a significant reduction in algal biomass when nutrient levels are not limiting phytoplankton growth is exemplified in the examples chosen from Table 6.1. The general conclusion is that the quantitative effects of grazing strengthen with enrichment and is supported by most factorial manipulations of grazers and nutrients (see Sarnelle 1992 for a review).

Such unimodal responses of specific-specific algal growth rates are well known from the literature (e.g. Elser *et al.* 1987; Vanni and Temte 1990 and Elser and Goldman 1991) and were observed in the present study as well (See Chapter Seven). The translation of this curve beyond the population level to a community-wide response was inevitable and was first done by Sager and Richman (1991) studying the functional interaction of phytoplankton and zooplankton along a trophic gradient in Lake Michigan. Their results take a mathematical construct away from the realms of theory - the unimodal response curve is a real phenomenon, operating not only at the boundary between zooplankton and phytoplankton but potentially at the microbial level as well. Pace and Funke (1991) suggest that the regulation of bacteria may vary across gradients of system productivity in aquatic environments, with resource control being more important in systems with low productivity such as Peter and Paul Lakes (described above).

The compensatory mechanisms of grazing mortality and nutrient regeneration fundamental to the unimodal response curve have particular relevance to the present study. In the majority of experiments total algal biomass (particularly if in the case of Lake Rotoroa with the fraction  $>80\ \mu\text{m}$  included) was non-responsive to grazing. This lack of a net immediate effect of grazing on algal biomass may reflect an equal balance between grazing loss and gains resulting from nutrient regeneration, as exemplified by the studies of Elser *et al.* (1987) and Vanni and Temte (1990). They argue that the net result of such compensatory processes would be a lack of a pronounced community biovolume response to zooplankton biomass. Table 6.1 illustrates two such examples of this apparent lack of response at the community level. McCauley and Briand (1979) found total phytoplankton volume was unaffected by reduced herbivore levels but that the relative density of the edible ( $<50\ \mu\text{m}$ ) fraction increased. The parallels to the seasonal experiments conducted in Lake Rotoroa (particularly for the algal size fraction  $<80\ \mu\text{m}$ ) are obvious. Kerfoot *et al.* (1988) also noted that total phytoplankton cell densities persisted at comparable levels before and after grazer fluctuations but that reduction in *Daphnia* abundance led to an immediate increase in highly edible flagellates. Mazumder *et al.* (1990b) argued that large inedible phytoplankton, which usually cannot compete with small cells, may take advantage of the available nutrients and increase in abundance following reduction in the abundance of nanoplankton by the large grazers. Therefore total algal biomass will be reduced less than nanoplankton biomass, and the effect of mesozooplankton grazing on water clarity will be greater than might be expected from changes in phytoplankton biomass or Chlorophyll *a* concentration alone. These studies all support the contention that a lack of response at the community level for phytoplankton is not indicative of a lack of response at the population level or amongst various size classes of the plankton. The variety of species-specific algal responses to the gradient of zooplankton biomasses found in the present study (Chapter Seven) clearly illustrate that studies based solely on community level responses omit a great deal of the underlying complexity inherent in planktonic assemblages.

Reviewing the zooplankton composition of the limnocorrals employed during the studies reported in Table 6.1 reveals a high incidence of communities dominated by cladocerans, in particular daphnids. This is a feature of most Northern Hemisphere enclosure based studies and has been noted previously (Scheda and Cowell 1988; Edgar 1989). This is not to say that cyclopoid or calanoid copepods have been deliberately removed or selectively reduced in abundance in these studies, but that they generally have contributed less than 20% of total zooplankton biomass and in most cases considerably less than 10%. The ability of daphnids to reduce algal biomass has been demonstrated in a number of experimental studies (e.g. Dawidowicz 1990; Faafeng *et al.* 1990; Vanni and Temte 1990; James and Salonen 1991; Elser and Goldman 1991) and modelling of daphnid-phytoplankton interactions has clearly revealed the potential for these zooplankters to reduce algal abundance (e.g. Liebold 1989; Sarnelle 1992). Given the importance of calanoid copepods in the food chains of oceans and lakes (De Mott and Watson 1991) it would appear that the potential for copepods to reduce algal biomass may have been underemphasised in the past. As Haney (1987) pointed out in his review of field studies based on zooplankton-cyanobacterial interactions, New Zealand eutrophic lakes are often dominated by species of the calanoid genera *Boeckella* and/or *Calamoecia* and this clearly contradicts the frequent observation from lakes in the Northern Hemisphere that cladocerans tend to dominate in eutrophic lakes.

New Zealand lakes provide interesting study sites for determining the impact of calanoid copepods on phytoplankton dynamics. In an enclosure based study Etheredge (1987) demonstrated the potential for the zooplankton community of Lake Rotomanuka, a clear water Waikato lake approximately 15 kms south of Lake Rotoroa, to substantially reduce total algal biomass. Later, in the same lake, I made a whole-year enclosure-based study on the role of grazing by *Calamoecia lucasi* (late stage copepodites and adults) grazing on phytoplankton (Edgar 1989). The methodologies employed were very similar to those of the present study and showed that *C. lucasi* significantly influenced

phytoplankton dynamics. Generally, as the biomass of the copepods varied during the course of the year so too did their influence on algal biomass. The highest levels of copepod biomass (during Summer 1988) resulted in the lowest levels of algal biomass - up to 50% reduction in the enclosures containing a (1X) ambient lake-wide biomass of grazers compared to grazer-free exclosures. *C. lucasi* contributed a substantial portion to the zooplankton biomass of both study lakes of the present investigation and its potential to contribute to a decline in algal biomass has been described above.

The influence of calanoid copepods on phytoplankton biomass and species-specific algal growth rates is not restricted to the upper-half of the North Island of New Zealand but has been noted in lakes across the country (Chapman and Green 1987; Burns 1991). The work of James and Forsyth (1990) on the volcanic plateau of the North Island of New Zealand, and Burns and Xu (1990) studying feeding of *Boeckella* species in South Island lakes provide clear evidence for the potential of New Zealand copepods to reduce algal abundance, particularly of filamentous cyanobacteria. James and Forsyth (1990) suggest that large filamentous algae have generally been considered inaccessible to most zooplankton species and that the studies supporting this opinion have mostly been on lakes dominated by the passive filter-feeding *Daphnia*. However, the zooplankton of their study lake, Lake Rotongaio, was dominated by calanoid copepods (*Boeckella propinqua* in particular) which were capable of both passive filtering and raptorial feeding. In Lake Rotongaio *Anabaena minutissima* var. *attenuata* contributed >90% of available phytoplankton cells, and measured loss rates showed it was the major food source of *B. propinqua*.

The ability of calanoid copepods, *Boeckella* species primarily, to consume filamentous cyanobacteria has also been recognised by Burns and Xu (1990) who examined the relative abilities of three species of *Boeckella* to graze on a range of cyanobacterial species. They discovered all the *Boeckella* species consumed cyanobacteria, some species at similar rates to *Cyclotella* (a paired food source). The grazing of these



copepod species dramatically decreased the trichome lengths of three of the algal species and the authors suggest this behaviour could possibly alter the potential susceptibility of these filamentous cyanobacteria to grazing by other zooplankton. This finding of reduction in trichome length associated with *Boeckella* feeding was also reported by James and Forsyth (1990) and the contention that New Zealand calanoid copepods appear to utilise cyanobacterial filaments as a food source was reviewed by Haney (1987).

The ability of calanoid copepods to reduce algal biomass has been noted in other studies as well (e.g. Henrikson *et al.* 1980; Olrik *et al.* 1984; Dorazio *et al.* 1987; Svensson and Stenson 1991; Lair 1992). It is interesting to note the only example in Table 6.1 in complete opposition to the trend noted above of substantial reduction in algal biomass being associated with a lack of phytoplankton nutrient limitation, came from the study of Svensson and Stenson (1991) working in Lake Lilla Stockelidsvatten (Sweden), a nutrient-poor forest lake. The dominant zooplankton species in this study was *Eudiaptomus gracilis* which made up 55-99% of zooplankton biovolume. This calanoid copepod caused substantial reductions in phytoplankton biomass and production.

McQueen and Post (1988) recognised the potential for an inability of zooplankton grazing to suppress phytoplankton biomass at the zooplankton-phytoplankton interface and this has been illustrated by numerous examples in Table 6.1. *Daphnia* constituted the major zooplankton biomass of this study and it may be that calanoid copepods, in particular, may provide a mechanism for increasing the coupling between grazer and producer interfaces. There has been a tendency to try to introduce large-bodied *Daphnia* into lakes lacking these species to induce drastic reductions in phytoplankton abundance (e.g. Vanni 1986b; Theiss *et al.* 1990). It may be that the injection of high biomasses of copepods could be equally, or even more, successful in lakes where large cyanobacterial species are present.

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In conclusion, this chapter has demonstrated the potential for the zooplankton of both Lakes Rotoroa and Pupuke to alter the biomass of phytoplankton, especially that portion  $\leq 80 \mu\text{m}$ , and that this influence varies seasonally. Comparisons with other enclosure based research indicates that the results of this study fall into a spectrum of possible responses by algae to zooplankton grazing and that there are definite links between response type and level of phytoplankton nutrient limitation. After an examination of phytoplankton species-specific responses, (Chapter Seven), possible zooplankton selectivity patterns (Chapter Eight) and the influence of zooplankton grazing on nutrient regimes (Chapter Nine), an attempt will be made to incorporate this material into current schemes depicting the variable influence of zooplankton herbivory on phytoplankton assemblages.

## CHAPTER SEVEN

### PHYTOPLANKTON SPECIES-SPECIFIC RESPONSES

#### 7.1 Introduction

In conjunction with the investigation of zooplankton herbivory on total phytoplankton biomass, an attempt was made to relate these community level responses to changes in the underlying algal populations. The net growth rate, in terms of a change in species population density, was regressed against zooplankton biomass for all algal species. All experiments had phytoplankton taxa whose growth rate responded negatively, positively or, in some cases, unimodally to zooplankton presence. A summary of each algal species response to grazing in both Lakes Rotoroa and Pupuke is presented in Tables 7.1 and 7.2. Several of these taxa show similar responses to those in other studies, however, there is considerable variation in response to grazing when the results of the present study are compared to the literature.

#### 7.2. Results

##### 7.2.1 Lake Rotoroa

In Experiment 1 (Autumn) there were six species of phytoplankton present in sufficient numbers for meaningful regression analyses (see Section 2.3.1). Three taxa, *Cryptomonas ovata* / *C. marssonii* (enumerated as one species because of morphological similarity), *Cyclotella stelligera* (Fig. 7.3) and *Tetrastrum triangulare*, displayed significantly reduced growth rates in the presence of a higher biomass of zooplankton. (See Table 7.3 for regression coefficients and significance levels). Two species, *Peridinium cinctum* and *Staurastrum leptocladum* var. *insigne*, showed no significant response to increasing zooplankton biomass (Fig. 7.2). The growth rate of *Dinobryon cylindricum* increased as zooplankton biomass increased (Fig. 7.1).

In Experiment 2 (Winter) six species were also abundant enough for analysis and responses to grazing were similar to those in Experiment 1. Again, the same three phytoplankton

species *Cryptomonas ovata* / *C. marssonii*, *Cyclotella stelligera* / *C. meneghiniana* (Fig. 7.6) and *Tetrastrum triangulare* were depressed by zooplankton. *Peridinium cinctum* again was unresponsive to zooplankton biomass as was *Oocystis* cf. *lacustris* (Fig. 7.5) (Table 7.3). In this experiment *Staurastrum leptocladum* var. *insigne* was an “increaser” at the 0.10 significance level (Fig. 7.4).

In Experiment Three (Spring) eight phytoplankton species growth rates were examined. Five taxa were classified as “decreasers”: *Asterionella formosa* (Fig. 7.8), *Cryptomonas ovata* / *C. marssonii*, *Cosmarium perfissum*, *Coelastrum reticulatum* and *Scenedesmus quadricauda* / *S. ecornis*. In this experiment *Tetrastrum triangulare* was unresponsive to increasing zooplankton biomass as was *Staurastrum leptocladum* var. *insigne* (Fig. 7.7 Table 7.3). *Elakatothrix gelatinosa* exhibited a unimodal response to grazer biomass (Fig. 7.9). This response was the only one of its type for Lake Rotoroa algal species.

In the last experiment, Experiment 4 (Summer), there were ten phytoplankton species present in numbers high enough to examine responses. Seven decreased with increasing zooplankton biomass: *Cryptomonas ovata* / *C. marssonii*, *Cosmarium perfissum*, *Staurodesmus unicornis* var. *gracilis*, *Tetrastrum triangulare*, *Scenedesmus quadricauda* / *S. ecornis* and *Cyclotella stelligera* / *C. meneghiniana* (Table 7.3). *Tetrastrum triangulare* (Fig. 7.12) illustrates this response type. As in Experiment 2 (Winter) both *Peridinium cinctum* and *Oocystis* cf. *lacustris* were unresponsive to grazing pressure (Fig. 7.11). *Elakatothrix gelatinosa* (Fig. 7.10) was the only algal species whose growth rate was positive in the presence of higher zooplankton biomass.

### 7.2.2 Lake Pupuke

In Experiment 5 (Autumn) *Staurastrum leptocladum* var. *insigne*, *Staurastrum pinque* (Fig. 7.14), *Achanthes* sp. and *Oocystis* cf. *lacustris* showed significant decreases in response to zooplankton additions. Seven other phytoplankters were unresponsive to the zooplankton biomass gradient. They were *Peridinium cinctum*, *Mougeotia* sp., *Staurastrum johnsonii*

var. *altuis*, *Fragilaria crotonensis*, *Cosmarium perfissum* (Fig. 7.13), *Closterium acutum* var. *variabile* and *Scenedesmus bijuga* var. *alternans* (Table 7.2).

In Experiment 6 (Winter) there were only five phytoplankton taxa present in sufficient numbers for analysis. One of these - *Fragilaria ulna*/F. u. var. *acus* was not included in the calculation of total algal biomass (<80µm) in Chapter Six (for reasons discussed in Chapter Three) but occurred in densities high enough to allow estimation of its species-specific response to a gradient of zooplankton biomass. In this lake the same was true for *Mougeotia* sp. in Experiment 5 (Winter) and Experiment 7 (Spring), and for *Closterium aciculare* in Experiment 8 (Summer). In the case of *Fragilaria ulna*/F. u. var. *acus* there was a significant reduction in growth rate with increasing zooplankton biomass (Fig. 7.16). The other four algal species present in Experiment 6 were *Peridinium cinctum*, *Fragilaria crotonensis*, *Oocystis* cf. *lacustris* and unidentified unicells (two combined species). All four phytoplankters showed no significant response to increasing grazer biomass (Table 7.3, Fig. 7.15).

Three of the four possible response categories were shown by the nine phytoplankters investigated in Experiment 7 (Spring). Growth rates of *Mougeotia* sp. and *Fragilaria crotonensis* declined with increasing grazer biomass (Fig. 7.19). Six species were non-responsive to grazer biomass. These were *Peridinium cinctum*, *Staurastrum johnsonii* var. *altuis*, *Staurastrum leptocladum* var. *insigne*, *Staurastrum pinque*, *Scenedesmus bijuga* var. *altenans* (Fig. 7.17) and unidentified unicells. *Oocystis* cf. *lacustris* displayed a significant unimodal response to the grazer gradient (Fig. 7.18).

In Experiment 8 (Summer) three phytoplankters had increased growth rates in the presence of higher zooplankton biomass. They were *Peridinium cinctum* (Fig. 7.20), *Elakatothrix gelatinosa* and *Oocystis* cf. *lacustris*. Six of the ten phytoplankters analysed were unresponsive to the gradient in zooplankton biomass. They were *Staurastrum johnsonii* var. *altuis*, *Closterium aciculare* (Fig. 7.21), *Fragilaria crotonensis*, *Staurastrum*

*leptocladum* var. *insigne*, *Staurostrum pinque* and *Cosmarium contractum* (Table 7.3). *Scenedesmus bijuga* var. *alternans* displayed a unimodal response to the grazer gradient (Fig. 7.22).

### 7.3 Discussion

#### *Achanthes*

*Achanthes* sp. decreased in Experiment 5 in Lake Pupuke. This was the only occasion this species was recorded in sufficient numbers for regression analyses to be performed. Sommer (1988) found *Achanthes minutissima* to be one of the most edible algae in his grazing experiments. Elser and Goldman (1991) also found *Achanthes* sp. decreased in the presence of both calanoid copepod and *Daphnia* gradients in biomass. Vanni (1986(b)) considered *Achanthes* sp. an edible diatom.

#### *Asterionella*

Again, in the only experiment where *Asterionella formosa* was present this species declined in growth rate in the presence of grazers. Vyhnalek (1983) found *Asterionella formosa* decreased in the presence of *Daphnia*, though Knisely and Geller (1986) found *Asterionella* was not grazed by daphnids but was grazed by *Cyclops* sp. Bergquist *et al.* (1985) recorded no response of growth rates of *Asterionella* to the presence of *Daphnia* and *Diaptomus* species, but that it declined in abundance in the presence of *Bosmina* and rotifers. In six experiments performed by Lehman and Sandgren (1985) *Asterionella formosa* decreased in two, was not responsive in two, and increased in abundance in the other two. Based on the brood size of resident zooplankters Sarnelle (1986) considered *Asterionella* supported reproduction in *Daphnia* species. Sommer (1988) considered *A. formosa* was of intermediate edibility as did Thompson *et al.* (1982). George *et al.* (1990) also considered *Asterionella* edible as did McCauley and Briand (1979), who suggested that *Asterionella* colonies were easily broken down into fragments by *Diaptomus* species and cladocerans alike. Conversely Kerfoot *et al.* (1988) and Sommer (1991) considered *Asterionella* inaccessible to *Daphnia* due to its large size. Support for its ingestion by

zooplankton comes from gut content analyses by Nadin-Hurley and Duncan (1976), Burns (1979) with the New Zealand calanoid copepod *Boeckella dilatata*, and Mason and Abdul-Hussein (1991).

### ***Closterium***

Both *Closterium aciculare* (Experiment 8) and *Closterium acutum* var. *variabile* (Experiment 5) were unresponsive to the zooplankton gradients in Lake Pupuke. Sarnelle (1986) considered *Closterium* sp. an edible green whereas Porter (1972) found no detectable experimental effect on the total number of desmids larger than 30µm (the case for both these *Closterium* species) in the presence or absence of grazers in small-volume bag experiments. *Closterium acutum* var. *variabile* decreased in one experiment and was non-responsive to the presence of *Calamoecia lucasi* in two other enclosure experiments conducted on another Waikato lake, Lake Rotomanuka (Edgar, 1989).

### ***Coelastrum***

*Coelastrum reticulatum* was categorised as a “decreaser” in both Experiments 3 and 4 on Lake Rotoroa. Vyhnalek (1983) also found *Daphnia* reduced the abundance of *C. reticulatum* in three experiments and had no effect in one. Both Sarnelle (1986) and Kerfoot *et al.* (1988) considered the genus resistant to grazing and Schoenberg and Carlson (1984) considered *Coelastrum* capable of viable gut passage. In another enclosure-based study *Coelastrum* species declined in abundance in the presence of *Calamoecia lucasi* in the only experiment where it was present in significant numbers (Edgar 1989).

### ***Cosmarium***

In both Experiments 3 and 4 in Lake Rotoroa *Cosmarium perfissum* decreased as zooplankton biomass increased. In Lake Pupuke *C. perfissum* was unresponsive to grazers in Experiment 5. This was also the case with *C. contractum* in Experiment 8 (Table 7.2). Bleiwas and Stokes (1990) found *Cosmarium impressulum* was grazed by *Bosmina*, *Diaphanosoma* and *Diaptomus* and Elser and Goldman (1991) recorded *C. bioculatum* as a

decreaser in the presence of a *Daphnia* gradient. Bergquist *et al.* (1985) found *Cosmarium* sp. decreased in one of two experiments with *Daphnia pulex* and *Diaptomus* and was unresponsive in the other. In two experiments with *Bosmina* and rotifers *Cosmarium* sp. was unresponsive. Lynch and Shapiro (1981) also found *Cosmarium* sp. decreased in the presence of large grazers (*Daphnia* spp.) but increased in the presence of small ones (e.g. *Ceriodaphnia*). Vanni and Temte (1990) recorded *Cosmarium* sp. as unresponsive to a gradient of *Daphnia* biomass and Soto and Hulbert (1991) found *Cosmarium* sp. was either unresponsive to grazing or increased in abundance in the presence of *Diaptomus* species. Green (1976) considered *Cosmarium* sp. inedible for *Calamoecia lucasi* and both Vanni (1986(b)) and Kerfoot *et al.* (1988) record *Cosmarium* sp. as resistant. Peer (1986) considered *Cosmarium* sp. edible based on size. This was supported by gut content analysis in his investigation and that of Lynch (1978).

### *Cryptomonas*

*Cryptomonas marssonii*/*C. ovata* occurred in all four experiments performed on Lake Rotorua. On every occasion it was categorised as a “decreaser”. Knisely and Geller (1986) and Elser and Goldman (1991) both found *Cryptomonas ovata* decreased in the presence of grazers. This was true also for *C. marssonii* in the enclosure experiments of Lehman and Sandgren (1985). These workers also found *C. rostrata* decreased in four of six experiments but was unresponsive in the other two. Havens and DeCosta (1985) found *C. erosa* decreased in the presence of *Bosmina* and cyclopoid nauplii. *Cryptomonas* species were grazed in the studies of Hargrave and Geen (1970), Vyhnalek (1983), Merrick and Ganf (1988), and Lundstedt and Brett (1991). Two species of *Cryptomonas* in the study of Elser *et al.* (1987) ranged in response from decreases, to unimodal, to unresponsive. *Cryptomonas ovata* was unresponsive to grazers in the investigation of Elser and Goldman (1991), where natural lake zooplankton were used rather than *Daphnia* species. This lack of response is also apparent in the work of Fott (1975), though he believed the unchanged density of *Cryptomonas* sp. represented a balance between high growth rate and zooplankton grazing. *Cryptomonas* exhibited no consistent response pattern to grazing by



*Daphnia* in the study of Schoenberg and Carlson (1984), and Sarnelle (1986) considered *Cryptomonas* sp. a poor food source for zooplankton. However, a large number of studies support the view of *Cryptomonas* as an edible alga, for example, Green (1976) studying *Calamoecia lucasi*; Thompson *et al.* (1982); Vanni (1986(b)) who considered *C. marssonii* and *Cryptomonas* sp. edible by *Bosmina* and *Ceriodaphnia*; Post and McQueen (1987) who considered *Cryptomonas* sp. highly vulnerable to grazing by *Daphnia* but suggested its high growth rate may counter herbivory; Kerfoot *et al.* (1988); Iwakuma *et al.* (1990); Wright and Shapiro (1990) and Mason and Abdul-Hussein (1991). The fact that *Cryptomonas* species has been used as a food source in many experimental studies of zooplankton feeding is further evidence of its edibility (e.g. McQueen 1970; MacIsaac and Gilbert 1989, 1991 (a) (b); Ahlgren *et al.* 1990; Burns and Xu 1990; Kirk and Gilbert 1990; Schulze and Folt 1990; Sierszen 1990; Havens 1991; James and Salomen 1991; Kirk 1991; and Xu and Burns 1991).

### *Cyclotella*

In Lake Rotoroa, when *Cyclotella stelligera* was present (in Experiment 1 (Autumn)), it declined in abundance with increasing zooplankton biomass. This was true also of *C. stelligera* / *C. meneghiniana* in Experiments 2 and 4 (see Table 7.1). Such a “decreaser” response also occurred in the studies of Havens and DeCosta (1985) who found *C. stelligera* decreased in abundance in the presence of *Bosmina* and cyclopoid nauplii; Vanni and Temte (1990) who showed *C. glomerata* decreased with gradients of either *Diacyclops* and cyclopoid copepods or *Daphnia*; Elser and Goldman (1991) who also found *C. glomerata* declined with a gradient of *Daphnia* biomass; and James and Forsyth (1990) who observed *C. meneghiniana* growth rate decline with an increasing biomass of *Boeckella*, *Ceriodaphnia* and *Bosmina*. Lynch and Shapiro (1981), and Merrick and Ganf (1988), found *Cyclotella* spp. increased in abundance in ungrazed treatments where zooplankton biomass was reduced. Conversely Elser and Goldman (1991) found *C. glomerata* unresponsive to *Diaptomus* and *Epischura* species, and *Cyclotella* sp. unresponsive to a biomass gradient of either *Daphnia* or combined *Daphnia*, *Diaptomus* and *Mesocyclops*. This is supported by

McQueen (1970) who considered *Cyclotella* sp. unutilised by *Diaptomus oregonensis*. Svensson and Stenson (1991) found *Cyclotella* sp. increased in the presence of *Eudiaptomus gracilis*. However, Green (1976) found that *Cyclotella* sp. was abundant in the gut contents of *Calamoecia lucasi*. Vanni (1986(b), and Wright and Shapiro (1990), considered *Cyclotella* species edible and nutritious. *Cyclotella* has been used as a food source in a number of zooplankton studies (e.g. Forsyth and James (1991), Burns and Xu (1990) *Boeckella*; James and Forsyth (1990); Havens (1991). Support for the ingestion of *Cyclotella* comes from the gut content analysis of Crumpton and Wetzel (1982); Burns (1979) report *Cyclotella* species in the guts of *Daphnia*, *Ceriodaphnia dubia*, *Bosmina meridionalis* and *Boeckella dilatata*; Toth *et al.* (1987); and Kobayashi (1991) who found more than 75% of the gut contents of *Bosmina meridionalis* contained *Cyclotella* and that it was also present in the guts of *Daphnia*, *Calamoecia lucasi* and *Boeckella triarticulata*. Centric diatoms have frequently been found to decrease in the presence of zooplankters (see Merrick and Ganf 1988 for a review) and this highly consistent response across all treatments in the present study mirrors an identical response for *C. stelligera* in enclosure studies with *Calamoecia* across four seasons on Lake Rotomanuka (Edgar, 1989).

### ***Dinobryon***

*Dinobryon cylindricum* increased in the presence of a gradient of zooplankton biomass in Lake Rotoroa during the course of Experiment 1 (Autumn). This type of response also occurred in the investigation of Bergquist *et al.* (1985) where *Dinobryon* species larger than 70µm in size increased in abundance in the presence of *Daphnia* and *Diaptomus*. In the same study, *Dinobryon* (>70µm) were unresponsive to the pressure of *Bosmina* and rotifers. Lehman and Sandgren (1985) found *D. cylindricum* non-responsive to grazing by *Daphnia* and *Diaptomus* and Elser *et al.* (1987) found *Dinobryon* sp. unresponsive in three of five experiments and unimodal in two others. However, *D. crenulatum*, *D. bavaricum* and *D. divergens* increased in density in the absence of *Eudiaptomus gracilis* in the enclosure investigation of Svensson and Stenson (1991), and Sarnelle (1986) considered *Dinobryon* sp. edible based on reproductive responses of *Daphnia* species and *Bosmina*

*longirostris*. Contrary to this view Knisely and Geller (1986) considered *Dinobryon* sp. never or poorly grazed by zooplankters, and McQueen and Post (1988) described *Dinobryon* sp. as a poor food source for *Daphnia*. Both Hessen *et al.* (1989) and Vanni and Findlay (1990) considered this genus inedible due to its large size.

### ***Elakatothrix***

*Elakatothrix gelatinosa* was present in summer in both Lakes Rotoroa and Pupuke (Experiments 4 and 8). In both instances this phytoplankter experienced increased growth rate with increasing zooplankton biomass. It was also present in Experiment 3 (Spring) in Lake Rotoroa where it displayed a unimodal response to the grazer gradient. In the enclosure investigation of Svensson and Stenson (1991) *E. biplex* displayed positive population development in the presence of *Eudiaptomus gracilis*. Sommer (1988) found that *E. gelatinosa* remained viable after gut passage through daphnids and so considered it resistant to zooplankton grazing. Sarnelle (1986) and Vanni (1986(b)) also classified *Elakatothrix* as resistant, but Elser and Goldman (1991) found that growth rates of *E. gelatinosa* experienced decreased growth in both *Daphnia* and a combined *Daphnia*, *Diaptomus* and *Holopedium* biomass gradients.

### ***Fragilaria***

*Fragilaria crotonensis* was present in all experiments performed on Lake Pupuke. This species was unresponsive in three seasons and declined in Spring (Experiment 3) with an increase in grazer biomass. *Fragilaria* sp. was also unresponsive to a gradient in both *Daphnia* biomass and a combined biomass gradient of *Daphnia*, *Diaptomus* and *Mesocyclops* in the investigation of Elser and Goldman (1991). Vanni and Temte (1990) found *F. crotonensis* decreased in four of five experiments with a range of zooplankton assemblages and was unresponsive in the other one. Bergquist *et al.* (1985) found *F. crotonensis* was unresponsive in the presence of *Bosmina* and rotifers but increased in abundance with *Daphnia pulex* and *Diaptomus*. Sarnelle (1986) noted large colonial *Fragilaria* sp. were positively correlated with *Daphnia catawba* brood size but that this

association was negative for *Bosmina*. Sommer (1988) considered *Synedra* (a related genus) *minuscule* (25-37µm) one of the most edible algae for *Daphnia* species. However, Knisely and Geller (1986) considered *Fragilaria* sp. of low grazability, and Thompson *et al.* (1982) described colonial *Fragilaria* as partly edible. Sommer (1991) considered *F. crotonensis* highly resistant to grazing.

*Fragilaria ulna* combined with *F. u.* var. *acus* occurred in Experiment 6 (Winter) in Lake Pupuke where its abundance decreased as grazer biomass increased (Table 7.2). Merrick and Ganf (1988) found all pennate diatoms increased in ungrazed treatments lacking *Boeckella*, *Calamoecia lucasi*, *Ceriodaphnia* and *Diaphanosoma*. Bergquist *et al.* (1985) found *Synedra* sp. decreased in the presence of *Bosmina* and rotifers, but increased in abundance in the presence of *Daphnia pulex* and *Diaptomus*. This “increaser” response was also recorded for *Fragilaria* and *Synedra* species in the presence of *Daphnia* by Schoenberg and Carlson (1984). Vanderploeg (1981) found *Fragilaria* fragments >35µm in the faecal pellets of *Diaptomus sicilis* and Thompson *et al.* 1982 considered *Synedra* sp. partly edible as did Knisely and Geller (1986). *Synedra acus* (130 - 280µm) was not one of the most edible algae in Sommer’s (1988) study but was still selected at an intermediate to high level by *Daphnia* species. However McCauley and Briand (1979), Vanni (1986(b)), Kerfoot *et al.* (1988), and Sommer (1991) considered *Synedra* sp. to be either resistant or inedible due to its large size.

### ***Mougeotia* sp.**

*Mougeotia* sp. occurred in Experiment 5 (Autumn) and Experiment 7 (Spring) in Lake Pupuke where it was either unresponsive or declined in abundance respectively. Bergquist *et al.* (1985) found *Mougeotia* sp. unresponsive in the presence of *Bosmina* and rotifers but increased in the presence of *Daphnia* and *Diaptomus*. Havens and DeCosta (1987) and Kerfoot *et al.* (1988) considered *M. viridis* and *Mougeotia* sp. inedible. Knisely and Geller (1986) described *M. thylespora* as never or poorly grazed by all zooplankton present in their study. However, Sommer (1988) considered *M. thylespora* was of intermediate edibility to

daphnids and Sommer (1991) classed *Mougeotia* sp. as resistant but not inedible for daphnids but inedible to small cladocera (e.g. *Chydorus* and *Bosmina*).

### *Oocystis*

*Oocystis* cf. *lacustris* was present in both Lakes Rotoroa and Pupuke and occurred in countable numbers in six experiments. In Lake Rotoroa *Oocystis* was unresponsive to the gradient in zooplankton biomass in Experiment 2 (Winter) and Experiment 4 (Summer). In Pupuke *Oocystis* displayed the full range of responses across all four seasonal experiments (Tables 7.1, 7.2). Elser *et al.* (1987) also found *Oocystis* sp. illustrated all four possible response categories. Vanni and Temte (1990) found *Oocystis* spp. either non-responsive or decreasing in abundance in the presence of grazers. Elser and Goldman (1991) found *Oocystis lacustris* decreased when exposed to a gradient in *Daphnia* biomass but was unresponsive to a gradient of *Daphnia*, *Diaptomus* and *Holopedium*. Vyhnalek (1983) found *Daphnia* negatively affected the abundance of *Oocystis* sp., and Lynch and Shapiro (1981) found *Oocystis* increased in the absence of *Daphnia*. Merrick and Ganf (1988) reported *Oocystis* sp. as unresponsive to a *Boeckella*, *Calamoecia lucasi*, *Ceriodaphnia* and *Diaphanosoma* assemblage. However, both Benndorf *et al.* (1984) and Soto and Hurlbert (1991) found *Oocystis* sp. increased in the presence of zooplankton. Green (1976) considered *Oocystis* ingestible by *Calamoecia lucasi* and this is supported by the review of gut content analyses of Chapman and Green (1987) for *Boeckella dilatata*, *Bosmina meridionalis*, *Chydorus* and *Daphnia carinata*; Hart (1987) for *Metadiaptomus meridianus*; Kobayashi (1991) for *Ceriodaphnia* species, and Mason and Abdul-Hussein (1991) who found *O. elliptica* in the guts of *Daphnia hyalina* and *Bosmina longirostris*. Despite being ingested *Oocystis* may not be digested, as has been suggested by Sarnelle (1986), Vanni (1986(b)), Post and McQueen (1987), Kerfoot *et al.* (1988), and Rodriguez *et al.* (1991). However, both Nadin-Hurley and Duncan (1976) and Sierszen (1990) used *Oocystis* sp. and *O. marssonii* respectively as an algal food source in zooplankton feeding experiments, and these species supported the growth of rotifers and daphnids alike.

### ***Peridinium***

*Peridinium cinctum* occurred in both lakes and was present in seven seasonal experiments. In Lake Rotoroa it was consistently unresponsive to grazer presence. This was true of the first three experiments in Lake Pupuke, however, in Experiment 8 (Summer) *P. cinctum* was categorised as an “increaser”. Grazing also caused *Peridinium* sp. to increase in abundance in the presence of *Diaptomus* species in the investigation of Soto and Hurlbert (1991). Elser *et al.* (1987) found three species of *Peridinium* were generally unresponsive to a gradient in grazer biomass. However, in two occasions *Peridinium* decreased in abundance and in two others the growth rate was unimodal. In two experiments with *Daphnia pulex* and *Diaptomus*, *Peridinium limbatum* was reduced in abundance in one and unaffected in the other (Bergquist *et al.* 1985). They also found *P. limbatum* decreased in two experiments with *Bosmina* and rotifers. Despite this Rodriguez *et al.* (1991) described *P. cinctum* as inedible. Ahlgren *et al.* (1990) considered zooplankton would have difficulties increasing in number or even surviving on *Peridinium* and Kerfoot *et al.* (1988) described *Peridinium* sp. as inaccessibly large.

### ***Scenedesmus***

Combined counts of *Scenedesmus ecornis* and *S. quadricauda* from Experiments 3 (Spring) and 4 (Summer) in Lake Rotoroa indicated that this genus declined in abundance with increasing zooplankton biomass. *Scenedesmus bijuga* var. *alternans* however, was unresponsive in two of three experiments where it occurred in Lake Pupuke and responded unimodally in the third (Table 7.2). *S. linearis* was also negatively affected by *Daphnia* in the enclosure study of Vyhnalek (1983), and *Scenedesmus* sp. increased in abundance in the absence of this genus in the investigation of Lynch and Shapiro (1981). Knisely and Geller (1986) found *Scenedesmus* sp. was grazed by both daphnids and copepods as was *S. acutus* with daphnids in the study of Hawkins and Lampert (1989). *S. bijuga* decreased in the presence of *Bosmina* and cyclopoid nauplii - Havens and DeCosta (1985) and *Scenedesmus* sp. was reduced in abundance by the grazing of diaptomids during the investigation of Soto and Hurlbert (1991). Support for grazing of *Scenedesmus* comes

from the work of Schoenberg and Carlson (1984) who considered *Scenedesmus* sp. edible as did Sarnelle (1986), Vanni (1986(b)) and Sommer (1988). The edibility of *Scenedesmus* is reviewed by Jeppesen *et al.* (1990). In addition, *Scenedesmus* species have been widely used as a food source in zooplankton feeding experiments (e.g. Fott 1975; Lampert and Taylor 1985; Lampert *et al.* 1986; Hawkins and Lampert 1989; Sager and Richman 1991, and Urabe 1991). This genus has also been observed in gut content analysis of a number of zooplankters. Peer (1986) found *S. quadricauda* and *Scenedesmus* sp. in the guts of *Chydorus*, *Alona* and ostracods. Based on size alone he considered these species edible. Mason and Abdul-Hussein (1991) also found *S. quadricauda* and *S. dimorphus* in the guts of *Daphnia hyalina* and *Bosmina longirostris* and noted *Daphnia* strongly selected for these species over the whole year's investigation. However, there are cases where suppression of growth rate was not consistent or was lacking for *Scenedesmus* species. Bergquist *et al.* (1985) found *S. quadricauda* decreased in both experiments involving *Daphnia pulex* and *Diaptomus* but was unresponsive in one experiment with *Bosmina* and rotifers and increased in abundance with grazer presence in the other. Elser and Goldman (1991) found both *S. quadricauda* and *S. dimorphus* were unresponsive to gradients in biomass of *Daphnia* and combined *Daphnia*, *Diaptomus* and *Mesocyclops*. Ahlgren *et al.* (1990) showed *Daphnia* had a positive growth rate on *S. acutus* but *S. quadricauda* was not considered good food for *Chydorus*. *Eubosmina* died in the presence of *S. acutus*. Kerfoot *et al.* (1988) considered *S. bijuga* grazer resistant and capable of exceptional resistance during gut passage. This may provide some explanation for the differences in grazer response between the different species of *Scenedesmus* encountered in Lakes Rotoroa and Pupuke.

### ***Staurostrum***

In Lake Rotoroa *Staurostrum leptocladum* var. *insigne* was present in the first three seasonal experiments where it was unresponsive to grazer biomass in two and increased in abundance in the other. A related genus - *Staurodesmus* - was represented by *S. unicornis* var. *gracilis* which was categorised as a "decreaser" in Experiment 4 (Summer) (see Table 7.1). In Lake

Pupuke *Staurastrum johnsonii* var. *altuis* was unresponsive to a gradient in zooplankton biomass in all three seasonal experiments. Conversely, both *S. leptocladum* var. *insigne* and *S. pinque* declined in abundance in the presence of grazers during autumn (Experiment 5). However, during both spring and summer experiments these two species were unresponsive to grazer presence. A lack of response for this genus is also recorded in the literature. Both Bergquist *et al.* (1985) and Vanni and Temte (1990) found *Staurastrum* species unresponsive to herbivory by a range of zooplankters. However, Green (1976) considered various *Staurastrum* species ingestible by *Calamoecia lucasi*, and both Burns (1979) and Mason and Abdul-Hussein (1991) have found *Staurastrum* species or the single arms of these species in the guts of *Boeckella dilatata*, *Daphnia carinata* and *Asplanchna* sp. or *Daphnia hyalina* and *Bosmina longirostris* respectively.

### ***Tetrastrum***

There is a lack of examples of the response of this genus to zooplankton herbivory in the literature. A genus of similar proportions, *Tetrædron*, is edible, as Kerfoot *et al.* (1988) and Soto and Hurlbert (1991) both found it was reduced in abundance by the grazing activity of *Daphnia pulex* and *Diaptomus* species. However *T. regulare* was unresponsive to grazing by *Bosmina* and rotifers in one experiment of Kerfoot *et al.* (1988). Matveev (1991) recorded *T. minimum* in the guts of *Daphnia galeata*, *Bosmina coregoni* and *Diaphanosoma* sp. In Lake Rotoroa *Tetrastrum triangulare* declined in abundance in the presence of grazers in three of four seasonal experiments and was unresponsive in one (Experiment 3 - Spring).

### **Unidentified Unicells**

In Lake Pupuke two small unidentified unicellular algae were counted in combination in two experiments (Table 7.2). In both instances their abundance was unaffected by the gradient in zooplankton biomass. However, Green (1976) suggested a small monad and an unidentified unicell were both of an ingestible size for *Calamoecia lucasi*. Unidentified flagellates and phytoflagellates (<5µm size) in the studies of Merrick and Ganf (1988) and James and Forsyth (1990), respectively, either increased in the absence of grazers or



increased in the presence of grazers. It is possible that the unicells of the present study had similar growth and grazing loss rates, which balanced out resulting in little change in abundance across grazer biomass gradients.

#### 7.4 Conclusions

Pooling all responses for each species across all seasonal experiments in both lakes yields 65 instances where a response was recognised. The majority (31) were non-responsive to gradients in zooplankton biomass. However, an appreciable number - 25 - were “decreasers”. Six were “increasers” and the remaining three unimodal. The frequencies of response types between the lakes however were different. In Lake Rotoroa 30 species responses were examined across all seasonal experiments and of these 18 (60%) were “decreasers”, eight (27%) were unresponsive, three (10%) were “increasers” and one was unimodal. In Lake Pupuke 35 species responses were examined of which seven (20%) were “decreasers”, 23 (66%) were unresponsive, six (17%) were increasers and two were unimodal. It would appear the majority response for algae in Lake Rotoroa was a declining abundance as zooplankton biomass increased whereas the majority of Lake Pupuke phytoplankters were unresponsive to grazing pressure.

Tables 7.1 and 7.2 indicate fairly consistent responses across seasonal experiments for individual phytoplankton taxa. *Oocystis* cf. *lacustris* in Lake Pupuke was the only alga which showed the full range of response types, both potential suppression and enhanced abundance in the presence of grazers. The majority were either non-responsive to decreasing or were non-responsive to increasing in abundance.

Ultimately the response of any phytoplankton taxon to zooplankton grazing depends on the relative strengths of direct selective grazing mortality and nutrient recycling (and its influence on resource abundance (Svensson and Stenson 1991)). This dual role of herbivory accounts for the complexity of zooplankton, phytoplankton interactions at both the community and population levels. A more detailed discussion of selectivity in the

zooplankton of the present study and their influence on nutrient regimes will be presented in Chapters Eight and Nine respectively. The species-specific responses described above will be re-examined in the light of these findings.

**Figure 7.1**

Regression of *Dinobryon cylindricum* growth rate (plankton units  $\text{ml}^{-1}.\text{day}^{-1}$ ) against zooplankton biomass ( $\text{mg}.\text{m}^{-3}$  dryweight). Species-specific algal growth rate was calculated from Day 0 to Day 6 of Experiment 1 (Autumn) in Lake Rotoroa. 95% confidence intervals are displayed for all linear regressions. For a complete statistical analysis see Table 7.3 pg 140.  $r^2 = 0.530$ ;  $p = 0.041$ .

**Figure 7.2**

Regression of *Peridinium cinctum* growth rate against zooplankton biomass during Experiment 1 (Autumn) in Lake Rotoroa. See Figure 7.1 for axes definitions and associated statistical analysis.  $r^2 = 0.026$ ;  $p = 0.705$ .

**Figure 7.3**

Regression of *Cyclotella stelligera* growth rate against zooplankton biomass during Experiment 1 (Autumn) in Lake Rotoroa. See Figure 7.1 for axes definitions and associated statistical analysis.  $r^2 = 0.911$ ;  $p = 0.000$ .

FIG.7.1. Dinobryon

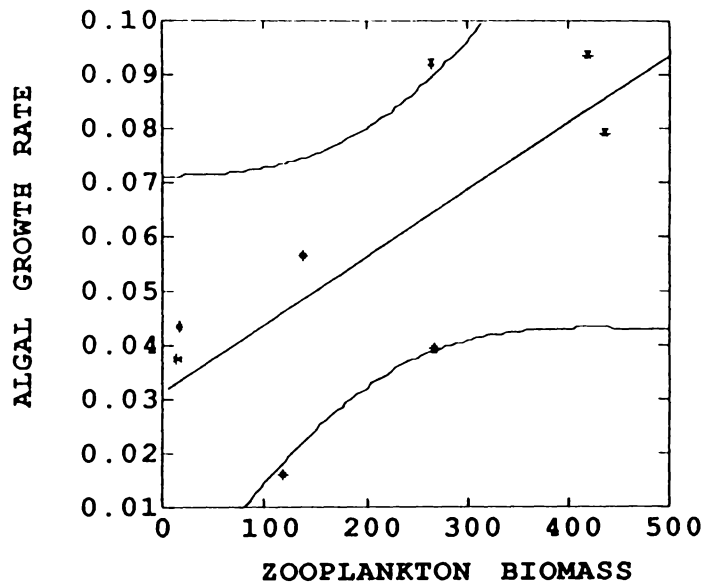


FIG.7.2. Peridinium

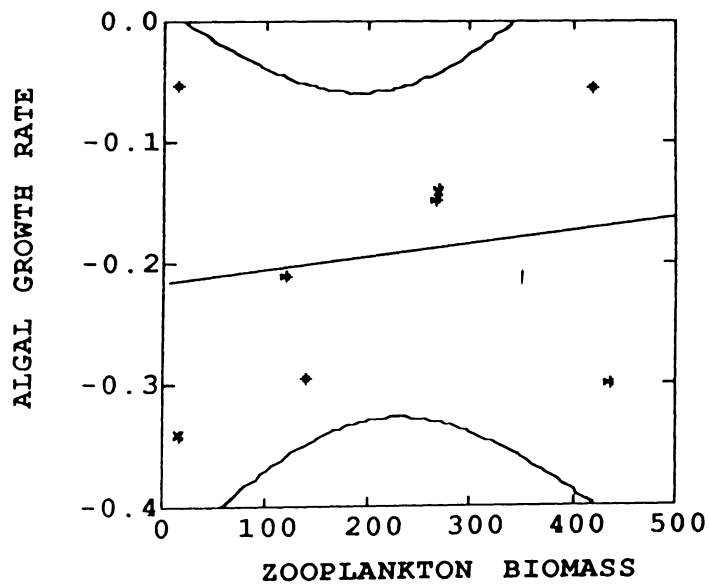


FIG.7.3. Cyclotella

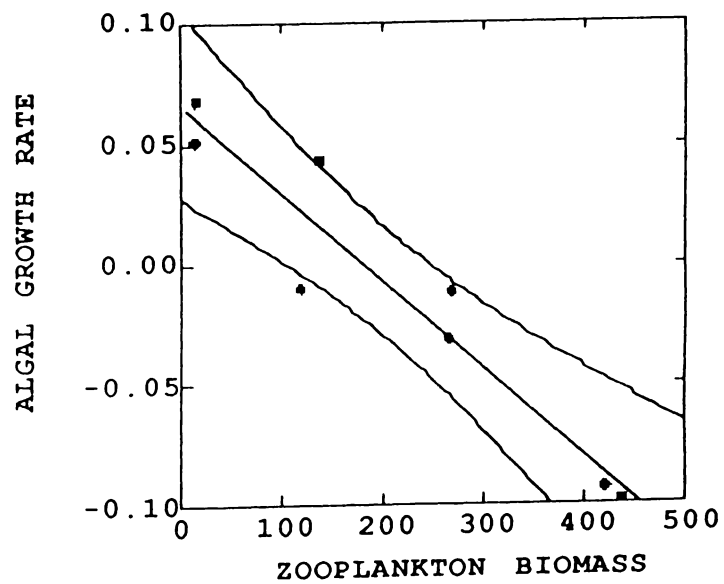


**Figure 7.4**

Regression of *Staurastrum leptocladum* var. *insigne* growth rate against zooplankton biomass during Experiment 2 (Winter) in Lake Rotoroa. See Figure 7.1 for axes definitions and associated statistical analysis.  $r^2 = 0.464$ ;  $p = 0.063$ .

**Figure 7.5**

Regression of *Oocystis* cf. *lacustris* growth rate against zooplankton biomass during Experiment 2 (Winter) in Lake Rotoroa. See Figure 7.1 for axes definitions and associated statistical analysis.  $r^2 = 0.265$ ;  $p = 0.192$ .

**Figure 7.6**

Regression of *Cryptomonas marssonii* + *C. ovata* growth rate against zooplankton biomass during Experiment 2 (Winter) in Lake Rotoroa. See Figure 7.1 for axes definitions and associated statistical analysis.  $r^2 = 0.926$ ;  $p = 0.000$ .

FIG.7.4. *Staurastrum*

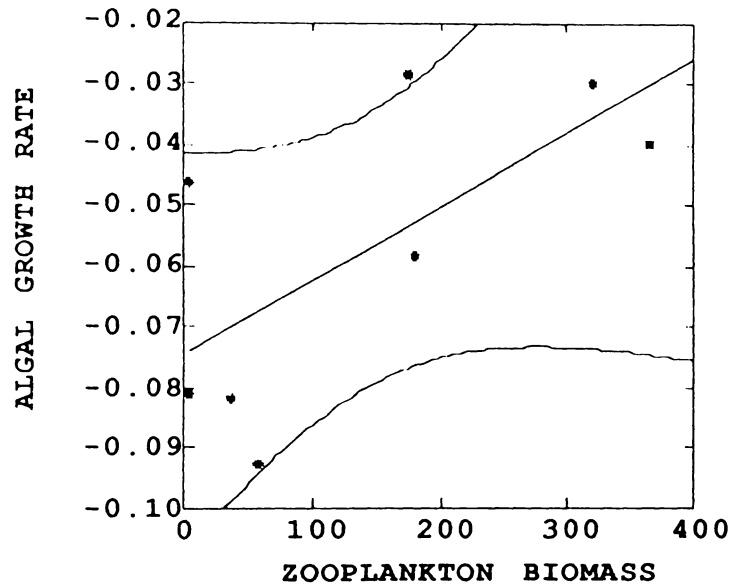


FIG.7.5. *Oocystis*

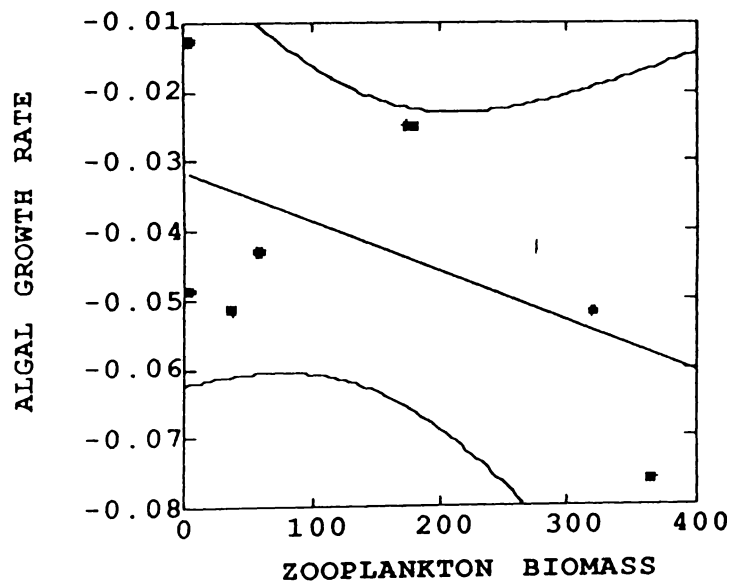


FIG.7.6. *Cryptomonas*

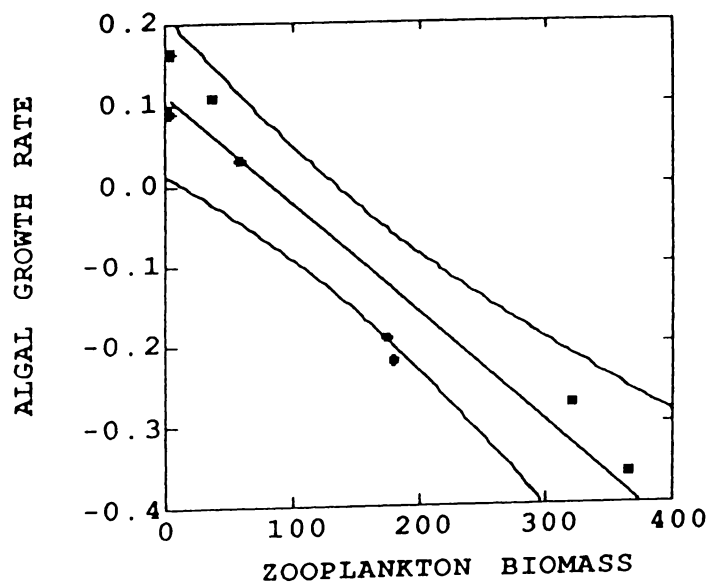


**Figure 7.7**  
Regression of *Staurastrum leptocladum* var. *insigne* growth rate against zooplankton biomass during Experiment 3 (Spring) in Lake Rotoroa. See Figure 7.1 for axes definitions and associated statistical analysis.  $r^2 = 0.134$   $p = 0.372$ .

**Figure 7.8**  
Regression of *Asterionella formosa* growth rate against zooplankton biomass during Experiment 3 (Spring) in Lake Rotoroa. See Figure 7.1 for axes definitions and associated statistical analysis.  $r^2 = 0.902$ ;  $p = 0.000$ .

**Figure 7.9**  
Regression of *Elakatothrix gelatinosa* growth rate against zooplankton biomass during Experiment 3 (Spring) in Lake Rotoroa. See Figure 7.1 for axes definitions and associated statistical analysis.  $r^2 = 0.651$ ;  $p = 0.072$ .

FIG.7.7. *Staurastrum*

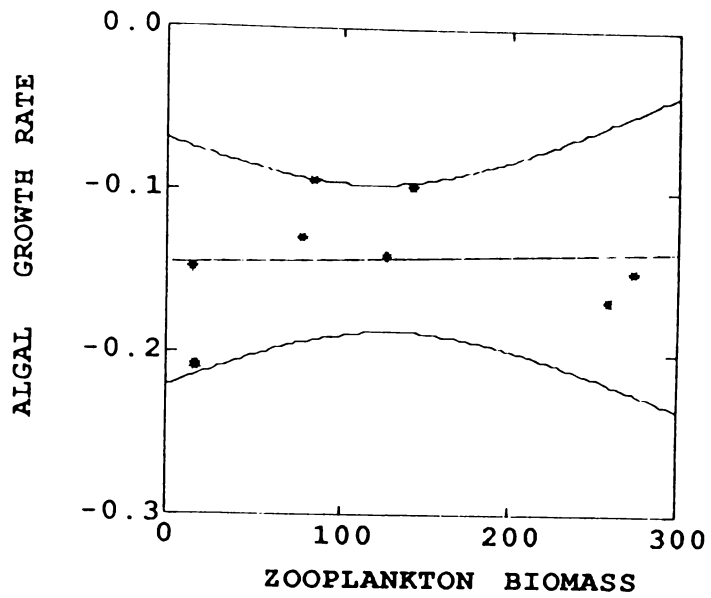


FIG.7.8. *Asterionella*

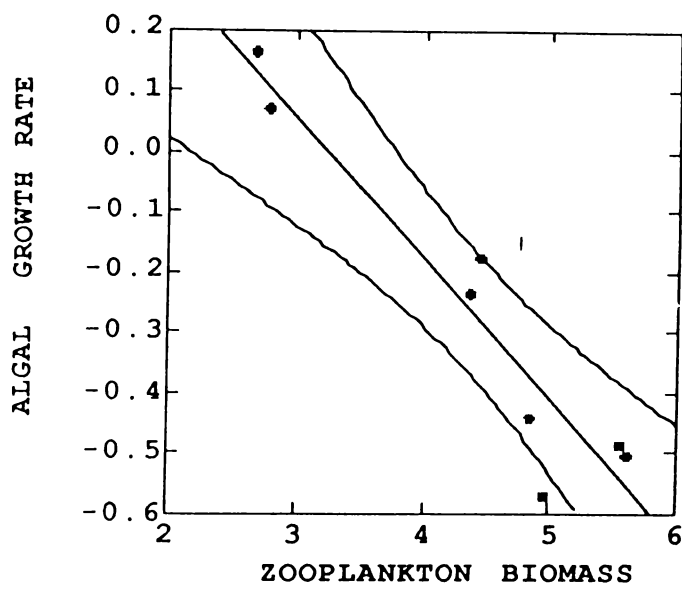


FIG.7.9. *Elakatothrix*

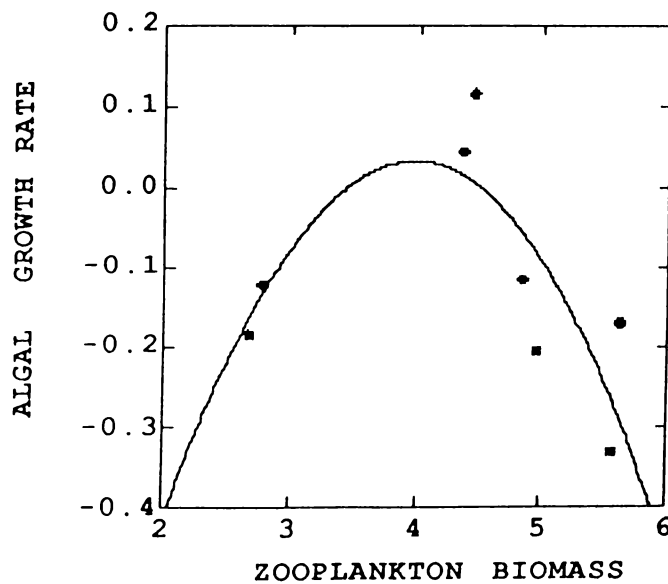




**Figure 7.10**

Regression of *Elakatothrix gelatinosa* growth rate against zooplankton biomass during Experiment 4 (Summer) in Lake Rotoroa. See Figure 7.1 for axes definitions and associated statistical analysis.  $r^2 = 0.861$   $p = 0.001$ .

**Figure 7.11**

Regression of *Peridinium cinctum* growth rate against zooplankton biomass during Experiment 4 (Summer) in Lake Rotoroa. See Figure 7.1 for axes definitions and associated statistical analysis.  $r^2 = 0.140$ ;  $p = 0.362$ .

**Figure 7.12**

Regression of *Tetrastrum triangulare* growth rate against zooplankton biomass during Experiment 4 (Summer) in Lake Rotoroa. See Figure 7.1 for axes definitions and associated statistical analysis.  $r^2 = 0.897$ ;  $p = 0.001$ .

FIG.7.10. Elakatothrix

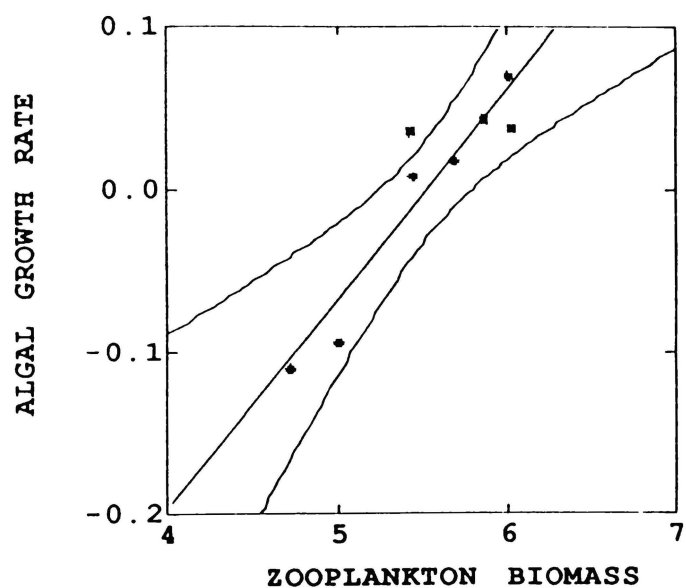


FIG.7.11. Peridinium

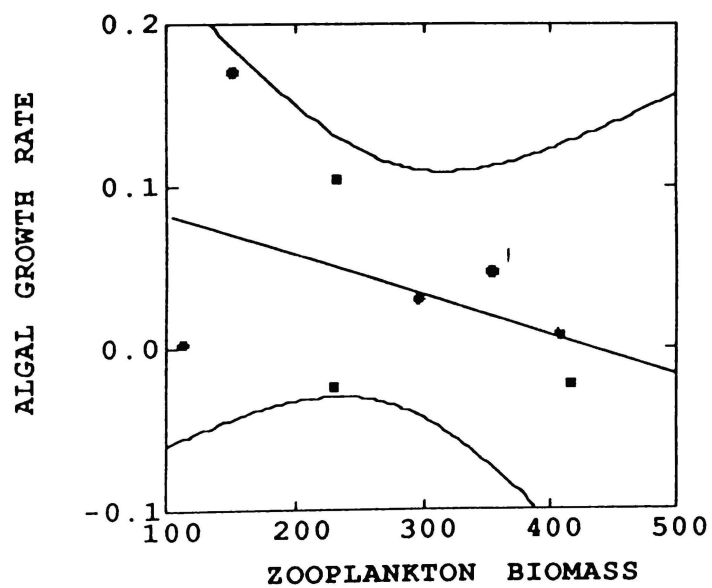


FIG.7.12. Tetrastrum

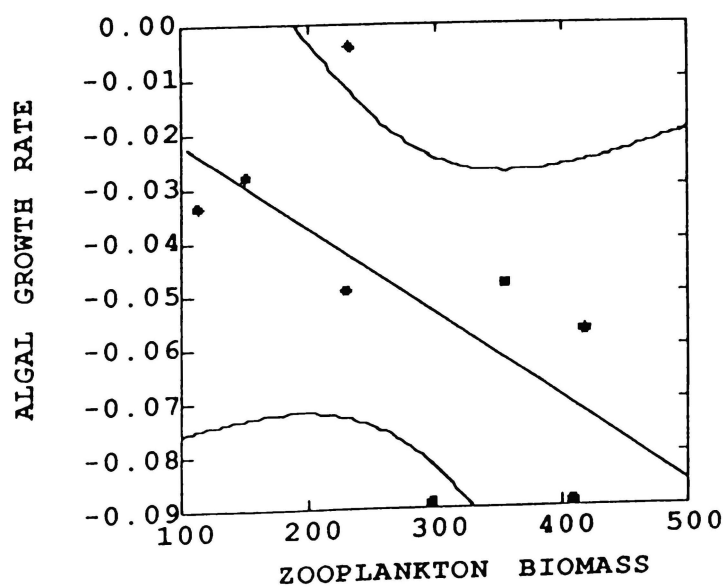


**Figure 7.13**

Regression of *Cosmarium perfissum* growth rate against zooplankton biomass during Experiment 5 (Autumn) in Lake Pupuke. See Figure 7.1 for axes definitions and associated statistical analysis.  $r^2 = 0.112$ ;  $p = 0.417$ .

**Figure 7.14**

Regression of *Staurastrum pinque* growth rate against zooplankton biomass during Experiment 5 (Autumn) in Lake Pupuke. See Figure 7.1 for axes definitions and associated statistical analysis.  $r^2 = 0.914$ ;  $p = 0.001$ .

FIG.7.13. Cosmarium

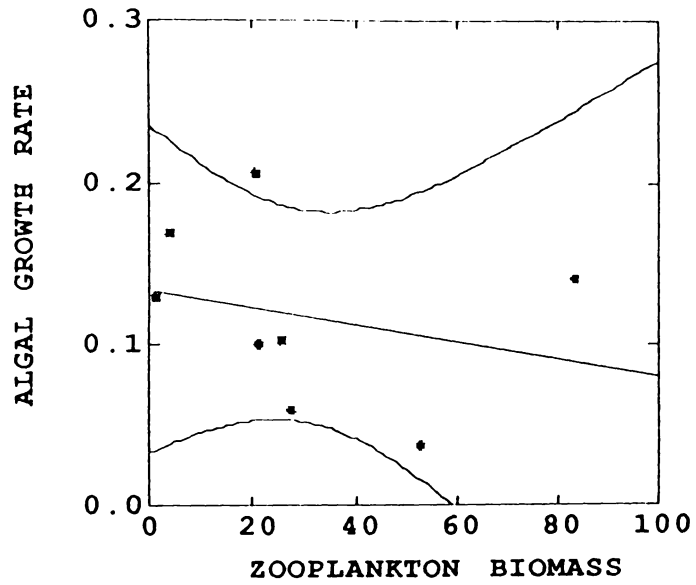


FIG.7.14. Staurastrum

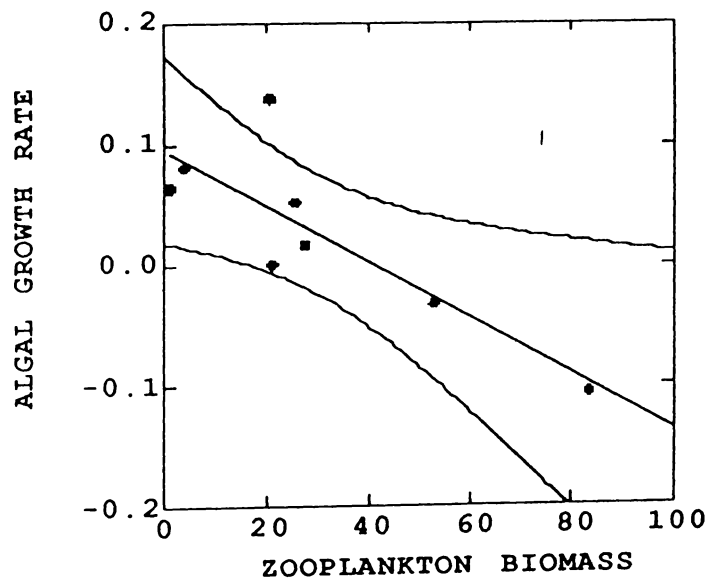


**Figure 7.15**

Regression of Unidentified Unicells' growth rate against zooplankton biomass during Experiment 6 (Winter) in Lake Pupuke. See Figure 7.1 for axes definitions and associated statistical analysis.  $r^2 = 0.088$ ;  $p = 0.475$ .

**Figure 7.16**

Regression of *Fragilaria ulna* + *F. u. var. acus* growth rate against zooplankton biomass during Experiment 6 (Winter) in Lake Pupuke. See Figure 7.1 for axes definitions and associated statistical analysis.  $r^2 = 0.955$ ;  $p = 0.000$ .

FIG.7.15. Unidentified Unicells

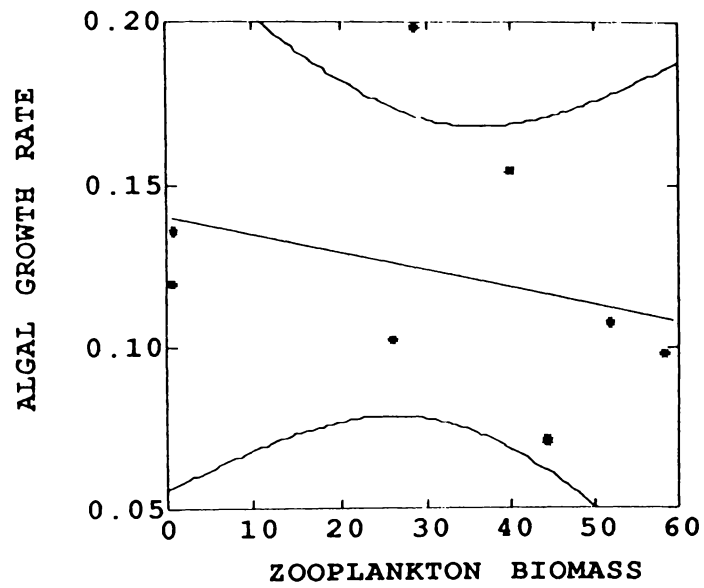


FIG.7.16. *Fragilaria ulna*

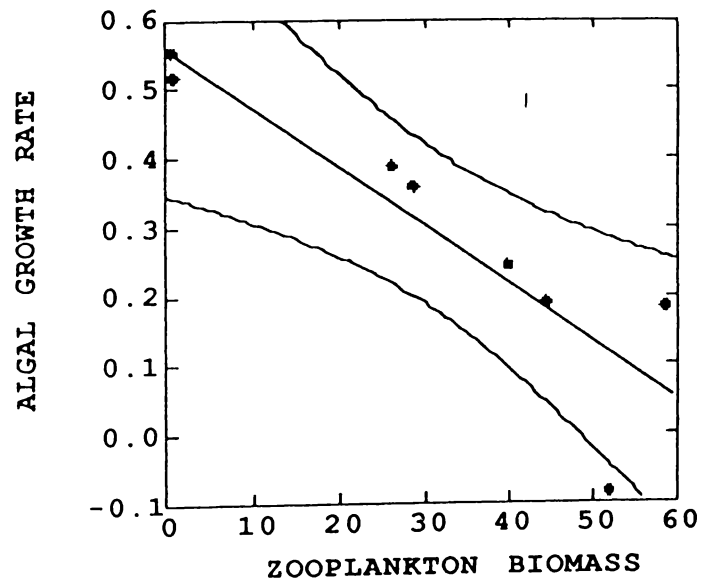


**Figure 7.17**

Regression of *Scenedesmus bijuga* var. *alternans* growth rate against zooplankton biomass during Experiment 7 (Spring) in Lake Pupuke. See Figure 7.1 for axes definitions and associated statistical analysis.  $r^2 = 0.059$ ;  $p = 0.561$ .

**Figure 7.18**

Regression of *Oocystis* cf. *lacustris* growth rate against zooplankton biomass during Experiment 7 (Spring) in Lake Pupuke. See Figure 7.1 for axes definitions and associated statistical analysis.  $r^2 = 0.900$ ;  $p = 0.003$ .

**Figure 7.19**

Regression of *Fragilaria crotonensis* growth rate against zooplankton biomass during Experiment 7 (Spring) in Lake Pupuke. See Figure 7.1 for axes definitions and associated statistical analysis.  $r^2 = 0.706$ ;  $p = 0.009$ .

FIG.7.17. *Scenedesmus*

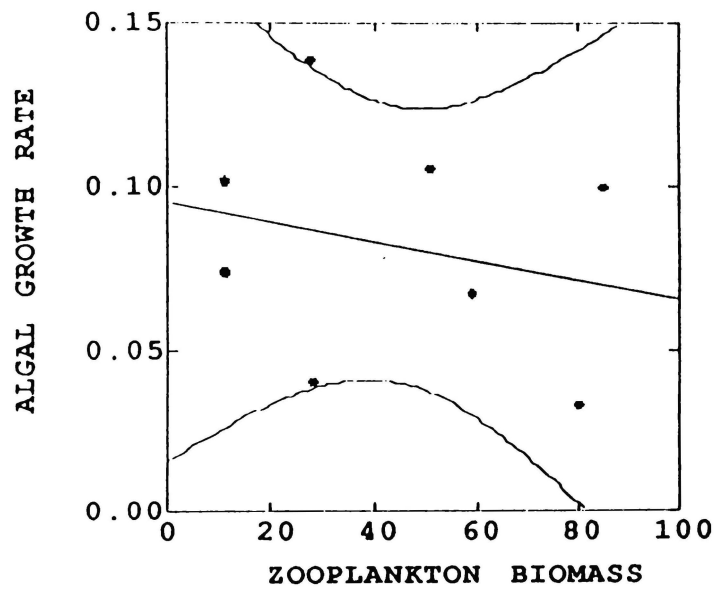


FIG.7.18. *Oocystis*

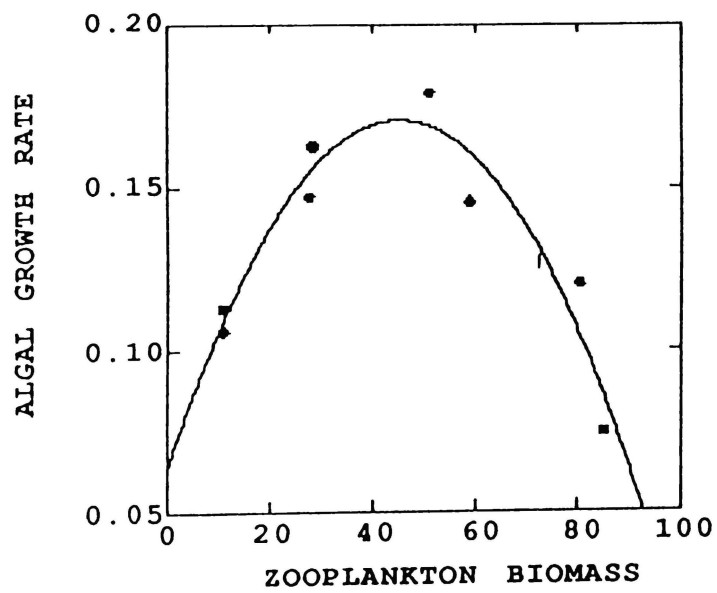


FIG.7.19. *Fragilaria*

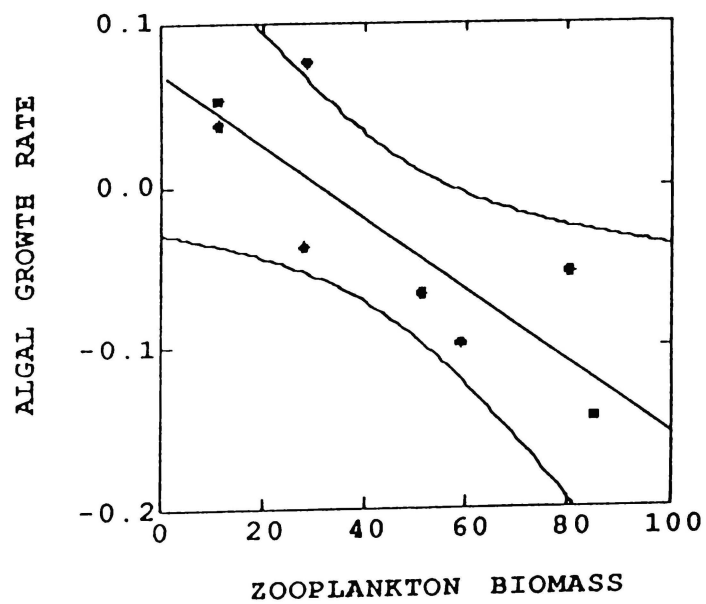




**Figure 7.20**

Regression of *Peridinium cinctum* growth rate against zooplankton biomass during Experiment 8 (Summer) in Lake Pupuke. See Figure 7.1 for axes definitions and associated statistical analysis.  $r^2 = 0.454$ ;  $p = 0.067$ .

**Figure 7.21**

Regression of *Closterium aciculare* growth rate against zooplankton biomass during Experiment 8 (Summer) in Lake Pupuke. See Figure 7.1 for axes definitions and associated statistical analysis.  $r^2 = 0.213$ ;  $p = 0.250$ .

**Figure 7.22**

Regression of *Scenedesmus bijuga* var. *alternans* growth rate against zooplankton biomass during Experiment 8 (Summer) in Lake Pupuke. See Figure 7.1 for axes definitions and associated statistical analysis.  $r^2 = 0.764$ ;  $p = 0.027$ .

FIG. 7.20. Peridinium

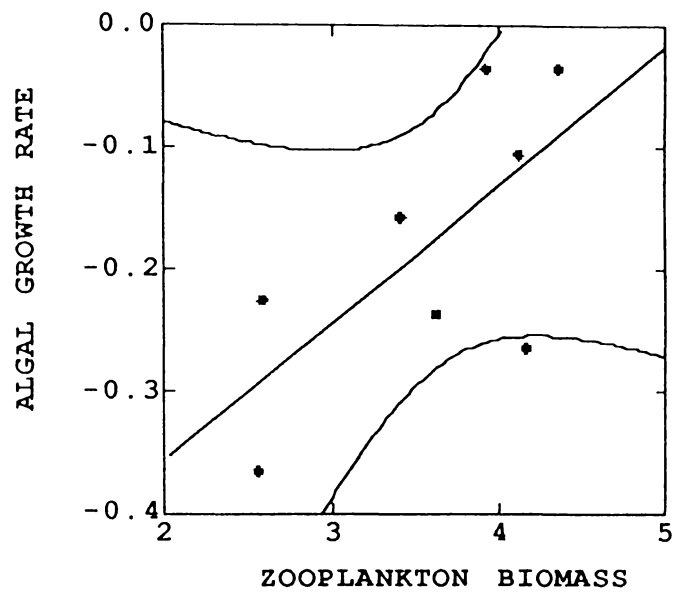


FIG. 7.21. Closterium

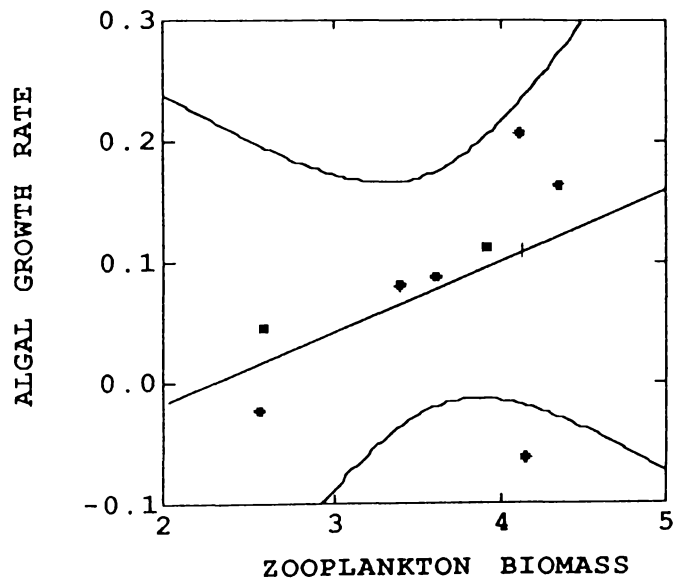


FIG. 7.22. Scenedesmus

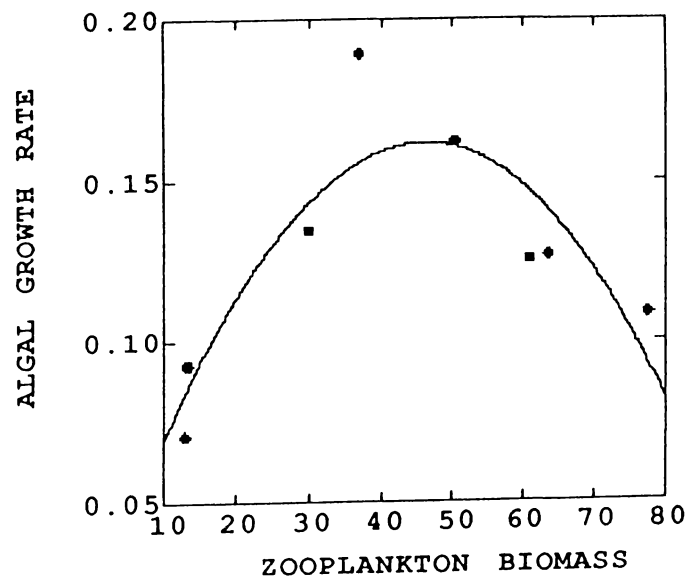


**Table 7.1** Response of phytoplankton growth rates ( $r$ ) to zooplankton manipulations in the four seasonal experiments conducted on Lake Rotoroa. Response key: N - no significant response; D - decreasing; I - increasing; U - unimodal; (-) - taxon too rare for analysis.

| <b>Taxon</b>                                             | <b>Exp 1<br/>(Autumn)</b> | <b>Exp 2<br/>(Winter)</b> | <b>Exp 3<br/>(Spring)</b> | <b>Exp 4<br/>(Summer)</b> |
|----------------------------------------------------------|---------------------------|---------------------------|---------------------------|---------------------------|
| <b>Chlorophyta</b>                                       |                           |                           |                           |                           |
| <i>Elakatothrix gelatinosa</i>                           | -                         | -                         | U*                        | I*                        |
| <i>Coelastrum reticulatum</i>                            | -                         | -                         | D*                        | D                         |
| <i>Cosmarium perfissum</i>                               | -                         | -                         | D                         | D                         |
| <i>Oocystis</i> cf. <i>lacustris</i>                     | -                         | N                         | -                         | N                         |
| <i>Scenedesmus ecornis</i><br>+ <i>S. quadricauda</i>    | -                         | -                         | D*                        | D                         |
| <i>Staurodesmus unicornis</i><br>var. <i>gracilis</i>    | -                         | -                         | -                         | D                         |
| <i>Staurastrum leptocladum</i><br>var. <i>insigne</i>    | N                         | I                         | N                         | -                         |
| <i>Tetrastrum triangulare</i>                            | D                         | D                         | N                         | D                         |
| <b>Chromophyta</b>                                       |                           |                           |                           |                           |
| <i>Asterionella formosa</i>                              | -                         | -                         | D*                        | -                         |
| <i>Cyclotella meneghiniana</i><br>+ <i>C. stelligera</i> | -                         | D                         | -                         | D*                        |
| <i>Cyclotella stelligera</i>                             | D                         | -                         | -                         | -                         |
| <i>Dinobryon cylindricum</i>                             | I                         | -                         | -                         | -                         |
| <b>Pyrrhophyta</b>                                       |                           |                           |                           |                           |
| <i>Cryptomonas marssonii</i><br>+ <i>C. ovata</i>        | D                         | D                         | D                         | D*                        |
| <i>Peridinium cinctum</i>                                | N                         | N                         | -                         | N                         |

\* Data had a better fit with log transformed zooplankton biomass

**Table 7.2** Response of phytoplankton growth rates ( $r$ ) to zooplankton manipulations in the four seasonal experiments conducted on Lake Pupuke. Response key: N - no significant response; D - decreasing; I - increasing; U - unimodal; (-) - taxon too rare for analysis.

| <b>Taxon</b>                                              | <b>Exp 5<br/>(Autumn)</b> | <b>Exp 6<br/>(Winter)</b> | <b>Exp 7<br/>(Spring)</b> | <b>Exp 8<br/>(Summer)</b> |
|-----------------------------------------------------------|---------------------------|---------------------------|---------------------------|---------------------------|
| <b>Chlorophyta</b>                                        |                           |                           |                           |                           |
| <i>Closterium aciculare</i>                               | -                         | -                         | -                         | N                         |
| <i>Closterium acutum</i><br>var. <i>variable</i>          | N                         | -                         | -                         | -                         |
| <i>Cosmarium contractum</i>                               | -                         | -                         | -                         | N                         |
| <i>Cosmarium perfissum</i>                                | N                         | -                         | -                         | -                         |
| <i>Elakatothrix gelatinosa</i>                            | -                         | -                         | -                         | I                         |
| <i>Mougeotia</i> sp.                                      | N                         | -                         | D                         |                           |
| <i>Oocystis</i> cf. <i>lacustris</i>                      | D                         | N                         | U                         | I                         |
| <i>Scenedesmus bijuga</i><br>var. <i>alternans</i>        | N                         | -                         | N                         | U                         |
| <i>Staurastrum johnsonii</i><br>var. <i>altuis</i>        | N                         | -                         | N                         | N                         |
| <i>Staurastrum leptocladum</i><br>var. <i>insigne</i>     | D                         | -                         | N                         | N                         |
| <i>Staurastrum pinque</i>                                 | D                         | -                         | N                         | N                         |
| <b>Chromophyta</b>                                        |                           |                           |                           |                           |
| <i>Achnanthes</i> sp.                                     | D*                        | -                         | -                         | -                         |
| <i>Fragilaria crotonensis</i>                             | N                         | N                         | D                         | N                         |
| <i>Fragilaria ulna</i><br>+ <i>F. u.</i> var. <i>acus</i> | -                         | D                         | -                         | -                         |
| <b>Pyrrhophyta</b>                                        |                           |                           |                           |                           |
| <i>Peridinium cinctum</i>                                 | N                         | N                         | N                         | I                         |
| Unidentified Unicells                                     | -                         | N                         | N                         | -                         |

\* Data had a better fit with log transformed zooplankton biomass

**Table 7.3 : Summary of regression analyses in Chapter Seven**

Regression of species-specific phytoplankton growth rate ( $r$ ) against total zooplankton biomass for Lake Rotoroa (Experiments 1-4) and Lake Pupuke (Experiments 5-8) on Day 6. Units for the intercept (constant) are plankton units (P.U.)  $\text{ml}^{-1}.\text{d}^{-1}$  ( $n = 8$ ).

**Experiment 1 (Autumn)**

| Taxon                          | Equation              | $r^2$ | p     | Figure |
|--------------------------------|-----------------------|-------|-------|--------|
| <i>Cryptomonas marssonii</i>   |                       |       |       |        |
| + <i>C. ovata</i>              | $y = 0.055 - 0.001x$  | 0.819 | 0.002 | -      |
| <i>Cyclotella stelligera</i>   | $y = 0.066 - 0.000x$  | 0.911 | 0.000 | 7.3    |
| <i>Dinobryon cylindricum</i>   | $y = 0.031 + 0.000x$  | 0.530 | 0.041 | 7.1    |
| <i>Peridinium cinctum</i>      | $y = -0.216 + 0.000x$ | 0.026 | 0.705 | 7.2    |
| <i>Staurastrum leptocladum</i> |                       |       |       |        |
| var. <i>insigne</i>            | $y = 0.182 - 0.017x$  | 0.339 | 0.130 | -      |
| <i>Tetrastrum triangulare</i>  | $y = -0.049 - 0.000x$ | 0.815 | 0.002 | -      |

**Experiment 2 (Winter)**

| Taxon                                | Equation              | $r^2$ | p     | Figure |
|--------------------------------------|-----------------------|-------|-------|--------|
| <i>Cryptomonas marssonii</i>         |                       |       |       |        |
| + <i>C. ovata</i>                    | $y = 0.122 - 0.001x$  | 0.926 | 0.000 | 7.6    |
| <i>Cyclotella meneghiniana</i>       |                       |       |       |        |
| + <i>C. stelligera</i>               | $y = -0.019 - 0.000x$ | 0.912 | 0.000 | -      |
| <i>Oocystis</i> cf. <i>lacustris</i> | $y = -0.031 - 0.000x$ | 0.265 | 0.192 | 7.5    |
| <i>Peridinium cinctum</i>            | $y = -0.041 - 0.000x$ | 0.157 | 0.331 | -      |
| <i>Staurastrum leptocladum</i>       |                       |       |       |        |
| var. <i>insigne</i>                  | $y = -0.075 + 0.000x$ | 0.464 | 0.063 | 7.4    |
| <i>Tetrastrum triangulare</i>        | $y = 0.045 - 0.000x$  | 0.789 | 0.003 | -      |

**Experiment 3 (Spring)**

| Taxon                                                 | Equation                         | r <sup>2</sup> | p     | Figure |
|-------------------------------------------------------|----------------------------------|----------------|-------|--------|
| <i>Asterionella formosa</i>                           | $y = 0.749 - 0.232x$             | 0.902*         | 0.000 | 7.8    |
| <i>Coelastrum reticulatum</i>                         | $y = 0.263 - 0.038x$             | 0.716*         | 0.008 | -      |
| <i>Cosmarium perfissum</i>                            | $y = -0.153 - 0.000x$            | 0.492          | 0.052 | -      |
| <i>Cryptomonas marssonii</i><br>+ <i>C. ovata</i>     | $y = 0.299 - 0.007x$             | 0.979+         | 0.000 | -      |
| <i>Elakatothrix gelatinosa</i>                        | $y = -1.822 + 0.936x - 0.118x^2$ | 0.651*         | 0.072 | 7.9    |
| <i>Scenedesmus ecornis</i><br>+ <i>S. quadricauda</i> | $y = 0.336 - 0.078x$             | 0.784*         | 0.003 | -      |
| <i>Staurastrum leptocladum</i><br>var. <i>insigne</i> | $y = -0.194 + 0.012x$            | 0.134          | 0.372 | 7.7    |
| <i>Tetrastrum triangulare</i>                         | $y = 0.064 - 0.038x$             | 0.276          | 0.182 | -      |

**Experiment 4 (Summer)**

| Taxon                                                    | Equation              | r <sup>2</sup> | p     | Figure |
|----------------------------------------------------------|-----------------------|----------------|-------|--------|
| <i>Coelastrum reticulatum</i>                            | $y = 0.149 - 0.000x$  | 0.534          | 0.039 | -      |
| <i>Cosmarium perfissum</i>                               | $y = 0.145 - 0.000x$  | 0.409          | 0.088 | -      |
| <i>Cryptomonas marssonii</i><br>+ <i>C. ovata</i>        | $y = 1.138 - 0.228x$  | 0.896+*        | 0.001 | -      |
| <i>Cyclotella meneghiniana</i><br>+ <i>C. stelligera</i> | $y = 0.854 - 0.161x$  | 0.967*         | 0.000 | -      |
| <i>Elakatothrix gelatinosa</i>                           | $y = -0.717 + 0.130x$ | 0.861*         | 0.001 | 7.10   |
| <i>Oocystis</i> cf. <i>lacustris</i>                     | $y = -0.006 - 0.000x$ | 0.382          | 0.102 | -      |
| <i>Peridinium cinctum</i>                                | $y = 0.333 - 0.053x$  | 0.140          | 0.362 | 7.11   |
| <i>Scenedesmus ecornis</i><br>+ <i>S. quadricauda</i>    | $y = 0.133 - 0.000x$  | 0.745          | 0.006 | -      |
| <i>Tetrastrum triangulare</i>                            | $y = 0.225 - 0.001x$  | 0.897          | 0.001 | 7.12   |

**Experiment 5 (Autumn)**

| Taxon                                                 | Equation              | r <sup>2</sup>     | p     | Figure |
|-------------------------------------------------------|-----------------------|--------------------|-------|--------|
| <i>Achnanthes</i> sp.                                 | $y = -0.152 - 0.031x$ | 0.763 **           | 0.010 | -      |
| <i>Closterium acutum</i><br>var. <i>variabile</i>     | $y = 0.001 - 0.001x$  | 0.089              | 0.472 | -      |
| <i>Cosmarium perfissum</i>                            | $y = 0.155 - 0.013x$  | 0.112              | 0.417 | 7.13   |
| <i>Fragilaria crotonensis</i>                         | $y = 0.073 - 0.001x$  | 0.149              | 0.345 | -      |
| <i>Mougeotia</i> sp.                                  | $y = 0.162 + 0.001x$  | 0.295              | 0.164 | -      |
| <i>Oocystis</i> cf. <i>lacustris</i>                  | $y = 0.176 - 0.003x$  | 0.566 <sup>+</sup> | 0.051 | -      |
| <i>Peridinium cinctum</i>                             | $y = -0.015 + 0.024x$ | 0.261              | 0.196 | -      |
| <i>Scenedesmus bijuga</i><br>var. <i>alternans</i>    | $y = 0.351 - 0.001x$  | 0.163              | 0.322 | -      |
| <i>Staurastrum johnsonii</i><br>var. <i>altuis</i>    | $y = 0.090 - 0.002x$  | 0.360              | 0.116 | -      |
| <i>Staurastrum leptocladum</i><br>var. <i>insigne</i> | $y = 0.072 - 0.001x$  | 0.428              | 0.078 | -      |
| <i>Staurastrum pinque</i>                             | $y = 0.076 - 0.002x$  | 0.914 <sup>+</sup> | 0.001 | 7.14   |

**Experiment 6 (Winter)**

| Taxon                                                     | Equation             | r <sup>2</sup> | p     | Figure |
|-----------------------------------------------------------|----------------------|----------------|-------|--------|
| <i>Fragilaria crotonensis</i>                             | $y = 0.359 - 0.003x$ | 0.333          | 0.134 | -      |
| <i>Fragilaria ulna</i><br>+ <i>F. u.</i> var. <i>acus</i> | $y = 0.538 - 0.007x$ | 0.955          | 0.000 | 7.16   |
| <i>Oocystis</i> cf. <i>lacustris</i>                      | $y = 0.244 + 0.001x$ | 0.108          | 0.426 | -      |
| <i>Peridinium cinctum</i>                                 | $y = 0.148 - 0.001x$ | 0.119          | 0.402 | -      |
| Unidentified unicells                                     | $y = 0.140 - 0.001x$ | 0.088          | 0.475 | 7.15   |

**Experiment 7 (Spring)**

| Taxon                                                 | Equation                        | r <sup>2</sup> | p     | Figure |
|-------------------------------------------------------|---------------------------------|----------------|-------|--------|
| <i>Fragilaria crotonensis</i>                         | $y = 0.068 - 0.002x$            | 0.706          | 0.009 | 7.19   |
| <i>Mougeotia</i> sp.                                  | $y = 0.115 - 0.002x$            | 0.559          | 0.033 | -      |
| <i>Oocystis</i> cf. <i>lacustris</i>                  | $y = 0.064 + 0.005x - 0.000x^2$ | 0.900          | 0.003 | 7.18   |
| <i>Peridinium cinctum</i>                             | $y = 0.106 - 0.000x$            | 0.016          | 0.768 | -      |
| <i>Scenedesmus bijuga</i><br>var. <i>alternans</i>    | $y = 0.096 - 0.000x$            | 0.059          | 0.561 | 7.17   |
| <i>Staurastrum johnsonii</i><br>var. <i>altuis</i>    | $y = 0.133 - 0.001x$            | 0.329          | 0.137 | -      |
| <i>Staurastrum leptocladum</i><br>var. <i>insigne</i> | $y = 0.062 - 0.000x$            | 0.085          | 0.484 | -      |
| <i>Staurastrum pinque</i>                             | $y = 0.035 + 0.012x$            | 0.350          | 0.122 | -      |
| Unidentified unicells                                 | $y = 0.152 - 0.001x$            | 0.131          | 0.378 | -      |

**Experiment 8 (Summer)**

| Taxon                                                 | Equation                        | r <sup>2</sup> | p     | Figure |
|-------------------------------------------------------|---------------------------------|----------------|-------|--------|
| <i>Closterium aciculare</i>                           | $y = -0.136 + 0.059x$           | 0.213          | 0.250 | 7.21   |
| <i>Cosmarium</i> cf. <i>contractum</i>                | $y = 0.157 - 0.042x$            | 0.213          | 0.250 | -      |
| <i>Elakatothrix gelatinosa</i>                        | $y = -0.048 + 0.004x$           | 0.844          | 0.003 | -      |
| <i>Fragilaria crotonensis</i>                         | $y = 0.044 + 0.001x$            | 0.128          | 0.385 | -      |
| <i>Oocystis</i> cf. <i>lacustris</i>                  | $y = -0.082 + 0.070x$           | 0.680          | 0.012 | -      |
| <i>Peridinium cinctum</i>                             | $y = -0.581 + 0.113x$           | 0.454          | 0.067 | 7.20   |
| <i>Scenedesmus bijuga</i><br>var. <i>alternans</i>    | $y = 0.012 + 0.006x - 0.000x^2$ | 0.764          | 0.027 | 7.22   |
| <i>Staurastrum johnsonii</i><br>var. <i>altuis</i>    | $y = -0.068 + 0.002x$           | 0.372          | 0.108 | -      |
| <i>Staurastrum leptocladum</i><br>var. <i>insigne</i> | $y = 0.144 - 0.004x$            | 0.001          | 0.931 | -      |
| <i>Staurastrum pinque</i>                             | $y = 0.005 + 0.002x$            | 0.206          | 0.259 | -      |

\* data had a better fit with log transformed zooplankton biomass

+ regressions with n = 7 due to the removal of one outlier



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## CHAPTER EIGHT

### ZOOPLANKTON SELECTIVITY

#### 8.1 Introduction

In New Zealand, few workers have made detailed parallel studies of zooplankton and algae, and little work has been done on feeding rates and selectivities (Chapman and Green 1987; Burns 1991). In this chapter plots were made of each phytoplankters response to grazing in relation to their GALD (Greatest Axial Linear Dimension) or SGALD (Second Greatest Axial Linear Dimension), and biovolume. This method has been used to determine any general pattern in the size and shape of the taxa which respond to grazing (Merrick and Ganf 1988; Edgar 1989). Plots were made for each experiment on both study lakes to determine if any change in selection of phytoplankters occurred seasonally.

#### 8.2 Results

##### 8.2.1 Lake Rotoroa

In Experiment 1 (Autumn Fig. 8.1) the smallest species of phytoplankton were 'decreasers' while those with GALD >50µm were either unresponsive to grazing or increased in abundance. The relationship between population growth rates and biovolume was less consistent as *Staurostrum leptocladum* var. *insigne* was unresponsive to herbivory, but the larger *Cryptomonas ovata* (+ *C. marsonnii*) declined in abundance.

Experiment 2 (Winter Fig. 8.1) again suggested selection for smaller sized algae, *Oocystis* cf. *lacustris* being the only exception. Relationship between population growth rates and biovolume was again unclear as phytoplankters less than 1,000 µm<sup>3</sup> in volume either decreased, increased or were unresponsive to grazers.

This selection for smaller sized species of algae continued to be a feature of Experiments 3 (Spring Fig. 8.1) and 4 (Summer Fig. 8.1). In only one case, *Asterionella formosa*, was an alga with a GALD larger than  $\sim 30\mu\text{m}$  significantly reduced in abundance (Fig. 8.1 Spring). Those phytoplankters with GALDS  $> 30\mu\text{m}$  were either unresponsive, unimodal or increasers. Response to biovolume was less consistent across experiments. However, there appeared to be an upper limit at approximately  $10,000\mu\text{m}^3$  above which algae were unresponsive to grazing.

Selection of smaller sized algae by zooplankton was also indicated from the relationship between SGALD and biovolume for Experiments 1 (Autumn Fig. 8.2) and 2 (Winter Fig. 8.2) in Lake Rotoroa. Phytoplankters with SGALD  $> 10\mu\text{m}$  were not grazed in these experiments. Responses in Experiment 3 (Spring Fig. 8.2) were not as consistent, with the smallest species, *Tetrastrum triangulare*, being unresponsive to grazing but the largest, *Asterionella formosa*, declining in abundance. Again, in Experiment 4 (Summer Fig. 8.2), the effect of grazing was variable across SGALD values, although there appeared to be more phytoplankton species of larger size being reduced in abundance, with two taxa  $> 20\mu\text{m}$  being consumed. This trend for an increase in the size (both for GALD and SGALD) of alga consumed was noticeable as the experiments progressed from winter to spring and finally into summer. Selection on the basis of biovolume was not consistent.

### 8.2.2 Lake Pupuke

In Experiment 5 (Autumn Fig. 8.3) a consistent grazing response in relation to either GALD or biovolume was not apparent. There were, however, no algal taxa with biovolumes  $> 10^3\mu\text{m}^3$  which responded to herbivory. There was no clear pattern in grazing selectivity in Experiment 6 (Winter Fig. 8.3) either. There were only five species present in significant numbers, the largest of which (*Fragilaria ulna* + *F. u.* var. *acus*) decreased in abundance. This lack of a consistent relationship between grazing response and morphology occurred also in Experiment 7 (Spring Fig. 8.3), with

phytoplankters of the smallest and largest GALDs and biovolumes being both grazed and unaffected.

In the summer experiment (Fig. 8.3 Experiment 8), there were no decreasing algal taxa. The majority of the increaser or unimodal responses were amongst the smallest (GALD and biovolume) species, with *Peridinium cinctum* the exception.

Plots of SGALD *versus* biovolume showed similar patterns to those of GALD (see Fig. 8.4). In general there was little relationship between response size (SGALD) or volume within an experiment. Across experiments there were more larger taxa consumed in Autumn and Spring. In winter there was only one decreaser and in summer none. The most striking feature of the plots for Lake Pupuke was the high number of unresponsive algal taxa compared with those for Lake Rotoroa where the majority of species were 'decreasers'.

Figure 8.5 presents those algal taxa for which a consistent or majority response type occurred in all experiments, from Lakes Rotoroa or Pupuke. *Dinobryon cylindricum* (GALD ~ 200µm) and *Closterium aciculare* (~ 310µm) have been removed to widen the scale on the x-axis (GALD). Their responses were 'increaser' and non-responsive respectively. It appeared that an equal number of species < 50µm in GALD were either 'decreasers' or were non-responsive. However, of those algae > 50µm in GALD only one, *Asterionella formosa*, was a decreaser. The majority of species with GALD > 50µm were non-responsive to grazer presence.

**Fig. 8.1** Species-specific growth rate responses of phytoplankton taxa plotted by Greatest Axial Linear Dimension (GALD) against biovolume for all seasonal experiments conducted in Lake Rotoroa. Autumn = Experiment 1; Winter = Experiment 2; Spring = Experiment 3; Summer = Experiment 4. - = decreaser; • = no response; + = increaser; u = unimodal.

Key to the symbols used for algal taxa in Figures 8.1 - 8.6.

- A = *Achnanthes* sp.
- As = *Asterionella formosa*
- Ca = *Closterium aciculare*
- Cc = *Cosmarium contractum*
- Cl = *Closterium acutum* var. *variable*
- Cm = *Cosmarium perfissum*
- Co = *Coelastrum reticulatum*
- Cr = *Cryptomonas marssonii*/*C. ovata*
- Cy = *Cyclotella meneghiniana*/*C. stelligera*
- Dc = *Dinobryon cylindrium*
- E = *Elakatothrix gelatinosa*
- Fc = *Fragilaria crotonensis*
- Fu = *Fragilaria ulna*/*F.u.* var. *acus*
- M = *Mougeotia* sp.
- O = *Oocystis* cf. *lacustris*
- Pc = *Peridinium cinctum*
- Sc = *Scenedesmus ecornis*, *S. quadricauda* (L. Rotoroa)
- Sc = *Scenedesmus bijuga* var. *alternans* (L. Pupuke)
- Sd = *Staurodesmus unicornis* var. *gracilis*
- Sj = *Staurastrum johnsonii* var. *altuis*
- Sl = *Staurastrum leptocladum* var. *insigne*
- Sp = *Staurastrum pinque*
- T = *Tetrastrum triangulare*
- Un = Unidentified unicells

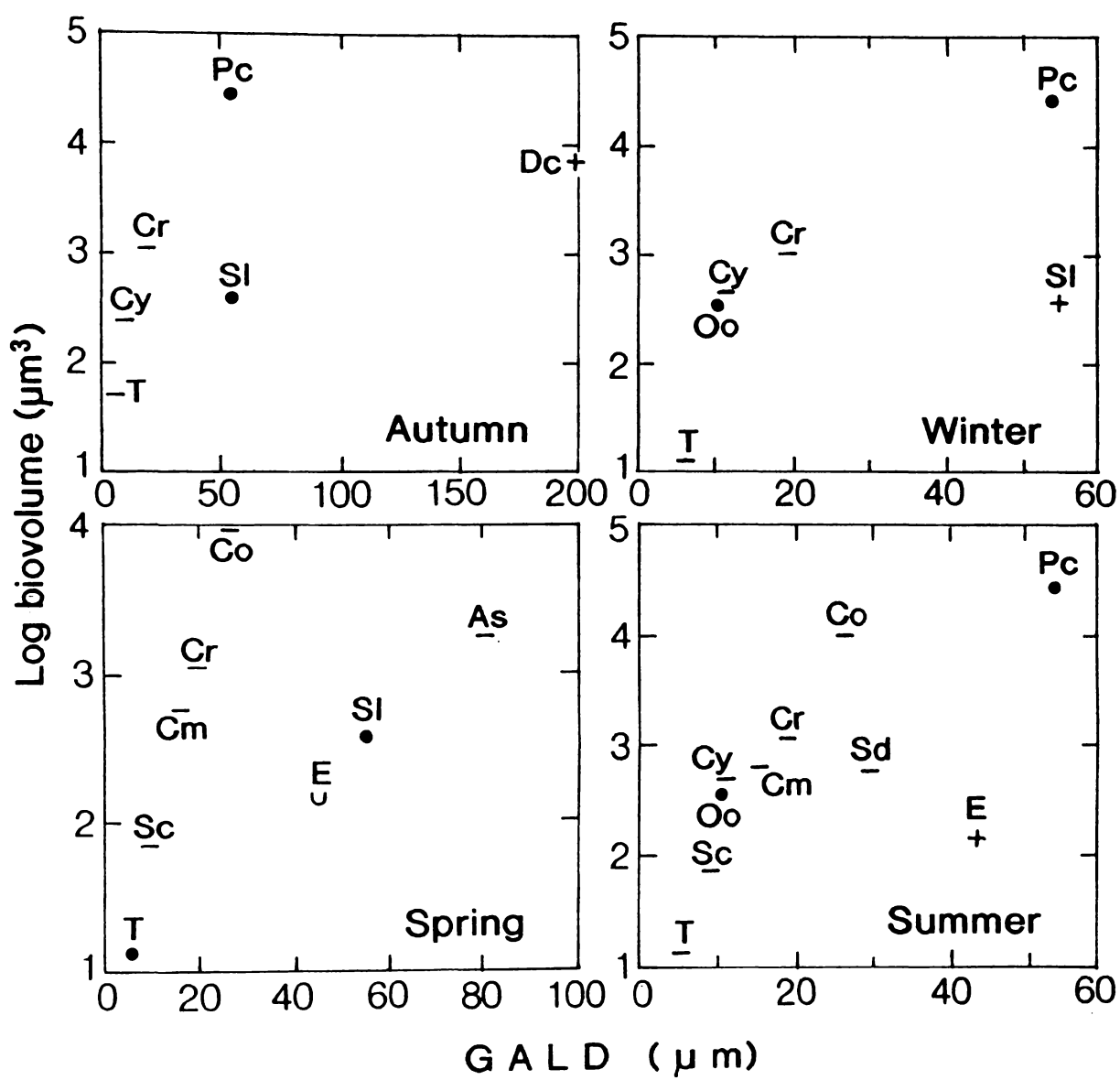


Figure 8.1: Lake Rotoroa

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**Fig. 8.2** Species-specific growth rate responses of phytoplankton taxa plotted by Second Greatest Axial Linear Dimension (SGALD) against biovolume for all season experiments conducted in Lake Rotoroa. See Fig. 8.1 for symbol definitions.

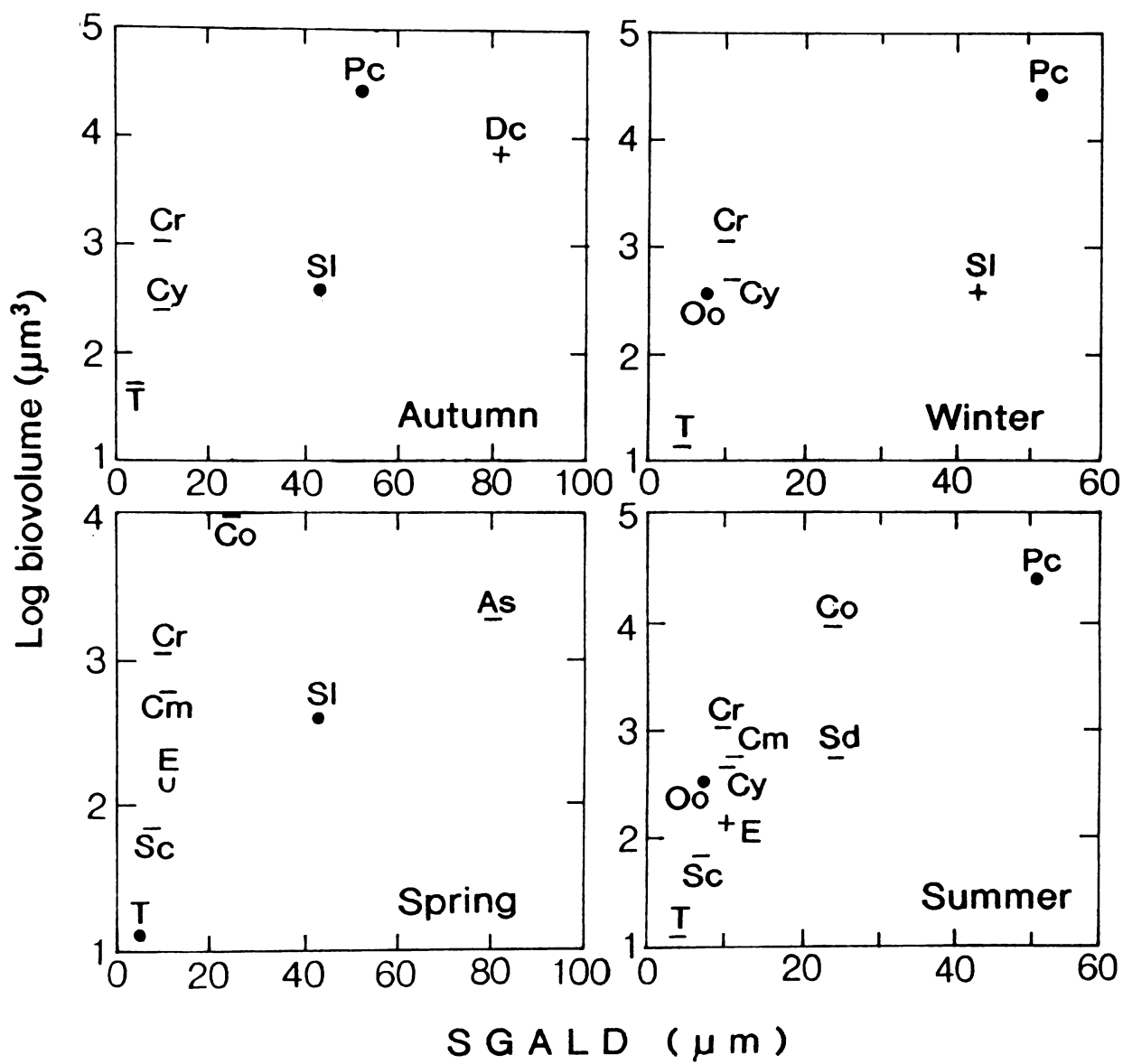


Figure 8.2: Lake Rotoroa

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**Fig. 8.3** Species-specific growth rate responses of phytoplankton taxa plotted by GALD against biovolume for all seasonal experiments conducted in Lake Pupuke. Autumn = Experiment 5; Winter = Experiment 6; Spring = Experiment 7; Summer = Experiment 8. See Fig. 8.1 for symbol definitions.



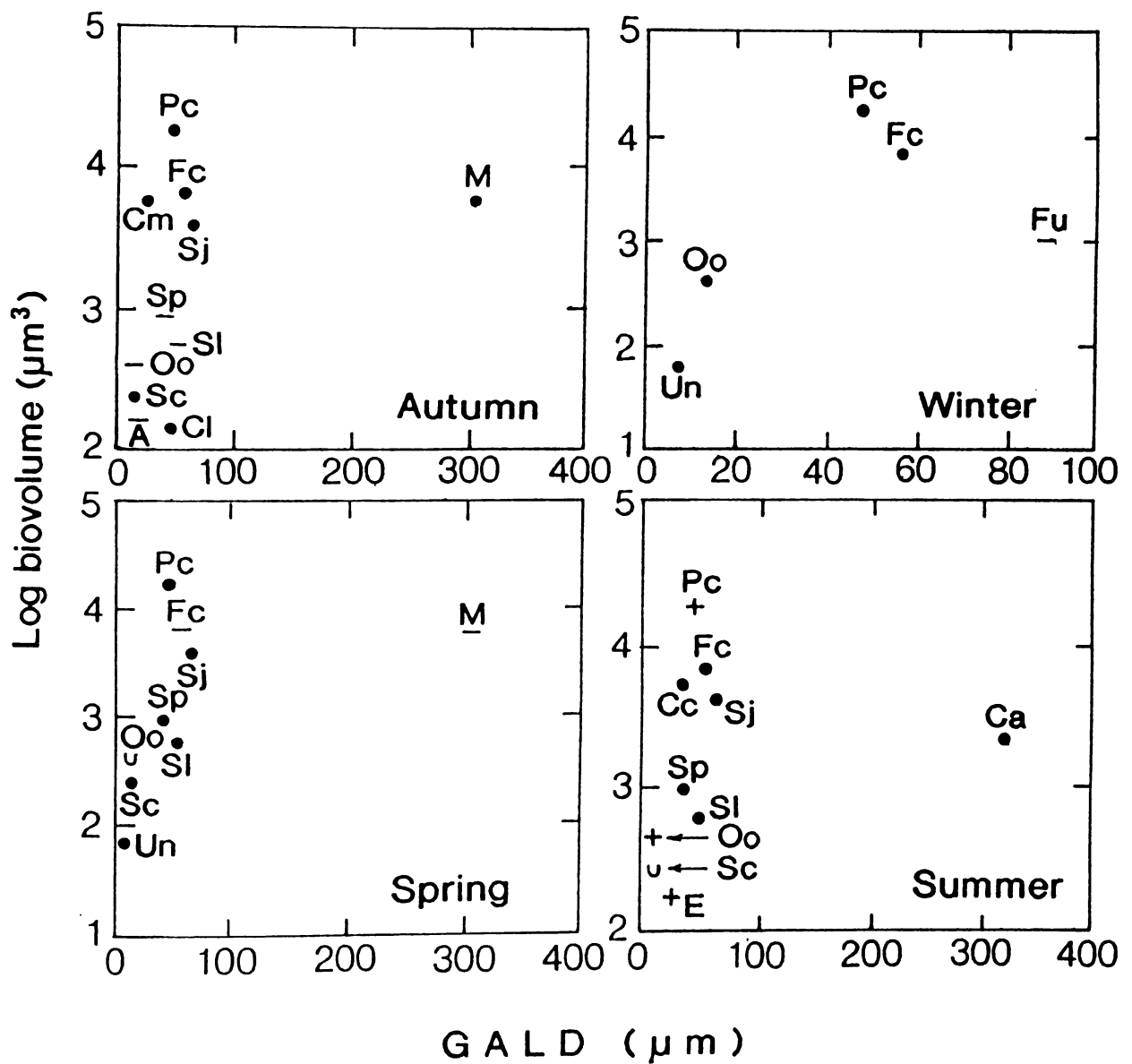


Figure 8.3: Lake Pupuke

**Fig. 8.4** Species-specific growth rate responses of phytoplankton taxa plotted by (SGALD) against biovolume for all season experiments conducted in Lake Pupuke. See Fig. 8.1 for symbol definitions.

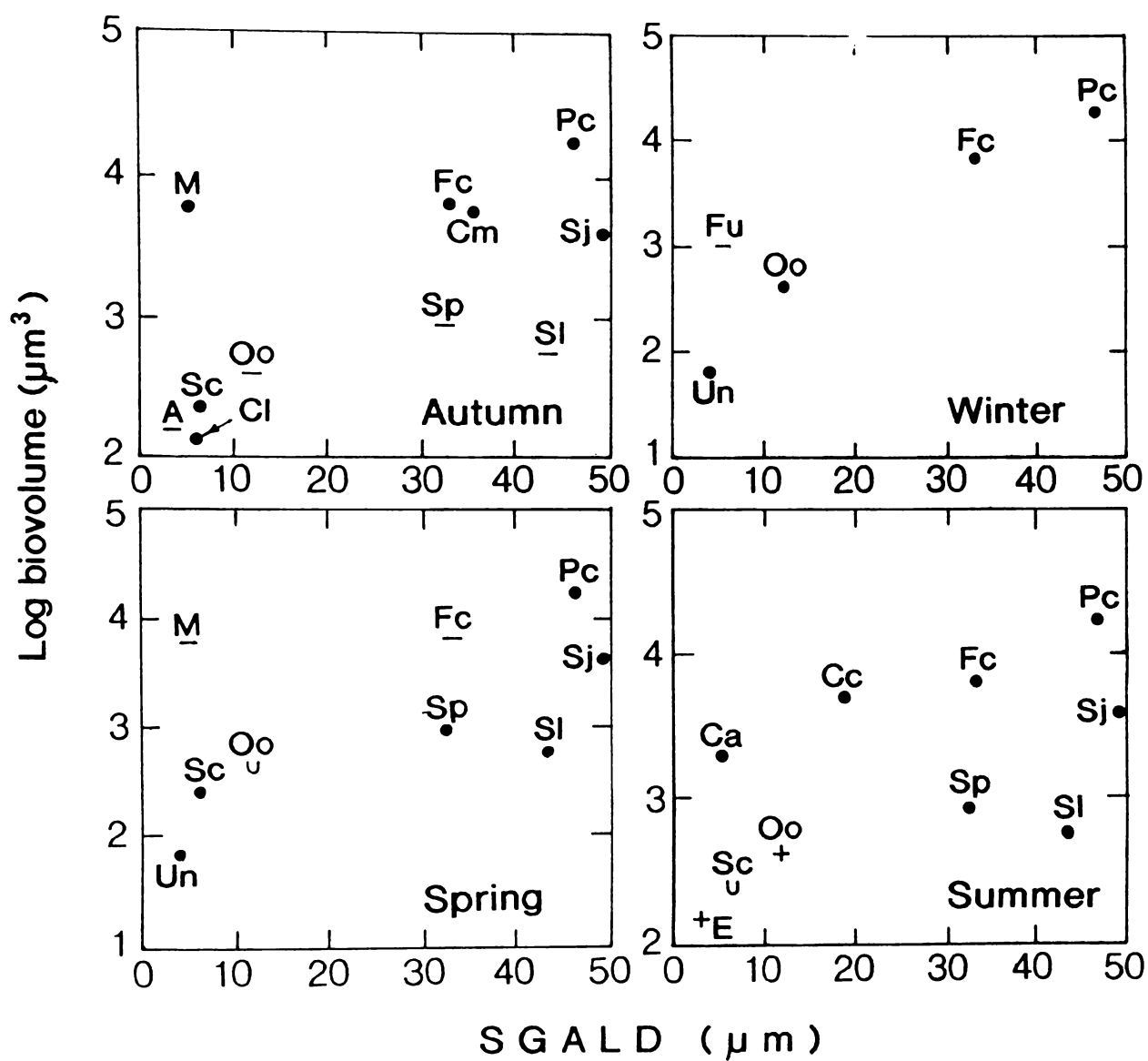


Figure 8.4: Lake Pupuke

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**Fig. 8.5** Summary of all species-specific growth rate responses of phytoplankton taxa plotted by GALD against biovolume for all seasonal experiments conducted in Lakes Rotoroa and Pupuke. See Fig. 8.1 for symbol definitions.

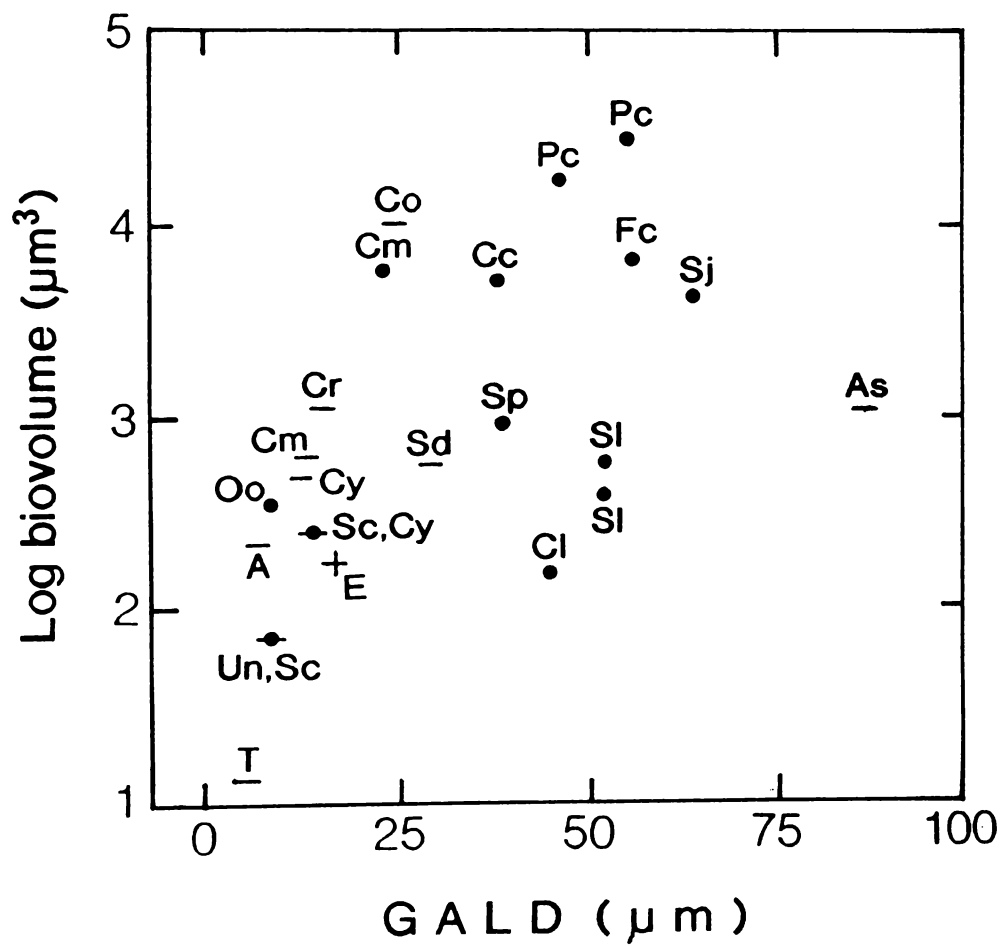


Figure 8.5: GALD vs Biovolume

**Fig. 8.6** Summary of all species-specific growth rate responses of phytoplankton taxa plotted by SGALD against biovolume for all seasonal experiments conducted in Lakes Rotoroa and Pupuke. See Fig. 8.1 for symbol definitions.

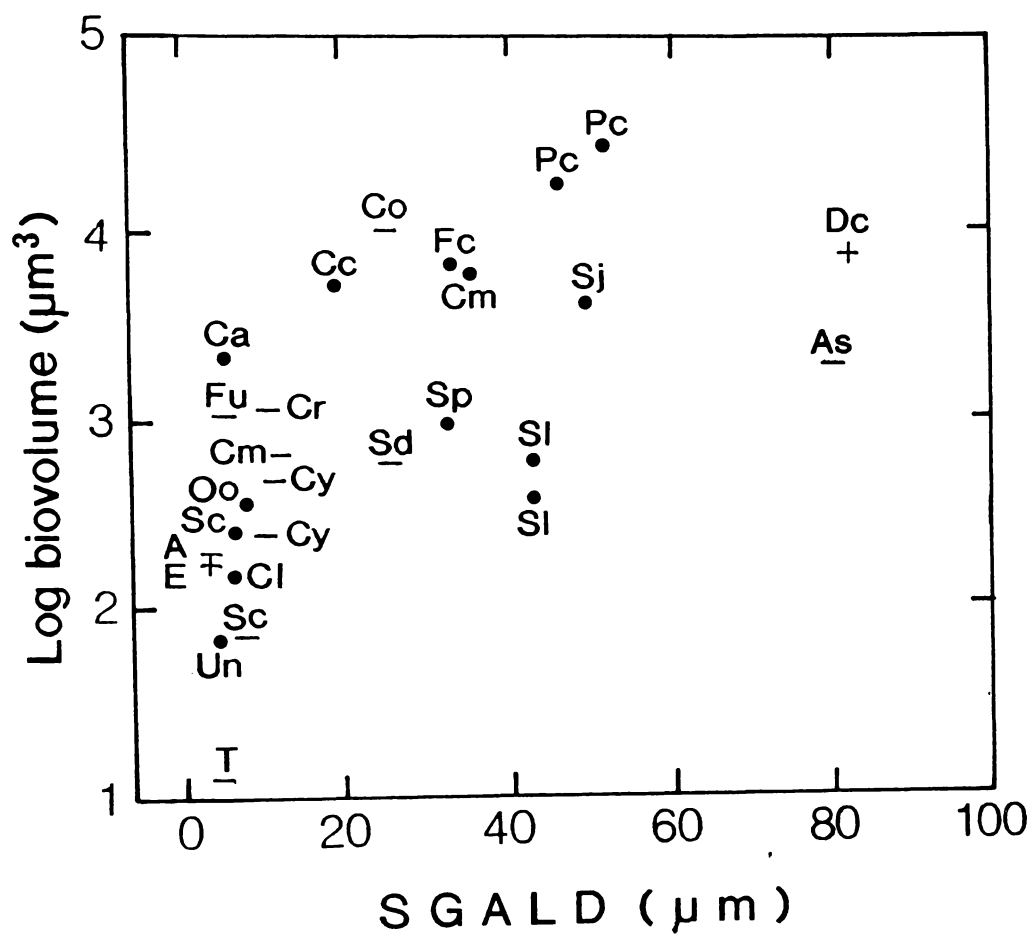


Figure: 8.6: SGALD vs Biovolume

The pattern of response to biovolume shown in Fig. 8.5 suggests a possible upper limit to the volume of algal taxa able to be consumed. Only one taxon, *Coelastrum reticulatum*, larger than  $\sim 6,000 \mu\text{m}^3$  was suppressed by zooplankton. No phytoplankters larger than  $10,000 \mu\text{m}^3$  were consumed. However, below  $1,000 \mu\text{m}^3$  responses were less consistent, with algae of the smallest sizes either suppressed by grazing or unresponsive.

The same approach was applied to SGALD (Fig. 8.6). The majority of phytoplankters with SGALD  $> 30 \mu\text{m}$  were non-responsive to grazing. Again *Asterionella formosa* was the only decreaser. Below  $30 \mu\text{m}$  in SGALD the majority response was suppression, followed by a number of non-responsive algae. The relationship between response and biovolume was similar to that shown in Fig. 8.5.

### 8.3 Discussion

There is a wide variety in modes of feeding within the various groups of freshwater zooplankton and there is similar variety in the characteristics of phytoplankton that might determine their edibility (Sterner 1989). In this study the zooplankton assemblage included two cladocerans (*Bosmina* and *Ceriodaphnia*), calanoid (*Calamoecia*) and cyclopoid (*Mesocyclops*) copepods, numerous rotifer species and naupliar and copepodite stages. The results presented in this chapter reflect the combined feeding selectivities of all these species and life stages, making generalisations difficult.

Morphology, particularly size, is often the only parameter reported in studies of selectivity. In this study there appeared to be a suppression of smaller sized (GALD) algae and this is a common feature of many investigations. Lampert *et al.* (1986) found small particles ( $< 35 \mu\text{m}$ ) were always in higher concentrations in enclosures lacking zooplankton. Mazumder *et al.* (1990(b)) recognised a strong effect of particle size on filtering rates, with mesozooplankton suppressing phytoplankters  $3\text{-}20 \mu\text{m}$  in size. Northcote *et al.* (1990) reported significantly reduced cell densities and biomass of



species < 15µm in size in the presence of zooplankton. Porter (1972) found no detectable grazing effect on larger algae (> 30µm) but suppression of phytoplankton 2-30µm in size. Bergquist *et al.* (1985) noted suppression of algae < 60µm in GALD by large zooplankters. Medium-sized algae (equivalent spherical diameter 15-50 µm) were proportionately most favoured by the elimination of grazers in the investigation of Svensson and Stenson (1991), and Vyhnalek (1983) found nanoplankton species < 40µm were suppressed by filter-feeding zooplankton but that net phytoplankton (> 40µm) had enhanced abundances.

These investigations all lend support to the view of seasonal succession in plankton communities as a transition from a spring algal assemblage dominated by smaller more edible phytoplankters to a summer community composed of higher abundances of larger, less edible algae (reviewed by Reynolds 1989). However, closer inspection of the literature shows that size is not a consistent predictor of phytoplankton susceptibility of grazing. In much of the above work specific measurements of the size limits of edible algae were not made but instead the food supply was fractionated into broad size classes. For example, although Lampert *et al.* (1986) found that the < 35µm fraction was suppressed by grazing and the 35 - 250µm fraction was enhanced, this did not imply that all taxa in the larger fraction were not grazed and *vice versa*. The same is true for the work of Porter (1972), Bergquist *et al.* (1985) and Vyhnalek (1983).

Lack of consistent relationship between grazing response and (GALD) was a feature of this study. Figs. 8.1 and 8.3 reveal instances where the smallest phytoplankters were unresponsive to grazing and the largest taxa suppressed. Other studies which have specifically examined algal morphology in relation to zooplankton selectivity have also found a similar lack of consistent relationship between size and grazability. Merrick and Ganf (1988) found phytoplankton size as measured by GALD did not determine the susceptibility of a taxon to grazing, as did Bergquist *et al.* (1985) and Horn (1985) who found that volume and surface area predicted response to grazing better than largest

linear dimension. However, Lehman and Sandgren (1985) found there was a tendency for small particles to be grazed more readily than large ones.

Consequently, other morphological characteristics may be more appropriate for characterising the selectivity of food particles. Examples are SGALD, volume, projected particle area, form coefficient, dimensionless surface area to volume ratio and the presence (or absence) of cell wall projections, motility, gelatinous sheaths and armour (Lewis 1978; Bergquist *et al.* 1985). In this study the relationship between grazability and SGALD differed little from that of grazability and GALD. Biovolume was also not a consistent predictor of algal response to herbivory as was the case with Merrick and Ganf (1988). In agreement with these workers, there appeared to be an upper limit to the volume of an alga consumed. In my study phytoplankters greater than  $10,000\mu\text{m}^3$  in volume were ungrazed. More work of this nature is required before generalisations can be made (Sterner 1989).

More direct measurements of food size limitations come from bead feeding research and gut content analysis. In New Zealand plastic beads ranging in size from  $1\mu\text{m}$  -  $100\mu\text{m}$  have been fed to both *Calamoecia lucasi* and *Ceriodaphnia dubia* (Green 1975; Moltzen (unpub. obs.)). Mean and maximum diameters of ingested beads were 9.55 - 11.03 and 17 for the copepod and 15.87 - 17.36 and 25 for the cladoceran respectively. Slight but significant differences were related to life stage, body size and sex of the animals (Chapman and Green 1987). Kobayashi (1991) reviewed work on the maximum food-particle sizes of cladocerans and copepods in the literature (based on gut content analyses) and found that Australian zooplankton consumed particles comparable to those for other zooplankton species in the Northern Hemisphere. For *Bosmina* species maximum food particles ranged between 14 -  $19\mu\text{m}$  ( $16\mu\text{m}$  for *B. meridionalis*); for *Ceriodaphnia* (9 -  $46\mu\text{m}$ ) and for *Calamoecia lucasi*  $28\mu\text{m}$ .

There was good agreement with the above range of ingested particle sizes and those algal species consistently suppressed in the present study. *Cyclotella*, *Tetrastrum*, *Cryptomonas*, *Scenedesmus*, *Achnanthes* and *Coelastrum* species were all classified as decreasers and they all lie in the size range 5.49 - 26.53µm (Appendix VI). However, much larger phytoplankters, for example *Asterionella formosa*, *Fragilaria ulna* (+ *F.u.* var. *acus*), and *Mougeotia* sp. (all with GALDs > 80µm) were suppressed by zooplankton as well. Because such large algae are both non-spherical and breakable, experiments with plastic spheres underestimate abilities to ingest large algae. In addition, much of the material examined in gut content analysis may be semi-digested and unrecognisable and the results may reflect a bias forward those few species which are recognisable (De Mott 1989). Large net algae may be swallowed by cladocerans after being broken in half, and calanoid copepods readily bite off parts of large net diatoms (Sterner 1989). The ability of New Zealand copepod species to feed on large filamentous cyanobacteria has been documented (see Chapter Six).

In view of the considerable flexibility in cladoceran and copepod feeding (including chemo and mechanoreception in copepods, De Mott and Watson (1991), changes in feeding behaviour during development, the influence of surface properties of algal particles, and changes in selectivity as a consequence of the nutritional status of both animal and phytoplankter, it is not surprising that generalisations about algal selectivities are difficult to make. This was recognised by McQueen (1990) when considering the edibility of phytoplankton to grazers in biomanipulation research. Until more is known about the mechanisms of algal selection, predictions about grazing impacts will remain tentative.

This basic lack of information about what factors influence particle selection by herbivores also applies to understanding the mechanisms (when present) governing change in particle selection over time. Sterner (1989) has reviewed those studies which have addressed invariant, variant or switching selectivity, and optimal foraging in

cladocerans and copepods. Researchers' views differ as to the importance of these processes and much of the associated methodology has been forcefully criticised. In New Zealand, I know of only two studies which have examined seasonal changes in size selective grazing and they have both looked exclusively at *Calamoecia lucasi* (Edgar 1989; Forsyth and James 1991).

I made an enclosure-based study on *Calamoecia* feeding in eutrophic Lake Rotomanuka and found this copepod appeared to select smaller size classes of phytoplankton from summer to autumn and into winter. In summer all algal taxa were suppressed, in autumn only those species smaller than 20µm were grazed, and by winter only *Cyclotella stelligera* (< 10µm) was suppressed. In spring this pattern was reversed as larger algae (up to 25µm) were eaten. The laboratory study of Forsyth and James (1991) on *Calamoecia* feeding suggested a negative correlation between selectivity and particle size, as the smallest size fraction was most often preferred. However, preference was for algae in the 0 - 3µm fraction in a system (Lake Okaro) where most of the phytoplankton was more than 20µm in size. Although temporal changes in selectivity did occur, selectivity was not thought to be strongly influenced by species succession and its associated changes in shape or taste of potential food or of total phytoplankton concentration.

In the present study there was a lack of changing seasonal selection by the zooplankton assemblage in Lake Pupuke. However, Lake Rotoroa zooplankters showed a tendency to consume larger algae from winter to spring and then into summer.

This is similar to the trend observed by *Calamoecia* in Lake Rotomanuka (Edgar 1989). This behaviour has links to optimal foraging theory where the degree of selectivity is dependent on the animal's nutrition (Sterner 1989). It is possible that in summer in Lake Rotoroa, when lake temperatures were higher (Table 4.4) and the animals' metabolism was also high, that the animals required more food, widened their dietary

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breath and therefore suppressed more of the phytoplankters (Fig. 8.1). When water temperatures were cooler, in spring and winter, the animals' metabolism would be lower and food requirements smaller. There may have been a selection towards those algae most easy to filter and digest rather than having a need to consume all available food to satisfy respiratory demand. A positive relationship between temperature and respiration has been established for New Zealand zooplankton (Green 1975), however a more detailed assessment of energy budgets is required.

The above hypothesis is speculative. The data supporting this view are limited and reflect an area of planktonic research in need of review and re-examination. Many of the problems associated with this study and similar research are associated with the difficulty in establishing direct selective mortalities of algal taxa against a background of confounding processes. A major complication in the examination of algal species-specific growth rates is the potential beneficial alteration in nutrient regimes associated with zooplankton feeding. It is this process which is the focus of the next chapter.

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## CHAPTER NINE

### NUTRIENT REGENERATION BY ZOOPLANKTON

#### 9.1 Introduction

Zooplankton can excrete considerable amounts of both dissolved nitrogen and phosphorus, and regeneration of these nutrients may stimulate phytoplankton growth, possibly balancing the loss of cells through zooplankton ingestion (Lehman 1980). The increased availability of these dissolved nutrients may result from direct excretion and egestion from zooplankters or by the cropping of the algal assemblage, reducing phytoplankton biomass and nutrient uptake rates (Sterner 1989).

In Spring and Summer on both Lakes Rotoroa and Pupuke water samples collected from the limnocorrals were analysed for ammonia nitrogen ( $\text{NH}_4$ ), nitrate ( $\text{NO}_3$ ), dissolved reactive phosphorus (DRP), dissolved organic phosphorus (DOP) and dissolved organic nitrogen (DON) (see 2.3.5). Concentrations of these nutrients reflect the net effect of zooplankton herbivory on nutrient dynamics in the limnocorrals. Regressing nutrient concentration against zooplankton biomass may indicate whether a higher biomass of grazers leads to higher rates of nutrient supply to the phytoplankton community (Moegenburg and Vanni 1991).

#### 9.2 Results

##### 9.2.1 Lake Rotoroa

In Experiment 3 (Spring) there was no significant change in the concentration of either DRP or  $\text{NO}_3$  with increasing zooplankton biomass. However, by Day 10 (22/10/90) both  $\text{NH}_4$  and DOP concentrations were higher in the zooplankton enclosures compared to the enclosure treatment (Figs 9.1; 9.2). By Day 3 (15/10/92) of the experiment there was a significant positive association between DON concentration and zooplankton biomass. This continued to Day 6 (Fig. 9.3: Table 9.1) but weakened on Day 10.

In Experiment 4 (Summer) the concentration of DRP was similar to that for Experiment 3. There was no significant increase in DRP with increasing zooplankton biomass on Days 3 (8/2/91) or 6 (11/2/91), however, by Day 10 (15/2/91) there was a significant positive association (Fig. 9.4). DOP concentrations were also positively associated with zooplankton biomass. There was no significant relationship on Day 3 but by Day 6 there was a significant positive association (Fig. 9.5: Table 9.1) which continued until the end of the experiment (Day 10), albeit slightly weakened. Neither  $\text{NH}_4$ ,  $\text{NO}_3$  or DON were significantly related to zooplankton biomass.

### **9.2.2 Lake Pupuke**

During Experiment 7 (Spring) there were no significant increases in the concentrations of DRP,  $\text{NH}_4$ ,  $\text{NO}_3$  or DON with increasing zooplankton biomass on any day. However, on Day 6 (14/10/91) there was a significant negative relationship between DRP concentration and grazer biomass and this association was also found on Day 10 (18/10/91) for  $\text{NO}_3$  and DON abundance. The only nutrients which had significantly increased in concentration with zooplankton biomass were DOP on Day 6 (Fig. 9.6). By Day 10 this relationship was non-significant. The most noticeable feature of the nutrient concentrations in Experiment 7 was how much lower all five groups were in comparison to Lake Rotoroa concentrations during Experiments 3 and 4. This was also the case in Experiment 8 (Summer) in Lake Pupuke.

**Fig. 9.1** Regression of Ammonia - N ( $\text{NH}_4$ ) concentration ( $\text{mg.m}^{-3}$ ) against zooplankton biomass (dryweight  $\text{mg.m}^{-3}$ ) in Experiment 3 (Spring), Day 10 in Lake Rotoroa. 95% confidence intervals are indicated. For a complete statistical analysis see Table 9.1 pg 164.  $r^2 = 0.483$ ;  $p = 0.056$ .

**Fig. 9.2** Regression of Dissolved Organic Phosphorus (DOP) concentration ( $\text{mg.m}^{-3}$ ) against zooplankton biomass (dryweight  $\text{mg.m}^{-3}$ ) in Experiment 3 (Spring), Day 10 in Lake Rotoroa. 95% confidence intervals are indicated.  $r^2 = 0.392$   $p = 0.097$ .

**Fig. 9.3** Regression of Dissolved Organic Nitrogen (DON) concentration ( $\text{mg.m}^{-3}$ ) against zooplankton biomass (dryweight  $\text{mg.m}^{-3}$ ) in Experiment 3 (Spring), Day 6 in Lake Rotoroa. 95% confidence intervals are indicated.  $r^2 = 0.744$   $p = 0.006$ .



Fig. 9.1

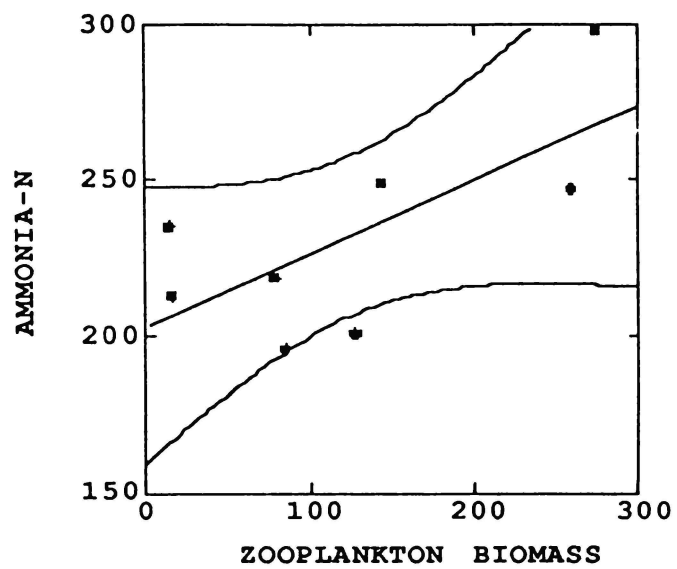


Fig. 9.2

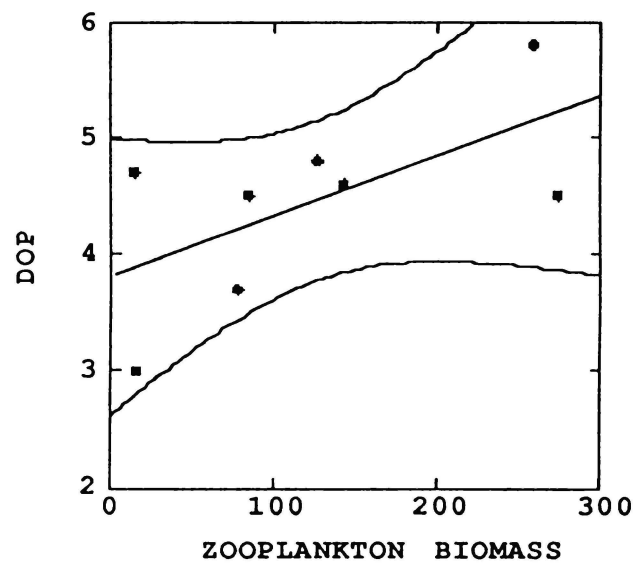
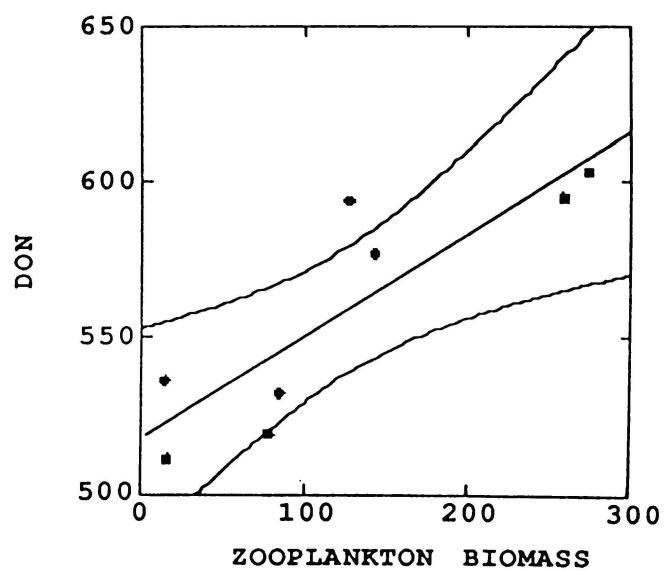


Fig. 9.3



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**Fig. 9.4** Regression of Dissolved Reactive Phosphorus (DRP) concentration ( $\text{mg.m}^{-3}$ ) against zooplankton biomass (dryweight  $\text{mg.m}^{-3}$ ) in Experiment 4 (Summer), Day 10 in Lake Rotoroa. 95% confidence intervals are indicated.  $r^2 = 0.392$   $p = 0.097$ .

**Fig. 9.5** Regression of Dissolved Organic Phosphorus (DOP) concentration ( $\text{mg.m}^{-3}$ ) against zooplankton biomass (dryweight  $\text{mg.m}^{-3}$ ) in Experiment 4 (Summer), Day 6 in Lake Rotoroa. 95% confidence intervals are indicated.  $r^2 = 0.421$ ;  $p = 0.082$ .

**Fig. 9.6** Regression of Dissolved Organic Phosphorus (DOP) concentration ( $\text{mg.m}^{-3}$ ) against zooplankton biomass (dryweight  $\text{mg.m}^{-3}$ ) in Experiment 7 (Spring), Day 6 in Lake Pupuke. 95% confidence intervals are indicated.  $r^2 = 0.707$   $p = 0.009$ .

Fig. 9.4

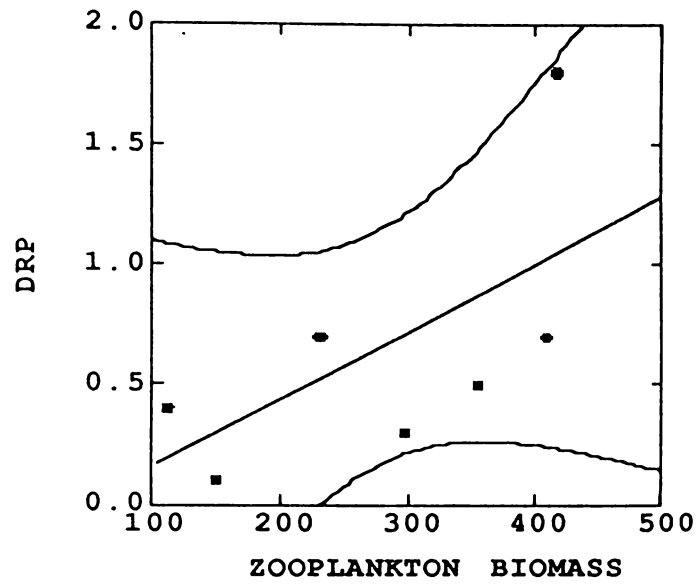


Fig. 9.5

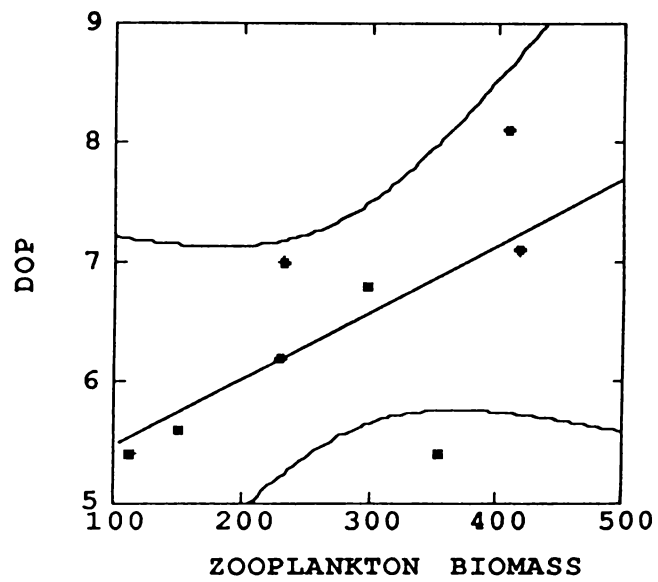


Fig. 9.6

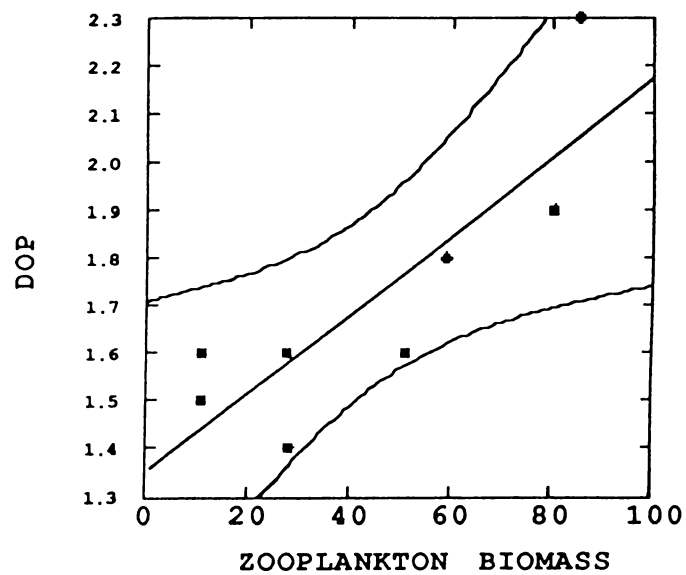


**Fig. 9.7** Regression of Ammonia - N ( $\text{NH}_4$ ) concentration ( $\text{mg.m}^{-3}$ ) against zooplankton biomass (dryweight  $\text{mg.m}^{-3}$ ) in Experiment 8 (Summer), Day 10 in Lake Pupuke. 95% confidence intervals are indicated.  $r^2 = 0.530$ ;  $p = 0.041$ .

**Fig. 9.8** Regression of Dissolved Organic Phosphorus (DOP) concentration ( $\text{mg.m}^{-3}$ ) against zooplankton biomass (dryweight  $\text{mg.m}^{-3}$ ) in Experiment 8 (Summer), Day 6 in Lake Pupuke. 95% confidence intervals are indicated.  $r^2 = 0.947$ ;  $p = 0.000$ .

**Fig. 9.9** Regression of Dissolved Organic Nitrogen (DON) concentration ( $\text{mg.m}^{-3}$ ) against zooplankton biomass (dryweight  $\text{mg.m}^{-3}$ ) in Experiment 8 (Summer), Day 6 in Lake Pupuke. 95% confidence intervals are indicated.  $r^2 = 0.569$ ;  $p = 0.031$ .

Fig. 9.7

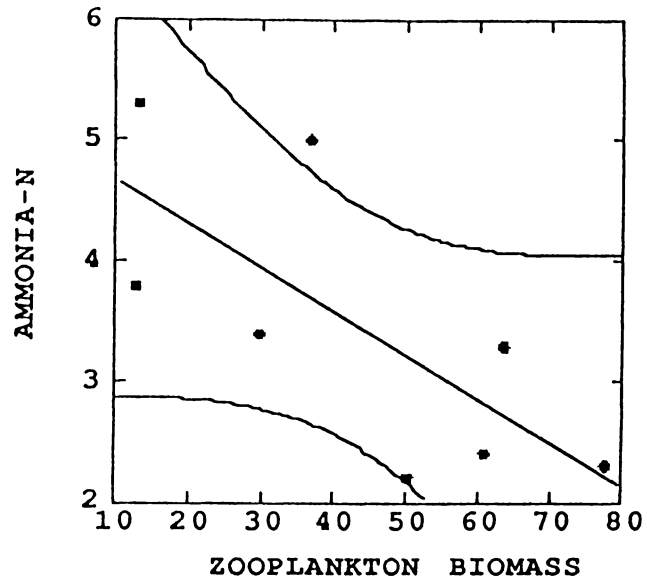


Fig. 9.8

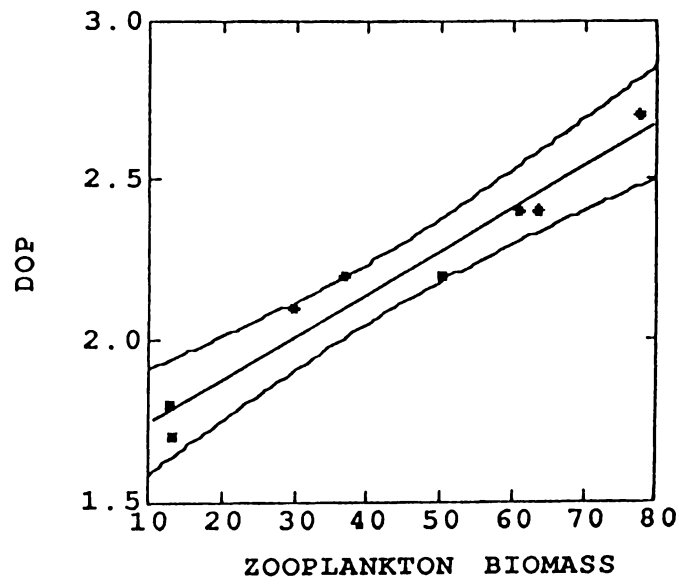


Fig. 9.9

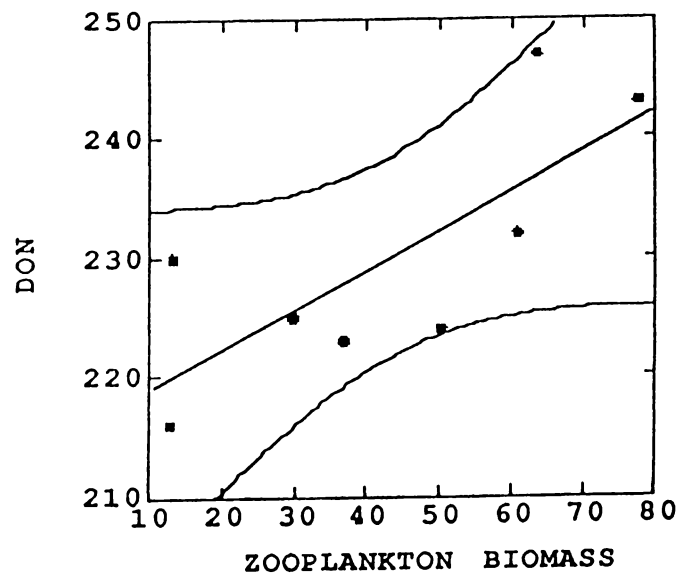


**Table 9.1** : Summary of regression analyses in Chapter Nine

Regression of nutrient concentration against total zooplankton biomass for Lake Rotoroa (Experiments 3 and 4) and Lake Pupuke (Experiments 7 and 8). Units for the intercept (constant) are  $\text{mg.m}^{-3}$  ( $n=8$ ).

| Experiment | Day | Nutrient      | Equation               | $r^2$ | p     | Figure |
|------------|-----|---------------|------------------------|-------|-------|--------|
| 3 (Spring) | 10  | $\text{NH}_4$ | $y = 203.312 + 0.233x$ | 0.483 | 0.056 | 9.1    |
| 3 (Spring) | 10  | DOP           | $y = 3.805 + 0.005x$   | 0.392 | 0.097 | 9.2    |
| 3 (Spring) | 6   | DON           | $y = 517.488 + 0.329x$ | 0.744 | 0.006 | 9.3    |
| 4 (Summer) | 10  | DRP           | $y = -0.125 + 0.003x$  | 0.392 | 0.097 | 9.4    |
| 4 (Summer) | 6   | DOP           | $y = 4.934 + 0.006x$   | 0.421 | 0.082 | 9.5    |
| 7 (Spring) | 6   | DOP           | $y = 1.352 + 0.008x$   | 0.707 | 0.009 | 9.6    |
| 8 (Summer) | 10  | $\text{NH}_4$ | $y = 5.030 - 0.036x$   | 0.530 | 0.041 | 9.7    |
| 8 (Summer) | 6   | DOP           | $y = 1.613 + 0.013x$   | 0.947 | 0.000 | 9.8    |
| 8 (Summer) | 6   | DON           | $y = 215.734 + 0.331x$ | 0.569 | 0.031 | 9.9    |

In Experiment 8 (Summer) there was no significant relationship between either DRP or  $\text{NO}_3$  concentration and grazer biomass on any day.  $\text{NH}_4$  concentration was significantly negatively associated on Day 3 (7/2/92), non-significant on Day 6 (10/2/92) and again negatively associated on Day 10 (14/2/92) (Fig. 9.7: Table 9.1). DOP concentrations were significantly higher on Day 3 in the zooplankton enclosures compared to the exclosure treatment. This association strengthened by Day 6 (Fig. 9.8) and continued until the end of Experiment 8 (Day 10). DON concentrations were not significantly associated with zooplankton biomass on Days 0 or 3 but by Day 6 there was a significant positive relationship (Fig. 9.9: Table 9.1). However, by Day 10 the relationship was again non-significant.

### 9.3 Discussion

Because zooplankton do not convert all or even a major share of their consumed prey into sustained consumer biomass, mortalities inflicted by them are necessarily coupled to releases of nutrients in one form or other (Lehman 1980). Plankton research has emphasised the positive effects on phytoplankton, specifically the stimulation of algal growth by zooplankton regeneration of limiting nutrients. Zooplankton nutrient regeneration is a complex function of zooplankton size and species composition, the quantity and quality of food sources, as well as various environmental factors (Carney and Elser 1990). Likewise, the response of the phytoplankton community to recycled nutrients may depend on ambient nutrient levels, environmental conditions and various species-specific factors.

This indirect mutualism whereby grazers increase the per capita availability of resources by regenerating nutrients may also occur when herbivory reduces algal population density and therefore total uptake rates of nutrients (Sterner 1990). Theoretical grazing/excretion models indicate that it is not true that all increases in algal productivity seen in experiments which manipulate grazer density are a result of nutrient regeneration. Some (perhaps most) of the sensitivity of algal

reproductive rates to grazer density occurs not because of nutrient release by grazers, but because grazers, by thinning the algal population, prevent algae from monopolising the resources that are in the dissolved pool (Sterner 1989).

The concentrations of nutrients analysed in this study result from the combined action of both forms of indirect mutualism. Because phytoplankton biomass did not remain unchanged in any experiment it is not clear how much of the changes in dissolved nutrients arose from direct excretion and egestion of unassimilated faecal material or from changes in phytoplankton uptake rates of nutrients. The concentrations of nutrients measured represent the net effect of herbivory on nutrient regimes in the limnocorrals (Moegenburg and Vanni 1991).

The most secure method for determining the influence of zooplankton grazing on nutrient dynamics is to measure the nutrients directly (as above) (Lehman 1980). However, the pools of dissolved inorganic nutrients in mesotrophic lakes (particularly during summer stratification) are often undetectable due to rapid algal uptake. This apparent lack of inorganic nutrients has encouraged research into the role of dissolved organic forms of nitrogen (DON) and phosphorus (DOP) in the nutrition of phytoplankton (Capblancq 1990). The availability and fate of DOP and DON and their relative importance to limnetic plankton have not been clearly resolved due to the lack of direct methods for their quantification. When the concentration of inorganic phosphate or nitrogen is low, a significant fraction of dissolved P or N may be DOP or DON. Studies of DOP and DON have shown them to be of predominantly large molecular weight or colloidal material, or urea and amino acids respectively (Bentzen *et al.* 1992). Due to their potential influence on nutrient dynamics their concentrations were also measured in this study in conjunction with dissolved reactive phosphorus, ammonia and nitrate.



Concentrations of all five nutrients in the limnocorrals during both spring and summer experiments on Lakes Rotoroa and Pupuke generally bracketed lake values adjacent to the sites of limnocorral deployment. Such agreement between nutrient levels in the lake and enclosed water has been noted in previous grazer manipulation research and lends further support to the value of limnocorrals in *in situ* research (Bloesch *et al.* 1988). Examination of nutrient concentrations in the limnocorrals between seasons and lakes indicates that the spring experiment in Lake Rotoroa had much higher levels of  $\text{NH}_4$  and  $\text{NO}_3$  than the summer experiment and that in general nutrient concentrations were higher in Lake Rotoroa limnocorrals than for Lake Pupuke in both experiments.

Regression of nutrient concentration against zooplankton biomass suggests that in the spring experiment on Lake Rotoroa DON was significantly higher in the presence of grazers by Day 6 and that by Day 10 this was also true for  $\text{NH}_4$  and DOP. Conversely, in the summer experiment no forms of nitrogen were significantly related to zooplankton biomass but DOP was positively associated by Day 6 and by Day 10 so too was DRP. In Lake Pupuke during the spring experiment only DOP on Day 6 displayed a significant positive increase in concentration with increasing zooplankton biomass and this was non-significant on Day 10. However, in the summer experiment both DOP and DON were significantly increased in the presence of grazers by Day 6.

In Lake Rotoroa total algal biomass  $\leq 80\mu\text{m}$  was significantly reduced by the gradient in zooplankton biomass in both spring and summer experiments. However, the fraction  $> 80\mu\text{m}$ , principally composed of colonies of *Botryococcus braunii*, tended to increase. It may be that nutrients were transferred through the excretion and egestion of unassimilated algal material in the more edible size fraction to this less edible phytoplankter (Lehman 1984, Sterner 1989). It would

appear herbivory made nitrogenous groups more available to the algae in the spring experiment and that phosphorus was made more available in summer.

In Lake Pupuke total algal biomass was significantly reduced by zooplankton in the spring experiment and it appears that active mortality may have been more important during this season than any increase in growth rates caused by increase in ambient nutrient concentrations due to indirect mutualism. However, in the summer experiment there was a significant increase in total algal biomass with increasing zooplankton biomass and it may be that increased levels of DOP and DON on Day 6 may account for part of this change. Lake Pupuke is a deep lake which stratifies during the summer season but is holomictic during spring. The data suggest that during spring ambient nutrient levels may be less limiting to phytoplankton growth than in summer and that the most important influence of zooplankton herbivory is algal mortality and not nutrient regeneration. In summer thermal stratification isolates the epilimnion from nutrient supply from lake bottom waters and increases in nutrient concentrations from zooplankton grazing may counter losses of algae through ingestion.

At the population level, the increase in algal biomass in the summer experiment on Lake Pupuke is reflected in the number of algal species experiencing increased growth rates in the presence of zooplankton, *Elakatothrix gelatinosa*, *Oocystis* cf. *lacustris* and *Peridinium cinctum* were all 'increasers' during this season and it may be that the higher levels of dissolved nitrogen and phosphorus in the limnocorrals were a possible cause of elevated growth rates (Elser *et al.* 1987). The unimodal response of *Scenedesmus bijuga* var. *alternans* is understandable if nutrient increases due to zooplankton grazing caused an initial growth enhancement but were offset at higher zooplankton biomass by higher ingestion rates (Elser and Goldman 1991).

In the spring experiment on Lake Pupuke there was a lack of significant enhancement of nutrient levels with increasing zooplankton biomass and this is also reflected in the lack of any algal taxon classified as an increaser. In the summer experiment in Lake Rotoroa *Elakatothrix gelatinosa* was an 'increaser' and it is possible that its increased growth rate may be a consequence of elevated levels of phosphorus due to zooplankton grazing. Again, as in the spring experiment on Lake Pupuke, in the spring experiment in Lake Rotoroa there were no 'increaser' species.

Recycling of nutrients by zooplankton has received less attention in New Zealand than elsewhere (Burns 1991). Work by James (1987) showed that excretion by calanoid copepods provides a major source of nitrogen for the phytoplankton of oligotrophic Lake Taupo, although not eutrophic Lake Rotongaio where phytoplankton were not nutrient-limited. However, reference to Table 6.1 provides a short review of much of the recent literature concerning the potential role of nutrient recycling/regeneration by zooplankton in limnocorral experiments. Of the seventeen studies in which nutrient regeneration by zooplankton was examined, five have been omitted due to either the confounding influence of fish presence or a lack of information about lake trophic status or level of potential nutrient limitation in the phytoplankton community.

Those studies conducted in oligotrophic or meso-oligotrophic lakes or in systems described as strongly nutrient limited all indicated that zooplankton grazing contributed significant sources of nutrients and/or reduced the level of nutrient limitation of the algae. In fact, Pace and Funke (1991) suggested that direct nutrient enrichment in oligotrophic Lakes Peter and Paul made nutrient regeneration from zooplankton unimportant. Conversely, all studies conducted in eutrophic systems indicated that regeneration of nutrients by zooplankton was insignificant. The only departure from this dichotomy is the study of Vanni and Temte (1990) in eutrophic

Lake Mendota where regeneration by zooplankton was considered negligible in the spring bloom and clear-water phase but may have balanced grazing losses during summer stratification. The parallels between this seasonal study and the present research are clear and reinforce the over-riding influence of ambient nutrient concentrations on the potential for zooplankton to reduce algal nutrient limitation.

To conclude, this investigation of the potential role of zooplankton grazing on algal biomass and nutrient dynamics supports the current view in plankton ecology that the relative strength of grazing and nutrient regeneration (reducing algal nutrient limitation) on phytoplankton varies seasonally in eutrophic lakes (Vanni and Temte 1990; Elser and Goldman 1991). Current theory suggests that both in lakes and marine environments, there is a shift from new production to regenerated production in passing from eutrophic to oligotrophic waters and from periods of vertical mixing to summer stratification (Capblancq 1990).

The information used in this study to establish a positive relationship between nutrient concentration in the dissolved pool and zooplankton biomass was based on a limited data set. To the extent that  $\text{NH}_4$ ,  $\text{NO}_3$  and  $\text{DRP}$  are normally rapidly sequestered by phytoplankton on their release to the water column, the positive relationships encountered in this study will be conservative indications of the potential role of zooplankton herbivory on increasing nutrient resources (Lehman 1980). Without assays or factorial nutrient additions in conjunction with estimates of grazing and nutrient release it is not possible to discern which nutrient or combination of nutrients is limiting to phytoplankton growth (Elser *et al.* 1990). Future research in this area of plankton dynamics should benefit from such a multi-disciplinary approach. However, the results of this study do support in a qualitative sense, the view that zooplankton grazing does vary seasonally and that the concentration of dissolved nutrients can be elevated in the presence of grazers. This ability of herbivory to increase resource supply to the water column provides an

explanation for increased growth rates of the phytoplankton both at the population and community level. Critical examination of the seasonal variation of grazing and nutrient limitation, and of the mechanisms accounting for this variation are lacking (Vanni and Temte 1990). It is hoped that evaluation of these influences should help refine models of plankton seasonal succession and aid in the development of conceptual models that integrate grazing and nutrient limitation, rather than depicting the two control processes as mutually exclusive. This synthesis of control processes is the subject of the next and final chapter.

## CHAPTER TEN

### SYNTHESIS AND APPLICATIONS

Populations and communities of organisms are influenced by a host of abiotic and biotic factors. Climate, nutrients, natural enemies (including parasites and pathogens), symbionts, competitors, decomposers and resource quality and quantity are among the many potential forces that determine population change and community structure (Hunter and Price 1992). One major challenge for the discipline of ecology is to measure the relative strengths of these forces, untangle interactions among them and so explain the patterns of plant and animal distribution and abundance that we see in nature.

There is a fundamental disagreement over whether bottom-up forces (for example, nutrient availability) or top-down forces (for example, predators) predominate in populations and communities. In terrestrial ecosystems there has been little synthesis of the relative roles of different ecological forces in determining population change and community structure. However, this synthesis is much better developed in aquatic systems reflecting the operation of a plurality of variables which together function comprehensively in regulating food-web dynamics (Gophen 1990; De Melo *et al.* 1992; Carpenter and Kitchell 1992). Indeed, current plankton research recognises that the dichotomy between these two forms of regulation can be artificial (Northcote 1988; Liebold 1989; Vanni and Temte 1990). Thus, the controversy concerning the importance of bottom-up and top-down effects, is probably not a question of “this or that” but “when and how much” (Hansson 1992).

Limnologists recognise that zooplankton grazing effects vary across lake type and from year to year (Jassby *et al.* 1990; Elser and Goldman 1991). It has also become apparent that the relative influence of grazing and nutrient limitation on phytoplankton

varies seasonally (Reynolds 1984; Lampert *et al.* 1986; Dorazio *et al.* 1987; Sterner 1989; Faafeng *et al.* 1990). “Historical factors (in that previous grazing pressure influences the subsequent phytoplankton community) and contemporary factors interact to determine the strength of grazing and nutrient limitation and their effects on community dynamics” (Vanni and Temte 1990).

The current study supports the view of interactive planktonic systems in which the relative strengths of structuring forces change seasonally. In Lake Rotorua zooplankton grazing had little impact on total algal biomass in the  $\leq 80\mu\text{m}$  size fraction during autumn, but caused considerable reductions in winter, spring and summer. The presence of herbivores increased the availability of nitrogen ( $\text{NH}_4$  and DON) in spring and phosphorus (DRP and DOP) in summer. In Lake Pupuke herbivory on the phytoplankton community reduced algal biomass in autumn, winter and spring but a positive relationship between algal standing crop and zooplankton biomass occurred in summer. Zooplankton altered nutrient concentrations little during spring but increased the availability of both DON and DOP during the summer experiment.

Organismal biology constrains the structure of communities implying many details of zooplankton herbivory on direct selective grazing and nutrient regeneration must be considered. However, a relatively low number of dominant interactions may explain much of what occurs in natural communities (Sterner 1989). Much current plankton research has focussed on experimental manipulations of grazer composition, biomass and levels of productivity - particularly in gradient-oriented enclosure studies. This work has illustrated the potential unimodal response of both species-specific algal growth rates and total algal biomass to a gradient in zooplankton biomass (see Section 6.3).

An important feature of much of this research was highlighted by Elser *et al.* (1987) who recognised a preponderance of algal species whose growth was not responsive to changes in zooplankton biomass. These authors suggested that grazing losses from increasing zooplankton biomass were generally offset by enhanced absolute growth rates due to increased nutrient recycling. A similar result was observed for algal taxa in the present study. This is particularly true of Lake Pupuke phytoplankton species, most of which were unresponsive to herbivory. The net response to grazers is the sum of two effects, one positive and the other negative, so that the lack of a net response does not mean no response at all (Sterner 1989).

*"The net result of such compensatory responses would be a lack of a pronounced community biovolume response to zooplankton biomass"* (Elser *et al.* 1987). The implications of these processes are influencing modern views of ecological structure and function. Currently ecologists disagree about the relevance of population phenomena to ecosystem processes, reflecting the dichotomy between reductionist and holistic views in ecology (Bergquist and Carpenter 1986). Some freshwater researchers argue that interactions among phytoplankton species are compensatory and largely irrelevant to primary production. Others suggest that large changes in primary production are due to interactions at the population level. This dualistic viewpoint echoes the need to synthesise the potential regulatory forces influencing community homeostasis.

The recognition of system hysteresis and the potential for multiple equilibria is a feature of current ecological theory (Scheffer 1990). This ability of the community to compensate after perturbations raises the question of the validity of experimental studies which focus solely on community-level responses. This is particularly relevant to enclosure-based manipulations of grazer biomass. The complex responses of individual phytoplankton taxa discussed in Chapter Seven reflect the complexity of plankton dynamics and provide adequate justification for the time consumed in making



the phytoplankton counts. One of the most obvious features of the literature emphasised in this chapter was the lack of adequate review material on species-specific responses of individual algae. There is little synthesis literature which has satisfactorily addressed the potential ingestibility, food quality or life-history strategies of phytoplankters (and the relative influences of direct selective mortality or nutrient regeneration).

Experimentation with gradients in zooplankton biomass has gone a long way towards deciphering the relative importance of herbivory in phytoplankton dynamics. However, presently there is a lack of understanding of the influence of productivity gradients on zooplankton-phytoplankton interactions (Carpenter and Kitchell 1992). This is reflected in theories aimed at predicting how the strength of trophic interactions vary as a function of lake nutrient loading and trophic status. Several hypotheses have been proposed. McQueen *et al.* (1986) suggested that zooplankton effects on phytoplankton will be greatest in oligotrophic systems where zooplankton can reduce nutrient-limited algal assemblages. This concept has been countered by Capblancq (1990) who reviewed recent literature on general trends of nutrient-plankton dynamics in fresh and marine waters. He suggests that experimental manipulations indicate strong top-down effects of zooplankton on phytoplankton in eutrophic lakes and support for this view can be obtained by reviewing Table 6.1 (Section 6.3). Persson *et al.* (1988) predicted that across a gradient in productivity, a zone of intense grazing pressure will be found in systems of intermediate productivity. Increased productivity is suggested to lead to a major decrease in the proportion of piscivorous fish resulting in less control of zooplanktivore predation on zooplankters and consequent decline in zooplankton grazing on algal biomass. Carney and Elser (1990), arguing from data on the coupling between zooplankton grazing and algal nutrient demand proposed that the importance of macrozooplankton grazing would be greatest in lakes of intermediate productivity.

Support for this latter view, of stronger coupling between zooplankton and phytoplankton in lakes of intermediate productivity has recently come from the enclosure based research of Elser and Goldman (1991). They suggest that food-web effects should be most strongly propagated in moderately productive lakes lacking proliferations of large, inedible algal taxa. However, a recent review of the strength of cascading trophic interactions by De Melo *et al.* (1992) fails to support any of the above proposals. They believe there is no doubt that negative interactions between trophic levels exist and that they can be mediated by system productivity. It would appear that there is a need for closer scrutiny of the nutrient paradigm (Carpenter and Kitchell 1992).

The author acknowledges the potential role of detritus, bacteria and picoplankton as food items for the zooplankton of this study. The role of the “microbial-loop” in freshwater ecosystems is currently an important focus of plankton research (Berman 1990; Pace and Funke 1991; Stockner 1991). New Zealand lakes are no exception with recent work indicating high densities of picoplankton particularly in oligotrophic South Island lakes (Burns and Stockner 1991). However, the focus of this study was on the role of zooplankton herbivory and its impact on total algal biomass. The intention in the following section is to relate these responses to potential restorative applications. From this view it is most important to know how the majority of phytoplankton biomass (nanno and net phytoplankton) influence water quality. I recognise and appreciate Carpenter and Kitchell’s (1992) criticism of “*more work is necessary*” (because theory predicts variable results, it is suggested that multiple field trials are needed in a wide variety of lake types) however, it is highly applicable to New Zealand lakes where there is a lack of understanding of the role of herbivory in structuring phytoplankton dynamics (Viner and White 1987).

The term “biomanipulation” was originally defined as management of aquatic communities by controlling natural populations of organisms aimed at water quality improvement (Shapiro 1980). Lake biomanipulation theory is based on the prediction that increased piscivore abundance will result in decreased planktivore abundance, increased zooplankton abundance and as a consequence of an increased zooplankton grazing pressure, reductions in phytoplankton abundance and improved water clarity (De Melo *et al.* 1992). In a broad sense, biomanipulation is similar to top-down forces, trophic cascade interactions and food-web manipulation (Gophen 1990). Since the biomanipulation concept was first introduced there have been many lake, pond and enclosure studies which have tested the hypothesis that changes in freshwater fish biomass might cascade down through the pelagic community. Results have been variable, both supporting and refuting the hypothesis depending on the chosen case study (Benndorf 1990).

One of the major problems associated with the technique is the problem of perpetuation of successful results due to the fact that biomanipulation experiments in the past have not been long lasting (Shapiro 1990). The results of biomanipulation experiments hitherto published do not offer a sufficient answer to this problem because only in exceptional cases were the experiments extended to more than two or three years (Benndorf 1990). In addition, reviewing studies which have assessed all of the possible trophic level interactions, McQueen (1990) suggested that the effects of changes at the top of the food-web dampen as they cascade down to phytoplankton and others have pointed out that apparent biomanipulation successes may have resulted not from cascading effects of zooplankton feeding on phytoplankton but from several alternate food-web interactions (Vanni and Findlay 1990). This has lead to a recent and provocative review of biomanipulation theory by De Melo *et al.* (1992) who suggested that “*far too many unanswered questions remain to presently advocate biomanipulation as a justifiable management strategy for lake rehabilitation*”.

Such reviews of the literature advocate the need for continued research in view of the variability of lake catchment geochemistry, littoral zone development, trophic state and food-web composition (Carpenter and Kitchell 1992). The current investigation exemplifies this need and to the author's knowledge is the only one of its kind to ever be conducted in New Zealand. However, there is strong criticism of the value of enclosure-based research to the interpretation of whole-lake phenomena. Carpenter (1988), Kitchell *et al.* (1988) and Frost *et al.* (1988) suggest that enclosure studies are not conducted at appropriate size and time scales and are therefore inadequate for assessing patterns in community-wide behaviour. Contrary to this view, De Melo *et al.* (1992) found little support for either argument and advocate the conservative conclusion that successful application of biomanipulation is unrelated to size of the experimental study system.

I believe enclosure based research has an important role to play in biomanipulation studies and serves as an interface between the proponents of whole-lake trials (Carpenter and Kitchell 1992) and those who urge caution in moving too rapidly toward management with food-web manipulations (Crowder *et al.* 1988). In addition, enclosure studies which restrict the number of trophic levels and control nutrient regimes can operate free from the confounding of results observed by De Melo *et al.* (1992). However, it is essential that the limitations of *in situ* enclosure-based results are recognised when generalisations are made about the lake ecosystem and this subject was brought into focus in the assessment of methodology (Chapter Three).

Chapter Six described the net effect of zooplankton herbivory on total algal biomass and serves as the basis for an assessment of the utility of biomanipulation of Lakes Rotorua and Pupuke. Of the eight seasonal experiments four resulted in significant declines in total algal biomass ( $\leq 80\mu\text{m}$ ), three lacked a significant response and in one there was a significant positive association between zooplankton and phytoplankton

biomass. Of the four experiments where herbivory resulted in algal biomass suppression three were conducted in Lake Rotoroa where total algal biomass ( $\leq 80\mu\text{m}$ ) represented only 15% of total algal biomass in fractions  $\leq 80\mu\text{m} + >80\mu\text{m}$ . Because of the potential for compensatory increases in the algal biomass fraction  $>80\mu\text{m}$  in Lake Rotoroa (see Chapter Six) it appears that only in one experiment (Experiment 7 (Spring) in Lake Pupuke) were there significant declines in algal biomass. If these results are interpreted in this appropriately conservative manner they support the view of McQueen *et al.* (1986) who suggest a lack of impact of zooplankton on phytoplankton biomass in eutrophic lakes. However, if the experiments are reviewed case by case then the results mirror the spectrum of possible impacts observed in the biomanipulation literature, probably as a reflection of the variation in the combined strength of top-down *versus* bottom-up forces operating over the annual cycle of seasonal succession (Vanni and Temte 1990).

Generalising the results of specific lake investigation(s) to New Zealand lakes as a whole is a difficult, and some might argue, pointless task. A recent review of zooplankton-phytoplankton biomass ratios in New Zealand lakes by Malthus and Mitchell (1990) is a case in point. These authors reviewed data on the relationship between annual mean dry weight of zooplankton and phytoplankton biomass expressed as cell volume or chlorophyll *a* content or similar-average total phosphorus concentration across nineteen New Zealand lakes. The evidence suggested that the relatively low zooplankton biomass of New Zealand lakes may be related to a tendency for them to be dominated by large algae that were not considered directly available as food for zooplankton.

As New Zealand lakes do not depart systematically from the chlorophyll : phosphorus relations observed elsewhere this lowered ratio of zooplankton to phytoplankton biomass could not be attributed to a low phytoplankton yield per unit phosphorus (Malthus and Mitchell 1990). They argued that large phytoplankton may be favoured

in New Zealand due to a preponderance of polymictic and monomictic mixing regimes which reduces the likelihood of large diatoms (*Melosira granulata* in particular) sedimenting out of the water column. Low inorganic nitrogen concentrations favour heterocystous cyanobacteria (considered a poor food source for zooplankton) and may reduce carbon to nitrogen ratios in algae, making them a poor quality food source. As a consequence of these patterns the authors believed New Zealand lakes would be prone to a shift in metabolism toward the sediments with an associated increased susceptibility to the development of large internal loads of nutrients which could increase lake sensitivity to accelerated eutrophication because of any increase in external nutrient loads.

If Lake Rotoroa is used as a case study then this proposition is well supported. Approximately 85% of the phytoplankton biomass of this lake is tied up in one species - *Botryococcus braunii* - and is largely unavailable to zooplankton grazers. However more than 90% of Lake Pupuke phytoplankton is  $\leq 80\mu\text{m}$  and two of the three species larger than  $80\mu\text{m}$  were decreaseers (*Mougeotia* sp. and *Fragilaria ulna* - see Chapter Seven). Experiment 7 (Spring) provides evidence for the potential of Lake Pupuke zooplankton to suppress algal biomass significantly. Malthus and Mitchell (1990) believe “the phytoplankton of New Zealand lakes are poorly exploited by zooplankton”. This contention is not fully supported by the present study - particularly when reviewing species-specific responses of algae - and is opposed by the growing literature advocating significant grazer mediated phytoplankton responses (e.g. Chapman and Green 1987; Etheredge 1987; Edgar 1989; James and Forsyth 1990; Burns and Xu 1990, and Burns 1991 (for a review)).

This literature supports the view that the relative importance of “top-down” and “bottom-up” controls of freshwater pelagic food webs varies seasonally and probably varies also with lake trophic status. The author agrees with Dorazio *et al.* (1987) who suggest that the variation stems just as much from differences in species composition

and behaviour as from relative differences in biomass of organisms of adjacent trophic levels. An example from my study would be the inability of the Lake Rotoroa zooplankton community to ingest the large colonial *Botryococcus braunii* which was absent in Lake Pupuke. The identities of individual species and environmental variation are as important determinants of population and community dynamics as are the number of levels in a food chain or the position of the system along a resource gradient (Hunter and Price 1992). It is this variation which counters the generalisations made by Malthus and Mitchell (1990).

The success of biomanipulation ultimately depends on the ability of zooplankton grazing to reduce algal biomass or mediate a change in algal composition which favours improved water clarity (Havens and Heath 1991). However, the utility of fish manipulations to increase zooplankton grazing pressure must be questioned in New Zealand due to the lack of fish species which prey on these herbivores (Malthus and Mitchell 1990). In New Zealand, studies of the impact of fish on zooplankton are relatively recent probably because there are no obligate planktivores and only three facultative planktivores - larval smelt (*Retropinna retropinna*), bullies (*Gobiomorphus cotidianus*) and koaro (*Galaxius brevipinnis*) (Chapman and Green 1987). Burns (1991) noted that studies of the gut contents and feeding behaviour of these fish show that it is the cladocerans, particularly the large cladocerans, that sustain the greatest impact from fish predation. However, she argued that the species composition of zooplankton in New Zealand lakes is probably less influenced by fish predation than those in lakes elsewhere that contain fish, because the latter frequently possess obligate planktivores.

Support for reduced predation effects on New Zealand zooplankton also comes from studies dealing with invertebrates. New Zealand lacks many of the invertebrate predators such as *Chaoborus*, *Mysis* or carnivorous cladocerans that are commonly found elsewhere. Carnivorous water mites and omnivorous cyclopoid copepods

occur, but are rarely, if ever, abundant, and feeding studies do not suggest that they are likely to have any substantial effects on zooplankton populations (Malthus and Mitchell 1990; Butler and Burns 1991). All of the above studies suggest a major contrast to most northern temperate lakes in which invertebrate and vertebrate predators are capable of exerting strong selective pressure on zooplankters. The major factor regulating macrozooplankton populations in New Zealand lakes is the quantity and quality of food available, and in some instances, parasitism (Burns 1991).

Methods aimed at reducing fish biomass in New Zealand lakes may in fact be more influential on nutrient release and regeneration rates than on direct selective mortality of the zooplankton. Northcote (1988) reviewed some of these “top-down” effects of fish on inland waters and De Melo *et al.* (1992) argue for a need to include more studies of these less direct influences of fish on phytoplankton dynamics. It may be that the removal or reduction of benthivorous fish in Lake Rotoroa could reduce internal nutrient regeneration and nutrient concentrations. They potentially influence phytoplankton nutrient demands through bioturbation, excretion and decomposition processes (Northcote 1988) and their decline might induce a shift to increased macrophyte biomass (Wise 1990; McQueen 1990). However, the potential positive impacts of fish reduction in Lake Rotoroa may be difficult to achieve because of the use of this lake by coarse-fish anglers.

Biomanipulation refers to manipulation of secondary or tertiary aquatic producers (Gophen 1990) and it may be argued that due to an “uncoupling” at the fish - zooplankton interface in New Zealand lakes that other “ecotechniques” such as the introduction of herbivorous zooplankton from outside the lake are required. The direct introduction of filter feeders to a lake can possibly induce longtime changes in ecosystems, for example, a switch from a phytoplankton dominated to a macrophyte dominated stable state (Moss 1990; Scheffer 1990). This approach has been successful in field trials with *Daphnia magna* (Theiss *et al.* 1990). However, it is



unlikely that introduced zooplankters will be any more effective at controlling large algae ( $< 80\mu\text{m}$ ) in Lake Rotoroa due to limitations in the size of the largest particles ingested (Kobayashi 1991).

The potential for phytophagous fish species to reduce algal abundance has been addressed in a number of overseas studies (e.g. Drenner *et al.* 1984; Drenner *et al.* 1989) with conflicting results. Silver carp introduction was very successful in reducing algal biomass in Lake Orakai (Carruthers 1986). However Northcote (1988) recognised the potential for this fish species to cause increases in phytoplankton biomass and productivity as well. Silver carp feeding releases nutrients from excretion in potentially high availability to algae. The concept of introducing exotic fish species (there are no native New Zealand fish which are strictly phytophagous) has met with increasing resistance in this country due to the potential for competition with native fish species (of varying feeding types) and possible habitat destruction. With a lack of knowledge on the influence of phytophagous fish on zooplankton and phytoplankton communities it must be conceded that their role in biomanipulation-oriented lake recovery requires a cautious approach.

In summary it appears that biomanipulation in the context of Lakes Rotoroa and Pupuke may be unwarranted. There is a definite “uncoupling” between Lake Rotoroa zooplankton and the bulk of the phytoplankton assemblage largely due to the presence of a considerable biomass of inedible algae (particularly *Botryococcus braunii* colonies). Strategies aimed at increased grazing pressure by herbivores - either by reductions in fish biomass or the introduction of additional grazers - are unlikely to increase utilisation of the phytoplankton. It would appear that nutrient diversion is crucial to the restoration of Lake Rotoroa reflecting the importance of reducing nutrient inputs in lake recovery (De Melo *et al.* 1992).

Lake Pupuke already has a substantial macrophyte community in the littoral zone and there is no need for a “shock” introduction of zooplankton or phytophagous fish to induce a change in community state (Scheffer 1990). The lake is undergoing natural improvements in water quality (Vant and Pridmore 1990). This is largely because to reductions in nutrient input slowly being manifest due to the long turnover period of the lake. This trend away from high algal biomass has resulted in more interest in the potential negative effects of high macrophyte biomass adjacent to residential and council land (Coffey 1990).

*“The only way to solve the problem and to identify the usefulness and limits of top-down control of food-webs as a management tool is to achieve a deeper insight into the complex interactions in aquatic ecosystems”* (Benndorf 1990). I hope the current study adds to the growing literature on the influence of zooplankton herbivory on natural phytoplankton assemblages. This is particularly in view of the lack of knowledge of seasonal variability in grazing effects and the influence of calanoid copepods in trophic structures. The above criticism of the practicality of biomanipulation in New Zealand is restricted to the analysis of two lakes and time alone will decide the future relevance of this restoration procedure. There are lessons to be learned from all experiments dealing with trophic-level manipulation - successes and apparent failures alike (Shapiro 1990). I believe the constructive criticism of theory is integral to scientific progress but I hope that such “demythologizing” (*sensu* De Melo *et al.* 1992) of biomanipulation theory does not reduce funding directed at understanding plankton dynamics. It is the potential application of this “pure” knowledge which allowed the author to conduct this study (see Acknowledgements).

With the current investigation as contemporary example, the reality is simply that lakes do differ and it is these idiosyncracies that make generalisations about food web interactions difficult to apply holistically. In attempts to explain variance in the relationship between nutrient load and producer abundance (Carpenter 1988) it is

important to recognise that inherent biological variation is in itself part of the explanation.

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## Appendix I : Ambient Lake surface water zooplankton biomass

As described in Chapter Two zooplankton sampling from both Lakes Rotoroa and Pupuke was conducted at the beginning of each seasonal experiment. Both discrete depth-series samples (at 1 metre depth intervals), and vertical net hauls (80µm mesh) were enumerated to establish ambient surface water (0 to 4m depth) zooplankton biomass (dry weight). The area under Figures 1-8 was established and used to calculate average zooplankton biomass  $\text{m}^{-3}$  in a water column four metres deep. This value was compared with that obtained from simultaneous net hauls to establish the efficiency with which the net sampled zooplankton (assuming 100% efficiency in calculating zooplankton biomass from integration of the discrete depth samples).

Figure 1: Plot of zooplankton biomass (crustaceans and *Asplanchna*) versus depth at the beginning of Experiment 1 (Autumn), Day-O (1/6/90) in Lake Rotoroa.

Zooplankton biomass  $\text{mg m}^{-3}$  calculated after integrating the area under Figure 1 was  $121.5 \text{ mg m}^{-3}$ . Zooplankton biomass  $\text{m}^{-3}$  calculated from vertical net hauls was  $95.5 \text{ mg m}^{-3}$  implying the 80µm net was 79.4% efficient.

Figure 2: Plot of zooplankton biomass (crustaceans and *Asplanchna*) versus depth at the beginning of Experiment 2 (Winter), Day-O (27/7/90) in Lake Rotoroa.

Zooplankton biomass  $\text{m}^{-3}$  calculated after integrating the area under Figure 2 was  $119.4 \text{ mg m}^{-3}$ . Zooplankton biomass  $\text{m}^{-3}$  calculated from vertical net hauls was 79.0 implying the 80µm net was 66.2% efficient.



FIG. 1.

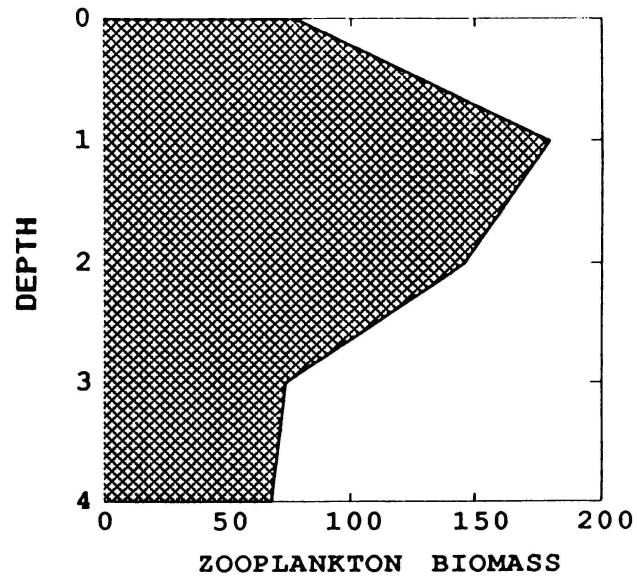
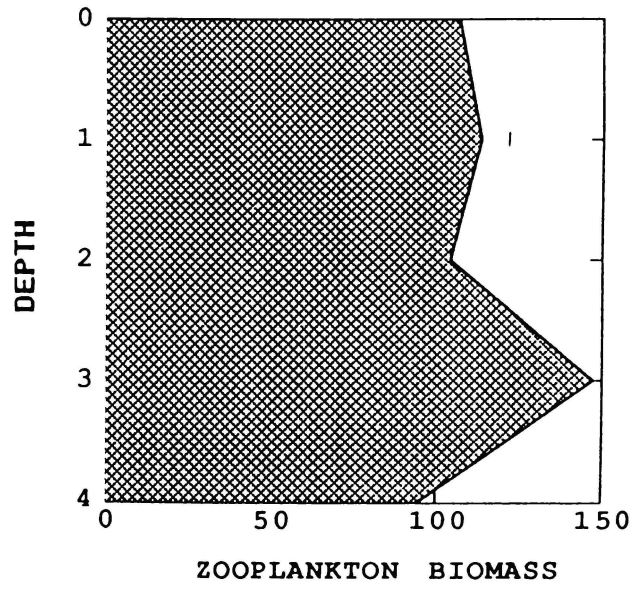


FIG. 2.



## Appendix I : Ambient Lake surface water zooplankton biomass

**Figure 3:** Plot of zooplankton biomass (crustaceans and *Asplanchna*) versus depth at the beginning of Experiment 3 (Spring), Day-0 (12/10/90) in Lake Rotoroa.

Zooplankton biomass  $\text{m}^{-3}$  calculated after integrating the area under Figure 3 was  $90.2 \text{ mg m}^{-3}$ . Zooplankton biomass  $\text{m}^{-3}$  calculated from vertical net hauls was  $105.9 \text{ mg m}^{-3}$  implying the  $80\mu\text{m}$  net was 117.5% efficient.

**Figure 4:** Plot of zooplankton biomass (crustaceans and *Asplanchna*) versus depth at the beginning of Experiment 4 (Summer), Day-0 (5/2/91) in Lake Rotoroa.

Zooplankton biomass  $\text{m}^{-3}$  calculated after integrating the area under Figure 4 was  $281.1 \text{ mg m}^{-3}$ . Zooplankton biomass  $\text{m}^{-3}$  calculated from vertical net hauls was  $333.0 \text{ mg m}^{-3}$  implying the  $80\mu\text{m}$  net was 118.5% efficient.

FIG. 3.

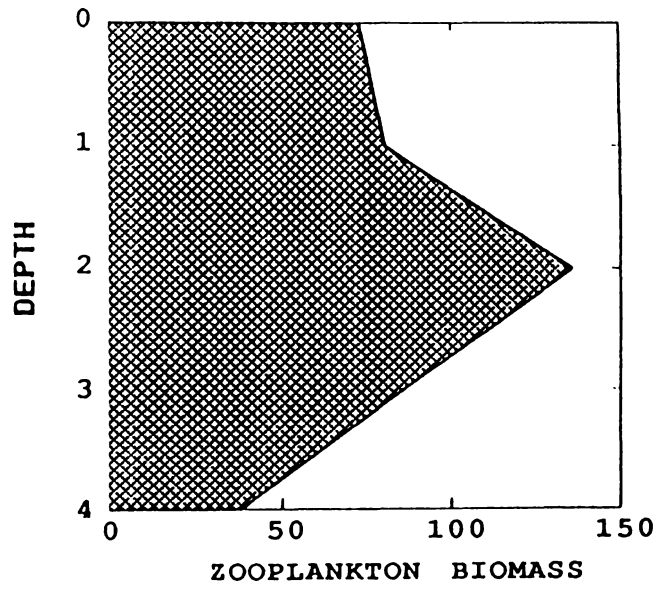
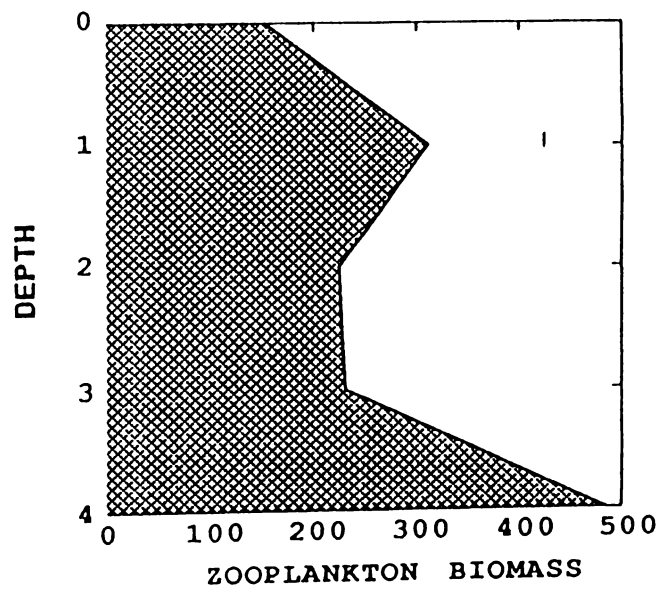


FIG. 4.



## Appendix I : Ambient Lake surface water zooplankton biomass

Figure 5: Plot of zooplankton biomass (crustaceans and *Asplanchna*) versus depth at the beginning of Experiment 5 (Autumn), Day-0 (21/5/91) in Lake Pupuke.

Zooplankton biomass  $\text{m}^{-3}$  calculated after integrating the area under Figure 5 was  $27.1 \text{ mg m}^{-3}$ . Zooplankton biomass  $\text{m}^{-3}$  calculated from vertical net hauls was  $21.7 \text{ mg m}^{-3}$  implying the  $80\mu\text{m}$  net was 80.16% efficient.

Figure 6: Plot of zooplankton biomass (crustaceans and *Asplanchna*) versus depth at the beginning of Experiment 6 (Winter), Day-0 (23/7/91) in Lake Pupuke.

Zooplankton biomass  $\text{m}^{-3}$  calculated after integrating the area under Figure 6 was  $17.5 \text{ mg m}^{-3}$ . Zooplankton biomass  $\text{m}^{-3}$  calculated from vertical net hauls was  $23.3 \text{ mg m}^{-3}$  implying the  $80\mu\text{m}$  net was 132.8% efficient.

FIG. 5.

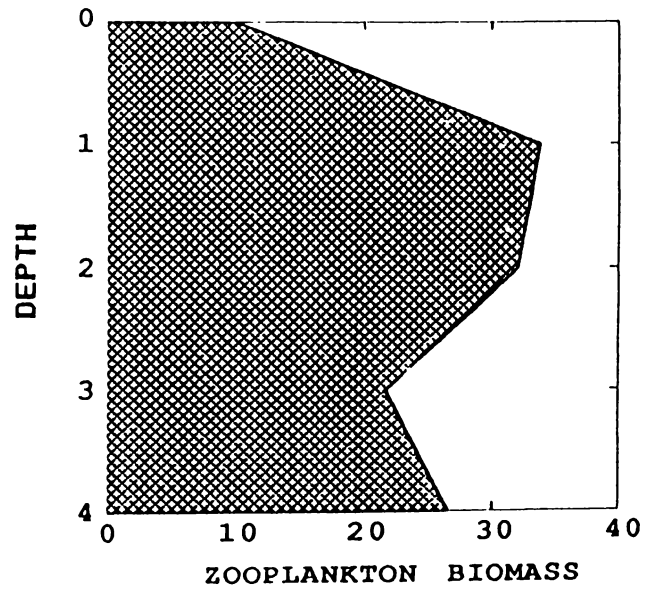
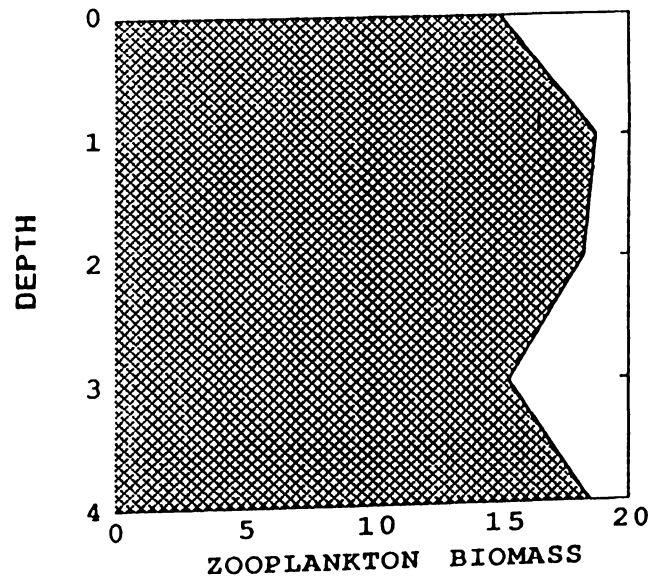


FIG. 6.



## Appendix I : Ambient Lake surface water zooplankton biomass

Figure 7: Plot of zooplankton biomass (crustaceans and *Asplanchna*) versus depth at the beginning of Experiment 7 (Spring), Day-0 (8/10/91) in Lake Pupuke.

Zooplankton biomass  $\text{m}^{-3}$  calculated after integrating the area under Figure 7 was  $27.7 \text{ mg m}^{-3}$ . Zooplankton biomass  $\text{m}^{-3}$  calculated from vertical net hauls was  $29.4 \text{ mg m}^{-3}$  implying the  $80\mu\text{m}$  net was 114.3% efficient.

Figure 8: Plot of zooplankton biomass (crustaceans and *Asplanchna*) versus depth at the beginning of Experiment 8 (Summer), Day-0 (4/2/92) in Lake Pupuke.

Zooplankton biomass  $\text{m}^{-3}$  calculated after integrating the area under Figure 8 was  $37.3 \text{ mg m}^{-3}$ . Zooplankton biomass  $\text{m}^{-3}$  calculated from vertical net hauls was  $45.9 \text{ mg m}^{-3}$  implying the  $80\mu\text{m}$  net was 123.1% efficient.

FIG. 7.

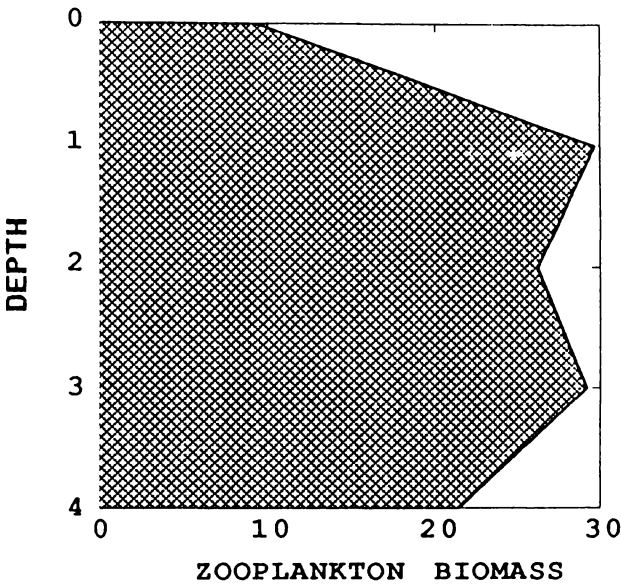
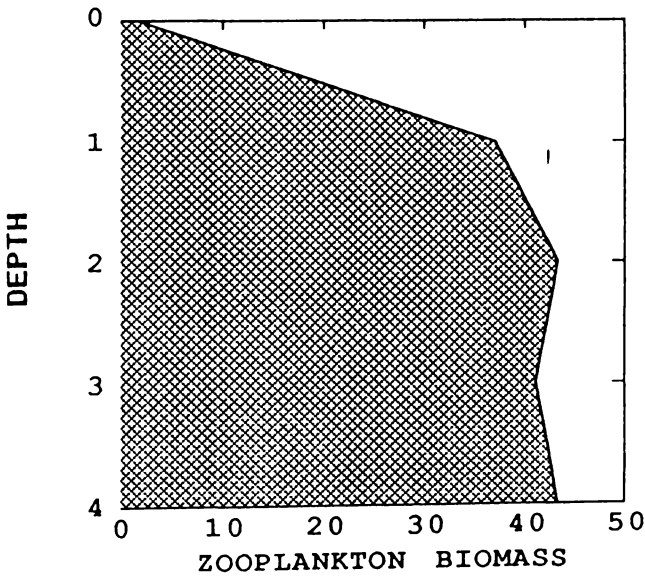


FIG. 8.



**Appendix II:** Average dry weight ( $\mu\text{g}$ ) of zooplankters obtained from the literature. Values are per individual.

| <b>Taxon</b>                                       | <b>Biomass (<math>\mu\text{g}</math>)</b> |
|----------------------------------------------------|-------------------------------------------|
| Arthropoda                                         |                                           |
| Copepoda                                           |                                           |
| Calanoida                                          |                                           |
| <i>Calamoecia</i> copepodites (I-IV)               | 0.538 <sup>1</sup>                        |
| <i>Calamoecia</i> adults (V-VI)                    | 1.580 <sup>1</sup>                        |
| Cyclopoida                                         |                                           |
| <i>Mesocyclops</i> copepodites                     | 1.300 <sup>2</sup>                        |
| <i>Mesocyclops</i> adults                          | 1.800 <sup>2</sup>                        |
| Total Nauplii                                      | 0.252 <sup>5</sup>                        |
| Diplostraca                                        |                                           |
| <i>Bosmina meridionalis</i>                        | 1.180 <sup>1</sup>                        |
| <i>Ceriodaphnia dubia</i><br>+ <i>C. pulchella</i> | 0.640 <sup>1</sup>                        |
| Rotatoria                                          |                                           |
| <i>Ascomorpha</i>                                  | 0.030 <sup>3</sup>                        |
| <i>Asplanchna</i>                                  | 0.102 <sup>1</sup>                        |
| <i>Conochilus</i>                                  | 0.080 <sup>3</sup>                        |
| <i>Filinia</i>                                     | 0.420 <sup>4,6</sup>                      |
| <i>Hexarthra</i>                                   | 0.100 <sup>3</sup>                        |
| <i>Keratella</i>                                   | 0.050 <sup>3,6</sup>                      |
| <i>Polyarthra</i>                                  | 0.060 <sup>3,6</sup>                      |
| <i>Pompholyx</i>                                   | 0.100 <sup>3</sup>                        |
| <i>Synchaeta</i>                                   | 0.100 <sup>3</sup>                        |
| <i>Trichocerca</i>                                 | 0.100 <sup>3,4,6</sup>                    |

- 
1. Chapman, M. A. *et al.* 1975
  2. Gophen, M. 1978
  3. Wetzel, R. G. and Likens, G. E. 1979
  4. Dumont, H. J. *et al.* 1975
  5. Culver, D. A. *et al.* 1985
  6. Bottrell, H.H. *et al.* 1976



**Appendix III** Fisher's Index of Dispersion ( $\chi^2$ ) for major algal species on the basal plate of the sedimentation chamber from a Lake Rotoroa sample. Seven randomly assigned transects across the basal plate were used in each calculation of mean plankton units ml<sup>-1</sup>. With six degrees of freedom a  $\chi^2$  value <12.59 implies random distribution of algae on the base plate.

| Taxa                                                  | Mean Plankton Units (mℓ <sup>-1</sup> ) | $\chi^2$ |
|-------------------------------------------------------|-----------------------------------------|----------|
| <i>Coelastrum reticulatum</i>                         | 44.739 (1)                              | 2.230    |
| <i>Cryptomonas ovata</i>                              | 56.591(1)                               | 3.608    |
| <i>Staurastrum leptocladum</i><br>var. <i>insigne</i> | 79.997(1)                               | 2.546    |
| <i>Cosmarium perfissum.</i>                           | 31.388(2)                               | 2.098    |
| <i>Elakatothrix gelatinosa</i>                        | 23.337(2)                               | 1.328    |
| <i>Scenedesmus quadricauda</i><br>+ <i>ecornis</i>    | 35.001(2)                               | 2.338    |

(1) Counts conducted on samples collected 7.6.90

(2) Counts conducted on samples collected 18.10.90

**Appendix III** Fisher's Index of Dispersion ( $\chi^2$ ) for major algal species across randomly chosen subsamples for Lake Rotoroa. Six subsamples were taken and one belt transect across the base plate counted per subsample. With five degrees of freedom a  $\chi^2$  value of <11.07 implies subsamples were randomly drawn from a particular sample.

| Taxa                                                  | Mean Plankton Units (m $\ell^{-1}$ ) | $\chi^2$ |
|-------------------------------------------------------|--------------------------------------|----------|
| <i>Coelastrum reticulatum</i>                         | 32.492 <sup>(1)</sup>                | 1.563    |
| <i>Cryptomonas ovata</i>                              | 56.517 <sup>(1)</sup>                | 1.245    |
| <i>Staurastrum leptocladum</i><br>var. <i>insigne</i> | 78.812 <sup>(1)</sup>                | 1.702    |
| <i>Cosmarium perfissum</i>                            | 29.353 <sup>(2)</sup>                | 1.714    |
| <i>Elakatothrix gelatinosa</i>                        | 23.310 <sup>(2)</sup>                | 0.103    |
| <i>Scenedesmus quadricauda</i><br>+ <i>ecornis</i>    | 33.411 <sup>(2)</sup>                | 2.180    |

(1) Counts conducted on samples collected 7.6.90

(2) Counts conducted on samples collected 18.10.90

**Appendix III** Fisher's Index of Dispersion ( $\chi^2$ ) for major algal species on the basal plate of the sedimentation chamber from a Lake Pupuke sample. Seven randomly assigned transects across the basal plate were used in each calculation of mean plankton units ml<sup>-1</sup>. With six degrees of freedom a  $\chi^2$  value <12.59 implies random distribution of algae on the base plate.

| Taxa                                              | Mean Plankton Units (m ℓ <sup>-1</sup> ) | $\chi^2$ |
|---------------------------------------------------|------------------------------------------|----------|
| <i>Coelastrum acutum</i><br>var. <i>variabile</i> | 28.480 <sup>(1)</sup>                    | 2.268    |
| <i>Oocystis</i> cf. <i>lacustris</i>              | 16.314 <sup>(1)</sup>                    | 8.060    |
| <i>Staurastrum pinque</i>                         | 35.116 <sup>(1)</sup>                    | 4.068    |
| <i>Cosmarium</i> cf. <i>contractum</i>            | 21.198 <sup>(2)</sup>                    | 1.954    |
| <i>Fragilaria crotonensis</i>                     | 31.613 <sup>(2)</sup>                    | 1.228    |
| <i>Tetraedron minimum</i>                         | 12.627 <sup>(2)</sup>                    | 1.715    |

(1) Counts conducted on samples collected 2.8.91

(2) Counts conducted on samples collected 14.2.92

**Appendix III** Fisher's Index of Dispersion ( $\chi^2$ ) for major algal species across randomly chosen subsamples from Lake Pupuke. Six subsamples were taken and one belt transect across the base plate counted per subsample. With five degrees of freedom a  $\chi^2$  value <11.07 implies subsamples were randomly drawn from a particular sample.

| Taxa                                           | Mean Plankton Units (m $\ell^{-1}$ ) | $\chi^2$ |
|------------------------------------------------|--------------------------------------|----------|
| <i>Closterium acutum</i> var. <i>variabile</i> | 30.248 <sup>(1)</sup>                | 2.031    |
| <i>Oocystis</i> cf. <i>lacustris</i>           | 29.531 <sup>(1)</sup>                | 4.008    |
| <i>Staurastrum pinque</i>                      | 16.474 <sup>(1)</sup>                | 3.988    |
| <i>Fragilaria crotonensis</i>                  | 31.584 <sup>(2)</sup>                | 3.538    |
| <i>Tetraedron minimum</i>                      | 12.405 <sup>(2)</sup>                | 2.074    |
| <i>Cosmarium</i> cf. <i>contractum</i>         | 23.643 <sup>(2)</sup>                | 3.611    |

(1) Counts conducted on samples collected 2.8.91

(2) Counts conducted on samples collected 14.2.92

Appendix IV : Experiment 1 Autumn Lake Rotoroa 1/6/90 - 11/6/90

| Day 0 (1/6/90)        | <i>Peridinium<br/>cinctum</i> | <i>Cryptomonas<br/>ovata and<br/>marssonii</i> | <i>Staurostrum<br/>leptocladum<br/>var.insigne</i> | <i>Staurodesmus<br/>unicornis<br/>var. gracilis</i> | <i>Trachelomonas<br/>volvicina</i> | <i>Pediastrum<br/>tetras</i> | <i>Coelastrum<br/>reticulatum</i> | <i>Cyclotella<br/>stelligera</i> | <i>Tetrastrum<br/>triangulare</i> | TOTAL<br>P.U. (ml-1) |
|-----------------------|-------------------------------|------------------------------------------------|----------------------------------------------------|-----------------------------------------------------|------------------------------------|------------------------------|-----------------------------------|----------------------------------|-----------------------------------|----------------------|
| <b>Exclosure</b>      |                               |                                                |                                                    |                                                     |                                    |                              |                                   |                                  |                                   |                      |
| P. U. (ml-1)          | 107.104                       | 48.221                                         | 43.553                                             | 17.629                                              | 12.963                             | 8.815                        | 34.74                             | 575.766                          | 4463.306                          | 5312.095             |
| S. D.                 | 108.903                       | 0.733                                          | 14.665                                             | 0                                                   | 3.666                              | 2.2                          | 0.733                             | 20.662                           | 193.741                           | 84.968               |
| Biomass (mg.m-3)      | 2824.98                       | 53.095                                         | 17.035                                             | 10.112                                              | 26.965                             | 3.864                        | 334.571                           | 140.971                          | 57.666                            | 3469.258             |
| <b>Enclosure (1X)</b> |                               |                                                |                                                    |                                                     |                                    |                              |                                   |                                  |                                   |                      |
| P.U. (ml-1)           | 49.5                          | 51.332                                         | 45.11                                              | 16.074                                              | 17.111                             | 10.37                        | 33.184                            | 615.077                          | 4652.411                          | 5490.167             |
| S.D.                  | 8.202                         | 0.733                                          | 8.666                                              | 2.2                                                 | 2.2                                | 1.467                        | 4.4                               | 50.944                           | 1114.557                          | 1063.016             |
| Biomass (mg.m-3)      | 1305.614                      | 56.52                                          | 17.643                                             | 9.22                                                | 35.594                             | 4.546                        | 319.59                            | 150.595                          | 60.109                            | 1959.432             |
| <b>Enclosure (2X)</b> |                               |                                                |                                                    |                                                     |                                    |                              |                                   |                                  |                                   |                      |
| P.U. (ml-1)           | 43.872                        | 57.554                                         | 41.48                                              | 16.074                                              | 10.889                             | 8.296                        | 35.777                            | 559.26                           | 4832.658                          | 5605.858             |
| S.D.                  | 13.051                        | 0.733                                          | 2.933                                              | 0.733                                               | 2.2                                | 1.467                        | 2.2                               | 97.524                           | 500.114                           | 613.622              |
| Biomass (mg.m-3)      | 1157.157                      | 63.371                                         | 16.224                                             | 9.22                                                | 22.651                             | 3.637                        | 344.558                           | 136.929                          | 62.438                            | 1816.184             |
| <b>Enclosure (4X)</b> |                               |                                                |                                                    |                                                     |                                    |                              |                                   |                                  |                                   |                      |
| P.U. (ml-1)           | 40.1                          | 61.702                                         | 39.406                                             | 14.518                                              | 12.444                             | 11.407                       | 33.703                            | 548.228                          | 5149.943                          | 5911.45              |
| S.D.                  | 11.597                        | 0.733                                          | 4.4                                                | 5.866                                               | 2.933                              | 2.933                        | 2.2                               | 74.989                           | 762.52                            | 847.639              |
| Biomass (mg.m-3)      | 1057.68                       | 67.938                                         | 15.412                                             | 8.327                                               | 25.887                             | 5.001                        | 324.584                           | 134.228                          | 66.537                            | 1705.594             |
| <b>Lake</b>           |                               |                                                |                                                    |                                                     |                                    |                              |                                   |                                  |                                   |                      |
| P.U. (ml-1)           | 21.988                        | 63.257                                         | 60.48                                              | 17.111                                              | 11.407                             | 11.407                       | 41.48                             | 608.644                          | 4988.613                          | 5824.386             |
| S.D.                  | 3.128                         | 2.933                                          | 5.395                                              | 0.733                                               | 2.933                              | 2.933                        | 0                                 | 78.458                           | 535.261                           | 624.051              |
| Biomass (mg.m-3)      | 579.957                       | 69.551                                         | 23.655                                             | 9.814                                               | 23.729                             | 5.001                        | 399.488                           | 149.02                           | 64.453                            | 1324.768             |

P.U. (ml-1) and Biomass (mg.m-3) are mean values where n = 4

Appendix IV : Experiment 1 Autumn Lake Rotoroa 1/6/90 - 11/6/90

| Day 3 (4/6/90)        | <i>Peridinium<br/>cinctum</i> | <i>Cryptomonas<br/>ovata and<br/>marssonii</i> | <i>Staurastrum<br/>leptocladum<br/>var.insigne</i> | <i>Staurodesmus<br/>unicornis<br/>var. gracilis</i> | <i>Trachelomonas<br/>volvicina</i> | <i>Pediastrum<br/>tetras</i> | <i>Coelastrum<br/>reticulatum</i> | <i>Cyclotella<br/>stelligera</i> | <i>Tetrastrum<br/>triangulare</i> | TOTAL<br>P.U. (ml-1) |
|-----------------------|-------------------------------|------------------------------------------------|----------------------------------------------------|-----------------------------------------------------|------------------------------------|------------------------------|-----------------------------------|----------------------------------|-----------------------------------|----------------------|
| <b>Exclosure</b>      |                               |                                                |                                                    |                                                     |                                    |                              |                                   |                                  |                                   |                      |
| P.U. (ml-1)           | 25.95                         | 83.479                                         | 74.146                                             | 26.962                                              | 18.666                             | 16.592                       | 80.886                            | 1140.2246                        | 4513.308                          | 5980.234             |
| S.D.                  | 3.182                         | 24.198                                         | 2.2                                                | 0                                                   | 11.732                             | 4.4                          | 38.13                             | 302.848                          | 383.258                           | 5.368                |
| Biomass (mg.m-3)      | 684.458                       | 91.917                                         | 29                                                 | 15.465                                              | 38.83                              | 7.274                        | 779.001                           | 279.178                          | 58.312                            | 1983.434             |
| <b>Enclosure (1X)</b> |                               |                                                |                                                    |                                                     |                                    |                              |                                   |                                  |                                   |                      |
| P.U. (ml-1)           | 38.43                         | 63.257                                         | 74.145                                             | 24.888                                              | 11.926                             | 15.555                       | 67.924                            | 782.663                          | 4310.157                          | 5388.944             |
| S.D.                  | 7.679                         | 2.933                                          | 3.665                                              | 1.467                                               | 2.2                                | 0                            | 3.666                             | 60.257                           | 735.593                           | 794.769              |
| Biomass (mg.m-3)      | 1013.632                      | 69.651                                         | 28.999                                             | 14.276                                              | 24.808                             | 6.819                        | 654.161                           | 191.627                          | 55.687                            | 2059.66              |
| <b>Enclosure (2X)</b> |                               |                                                |                                                    |                                                     |                                    |                              |                                   |                                  |                                   |                      |
| P.U. (ml-1)           | 54.056                        | 31.11                                          | 73.109                                             | 22.814                                              | 10.37                              | 15.037                       | 55.998                            | 523.5                            | 2858.245                          | 3644.238             |
| S.D.                  | 7.456                         | 8.799                                          | 0.733                                              | 2.933                                               | 1.467                              | 2.2                          | 11.732                            | 78.206                           | 312.732                           | 409.879              |
| Biomass (mg.m-3)      | 1425.771                      | 34.255                                         | 28.594                                             | 13.086                                              | 21.572                             | 6.592                        | 539.308                           | 128.174                          | 36.929                            | 2234.28              |
| <b>Enclosure (4X)</b> |                               |                                                |                                                    |                                                     |                                    |                              |                                   |                                  |                                   |                      |
| P.U. (ml-1)           | 39.087                        | 24.37                                          | 33.184                                             | 10.889                                              | 16.074                             | 10.889                       | 36.295                            | 436.95                           | 2842.062                          | 3449.798             |
| S.D.                  | 21.319                        | 21.265                                         | 23.465                                             | 0.733                                               | 15.399                             | 5.133                        | 16.132                            | 157.473                          | 387.973                           | 175.451              |
| Biomass (mg.m-3)      | 1030.961                      | 26.833                                         | 12.979                                             | 6.246                                               | 33.437                             | 4.773                        | 349.552                           | 106.983                          | 36.719                            | 1608.482             |
| <b>Lake</b>           |                               |                                                |                                                    |                                                     |                                    |                              |                                   |                                  |                                   |                      |
| P.U. (ml-1)           | 10.547                        | 45.606                                         | 65.331                                             | 10.37                                               | 12.963                             | 12.963                       | 35.496                            | 519.55                           | 2639.029                          | 3351.854             |
| S.D.                  | 0                             | 8.768                                          | 10.266                                             | 0                                                   | 3.666                              | 2.2                          | 3.27                              | 72.62                            | 100.842                           | 152.625              |
| Biomass (mg.m-3)      | 278.188                       | 50.216                                         | 25.552                                             | 5.948                                               | 26.965                             | 5.683                        | 341.857                           | 127.207                          | 34.096                            | 895.712              |

Appendix IV : Experiment 1 Autumn Lake Rotoroa 1/6/90 - 11/6/90

| Day 6 (7/6/90)        | <i>Peridinium<br/>cinctum</i> | <i>Cryptomonas<br/>ovata and<br/>marssonii</i> | <i>Staurastrum<br/>leptocladum<br/>var.insigne</i> | <i>Staurodesmus<br/>unicornis<br/>var. gracilis</i> | <i>Trachelomonas<br/>volvicina</i> | <i>Pediastrum<br/>tetras</i> | <i>Coelastrum<br/>reticulatum</i> | <i>Cyclotella<br/>stelligera</i> | <i>Tetrastrum<br/>triangulare</i> | TOTAL<br>P.U. (ml-1) |
|-----------------------|-------------------------------|------------------------------------------------|----------------------------------------------------|-----------------------------------------------------|------------------------------------|------------------------------|-----------------------------------|----------------------------------|-----------------------------------|----------------------|
| <b>Exclosure</b>      |                               |                                                |                                                    |                                                     |                                    |                              |                                   |                                  |                                   |                      |
| P.U. (ml-1)           | 22.783                        | 68.961                                         | 99.552                                             | 16.074                                              | 4.148                              | 17.629                       | 26.962                            | 821.618                          | 3203.488                          | 4281.213             |
| S.D.                  | 1.39                          | 13.932                                         | 4.4                                                | 2.2                                                 | 0                                  | 1.467                        | 2.933                             | 28.592                           | 348.904                           | 296.924              |
| Biomass (mg.m-3)      | 600.926                       | 75.931                                         | 38.937                                             | 9.22                                                | 8.629                              | 7.728                        | 259.667                           | 201.165                          | 41.389                            | 1243.591             |
| <b>Enclosure (1X)</b> |                               |                                                |                                                    |                                                     |                                    |                              |                                   |                                  |                                   |                      |
| P.U. (ml-1)           | 10.871                        | 45.11                                          | 77.775                                             | 22.296                                              | 6.222                              | 11.927                       | 26.962                            | 682.221                          | 3263.586                          | 4146.968             |
| S.D.                  | 2.08                          | 27.131                                         | 8.799                                              | 5.133                                               | 1.467                              | 5.131                        | 1.467                             | 98.176                           | 1077.277                          | 1168.188             |
| Biomass (mg.m-3)      | 286.734                       | 49.669                                         | 30.419                                             | 12.788                                              | 12.943                             | 5.228                        | 259.667                           | 167.035                          | 42.166                            | 866.65               |
| <b>Enclosure (2X)</b> |                               |                                                |                                                    |                                                     |                                    |                              |                                   |                                  |                                   |                      |
| P.U. (ml-1)           | 18.33                         | 17.111                                         | 70.516                                             | 23.333                                              | 8.816                              | 17.111                       | 61.183                            | 489.45                           | 2446.15                           | 3151.998             |
| S.D.                  | 4.843                         | 13.442                                         | 16.132                                             | 12.466                                              | 0.732                              | 0.733                        | 23.465                            | 44.477                           | 43.77                             | 147.353              |
| Biomass (mg.m-3)      | 483.46                        | 18.84                                          | 27.58                                              | 13.383                                              | 18.338                             | 7.501                        | 589.244                           | 119.837                          | 31.604                            | 1309.788             |
| <b>Enclosure (4X)</b> |                               |                                                |                                                    |                                                     |                                    |                              |                                   |                                  |                                   |                      |
| P.U. (ml-1)           | 15.385                        | 15.037                                         | 69.479                                             | 19.703                                              | 6.741                              | 7.779                        | 30.073                            | 307.949                          | 2363.314                          | 2835.458             |
| S.D.                  | 10.464                        | 6.599                                          | 17.598                                             | 5.866                                               | 0.733                              | 0.735                        | 2.933                             | 35.994                           | 56.727                            | 50.728               |
| Biomass (mg.m-3)      | 405.796                       | 16.556                                         | 27.175                                             | 11.301                                              | 14.022                             | 3.41                         | 289.629                           | 75.398                           | 30.534                            | 873.82               |
| <b>Lake</b>           |                               |                                                |                                                    |                                                     |                                    |                              |                                   |                                  |                                   |                      |
| P.U. (ml-1)           | 24.422                        | 47.444                                         | 66.887                                             | 18.148                                              | 19                                 | 10.371                       | 32.147                            | 565.69                           | 3565.002                          | 4349.109             |
| S.D.                  | 3.773                         | 10.631                                         | 10.999                                             | 0.733                                               | 0.472                              | 2.932                        | 5.866                             | 63.343                           | 64.768                            | 31.571               |
| Biomass (mg.m-3)      | 644.156                       | 52.239                                         | 26.161                                             | 10.409                                              | 39.524                             | 4.546                        | 309.603                           | 138.504                          | 46.06                             | 1271.201             |

Appendix IV : Experiment 1 Autumn Lake Rotoroa 1/6/90 - 11/6/90

| Day 10 (11/6/90)      | <i>Peridinium<br/>cinctum</i> | <i>Cryptomonas<br/>ovata and<br/>marssonii</i> | <i>Staurastrum<br/>leptocladum<br/>var.insigne</i> | <i>Staurodesmus<br/>unicornis<br/>var. gracilis</i> | <i>Trachelomonas<br/>volvicina</i> | <i>Pediastrum<br/>tetras</i> | <i>Coelastrum<br/>reticulatum</i> | <i>Cyclotella<br/>stelligera</i> | <i>Tetrastrum<br/>triangulare</i> | TOTAL<br>P.U. (ml-1) |
|-----------------------|-------------------------------|------------------------------------------------|----------------------------------------------------|-----------------------------------------------------|------------------------------------|------------------------------|-----------------------------------|----------------------------------|-----------------------------------|----------------------|
| <b>Exclosure</b>      |                               |                                                |                                                    |                                                     |                                    |                              |                                   |                                  |                                   |                      |
| P.U. (ml-1)           | 29.077                        | 100.071                                        | 146.217                                            | 33.184                                              | 16.074                             | 14.518                       | 64.294                            | 1197.302                         | 3370.06                           | 4970.796             |
| S.D.                  | 1.872                         | 15.399                                         | 33.73                                              | 13.199                                              | 5.133                              | 5.866                        | 1.467                             | 9.337                            | 496.474                           | 564.067              |
| Biomass (mg.m-3)      | 766.923                       | 110.186                                        | 57.188                                             | 19.034                                              | 33.437                             | 6.364                        | 619.206                           | 293.147                          | 43.541                            | 1949.027             |
| <b>Enclosure (1X)</b> |                               |                                                |                                                    |                                                     |                                    |                              |                                   |                                  |                                   |                      |
| P.U. (ml-1)           | 9.971                         | 35.258                                         | 132.736                                            | 35.258                                              | 6.741                              | 10.889                       | 37.332                            | 924.966                          | 3735.29                           | 4928.44              |
| S.D.                  | 1.967                         | 4.4                                            | 38.13                                              | 7.333                                               | 0.733                              | 3.666                        | 1.467                             | 93.283                           | 927.597                           | 1055.111             |
| Biomass (mg.m-3)      | 262.996                       | 38.822                                         | 51.916                                             | 20.224                                              | 14.022                             | 4.773                        | 359.539                           | 226.469                          | 48.26                             | 1027.019             |
| <b>Enclosure (2X)</b> |                               |                                                |                                                    |                                                     |                                    |                              |                                   |                                  |                                   |                      |
| P.U. (ml-1)           | 18.506                        | 13.481                                         | 111.478                                            | 32.147                                              | 8.296                              | 8.296                        | 45.628                            | 490.457                          | 2205.9                            | 2934.188             |
| S.D.                  | 5.025                         | 2.933                                          | 0.733                                              | 2.933                                               | 1.467                              | 5.866                        | 13.199                            | 115.698                          | 212.698                           | 72.176               |
| Biomass (mg.m-3)      | 488.102                       | 14.844                                         | 43.601                                             | 18.439                                              | 17.258                             | 3.637                        | 439.436                           | 120.083                          | 28.5                              | 1173.901             |
| <b>Enclosure (4X)</b> |                               |                                                |                                                    |                                                     |                                    |                              |                                   |                                  |                                   |                      |
| P.U. (ml-1)           | 15.174                        | 4.667                                          | 106.811                                            | 43.036                                              | 5.704                              | 3.111                        | 31.11                             | 409.2                            | 2133.318                          | 2752.129             |
| S.D.                  | 9.495                         | 0.733                                          | 29.331                                             | 22.731                                              | 0.733                              | 1.467                        | 7.333                             | 114.693                          | 614.342                           | 780.401              |
| Biomass (mg.m-3)      | 400.23                        | 5.138                                          | 41.776                                             | 24.685                                              | 11.865                             | 1.364                        | 299.616                           | 100.189                          | 27.562                            | 912.424              |
| <b>Lake</b>           |                               |                                                |                                                    |                                                     |                                    |                              |                                   |                                  |                                   |                      |
| P.U. (ml-1)           | 14.055                        | 29.036                                         | 96.441                                             | 29.555                                              | 7.259                              | 4.667                        | 33.184                            | 838.053                          | 3214.194                          | 4266.443             |
| S.D.                  | 1.269                         | 4.4                                            | 14.665                                             | 6.599                                               | 1.467                              | 0.733                        | 0                                 | 29.631                           | 190.656                           | 165.622              |
| Biomass (mg.m-3)      | 370.715                       | 31.971                                         | 37.72                                              | 16.952                                              | 15.1                               | 2.046                        | 319.59                            | 205.189                          | 41.527                            | 1040.811             |



# Appendix IV : Experiment 2 Winter Lake Rotoroa 27/7/90 - 6/8/90

| Day 0 (27/7/92)       | <i>Peridinium<br/>cinctum</i> | <i>Cryptomonas<br/>ovata and<br/>marssonii</i> | <i>Staurastrum<br/>leptocladum<br/>var.insigne</i> | <i>Trachelomonas<br/>volvicina</i> | <i>Coelastrum<br/>reticulatum</i> | <i>Pediastrum<br/>tetras</i> | <i>Scenedesmus<br/>ecornis +<br/>quadricauda</i> | <i>Fragilaria<br/>capucina</i> | <i>Cyclotella<br/>stelligera +<br/>meneghiniana</i> | <i>Tetrastrum<br/>triangulare</i> | <i>Oocystis<br/>cf. lacustris</i> | TOTAL<br>P.U. (ml-1) |
|-----------------------|-------------------------------|------------------------------------------------|----------------------------------------------------|------------------------------------|-----------------------------------|------------------------------|--------------------------------------------------|--------------------------------|-----------------------------------------------------|-----------------------------------|-----------------------------------|----------------------|
| <b>Exclosure</b>      |                               |                                                |                                                    |                                    |                                   |                              |                                                  |                                |                                                     |                                   |                                   |                      |
| P.U. (ml-1)           | 22.087                        | 57.554                                         | 107.589                                            | 6.222                              | 4.667                             | 2.852                        | 300.282                                          | 22.814                         | 4923.513                                            | 1033.727                          | 376.779                           | 6858.084             |
| S.D.                  | 0.469                         | 5.254                                          | 8.855                                              | 3.787                              | 1.796                             | 0.519                        | 72.026                                           | 5.219                          | 287.135                                             | 92.665                            | 17.638                            | 264.722              |
| Biomass (mg.m-3)      | 582.555                       | 63.371                                         | 42.08                                              | 12.943                             | 44.942                            | 1.25                         | 21.209                                           | 8.611                          | 2366.831                                            | 13.356                            | 93.031                            | 3250.179             |
| <b>Enclosure (1X)</b> |                               |                                                |                                                    |                                    |                                   |                              |                                                  |                                |                                                     |                                   |                                   |                      |
| P.U. (ml-1)           | 20.732                        | 65.59                                          | 106.293                                            | 2.852                              | 5.444                             | 1.815                        | 334.709                                          | 26.184                         | 5070.582                                            | 1043.388                          | 381.61                            | 7059.198             |
| S.D.                  | 1.858                         | 7.915                                          | 4.973                                              | 0.519                              | 2.727                             | 0.993                        | 78.532                                           | 12.281                         | 230.259                                             | 86.05                             | 51.425                            | 244.795              |
| Biomass (mg.m-3)      | 546.815                       | 72.22                                          | 41.573                                             | 5.932                              | 52.433                            | 0.796                        | 23.641                                           | 9.883                          | 2437.53                                             | 13.481                            | 94.223                            | 3298.526             |
| <b>Enclosure (2X)</b> |                               |                                                |                                                    |                                    |                                   |                              |                                                  |                                |                                                     |                                   |                                   |                      |
| P.U. (ml-1)           | 20.461                        | 66.368                                         | 102.663                                            | 7.259                              | 2.074                             | 2.593                        | 381.282                                          | 32.406                         | 4872.462                                            | 1002.329                          | 364.703                           | 6854.599             |
| S.D.                  | 2.479                         | 3.592                                          | 9.08                                               | 2.24                               | 1.467                             | 1.986                        | 47.224                                           | 5.766                          | 339.516                                             | 24.153                            | 33.814                            | 301.399              |
| Biomass (mg.m-3)      | 539.667                       | 73.076                                         | 40.154                                             | 15.1                               | 19.974                            | 1.137                        | 26.93                                            | 12.231                         | 2342.29                                             | 12.95                             | 90.049                            | 3173.559             |
| <b>Enclosure (4X)</b> |                               |                                                |                                                    |                                    |                                   |                              |                                                  |                                |                                                     |                                   |                                   |                      |
| P.U. (ml-1)           | 20.325                        | 59.368                                         | 97.478                                             | 8.555                              | 4.926                             | 3.63                         | 375.25                                           | 24.888                         | 4867.706                                            | 1069.956                          | 362.288                           | 6894.369             |
| S.D.                  | 1.232                         | 7.4                                            | 3.491                                              | 4.094                              | 2.138                             | 3.834                        | 13.531                                           | 4.937                          | 292.229                                             | 117.63                            | 25.561                            | 339.555              |
| Biomass (mg.m-3)      | 536.093                       | 65.369                                         | 38.126                                             | 17.797                             | 47.439                            | 1.591                        | 26.504                                           | 9.394                          | 2340.004                                            | 13.824                            | 89.452                            | 3185.593             |
| <b>LAKE</b>           |                               |                                                |                                                    |                                    |                                   |                              |                                                  |                                |                                                     |                                   |                                   |                      |
| P.U. (ml-1)           | 9.079                         | 62.739                                         | 110.441                                            | 9.852                              | 4.667                             | 1.037                        | 304.348                                          | 31.11                          | 3633.778                                            | 1299.405                          | 299.491                           | 5765.944             |
| S.D.                  | 2.108                         | 9.533                                          | 13.932                                             | 2.2                                | 0.733                             | 1.467                        | 13.663                                           | 7.333                          | 380.657                                             | 20.494                            | 40.988                            | 406.731              |
| Biomass (mg.m-3)      | 239.455                       | 69.08                                          | 43.195                                             | 20.493                             | 44.942                            | 0.455                        | 21.496                                           | 11.742                         | 1746.83                                             | 16.788                            | 73.947                            | 2288.425             |

P.U. (ml-1) and Biomass (mg.m-3) are mean values where n = 4

# Appendix IV : Experiment 2 Winter Lake Rotoroa 27/7/90 - 6/8/90

| Day 3 (30/7/90)       | <i>Peridinium<br/>cinctum</i> | <i>Cryptomonas<br/>ovata and<br/>marssonii</i> | <i>Staurastrum<br/>leptocladum<br/>var.insigne</i> | <i>Trachelomonas<br/>volvicina</i> | <i>Coelastrum<br/>reticulatum</i> | <i>Pediastrum<br/>tetras</i> | <i>Scenedesmus<br/>ecornis +<br/>quadricauda</i> | <i>Fragilaria<br/>capucina</i> | <i>Cyclotella<br/>stelligera +<br/>meneghiniana</i> | <i>Tetrastrum<br/>triangulare</i> | <i>Oocystis<br/>cf. lacustris</i> | TOTAL<br>P.U. (ml-1) |
|-----------------------|-------------------------------|------------------------------------------------|----------------------------------------------------|------------------------------------|-----------------------------------|------------------------------|--------------------------------------------------|--------------------------------|-----------------------------------------------------|-----------------------------------|-----------------------------------|----------------------|
| <b>Enclosure</b>      |                               |                                                |                                                    |                                    |                                   |                              |                                                  |                                |                                                     |                                   |                                   |                      |
| P.U. (ml-1)           | 15.718                        | 110.959                                        | 78.294                                             | 10.629                             | 3.111                             | 3.37                         | 377.843                                          | 55.998                         | 5229.575                                            | 1383.938                          | 388.855                           | 7658.29              |
| S.D.                  | 3.94                          | 10.405                                         | 8.403                                              | 7.448                              | 1.467                             | 3.426                        | 67.962                                           | 13.783                         | 998.199                                             | 65.227                            | 92.118                            | 854.498              |
| Biomass (mg.m-3)      | 414.579                       | 122.175                                        | 30.622                                             | 22.111                             | 29.962                            | 1.477                        | 26.687                                           | 21.136                         | 2513.961                                            | 17.88                             | 96.012                            | 3296.603             |
| <b>Enclosure (1X)</b> |                               |                                                |                                                    |                                    |                                   |                              |                                                  |                                |                                                     |                                   |                                   |                      |
| P.U. (ml-1)           | 14.295                        | 86.071                                         | 81.145                                             | 5.963                              | 4.667                             | 5.704                        | 361.018                                          | 44.073                         | 4351.818                                            | 1325.972                          | 391.271                           | 6671.996             |
| S.D.                  | 1.601                         | 17.537                                         | 16.096                                             | 0.519                              | 1.037                             | 3.439                        | 76.142                                           | 7.875                          | 642.8                                               | 105.647                           | 52.621                            | 648.604              |
| Biomass (mg.m-3)      | 377.052                       | 94.771                                         | 31.738                                             | 12.404                             | 44.942                            | 2.5                          | 25.499                                           | 16.635                         | 2092.006                                            | 17.132                            | 96.609                            | 2811.287             |
| <b>Enclosure (2X)</b> |                               |                                                |                                                    |                                    |                                   |                              |                                                  |                                |                                                     |                                   |                                   |                      |
| P.U. (ml-1)           | 6.301                         | 41.221                                         | 80.368                                             | 4.407                              | 4.407                             | 4.148                        | 341.355                                          | 33.181                         | 3679.925                                            | 1200.379                          | 326.059                           | 5721.75              |
| S.D.                  | 3.225                         | 4.51                                           | 11.532                                             | 2.856                              | 2.138                             | 2.074                        | 56.046                                           | 4.057                          | 199.038                                             | 70.278                            | 103.264                           | 314.92               |
| Biomass (mg.m-3)      | 166.189                       | 45.387                                         | 31.433                                             | 9.168                              | 42.446                            | 1.818                        | 24.11                                            | 12.524                         | 1769.013                                            | 15.509                            | 80.507                            | 2198.105             |
| <b>Enclosure (4X)</b> |                               |                                                |                                                    |                                    |                                   |                              |                                                  |                                |                                                     |                                   |                                   |                      |
| P.U. (ml-1)           | 3.523                         | 20.222                                         | 83.738                                             | 2.333                              | 4.148                             | 1.556                        | 259.482                                          | 21.777                         | 3747.943                                            | 1120.676                          | 251.186                           | 5516.583             |
| S.D.                  | 1.729                         | 6.364                                          | 6.244                                              | 0.993                              | 1.467                             | 1.339                        | 40.718                                           | 4.234                          | 790.211                                             | 90.971                            | 64.084                            | 836.673              |
| Biomass (mg.m-3)      | 92.91                         | 22.265                                         | 32.752                                             | 4.854                              | 39.949                            | 0.682                        | 18.327                                           | 8.22                           | 1801.711                                            | 14.479                            | 62.02                             | 2098.168             |
| <b>Lake</b>           |                               |                                                |                                                    |                                    |                                   |                              |                                                  |                                |                                                     |                                   |                                   |                      |
| P.U. (ml-1)           | 9.892                         | 87.108                                         | 78.294                                             | 11.926                             | 7.778                             | 4.148                        | 289.857                                          | 39.925                         | 4707.488                                            | 1004.744                          | 246.356                           | 6487.513             |
| S.D.                  | 0.575                         | 11.732                                         | 15.399                                             | 2.2                                | 0.733                             | 0                            | 31.224                                           | 0.733                          | 964.76                                              | 27.325                            | 6.831                             | 994.982              |
| Biomass (mg.m-3)      | 260.899                       | 95.913                                         | 30.622                                             | 24.808                             | 74.904                            | 1.818                        | 20.473                                           | 15.069                         | 2262.984                                            | 12.981                            | 60.828                            | 2861.298             |

# Appendix IV : Experiment 2 Winter Lake Rotoroa 27/7/90 - 6/8/90

| Day 6 (2/8/90)        | <i>Peridinium<br/>cinctum</i> | <i>Cryptomonas<br/>ovata and<br/>marssonii</i> | <i>Staurastrum<br/>leptocladum<br/>var.insigne</i> | <i>Trachelomonas<br/>volvicina</i> | <i>Coelastrum<br/>reticulatum</i> | <i>Pediastrum<br/>tetras</i> | <i>Scenedesmus<br/>ecornis +<br/>quadricauda</i> | <i>Fragilaria<br/>capucina</i> | <i>Cyclotella<br/>stelligera +<br/>meneghiniana</i> | <i>Tetrastrum<br/>triangulare</i> | <i>Oocystis<br/>cf. lacustris</i> | TOTAL<br>P.U. (ml-1) |
|-----------------------|-------------------------------|------------------------------------------------|----------------------------------------------------|------------------------------------|-----------------------------------|------------------------------|--------------------------------------------------|--------------------------------|-----------------------------------------------------|-----------------------------------|-----------------------------------|----------------------|
| <b>Exclosure</b>      |                               |                                                |                                                    |                                    |                                   |                              |                                                  |                                |                                                     |                                   |                                   |                      |
| P.U. (ml-1)           | 28.252                        | 125.477                                        | 73.627                                             | 7.259                              | 5.185                             | 5.185                        | 334.982                                          | 71.035                         | 4687.177                                            | 1357.371                          | 316.398                           | 7011.946             |
| S.D.                  | 24.209                        | 35.075                                         | 10.266                                             | 5.15                               | 1.197                             | 0.847                        | 76.794                                           | 8.572                          | 236.951                                             | 50.816                            | 75.403                            | 324.927              |
| Biomass (mg.m-3)      | 745.17                        | 138.16                                         | 28.797                                             | 15.1                               | 49.936                            | 2.273                        | 23.66                                            | 26.811                         | 2253.219                                            | 17.537                            | 78.122                            | 3378.786             |
| <b>Enclosure (1X)</b> |                               |                                                |                                                    |                                    |                                   |                              |                                                  |                                |                                                     |                                   |                                   |                      |
| P.U. (ml-1)           | 11.653                        | 99.293                                         | 62.998                                             | 5.704                              | 3.889                             | 4.926                        | 324.789                                          | 57.813                         | 3765.909                                            | 1214.871                          | 287.415                           | 5839.258             |
| S.D.                  | 0.964                         | 14.82                                          | 7.96                                               | 1.339                              | 2.299                             | 0.993                        | 14.977                                           | 4.589                          | 119.141                                             | 74.155                            | 44.883                            | 204.569              |
| Biomass (mg.m-3)      | 307.36                        | 109.329                                        | 24.64                                              | 11.865                             | 37.452                            | 2.159                        | 22.94                                            | 21.821                         | 1810.348                                            | 15.696                            | 70.966                            | 2434.575             |
| <b>Enclosure (2X)</b> |                               |                                                |                                                    |                                    |                                   |                              |                                                  |                                |                                                     |                                   |                                   |                      |
| P.U. (ml-1)           | 15.583                        | 19.185                                         | 79.59                                              | 4.148                              | 3.889                             | 2.333                        | 268.979                                          | 27.481                         | 2856.11                                             | 1147.244                          | 313.983                           | 4738.522             |
| S.D.                  | 10.102                        | 1.796                                          | 13.263                                             | 2.24                               | 1.771                             | 0.993                        | 71.969                                           | 2.159                          | 610.443                                             | 116.033                           | 22.998                            | 628.379              |
| Biomass (mg.m-3)      | 411.005                       | 21.124                                         | 31.129                                             | 8.629                              | 37.452                            | 1.023                        | 18.998                                           | 10.372                         | 1372.987                                            | 14.822                            | 77.525                            | 2005.068             |
| <b>Enclosure (4X)</b> |                               |                                                |                                                    |                                    |                                   |                              |                                                  |                                |                                                     |                                   |                                   |                      |
| P.U. (ml-1)           | 8.266                         | 9.074                                          | 79.071                                             | 2.593                              | 2.074                             | 3.889                        | 228.166                                          | 15.296                         | 1919.797                                            | 845.338                           | 246.356                           | 3359.917             |
| S.D.                  | 2.872                         | 4.51                                           | 4.094                                              | 2.469                              | 1.893                             | 3.426                        | 22.46                                            | 5.036                          | 133.729                                             | 110.575                           | 42.844                            | 108.523              |
| Biomass (mg.m-3)      | 218.011                       | 9.991                                          | 30.926                                             | 5.393                              | 19.974                            | 1.705                        | 16.115                                           | 5.773                          | 922.885                                             | 10.922                            | 60.828                            | 1302.523             |
| <b>Lake</b>           |                               |                                                |                                                    |                                    |                                   |                              |                                                  |                                |                                                     |                                   |                                   |                      |
| P.U. (ml-1)           | 7.59                          | 92.293                                         | 60.146                                             | 15.037                             | 6.74                              | 4.148                        | 257.763                                          | 55.48                          | 5020.411                                            | 1009.575                          | 270.508                           | 6799.689             |
| S.D.                  | 2.686                         | 17.598                                         | 11.732                                             | 2.2                                | 0.735                             | 1.467                        | 61.482                                           | 0.733                          | 594.127                                             | 20.494                            | 13.663                            | 712.743              |
| Biomass (mg.m-3)      | 200.194                       | 101.622                                        | 23.524                                             | 31.28                              | 64.907                            | 1.818                        | 18.206                                           | 20.94                          | 2413.412                                            | 13.044                            | 66.791                            | 2955.738             |

# Appendix IV : Experiment 2 Winter Lake Rotoroa 27/7/90 - 6/8/90

| Day 10 (6/8/90)       | <i>Peridinium<br/>cinctum</i> | <i>Cryptomonas<br/>ovata and<br/>marssonii</i> | <i>Staurostrum<br/>leptocladum<br/>var.insigne</i> | <i>Trachelomonas<br/>volvicina</i> | <i>Coelastrum<br/>reticulatum</i> | <i>Pediastrum<br/>tetras</i> | <i>Scenedesmus<br/>ecornis +<br/>quadricauda</i> | <i>Fragilaria<br/>capucina</i> | <i>Cyclotella<br/>stelligera +<br/>meneghiniana</i> | <i>Tetrastrum<br/>triangulare</i> | <i>Oocystis<br/>cf. lacustris</i> | TOTAL<br>P.U. (ml-1) |
|-----------------------|-------------------------------|------------------------------------------------|----------------------------------------------------|------------------------------------|-----------------------------------|------------------------------|--------------------------------------------------|--------------------------------|-----------------------------------------------------|-----------------------------------|-----------------------------------|----------------------|
| <b>Exclosure</b>      |                               |                                                |                                                    |                                    |                                   |                              |                                                  |                                |                                                     |                                   |                                   |                      |
| P.U. (ml-1)           | 18.359                        | 167.735                                        | 65.59                                              | 3.111                              | 1.556                             | 5.185                        | 281.41                                           | 76.22                          | 4234.515                                            | 1053.049                          | 248.771                           | 6155.5               |
| S.D.                  | 4.234                         | 28.718                                         | 9.924                                              | 1.467                              | 1.037                             | 1.893                        | 51.628                                           | 16.21                          | 458.891                                             | 83.107                            | 46.249                            | 506.677              |
| Biomass (mg.m-3)      | 484.244                       | 184.689                                        | 25.654                                             | 6.472                              | 14.981                            | 2.273                        | 19.876                                           | 28.768                         | 2035.616                                            | 13.605                            | 61.424                            | 2877.603             |
| <b>Enclosure (1X)</b> |                               |                                                |                                                    |                                    |                                   |                              |                                                  |                                |                                                     |                                   |                                   |                      |
| P.U. (ml-1)           | 18.147                        | 62.22                                          | 66.368                                             | 4.148                              | 1.037                             | 4.926                        | 230.335                                          | 39.925                         | 2668.489                                            | 1062.71                           | 251.186                           | 4409.491             |
| S.D.                  | 4.323                         | 16.807                                         | 3.88                                               | 1.467                              | 0.847                             | 0.993                        | 40.333                                           | 6.017                          | 292.944                                             | 89.592                            | 36.148                            | 221.098              |
| Biomass (mg.m-3)      | 478.646                       | 68.509                                         | 25.958                                             | 8.629                              | 9.987                             | 2.159                        | 16.269                                           | 15.069                         | 1282.796                                            | 13.73                             | 62.02                             | 1983.773             |
| <b>Enclosure (2X)</b> |                               |                                                |                                                    |                                    |                                   |                              |                                                  |                                |                                                     |                                   |                                   |                      |
| P.U. (ml-1)           | 17.885                        | 12.963                                         | 65.072                                             | 2.074                              | 6.222                             | 5.704                        | 226.023                                          | 18.666                         | 2757.846                                            | 934.702                           | 200.466                           | 4247.622             |
| S.D.                  | 9.254                         | 6.694                                          | 14.527                                             | 2.24                               | 3.279                             | 3.224                        | 41.377                                           | 9.159                          | 503.561                                             | 126.225                           | 49.498                            | 587.488              |
| Biomass (mg.m-3)      | 471.736                       | 14.273                                         | 25.451                                             | 4.314                              | 59.923                            | 2.5                          | 15.964                                           | 7.045                          | 1325.752                                            | 12.076                            | 49.497                            | 1988.532             |
| <b>Enclosure (4X)</b> |                               |                                                |                                                    |                                    |                                   |                              |                                                  |                                |                                                     |                                   |                                   |                      |
| P.U. (ml-1)           | 10.568                        | 8.555                                          | 64.812                                             | 4.926                              | 2.593                             | 2.333                        | 74.709                                           | 8.296                          | 1235.19                                             | 475.804                           | 137.669                           | 2025.454             |
| S.D.                  | 3.341                         | 0.993                                          | 13.265                                             | 2.299                              | 2.61                              | 2.138                        | 31.556                                           | 1.893                          | 441.094                                             | 86.184                            | 28.849                            | 513.479              |
| Biomass (mg.m-3)      | 278.742                       | 9.42                                           | 25.349                                             | 10.247                             | 24.968                            | 1.023                        | 5.277                                            | 3.131                          | 593.78                                              | 6.147                             | 33.992                            | 992.076              |
| <b>Lake</b>           |                               |                                                |                                                    |                                    |                                   |                              |                                                  |                                |                                                     |                                   |                                   |                      |
| P.U. (ml-1)           | 17.751                        | 117.7                                          | 40.962                                             | 15.037                             | 4.667                             | 6.222                        | 214.479                                          | 111.478                        | 5513.978                                            | 850.168                           | 173.898                           | 7066.337             |
| S.D.                  | 1.341                         | 5.133                                          | 9.533                                              | 0.733                              | 2.2                               | 1.467                        | 0.733                                            | 0.733                          | 247.697                                             | 204.941                           | 0                                 | 468.644              |
| Biomass (mg.m-3)      | 468.188                       | 129.597                                        | 16.021                                             | 31.28                              | 44.942                            | 2.728                        | 15.149                                           | 42.076                         | 2650.68                                             | 10.984                            | 42.937                            | 3454.581             |

# Appendix IV : Experiment 3 Spring Lake Rotoroa 12/10/90 - 22/10/90

| Day 0 (12/10/90)      | <i>Peridinium<br/>cinctum</i> | <i>Asterionella<br/>formosa</i> | <i>Cryptomonas<br/>ovata and<br/>marssonii</i> | <i>Staurastrum<br/>leptocladum<br/>var.insigne</i> | <i>Staurodesmus<br/>unicornis var.<br/>gracilis</i> | <i>Cosmarium<br/>perfissum</i> | <i>Elakatothrix<br/>gelatinosa</i> | <i>Pediastrum<br/>tetras</i> | <i>Coelastrum<br/>reticulatum</i> | <i>Scenedesmus<br/>quadricauda<br/>and ecornis</i> | <i>Tetrastrum<br/>triangulare<br/>cf. lacustris</i> | <i>Oocystis</i> | TOTAL<br>P.U. (ml-1) |
|-----------------------|-------------------------------|---------------------------------|------------------------------------------------|----------------------------------------------------|-----------------------------------------------------|--------------------------------|------------------------------------|------------------------------|-----------------------------------|----------------------------------------------------|-----------------------------------------------------|-----------------|----------------------|
| <b>Exclosure</b>      |                               |                                 |                                                |                                                    |                                                     |                                |                                    |                              |                                   |                                                    |                                                     |                 |                      |
| P.U. (ml-1)           | 2.981                         | 6.843                           | 25.925                                         | 59.628                                             | 6.741                                               | 73.627                         | 24.37                              | 4.926                        | 18.407                            | 24.37                                              | 451.652                                             | 150.632         | 850.099              |
| S.D.                  | 2.179                         | 0.513                           | 6.279                                          | 4.359                                              | 1.339                                               | 4.937                          | 7.308                              | 2.138                        | 2.299                             | 3.834                                              | 71.158                                              | 28.552          | 89.281               |
| Biomass (mg.m-3)      | 78.627                        | 12.918                          | 28.545                                         | 23.322                                             | 3.866                                               | 44.357                         | 3.453                              | 2.159                        | 177.273                           | 1.721                                              | 5.835                                               | 52.955          | 435.032              |
| <b>Enclosure (1X)</b> |                               |                                 |                                                |                                                    |                                                     |                                |                                    |                              |                                   |                                                    |                                                     |                 |                      |
| P.U. (ml-1)           | 0.945                         | 4.185                           | 17.871                                         | 49.728                                             | 5.698                                               | 66.952                         | 21.756                             | 3.367                        | 17.353                            | 25.512                                             | 344.303                                             | 142.755         | 700.423              |
| S.D.                  | 0.292                         | 0.454                           | 3.723                                          | 5.627                                              | 0.423                                               | 4.939                          | 8.574                              | 0.518                        | 1.718                             | 5.1                                                | 35.28                                               | 11.236          | 45.257               |
| Biomass (mg.m-3)      | 24.925                        | 7.9                             | 19.677                                         | 19.45                                              | 3.268                                               | 40.336                         | 3.083                              | 1.476                        | 167.124                           | 1.802                                              | 4.448                                               | 50.185          | 343.675              |
| <b>Enclosure (2X)</b> |                               |                                 |                                                |                                                    |                                                     |                                |                                    |                              |                                   |                                                    |                                                     |                 |                      |
| P.U. (ml-1)           | 2.116                         | 4.486                           | 21.368                                         | 51.541                                             | 6.216                                               | 59.311                         | 18.907                             | 3.238                        | 14.504                            | 24.346                                             | 333.27                                              | 143.623         | 682.925              |
| S.D.                  | 1.546                         | 0.734                           | 8.04                                           | 10.586                                             | 1.938                                               | 4.719                          | 3.423                              | 1.711                        | 3.663                             | 2.773                                              | 46.16                                               | 10.502          | 44.984               |
| Biomass (mg.m-3)      | 55.818                        | 8.469                           | 23.527                                         | 20.159                                             | 3.565                                               | 35.733                         | 2.679                              | 1.419                        | 139.686                           | 1.72                                               | 4.306                                               | 50.49           | 347.572              |
| <b>Enclosure (4X)</b> |                               |                                 |                                                |                                                    |                                                     |                                |                                    |                              |                                   |                                                    |                                                     |                 |                      |
| P.U. (ml-1)           | 1.572                         | 4.595                           | 16.971                                         | 49.484                                             | 5.57                                                | 69.042                         | 22.8                               | 4.922                        | 17.618                            | 27.201                                             | 368.301                                             | 169.382         | 757.458              |
| S.D.                  | 1.631                         | 0.742                           | 6.745                                          | 10.023                                             | 1.148                                               | 9.587                          | 6.01                               | 0.669                        | 4.853                             | 2.718                                              | 90.505                                              | 67.213          | 191.123              |
| Biomass (mg.m-3)      | 41.47                         | 8.675                           | 18.686                                         | 19.354                                             | 3.195                                               | 41.595                         | 3.231                              | 2.158                        | 169.676                           | 1.921                                              | 4.758                                               | 59.546          | 374.266              |
| <b>Lake</b>           |                               |                                 |                                                |                                                    |                                                     |                                |                                    |                              |                                   |                                                    |                                                     |                 |                      |
| P.U. (ml-1)           | 2.498                         | 5.333                           | 22.533                                         | 62.638                                             | 8.029                                               | 71.484                         | 17.094                             | 6.475                        | 18.13                             | 28.49                                              | 388.815                                             | 201.411         | 832.929              |
| S.D.                  | 0.095                         | 0.286                           | 3.297                                          | 3.719                                              | 0.366                                               | 2.93                           | 3.663                              | 1.831                        | 2.198                             | 2.93                                               | 44.399                                              | 24.759          | 82.845               |
| Biomass (mg.m-3)      | 65.874                        | 10.067                          | 24.811                                         | 24.499                                             | 4.605                                               | 43.066                         | 2.422                              | 2.839                        | 174.607                           | 2.012                                              | 5.023                                               | 70.806          | 430.632              |

P.U. (ml-1) and Biomass (mg.m-3) are mean values where n = 4

# Appendix IV : Experiment 3 Spring Lake Rotoroa 12/10/90 - 22/10/90

| Day 3 (15/10/90)      | <i>Peridinium<br/>cinctum</i> | <i>Asterionella<br/>formosa</i> | <i>Cryptomonas<br/>ovata and<br/>marssonii</i> | <i>Staurastrum<br/>leptocladum<br/>var.insigne</i> | <i>Stauroidesmus<br/>unicornis var.<br/>gracilis</i> | <i>Cosmarium<br/>perfissum</i> | <i>Elakatothrix<br/>gelatinosa</i> | <i>Pediastrum<br/>tetras</i> | <i>Coelastrum<br/>reticulatum</i> | <i>Scenedesmus<br/>quadricauda<br/>and ecornis</i> | <i>Tetrastrum<br/>triangulare</i> | <i>Oocystis<br/>cf. lacustris</i> | TOTAL<br>P.U. (ml-1) |
|-----------------------|-------------------------------|---------------------------------|------------------------------------------------|----------------------------------------------------|------------------------------------------------------|--------------------------------|------------------------------------|------------------------------|-----------------------------------|----------------------------------------------------|-----------------------------------|-----------------------------------|----------------------|
| <b>Exclosure</b>      |                               |                                 |                                                |                                                    |                                                      |                                |                                    |                              |                                   |                                                    |                                   |                                   |                      |
| P.U. (ml-1)           | 3.038                         | 6.885                           | 72.65                                          | 23.334                                             | 9.065                                                | 30.045                         | 37.944                             | 10.101                       | 26.548                            | 39.498                                             | 342.93                            | 199.472                           | 801.507              |
| S.D.                  | 0.885                         | 1.547                           | 27.02                                          | 9.973                                              | 1.233                                                | 1.938                          | 10.534                             | 2.093                        | 6.812                             | 6.838                                              | 49.728                            | 26.237                            | 52.877               |
| Biomass (mg.m-3)      | 80.117                        | 12.998                          | 79.993                                         | 9.126                                              | 5.2                                                  | 18.101                         | 5.377                              | 4.428                        | 255.675                           | 2.79                                               | 4.431                             | 70.124                            | 548.358              |
| <b>Enclosure (1X)</b> |                               |                                 |                                                |                                                    |                                                      |                                |                                    |                              |                                   |                                                    |                                   |                                   |                      |
| P.U. (ml-1)           | 1.89                          | 3.105                           | 7.382                                          | 38.721                                             | 8.029                                                | 38.203                         | 35.742                             | 7.382                        | 17.48                             | 30.951                                             | 268.065                           | 167.384                           | 624.332              |
| S.D.                  | 1.774                         | 0.967                           | 2.817                                          | 6.516                                              | 3.526                                                | 3.623                          | 5.4                                | 1.955                        | 6.651                             | 7.757                                              | 18.286                            | 12.667                            | 33.56                |
| Biomass (mg.m-3)      | 49.851                        | 5.862                           | 8.128                                          | 15.144                                             | 4.605                                                | 23.015                         | 5.065                              | 3.236                        | 168.347                           | 2.186                                              | 3.463                             | 58.844                            | 347.746              |
| <b>Enclosure (2X)</b> |                               |                                 |                                                |                                                    |                                                      |                                |                                    |                              |                                   |                                                    |                                   |                                   |                      |
| P.U. (ml-1)           | 0.844                         | 1.046                           | 1.036                                          | 28.879                                             | 6.087                                                | 30.562                         | 15.799                             | 4.403                        | 24.994                            | 21.238                                             | 246.33                            | 62.759                            | 443.975              |
| S.D.                  | 0.767                         | 0.231                           | 0.423                                          | 2.972                                              | 1.711                                                | 6.579                          | 3.344                              | 1.233                        | 4.3                               | 2.43                                               | 43.38                             | 19.167                            | 31.312               |
| Biomass (mg.m-3)      | 22.255                        | 1.975                           | 1.141                                          | 11.295                                             | 3.491                                                | 18.412                         | 2.239                              | 1.93                         | 240.709                           | 1.5                                                | 3.183                             | 22.063                            | 330.192              |
| <b>Enclosure (4X)</b> |                               |                                 |                                                |                                                    |                                                      |                                |                                    |                              |                                   |                                                    |                                   |                                   |                      |
| P.U. (ml-1)           | 0.743                         | 0.068                           | 1.295                                          | 17.871                                             | 5.439                                                | 20.202                         | 5.439                              | 8.806                        | 25.641                            | 18.648                                             | 169.05                            | 43.827                            | 317.028              |
| S.D.                  | 0.286                         | 0.095                           | 0.366                                          | 4.029                                              | 0.366                                                | 1.465                          | 0.366                              | 0.733                        | 8.424                             | 0.733                                              | 34.153                            | 0.98                              | 25.672               |
| Biomass (mg.m-3)      | 19.584                        | 0.127                           | 1.426                                          | 6.99                                               | 3.12                                                 | 12.171                         | 0.771                              | 3.86                         | 246.945                           | 1.317                                              | 2.184                             | 15.407                            | 313.902              |
| <b>Lake</b>           |                               |                                 |                                                |                                                    |                                                      |                                |                                    |                              |                                   |                                                    |                                   |                                   |                      |
| P.U. (ml-1)           | 2.835                         | 4.05                            | 19.166                                         | 32.893                                             | 7.511                                                | 28.49                          | 29.267                             | 4.144                        | 22.274                            | 23.31                                              | 362.25                            | 192.696                           | 728.886              |
| S.D.                  | 0.764                         | 0.764                           | 0.733                                          | 4.029                                              | 1.831                                                | 5.128                          | 4.762                              | 2.198                        | 2.93                              | 2.198                                              | 54.645                            | 28.788                            | 21.828               |
| Biomass (mg.m-3)      | 74.776                        | 7.646                           | 21.103                                         | 12.865                                             | 4.308                                                | 17.164                         | 4.147                              | 1.817                        | 214.518                           | 1.646                                              | 4.68                              | 67.742                            | 432.413              |

# Appendix IV : Experiment 3 Spring Lake Rotoroa 12/10/90 - 22/10/90

| Day 6(18/10/90)       | <i>Peridinium<br/>cinctum</i> | <i>Asterionella<br/>formosa</i> | <i>Cryptomonas<br/>ovata and<br/>marssonii</i> | <i>Staurastrum<br/>leptocladum<br/>var.insigne</i> | <i>Staurodesmus<br/>unicornis var.<br/>gracilis</i> | <i>Cosmarium<br/>perfissum</i> | <i>Elakatothrix<br/>gelatinosa</i> | <i>Pediastrum<br/>tetras</i> | <i>Coelastrum<br/>reticulatum</i> | <i>Scenedesmus<br/>quadricauda<br/>and ecornis</i> | <i>Tetrastrum<br/>triangulare</i> | <i>Oocystis<br/>cf. lacustris</i> | TOTAL<br>P.U. (ml-1) |
|-----------------------|-------------------------------|---------------------------------|------------------------------------------------|----------------------------------------------------|-----------------------------------------------------|--------------------------------|------------------------------------|------------------------------|-----------------------------------|----------------------------------------------------|-----------------------------------|-----------------------------------|----------------------|
| <b>Exclosure</b>      |                               |                                 |                                                |                                                    |                                                     |                                |                                    |                              |                                   |                                                    |                                   |                                   |                      |
| P.U. (ml-1)(ml-1)     | 4.118                         | 14.175                          | 51.282                                         | 20.591                                             | 21.238                                              | 26.03                          | 9.82                               | 14.763                       | 48.433                            | 46.62                                              | 336.893                           | 137.025                           | 730.985              |
| S.D.                  | 2.222                         | 4.127                           | 14.148                                         | 6.516                                              | 4.652                                               | 5.68                           | 2.163                              | 4.681                        | 5.223                             | 6.511                                              | 37.698                            | 53.771                            | 42.21                |
| Biomass (mg.m-3)      | 108.603                       | 26.76                           | 56.466                                         | 8.053                                              | 12.182                                              | 15.682                         | 1.391                              | 6.472                        | 466.451                           | 3.293                                              | 4.353                             | 48.171                            | 757.876              |
| <b>Enclosure (1X)</b> |                               |                                 |                                                |                                                    |                                                     |                                |                                    |                              |                                   |                                                    |                                   |                                   |                      |
| P.U. (ml-1)           | 0.945                         | 1.215                           | 5.18                                           | 25.382                                             | 5.31                                                | 24.605                         | 34.582                             | 6.087                        | 26.807                            | 36.131                                             | 262.028                           | 102.347                           | 530.616              |
| S.D.                  | 0.382                         | 0.22                            | 1.403                                          | 1.984                                              | 2.001                                               | 3.842                          | 13.517                             | 0.259                        | 2.331                             | 1.711                                              | 46.891                            | 38.538                            | 97.061               |
| Biomass (mg.m-3)      | 24.925                        | 2.294                           | 5.704                                          | 9.927                                              | 3.045                                               | 14.824                         | 4.9                                | 2.668                        | 258.169                           | 2.552                                              | 3.385                             | 35.98                             | 368.374              |
| <b>Enclosure (2X)</b> |                               |                                 |                                                |                                                    |                                                     |                                |                                    |                              |                                   |                                                    |                                   |                                   |                      |
| P.U. (ml-1)           | 0.371                         | 0.236                           | 0.518                                          | 25.253                                             | 4.015                                               | 17.224                         | 7.511                              | 4.403                        | 26.548                            | 14.245                                             | 112.298                           | 29.894                            | 242.514              |
| S.D.                  | 0.485                         | 0.129                           | 0.423                                          | 3.862                                              | 1.955                                               | 5.289                          | 3.235                              | 1.611                        | 3.176                             | 1.233                                              | 27.99                             | 8.864                             | 36.896               |
| Biomass (mg.m-3)      | 9.792                         | 0.446                           | 0.57                                           | 9.877                                              | 2.303                                               | 10.376                         | 1.064                              | 1.93                         | 255.675                           | 1.006                                              | 1.451                             | 10.509                            | 305                  |
| <b>Enclosure (4X)</b> |                               |                                 |                                                |                                                    |                                                     |                                |                                    |                              |                                   |                                                    |                                   |                                   |                      |
| P.U. (ml-1)           | 0.304                         | 0.236                           | 0.907                                          | 19.037                                             | 3.238                                               | 15.022                         | 5.439                              | 5.051                        | 22.663                            | 14.504                                             | 170.258                           | 58.058                            | 314.715              |
| S.D.                  | 0.299                         | 0.129                           | 1.488                                          | 2.972                                              | 1.711                                               | 6.872                          | 2.624                              | 3.445                        | 5.204                             | 2.43                                               | 78.812                            | 34.704                            | 99.497               |
| Biomass (mg.m-3)      | 8.012                         | 0.446                           | 0.998                                          | 7.446                                              | 1.857                                               | 9.05                           | 0.771                              | 2.214                        | 218.259                           | 1.024                                              | 2.2                               | 20.41                             | 272.687              |
| <b>Lake</b>           |                               |                                 |                                                |                                                    |                                                     |                                |                                    |                              |                                   |                                                    |                                   |                                   |                      |
| P.U. (ml-1)           | 1.08                          | 2.633                           | 32.893                                         | 25.641                                             | 4.921                                               | 28.231                         | 51.541                             | 4.662                        | 22.792                            | 31.339                                             | 369.495                           | 171.997                           | 747.225              |
| S.D.                  | 0.191                         | 0.286                           | 3.297                                          | 1.831                                              | 0.366                                               | 2.564                          | 12.087                             | 1.465                        | 5.861                             | 5.494                                              | 85.383                            | 24.64                             | 57.336               |
| Biomass (mg.m-3)      | 28.486                        | 4.97                            | 36.218                                         | 10.029                                             | 2.823                                               | 17.008                         | 7.303                              | 2.044                        | 219.506                           | 2.213                                              | 4.774                             | 60.466                            | 395.839              |

# Appendix IV : Experiment 3 Spring Lake Rotoroa 12/10/90 - 22/10/90

| Day 10(22/10/90)      | <i>Peridinium<br/>cinctum</i> | <i>Asterionella<br/>formosa</i> | <i>Cryptomonas<br/>ovata and<br/>marssonii</i> | <i>Staurastrum<br/>leptocladum<br/>var.insigne</i> | <i>Staurodesmus<br/>unicornis var.<br/>gracilis</i> | <i>Cosmarium<br/>perfissum</i> | <i>Elakatothrix<br/>gelatinosa</i> | <i>Pediastrum<br/>tetras</i> | <i>Coelastrum<br/>reticulatum</i> | <i>Scenedesmus<br/>quadricauda<br/>and eornis</i> | <i>Tetrastrum<br/>triangulare</i> | <i>Oocystis<br/>cf. lacustris</i> | TOTAL<br>P.U. (ml-1) |
|-----------------------|-------------------------------|---------------------------------|------------------------------------------------|----------------------------------------------------|-----------------------------------------------------|--------------------------------|------------------------------------|------------------------------|-----------------------------------|---------------------------------------------------|-----------------------------------|-----------------------------------|----------------------|
| <b>Enclosure</b>      |                               |                                 |                                                |                                                    |                                                     |                                |                                    |                              |                                   |                                                   |                                   |                                   |                      |
| P.U. (ml-1)(ml-1)     | 6.446                         | 16.335                          | 52.318                                         | 26.159                                             | 35.354                                              | 36.649                         | 6.993                              | 15.54                        | 77.959                            | 91.427                                            | 443.153                           | 131.296                           | 939.627              |
| S.D.                  | 2.534                         | 6.056                           | 15.007                                         | 4.24                                               | 6.955                                               | 5.881                          | 2.976                              | 4.456                        | 5.392                             | 20.02                                             | 46.891                            | 17.014                            | 60.191               |
| Biomass (mg.m-3)      | 170.027                       | 30.837                          | 57.606                                         | 10.231                                             | 20.278                                              | 22.079                         | 0.991                              | 6.812                        | 750.811                           | 6.457                                             | 5.726                             | 46.517                            | 1128.013             |
| <b>Enclosure (1X)</b> |                               |                                 |                                                |                                                    |                                                     |                                |                                    |                              |                                   |                                                   |                                   |                                   |                      |
| P.U. (ml-1)           | 0.236                         | 0.371                           | 1.425                                          | 25.771                                             | 5.439                                               | 11.008                         | 23.569                             | 3.238                        | 26.418                            | 19.943                                            | 115.92                            | 35.287                            | 268.624              |
| S.D.                  | 0.231                         | 0.418                           | 1.295                                          | 5.957                                              | 0.518                                               | 1.149                          | 6.194                              | 1.224                        | 3.663                             | 2.448                                             | 17.19                             | 5.617                             | 35.461               |
| Biomass (mg.m-3)      | 6.231                         | 0.701                           | 1.568                                          | 10.079                                             | 3.12                                                | 6.632                          | 3.34                               | 1.419                        | 254.428                           | 1.409                                             | 1.498                             | 12.405                            | 302.83               |
| <b>Enclosure (2X)</b> |                               |                                 |                                                |                                                    |                                                     |                                |                                    |                              |                                   |                                                   |                                   |                                   |                      |
| P.U. (ml-1)           | 0.054                         | 0.068                           | 1.036                                          | 19.814                                             | 4.662                                               | 6.346                          | 6.216                              | 2.72                         | 26.936                            | 10.749                                            | 51.923                            | 16.695                            | 147.196              |
| S.D.                  | 0.068                         | 0.078                           | 0.598                                          | 5.649                                              | 0.946                                               | 1.711                          | 1.938                              | 1.658                        | 2.9                               | 2.001                                             | 14.952                            | 2.367                             | 12.12                |
| Biomass (mg.m-3)      | 0.89                          | 0.127                           | 1.141                                          | 7.749                                              | 2.674                                               | 3.823                          | 0.881                              | 1.192                        | 259.417                           | 0.759                                             | 0.671                             | 5.869                             | 285.193              |
| <b>Enclosure (4X)</b> |                               |                                 |                                                |                                                    |                                                     |                                |                                    |                              |                                   |                                                   |                                   |                                   |                      |
| P.U. (ml-1)           | 0.101                         | 0                               | 1.425                                          | 10.36                                              | 0.648                                               | 7.382                          | 1.295                              | 5.439                        | 30.303                            | 17.871                                            | 117.128                           | 28.648                            | 220.598              |
| S.D.                  | 0.129                         | 0                               | 0.259                                          | 3.807                                              | 0.981                                               | 2.88                           | 1.233                              | 1.769                        | 9.649                             | 2.853                                             | 19.47                             | 11.013                            | 22.519               |
| Biomass (mg.m-3)      | 2.671                         | 0                               | 1.568                                          | 4.052                                              | 0.371                                               | 4.447                          | 0.184                              | 2.384                        | 291.844                           | 1.262                                             | 1.513                             | 10.071                            | 320.368              |
| <b>Lake</b>           |                               |                                 |                                                |                                                    |                                                     |                                |                                    |                              |                                   |                                                   |                                   |                                   |                      |
| P.U. (ml-1)           | 0.878                         | 0.878                           | 19.943                                         | 22.533                                             | 8.547                                               | 19.684                         | 20.979                             | 3.367                        | 26.677                            | 38.591                                            | 306.705                           | 133.182                           | 601.963              |
| S.D.                  | 0.286                         | 0.286                           | 6.959                                          | 0.366                                              | 1.099                                               | 0.733                          | 4.762                              | 0.366                        | 1.831                             | 2.564                                             | 78.552                            | 18.294                            | 97.213               |
| Biomass (mg.m-3)      | 23.145                        | 1.657                           | 21.959                                         | 8.813                                              | 4.902                                               | 11.859                         | 2.973                              | 1.476                        | 256.922                           | 2.726                                             | 3.963                             | 46.82                             | 387.214              |



# Appendix IV : Experiment 4 Summer Lake Rotoroa 5/2/91 - 15/2/91

| Day 0 (5/2/91)        | <i>Peridinium<br/>cinctum</i> | <i>Cryptomonas<br/>ovata</i> | <i>Pediastrum<br/>tetras</i> | <i>Cosmarium<br/>perforatum</i> | <i>Stauronotus<br/>unicornis var.<br/>gracilis</i> | <i>Coelastrum<br/>reticulatum</i> | <i>Elakatothrix<br/>gelatinosa</i> | <i>Tetrastrum<br/>triangulare</i> | <i>Scenedesmus<br/>quadricauda<br/>and eornis</i> | <i>Oocystis<br/>cf. lacustris</i> | <i>Cyclotella<br/>stelligera +<br/>meneghiniana</i> | TOTAL<br>P.U. (ml-1) |
|-----------------------|-------------------------------|------------------------------|------------------------------|---------------------------------|----------------------------------------------------|-----------------------------------|------------------------------------|-----------------------------------|---------------------------------------------------|-----------------------------------|-----------------------------------------------------|----------------------|
| <b>Enclosure</b>      |                               |                              |                              |                                 |                                                    |                                   |                                    |                                   |                                                   |                                   |                                                     |                      |
| P.U. (ml-1)           | 13.211                        | 60.146                       | 22.296                       | 172.179                         | 258.455                                            | 465.46                            | 61.702                             | 653.688                           | 189.485                                           | 262.888                           | 604.734                                             | 2764.242             |
| S.D.                  | 4.112                         | 13.007                       | 4.973                        | 24.614                          | 82.056                                             | 33.932                            | 4.599                              | 129.071                           | 29.852                                            | 16.798                            | 28.992                                              | 177.56               |
| Biomass (mg.m-3)      | 348.461                       | 66.226                       | 9.774                        | 103.731                         | 148.247                                            | 2505.944                          | 8.743                              | 8.446                             | 13.383                                            | 117.645                           | 290.708                                             | 3621.307             |
| <b>Enclosure (1X)</b> |                               |                              |                              |                                 |                                                    |                                   |                                    |                                   |                                                   |                                   |                                                     |                      |
| P.U. (ml-1)           | 19.444                        | 83.738                       | 19.444                       | 168.775                         | 241.737                                            | 498.045                           | 48.998                             | 627.965                           | 173.102                                           | 262.119                           | 565.169                                             | 2708.535             |
| S.D.                  | 6.785                         | 28.227                       | 2.856                        | 6.519                           | 12.923                                             | 156.733                           | 4.265                              | 43.919                            | 29.835                                            | 8.658                             | 80.637                                              | 199.68               |
| Biomass (mg.m-3)      | 512.863                       | 92.202                       | 8.524                        | 101.68                          | 138.658                                            | 2681.373                          | 6.943                              | 8.113                             | 12.226                                            | 117.301                           | 271.688                                             | 3951.571             |
| <b>Enclosure (2X)</b> |                               |                              |                              |                                 |                                                    |                                   |                                    |                                   |                                                   |                                   |                                                     |                      |
| P.U. (ml-1)           | 27.002                        | 98.256                       | 18.407                       | 158.035                         | 246.573                                            | 454.472                           | 58.331                             | 630.38                            | 174.713                                           | 309.832                           | 562.753                                             | 2738.754             |
| S.D.                  | 7.028                         | 6.524                        | 5.95                         | 13.083                          | 66.664                                             | 91.935                            | 10.314                             | 29.908                            | 49.665                                            | 33.509                            | 80.589                                              | 219.82               |
| Biomass (mg.m-3)      | 712.2                         | 108.187                      | 8.069                        | 95.21                           | 141.432                                            | 2446.788                          | 8.266                              | 8.145                             | 12.34                                             | 138.653                           | 270.527                                             | 3949.815             |
| <b>Enclosure (4X)</b> |                               |                              |                              |                                 |                                                    |                                   |                                    |                                   |                                                   |                                   |                                                     |                      |
| P.U. (ml-1)           | 28.23                         | 111.218                      | 18.925                       | 159.656                         | 270.465                                            | 486.156                           | 59.109                             | 625.55                            | 148.336                                           | 259.13                            | 591.736                                             | 2758.511             |
| S.D.                  | 3.688                         | 27.35                        | 4.743                        | 8.862                           | 17.482                                             | 96.874                            | 5.805                              | 33.814                            | 4.731                                             | 27.074                            | 87.262                                              | 31.386               |
| Biomass (mg.m-3)      | 744.583                       | 122.46                       | 8.296                        | 96.186                          | 155.136                                            | 2617.368                          | 8.376                              | 8.082                             | 10.477                                            | 115.963                           | 284.459                                             | 4171.387             |
| <b>Lake</b>           |                               |                              |                              |                                 |                                                    |                                   |                                    |                                   |                                                   |                                   |                                                     |                      |
| P.U. (ml-1)           | 31.715                        | 83.479                       | 14.518                       | 174.68                          | 224.456                                            | 434.592                           | 50.813                             | 565.169                           | 165.735                                           | 261.629                           | 560.338                                             | 2567.121             |
| S.D.                  | 6.909                         | 38.863                       | 0                            | 32.352                          | 18.181                                             | 125.854                           | 1.467                              | 20.494                            | 42.956                                            | 73.34                             | 13.663                                              | 155.634              |
| Biomass (mg.m-3)      | 836.503                       | 91.917                       | 6.364                        | 105.237                         | 128.746                                            | 2339.756                          | 7.2                                | 7.302                             | 11.706                                            | 117.081                           | 269.366                                             | 3921.179             |

P.U. (ml-1) and Biomass (mg.m-3) are mean values where n = 4

# Appendix IV : Experiment 4 Summer Lake Rotoroa 5/2/91 - 15/2/91

| Day 3 (8/2/91)        | <i>Peridinium<br/>cinctum</i> | <i>Cryptomonas<br/>ovata</i> | <i>Pediastrum<br/>tetras</i> | <i>Cosmarium<br/>perfissum</i> | <i>Staurodesmus<br/>unicornis var.<br/>gracilis</i> | <i>Coelastrum<br/>reticulatum</i> | <i>Plakatothrix<br/>gelatinosa</i> | <i>Tetrastrum<br/>triangulare</i> | <i>Scenedesmus<br/>quadricauda<br/>and ecornis</i> | <i>Oocystis<br/>cf. lacustris</i> | <i>Cyclotella<br/>stelligera +<br/>meneghiniana</i> | TOTAL<br>P.U. (ml-1) |
|-----------------------|-------------------------------|------------------------------|------------------------------|--------------------------------|-----------------------------------------------------|-----------------------------------|------------------------------------|-----------------------------------|----------------------------------------------------|-----------------------------------|-----------------------------------------------------|----------------------|
| <b>Exclosure</b>      |                               |                              |                              |                                |                                                     |                                   |                                    |                                   |                                                    |                                   |                                                     |                      |
| P.U. (ml-1)           | 18.861                        | 106.293                      | 26.962                       | 301.741                        | 336.908                                             | 766.833                           | 60.146                             | 1131.178                          | 272.015                                            | 258.269                           | 881.566                                             | 4160.771             |
| S.D.                  | 13.372                        | 27.986                       | 4.061                        | 56.553                         | 65.787                                              | 154.781                           | 14.908                             | 190.837                           | 34.43                                              | 19.531                            | 160.573                                             | 346.276              |
| Biomass (mg.m-3)      | 497.485                       | 117.037                      | 11.82                        | 181.787                        | 193.247                                             | 4128.477                          | 8.523                              | 14.615                            | 19.212                                             | 115.578                           | 423.787                                             | 5711.566             |
| <b>Enclosure (1X)</b> |                               |                              |                              |                                |                                                     |                                   |                                    |                                   |                                                    |                                   |                                                     |                      |
| P.U. (ml-1)           | 28.328                        | 59.368                       | 25.925                       | 333.395                        | 298.358                                             | 434.304                           | 60.665                             | 758.389                           | 184.319                                            | 230.349                           | 562.753                                             | 2976.152             |
| S.D.                  | 1.093                         | 4.005                        | 2.24                         | 46.275                         | 15.798                                              | 43.413                            | 10.036                             | 30.037                            | 42.976                                             | 37.335                            | 66.174                                              | 79.454               |
| Biomass (mg.m-3)      | 747.187                       | 65.369                       | 11.365                       | 200.857                        | 171.135                                             | 2338.206                          | 8.596                              | 9.798                             | 13.018                                             | 103.083                           | 270.527                                             | 3939.142             |
| <b>Enclosure (2X)</b> |                               |                              |                              |                                |                                                     |                                   |                                    |                                   |                                                    |                                   |                                                     |                      |
| P.U. (ml-1)           | 27.746                        | 36.814                       | 20.481                       | 268.055                        | 271.627                                             | 612.164                           | 53.924                             | 654.533                           | 196.283                                            | 229.954                           | 543.431                                             | 2915.11              |
| S.D.                  | 15.392                        | 8.143                        | 4.348                        | 70.032                         | 24.046                                              | 65.937                            | 16.807                             | 160.185                           | 82.285                                             | 11.032                            | 70.719                                              | 326.75               |
| Biomass (mg.m-3)      | 731.836                       | 40.535                       | 8.978                        | 161.492                        | 155.803                                             | 3295.766                          | 7.641                              | 8.457                             | 13.87                                              | 102.907                           | 261.238                                             | 4788.523             |
| <b>Enclosure (4X)</b> |                               |                              |                              |                                |                                                     |                                   |                                    |                                   |                                                    |                                   |                                                     |                      |
| P.U. (ml-1)           | 35.232                        | 22.814                       | 17.629                       | 226.965                        | 253.799                                             | 536.967                           | 59.887                             | 490.296                           | 162.555                                            | 218.967                           | 316.398                                             | 2341.508             |
| S.D.                  | 25.657                        | 4.148                        | 3.053                        | 46.629                         | 27.494                                              | 84.41                             | 7.544                              | 125.81                            | 40.784                                             | 22.514                            | 93.791                                              | 322.218              |
| Biomass (mg.m-3)      | 929.288                       | 25.12                        | 7.728                        | 136.737                        | 145.577                                             | 2890.92                           | 8.486                              | 6.335                             | 11.481                                             | 97.99                             | 152.099                                             | 4411.76              |
| <b>Lake</b>           |                               |                              |                              |                                |                                                     |                                   |                                    |                                   |                                                    |                                   |                                                     |                      |
| P.U. (ml-1)           | 48.4                          | 141.46                       | 16.074                       | 283.128                        | 287.02                                              | 523.824                           | 61.702                             | 941.948                           | 181.099                                            | 259.188                           | 598.982                                             | 3342.823             |
| S.D.                  | 2.404                         | 9.702                        | 0.733                        | 6.89                           | 56.88                                               | 21.655                            | 3.666                              | 6.831                             | 4.168                                              | 0                                 | 27.325                                              | 43.739               |
| Biomass (mg.m-3)      | 1276.601                      | 155.759                      | 7.046                        | 170.573                        | 164.632                                             | 2820.161                          | 8.743                              | 12.17                             | 12.791                                             | 115.989                           | 287.943                                             | 5032.408             |

# Appendix IV : Experiment 4 Summer Lake Rotoroa 5/2/91 - 15/2/91

| Day 6 (11/2/91)       | <i>Peridinium<br/>cinctum</i> | <i>Cryptomonas<br/>ovata</i> | <i>Pediastrum<br/>tetras</i> | <i>Cosmarium<br/>perfisum</i> | <i>Staurodesmus<br/>unicornis var.<br/>gracilis</i> | <i>Coelastrum<br/>reticulatum</i> | <i>Elakatothrix<br/>gelatinosa</i> | <i>Tetrastrum<br/>triangulare</i> | <i>Scenedesmus<br/>quadricauda<br/>and ecornis</i> | <i>Oocystis<br/>cf. lacustris</i> | <i>Cyclotella<br/>stelligera +<br/>meneghiniana</i> | TOTAL<br>P.U. (ml-1) |
|-----------------------|-------------------------------|------------------------------|------------------------------|-------------------------------|-----------------------------------------------------|-----------------------------------|------------------------------------|-----------------------------------|----------------------------------------------------|-----------------------------------|-----------------------------------------------------|----------------------|
| <b>Enclosure</b>      |                               |                              |                              |                               |                                                     |                                   |                                    |                                   |                                                    |                                   |                                                     |                      |
| P.U. (ml-1)           | 22.832                        | 98.256                       | 26.184                       | 348.843                       | 417.722                                             | 941.904                           | 33.443                             | 1238.864                          | 327.555                                            | 218.57                            | 953.746                                             | 4627.921             |
| S.D.                  | 8.965                         | 11.084                       | 2.45                         | 50.31                         | 60.096                                              | 215.327                           | 3.727                              | 247.596                           | 52.18                                              | 26.942                            | 136.647                                             | 332.95               |
| Biomass (mg.m-3)      | 602.225                       | 108.187                      | 11.479                       | 210.164                       | 239.601                                             | 5071.023                          | 4.739                              | 16.006                            | 23.135                                             | 97.812                            | 458.485                                             | 6842.856             |
| <b>Enclosure (1X)</b> |                               |                              |                              |                               |                                                     |                                   |                                    |                                   |                                                    |                                   |                                                     |                      |
| P.U. (ml-1)           | 24.187                        | 31.888                       | 19.185                       | 346.393                       | 315.757                                             | 661.856                           | 55.739                             | 528.594                           | 217.392                                            | 225.927                           | 486.644                                             | 2913.562             |
| S.D.                  | 3.835                         | 6.301                        | 2.61                         | 2.416                         | 46.909                                              | 35.673                            | 1.771                              | 89.218                            | 20.19                                              | 42.758                            | 71.6                                                | 212.582              |
| Biomass (mg.m-3)      | 637.951                       | 35.111                       | 8.41                         | 208.688                       | 181.115                                             | 3563.302                          | 7.898                              | 6.829                             | 15.354                                             | 101.105                           | 233.94                                              | 4999.703             |
| <b>Enclosure (2X)</b> |                               |                              |                              |                               |                                                     |                                   |                                    |                                   |                                                    |                                   |                                                     |                      |
| P.U. (ml-1)           | 33.954                        | 38.369                       | 15.296                       | 335.298                       | 332.944                                             | 661.075                           | 69.738                             | 367.118                           | 226.238                                            | 207.492                           | 371.949                                             | 2659.469             |
| S.D.                  | 14.271                        | 11.516                       | 3.097                        | 35.972                        | 30.715                                              | 114.275                           | 6.95                               | 84.591                            | 29.998                                             | 38.702                            | 82.166                                              | 124.754              |
| Biomass (mg.m-3)      | 895.579                       | 42.247                       | 6.705                        | 202.003                       | 190.973                                             | 3559.096                          | 9.882                              | 4.743                             | 15.979                                             | 92.855                            | 178.803                                             | 5198.866             |
| <b>Enclosure (4X)</b> |                               |                              |                              |                               |                                                     |                                   |                                    |                                   |                                                    |                                   |                                                     |                      |
| P.U. (ml-1)           | 26.956                        | 25.925                       | 15.555                       | 250.029                       | 274.699                                             | 491.742                           | 81.923                             | 181.144                           | 133.818                                            | 168.012                           | 287.415                                             | 1937.216             |
| S.D.                  | 5.093                         | 7.989                        | 2.54                         | 37.677                        | 20.974                                              | 140.039                           | 14.932                             | 48.865                            | 23.904                                             | 21.655                            | 32.881                                              | 212.868              |
| Biomass (mg.m-3)      | 710.999                       | 28.545                       | 6.819                        | 150.632                       | 157.564                                             | 2647.439                          | 11.608                             | 2.34                              | 9.452                                              | 75.187                            | 138.166                                             | 3938.753             |
| <b>Lake</b>           |                               |                              |                              |                               |                                                     |                                   |                                    |                                   |                                                    |                                   |                                                     |                      |
| P.U. (ml-1)           | 55.791                        | 183.305                      | 14                           | 371.896                       | 253.45                                              | 527.049                           | 43.036                             | 589.321                           | 240.949                                            | 237.038                           | 391.271                                             | 2907.104             |
| S.D.                  | 0.861                         | 22.776                       | 2.2                          | 38.84                         | 17.466                                              | 134.42                            | 19.798                             | 40.988                            | 0.501                                              | 40.014                            | 20.494                                              | 257.036              |
| Biomass (mg.m-3)      | 1471.546                      | 201.833                      | 6.137                        | 224.052                       | 145.376                                             | 2837.526                          | 6.098                              | 7.614                             | 17.018                                             | 106.077                           | 188.092                                             | 5211.371             |

# Appendix IV : Experiment 4 Summer Lake Rotoroa 5/2/91 - 15/2/91

| Day 10 (15/2/91)      | <i>Peridinium<br/>cinctum</i> | <i>Cryptomonas<br/>ovata</i> | <i>Pediastrum<br/>tetras</i> | <i>Cosmarium<br/>perfisum</i> | <i>Staurodesmus<br/>unicornis var.<br/>gracilis</i> | <i>Coelastrum<br/>reticulatum</i> | <i>Elakatothrix<br/>gelatinosa</i> | <i>Tetrastrum<br/>triangulare</i> | <i>Scenedesmus<br/>quadricauda<br/>and ecornis</i> | <i>Oocystis<br/>cf. lacustris</i> | <i>Cyclotella<br/>stelligera +<br/>meneghiniana</i> | TOTAL<br>P.U. (ml-1) |
|-----------------------|-------------------------------|------------------------------|------------------------------|-------------------------------|-----------------------------------------------------|-----------------------------------|------------------------------------|-----------------------------------|----------------------------------------------------|-----------------------------------|-----------------------------------------------------|----------------------|
| <b>Exclosure</b>      |                               |                              |                              |                               |                                                     |                                   |                                    |                                   |                                                    |                                   |                                                     |                      |
| P.U. (ml-1)           | 16.26                         | 26.184                       | 23.333                       | 317.936                       | 479.36                                              | 976.549                           | 12.963                             | 801.863                           | 273.308                                            | 177.168                           | 1060.611                                            | 4165.534             |
| S.D.                  | 6.867                         | 9.29                         | 4.191                        | 104.819                       | 104.44                                              | 198.462                           | 3.834                              | 142.206                           | 45.436                                             | 27.497                            | 210.88                                              | 356.16               |
| Biomass (mg.m-3)      | 428.875                       | 28.831                       | 10.229                       | 191.544                       | 274.956                                             | 5257.543                          | 1.837                              | 10.36                             | 19.304                                             | 79.284                            | 509.857                                             | 6812.619             |
| <b>Enclosure (1X)</b> |                               |                              |                              |                               |                                                     |                                   |                                    |                                   |                                                    |                                   |                                                     |                      |
| P.U. (ml-1)           | 29.356                        | 54.443                       | 16.592                       | 316.31                        | 356.029                                             | 643.316                           | 23.851                             | 169.068                           | 187.252                                            | 174.545                           | 359.872                                             | 2330.633             |
| S.D.                  | 5.585                         | 23.503                       | 3.88                         | 39.937                        | 37.106                                              | 106.574                           | 4.234                              | 90.112                            | 16.898                                             | 28.148                            | 127.04                                              | 189.977              |
| Biomass (mg.m-3)      | 774.282                       | 59.946                       | 7.274                        | 190.564                       | 204.214                                             | 3463.486                          | 3.38                               | 2.184                             | 13.226                                             | 78.111                            | 172.998                                             | 4969.664             |
| <b>Enclosure (2X)</b> |                               |                              |                              |                               |                                                     |                                   |                                    |                                   |                                                    |                                   |                                                     |                      |
| P.U. (ml-1)           | 57.442                        | 55.22                        | 16.592                       | 312.637                       | 372.209                                             | 654.048                           | 40.443                             | 125.593                           | 195.167                                            | 131.892                           | 214.957                                             | 2176.201             |
| S.D.                  | 18.755                        | 12.739                       | 1.893                        | 105.76                        | 43.507                                              | 67.122                            | 8.758                              | 45.314                            | 32.89                                              | 18.295                            | 63.78                                               | 57.877               |
| Biomass (mg.m-3)      | 1515.093                      | 60.802                       | 7.274                        | 188.351                       | 213.496                                             | 3521.264                          | 5.731                              | 1.623                             | 13.785                                             | 59.023                            | 103.334                                             | 5689.774             |
| <b>Enclosure (4X)</b> |                               |                              |                              |                               |                                                     |                                   |                                    |                                   |                                                    |                                   |                                                     |                      |
| P.U. (ml-1)           | 35.563                        | 29.295                       | 19.185                       | 281.311                       | 327.151                                             | 639.491                           | 64.294                             | 33.814                            | 161.518                                            | 190.915                           | 183.559                                             | 1966.094             |
| S.D.                  | 8.851                         | 9.212                        | 3.542                        | 28.74                         | 60.457                                              | 121.686                           | 12.53                              | 5.578                             | 19.549                                             | 30.967                            | 61.609                                              | 208.287              |
| Biomass (mg.m-3)      | 938.018                       | 32.256                       | 8.41                         | 169.479                       | 187.651                                             | 3442.889                          | 9.11                               | 0.437                             | 11.408                                             | 85.436                            | 88.24                                               | 4973.335             |
| <b>Lake</b>           |                               |                              |                              |                               |                                                     |                                   |                                    |                                   |                                                    |                                   |                                                     |                      |
| P.U. (ml-1)           | 26.142                        | 110.428                      | 8.296                        | 583.964                       | 206.208                                             | 396.538                           | 32.666                             | 338.135                           | 256.123                                            | 226.591                           | 352.627                                             | 2537.725             |
| S.D.                  | 4.01                          | 27.113                       | 0                            | 99.725                        | 37.471                                              | 50.152                            | 3.666                              | 13.663                            | 32.69                                              | 33.23                             | 88.808                                              | 161.768              |
| Biomass (mg.m-3)      | 689.773                       | 121.59                       | 3.637                        | 351.815                       | 118.279                                             | 2134.879                          | 4.629                              | 4.369                             | 18.09                                              | 101.402                           | 169.515                                             | 3717.976             |

# Appendix IV : Experiment 5 Autumn Lake Pupuke 21/5/91 - 31/5/91

| Day 0 (21/5/91)       | <i>Peridinium<br/>cinctum</i> | <i>Staurastrum<br/>johnsonii<br/>var. altuis</i> | <i>Fragilaria<br/>crotonensis</i> | <i>Staurastrum<br/>leptocladum<br/>var. insigne</i> | <i>Staurastrum<br/>pinque</i> | <i>Cosmarium<br/>contractum</i> | <i>Achnanthes<br/>sp.</i> | <i>Oocystis<br/>cf.<br/>lacustris</i> | <i>Closterium<br/>acutum var.<br/>variabile</i> | <i>Scenedesmus<br/>bijuga var.<br/>alternans</i> | <i>Cryptomonas<br/>ovata and<br/>marssonii</i> | <i>Trachelomonas<br/>volvicina</i> | TOTAL<br>P.U. (ml-1) |
|-----------------------|-------------------------------|--------------------------------------------------|-----------------------------------|-----------------------------------------------------|-------------------------------|---------------------------------|---------------------------|---------------------------------------|-------------------------------------------------|--------------------------------------------------|------------------------------------------------|------------------------------------|----------------------|
| <b>Exclosure</b>      |                               |                                                  |                                   |                                                     |                               |                                 |                           |                                       |                                                 |                                                  |                                                |                                    |                      |
| P.U. (ml-1)           | 18.235                        | 36.491                                           | 207.405                           | 89.773                                              | 17.702                        | 10.788                          | 26.142                    | 8.575                                 | 24.757                                          | 4.841                                            | 8.715                                          | 5.257                              | 458.68               |
| S.D.                  | 6.671                         | 8.333                                            | 47.719                            | 8.61                                                | 6.186                         | 3.511                           | 2.537                     | 1.392                                 | 3.166                                           | 2.274                                            | 2.943                                          | 3.398                              | 52.089               |
| Biomass (mg.m-3)      | 309.407                       | 146.099                                          | 1327.194                          | 52.855                                              | 16.348                        | 53.904                          | 4.599                     | 3.66                                  | 3.687                                           | 1.222                                            | 14.169                                         | 25.627                             | 1958.771             |
| <b>Enclosure (1X)</b> |                               |                                                  |                                   |                                                     |                               |                                 |                           |                                       |                                                 |                                                  |                                                |                                    |                      |
| P.U. (ml-1)           | 17.502                        | 34.533                                           | 306.229                           | 76.44                                               | 16.789                        | 8.714                           | 27.458                    | 10.115                                | 26.075                                          | 3.388                                            | 5.827                                          | 5.436                              | 538.498              |
| S.D.                  | 6.058                         | 10.136                                           | 219.909                           | 8.697                                               | 2.396                         | 0.942                           | 6.146                     | 5.381                                 | 6.006                                           | 2.193                                            | 2.251                                          | 2.953                              | 244.888              |
| Biomass (mg.m-3)      | 296.973                       | 138.258                                          | 1957.57                           | 45.005                                              | 15.505                        | 43.542                          | 4.83                      | 4.317                                 | 3.884                                           | 0.855                                            | 9.474                                          | 26.471                             | 2548.683             |
| <b>Enclosure (2X)</b> |                               |                                                  |                                   |                                                     |                               |                                 |                           |                                       |                                                 |                                                  |                                                |                                    |                      |
| P.U. (ml-1)           | 11.34                         | 25.984                                           | 145.642                           | 65.656                                              | 17.558                        | 8.436                           | 21.982                    | 8.986                                 | 26.406                                          | 3.18                                             | 4.977                                          | 2.627                              | 342.773              |
| S.D.                  | 1.057                         | 3.308                                            | 27.306                            | 12.326                                              | 2.135                         | 2.233                           | 1.047                     | 1.047                                 | 3.14                                            | 1.588                                            | 1.564                                          | 1.14                               | 42.452               |
| Biomass (mg.m-3)      | 192.414                       | 104.033                                          | 931.969                           | 38.655                                              | 16.215                        | 42.153                          | 3.867                     | 3.835                                 | 3.933                                           | 0.803                                            | 8.092                                          | 12.805                             | 1358.774             |
| <b>Enclosure (4X)</b> |                               |                                                  |                                   |                                                     |                               |                                 |                           |                                       |                                                 |                                                  |                                                |                                    |                      |
| P.U. (ml-1)           | 8.269                         | 30.639                                           | 125.929                           | 81.946                                              | 15.622                        | 7.051                           | 25.991                    | 8.848                                 | 29.724                                          | 8.298                                            | 13.272                                         | 2.903                              | 358.491              |
| S.D.                  | 2.147                         | 4.457                                            | 20.51                             | 13.861                                              | 2.038                         | 4.123                           | 5.148                     | 3.497                                 | 11.812                                          | 4.189                                            | 7.378                                          | 1.047                              | 18.947               |
| Biomass (mg.m-3)      | 140.302                       | 122.67                                           | 805.822                           | 48.247                                              | 14.428                        | 35.232                          | 4.572                     | 3.776                                 | 4.427                                           | 2.094                                            | 21.579                                         | 14.153                             | 1217.301             |
| <b>Lake</b>           |                               |                                                  |                                   |                                                     |                               |                                 |                           |                                       |                                                 |                                                  |                                                |                                    |                      |
| P.U. (ml-1)           | 7.965                         | 24.58                                            | 102.838                           | 63.042                                              | 15.208                        | 4.977                           | 21.291                    | 8.019                                 | 25.991                                          | 1.659                                            | 9.678                                          | 1.383                              | 286.629              |
| S.D.                  | 1.527                         | 2.376                                            | 8.115                             | 1.564                                               | 0.391                         | 0.782                           | 4.301                     | 1.173                                 | 0.782                                           | 0.782                                            | 3.519                                          | 0.391                              | 7.008                |
| Biomass (mg.m-3)      | 135.148                       | 98.411                                           | 658.064                           | 37.117                                              | 14.045                        | 24.87                           | 3.745                     | 3.422                                 | 3.871                                           | 0.419                                            | 15.734                                         | 6.74                               | 1001.585             |

P.U. (ml-1) and Biomass (mg.m-3) are mean values where n = 4

# Appendix IV : Experiment 5 Autumn Lake Pupuke 21/5/91 - 31/5/91

| Day 3 (24/5/91)       | <i>Peridinium<br/>cinctum</i> | <i>Staurastrum<br/>johnsonii<br/>var. altuis</i> | <i>Fragilaria<br/>crotonensis</i> | <i>Staurastrum<br/>leptocladum<br/>var. insigne</i> | <i>Staurastrum<br/>pinque</i> | <i>Cosmarium<br/>contractum</i> | <i>Achnanthes<br/>sp.</i> | <i>Oocystis<br/>cf.<br/>lacustris</i> | <i>Closterium<br/>acutum var.<br/>variabile</i> | <i>Scenedesmus<br/>bijuga var.<br/>alternans</i> | <i>Cryptomonas<br/>ovata and<br/>marssonii</i> | <i>Trachelomonas<br/>volvicina</i> | TOTAL<br>P.U. (ml-1) |
|-----------------------|-------------------------------|--------------------------------------------------|-----------------------------------|-----------------------------------------------------|-------------------------------|---------------------------------|---------------------------|---------------------------------------|-------------------------------------------------|--------------------------------------------------|------------------------------------------------|------------------------------------|----------------------|
| <b>Exclosure</b>      |                               |                                                  |                                   |                                                     |                               |                                 |                           |                                       |                                                 |                                                  |                                                |                                    |                      |
| P.U. (ml-1)           | 24.557                        | 53.715                                           | 364.018                           | 125.708                                             | 23.088                        | 12.857                          | 19.355                    | 14.655                                | 29.309                                          | 18.94                                            | 5.807                                          | 2.489                              | 694.496              |
| S.D.                  | 1.909                         | 7.033                                            | 52.586                            | 13.097                                              | 3.997                         | 3.623                           | 4.714                     | 5.896                                 | 0.782                                           | 5.116                                            | 0.319                                          | 0.319                              | 59.647               |
| Biomass (mg.m-3)      | 416.668                       | 215.058                                          | 2329.364                          | 74.012                                              | 21.322                        | 64.246                          | 3.405                     | 6.254                                 | 4.365                                           | 4.78                                             | 9.441                                          | 12.131                             | 3161.047             |
| <b>Enclosure (1X)</b> |                               |                                                  |                                   |                                                     |                               |                                 |                           |                                       |                                                 |                                                  |                                                |                                    |                      |
| P.U. (ml-1)           | 16.714                        | 44.878                                           | 249.412                           | 100.421                                             | 22.12                         | 11.337                          | 17.696                    | 13.297                                | 34.459                                          | 23.387                                           | 5.53                                           | 2.074                              | 541.324              |
| S.D.                  | 3.216                         | 13.834                                           | 79.9                              | 8.731                                               | 5.548                         | 3.626                           | 3.095                     | 3.713                                 | 11.682                                          | 2.31                                             | 5.904                                          | 0.944                              | 95.088               |
| Biomass (mg.m-3)      | 283.594                       | 179.677                                          | 1595.999                          | 59.124                                              | 20.429                        | 56.647                          | 3.113                     | 5.675                                 | 5.132                                           | 5.902                                            | 8.991                                          | 10.109                             | 2234.393             |
| <b>Enclosure (2X)</b> |                               |                                                  |                                   |                                                     |                               |                                 |                           |                                       |                                                 |                                                  |                                                |                                    |                      |
| P.U. (ml-1)           | 20.594                        | 59.522                                           | 375.808                           | 114.835                                             | 23.226                        | 13.687                          | 16.728                    | 13.963                                | 21.567                                          | 21.982                                           | 8.848                                          | 4.286                              | 695.045              |
| S.D.                  | 6.98                          | 18.242                                           | 141.038                           | 20.194                                              | 2.258                         | 2.136                           | 1.936                     | 1.827                                 | 5.323                                           | 1.827                                            | 4.039                                          | 2.869                              | 172.038              |
| Biomass (mg.m-3)      | 349.438                       | 238.307                                          | 2404.807                          | 67.61                                               | 21.45                         | 68.391                          | 2.943                     | 5.959                                 | 3.212                                           | 5.548                                            | 14.386                                         | 20.893                             | 3202.944             |
| <b>Enclosure (4X)</b> |                               |                                                  |                                   |                                                     |                               |                                 |                           |                                       |                                                 |                                                  |                                                |                                    |                      |
| P.U. (ml-1)           | 17.158                        | 48.574                                           | 266.594                           | 117.138                                             | 17.558                        | 11.475                          | 19.217                    | 15.899                                | 27.235                                          | 27.374                                           | 8.295                                          | 1.936                              | 578.451              |
| S.D.                  | 5.803                         | 16.824                                           | 101.127                           | 22.444                                              | 3.623                         | 4.048                           | 6.407                     | 0.944                                 | 6.471                                           | 5.861                                            | 4.905                                          | 0.553                              | 115.171              |
| Biomass (mg.m-3)      | 291.128                       | 194.475                                          | 1705.947                          | 68.966                                              | 16.215                        | 57.338                          | 3.38                      | 6.785                                 | 4.056                                           | 6.909                                            | 13.487                                         | 9.435                              | 2378.122             |
| <b>Lake</b>           |                               |                                                  |                                   |                                                     |                               |                                 |                           |                                       |                                                 |                                                  |                                                |                                    |                      |
| P.U. (ml-1)           | 9.585                         | 5.535                                            | 107.45                            | 78                                                  | 17.973                        | 6.083                           | 15.208                    | 5.254                                 | 27.65                                           | 3.871                                            | 15.761                                         | 1.659                              | 294.027              |
| S.D.                  | 5.155                         | 0.191                                            | 1.485                             | 1.556                                               | 1.173                         | 0.782                           | 2.737                     | 0.391                                 | 0.782                                           | 0                                                | 0.391                                          | 1.564                              | 0.823                |
| Biomass (mg.m-3)      | 162.636                       | 22.16                                            | 687.577                           | 45.923                                              | 16.598                        | 30.396                          | 2.675                     | 2.242                                 | 4.118                                           | 0.977                                            | 25.625                                         | 8.087                              | 1009.015             |

# Appendix IV : Experiment 5 Autumn Lake Pupuke 21/5/91 - 31/5/91

| Day 6 (27/5/91)       | <i>Peridinium<br/>cinctum</i> | <i>Staurastrum<br/>johnsonii<br/>var. altuis</i> | <i>Fragilaria<br/>crotonensis</i> | <i>Staurastrum<br/>leptocladum<br/>var. insigne</i> | <i>Staurastrum<br/>pinque</i> | <i>Cosmarium<br/>contractum</i> | <i>Achnanthes<br/>sp.</i> | <i>Oocystis<br/>cf.<br/>lacustris</i> | <i>Closterium<br/>acutum var.<br/>variabile</i> | <i>Scenedesmus<br/>bijuga var.<br/>alternans</i> | <i>Cryptomonas<br/>ovata and<br/>marssonii</i> | <i>Trachelomonas<br/>volvicina</i> | TOTAL<br>P.U. (ml-1) |
|-----------------------|-------------------------------|--------------------------------------------------|-----------------------------------|-----------------------------------------------------|-------------------------------|---------------------------------|---------------------------|---------------------------------------|-------------------------------------------------|--------------------------------------------------|------------------------------------------------|------------------------------------|----------------------|
| <b>Exclosure</b>      |                               |                                                  |                                   |                                                     |                               |                                 |                           |                                       |                                                 |                                                  |                                                |                                    |                      |
| P.U. (ml-1)           | 18.05                         | 55.678                                           | 285.385                           | 131.503                                             | 27.374                        | 26.129                          | 9.125                     | 23.779                                | 14.793                                          | 27.374                                           | 2.489                                          | 2.35                               | 624.028              |
| S.D.                  | 2.06                          | 3.415                                            | 17.329                            | 8.946                                               | 5.72                          | 1.226                           | 2.142                     | 2.747                                 | 1.14                                            | 2.765                                            | 1.316                                          | 0.529                              | 15.986               |
| Biomass (mg.m-3)      | 306.268                       | 222.918                                          | 1826.192                          | 77.424                                              | 25.281                        | 130.565                         | 1.605                     | 10.148                                | 2.203                                           | 6.909                                            | 4.046                                          | 11.457                             | 2625.015             |
| <b>Enclosure (1X)</b> |                               |                                                  |                                   |                                                     |                               |                                 |                           |                                       |                                                 |                                                  |                                                |                                    |                      |
| P.U. (ml-1)           | 18.155                        | 65.132                                           | 437.314                           | 123.752                                             | 26.406                        | 22.397                          | 6.36                      | 17.143                                | 24.747                                          | 28.894                                           | 3.18                                           | 2.074                              | 775.553              |
| S.D.                  | 7.595                         | 5.073                                            | 59.378                            | 56.926                                              | 12.085                        | 8.865                           | 0.958                     | 4.692                                 | 5.388                                           | 5.156                                            | 2.274                                          | 1.454                              | 100.014              |
| Biomass (mg.m-3)      | 308.049                       | 260.77                                           | 2798.39                           | 72.86                                               | 24.387                        | 111.913                         | 1.119                     | 7.316                                 | 3.686                                           | 7.292                                            | 5.17                                           | 10.109                             | 3611.061             |
| <b>Enclosure (2X)</b> |                               |                                                  |                                   |                                                     |                               |                                 |                           |                                       |                                                 |                                                  |                                                |                                    |                      |
| P.U. (ml-1)           | 25.43                         | 31.6                                             | 155.601                           | 82.528                                              | 21.844                        | 13.963                          | 4.839                     | 20.046                                | 26.682                                          | 31.521                                           | 5.254                                          | 2.765                              | 422.073              |
| S.D.                  | 11.568                        | 5.913                                            | 35.515                            | 10.651                                              | 5.138                         | 3.815                           | 1.77                      | 2.76                                  | 6.642                                           | 3.161                                            | 2.452                                          | 1.428                              | 68.162               |
| Biomass (mg.m-3)      | 431.494                       | 126.516                                          | 995.699                           | 48.589                                              | 20.173                        | 69.773                          | 0.851                     | 8.555                                 | 3.974                                           | 7.955                                            | 8.542                                          | 13.479                             | 1735.6               |
| <b>Enclosure (4X)</b> |                               |                                                  |                                   |                                                     |                               |                                 |                           |                                       |                                                 |                                                  |                                                |                                    |                      |
| P.U. (ml-1)           | 13.438                        | 22.439                                           | 139.149                           | 75.772                                              | 10.507                        | 11.06                           | 7.742                     | 23.364                                | 28.756                                          | 31.659                                           | 13.825                                         | 1.797                              | 379.508              |
| S.D.                  | 2.126                         | 6.56                                             | 47.216                            | 7.097                                               | 4.8                           | 2.258                           | 3.962                     | 13.306                                | 24.92                                           | 5.215                                            | 11.869                                         | 0.944                              | 37.85                |
| Biomass (mg.m-3)      | 228.008                       | 89.837                                           | 890.42                            | 44.611                                              | 9.704                         | 55.266                          | 1.362                     | 9.971                                 | 4.283                                           | 7.99                                             | 22.478                                         | 8.761                              | 1372.691             |
| <b>Lake</b>           |                               |                                                  |                                   |                                                     |                               |                                 |                           |                                       |                                                 |                                                  |                                                |                                    |                      |
| P.U. (ml-1)           | 15.908                        | 12.33                                            | 90.85                             | 63.639                                              | 15.761                        | 5.53                            | 12.996                    | 6.36                                  | 7.189                                           | 11.06                                            | 4.977                                          | 3.318                              | 249.916              |
| S.D.                  | 0.214                         | 6.364                                            | 28.072                            | 0.844                                               | 3.519                         | 0.782                           | 1.955                     | 1.173                                 | 0.782                                           | 0.782                                            | 5.474                                          | 0                                  | 29.414               |
| Biomass (mg.m-3)      | 269.914                       | 49.366                                           | 581.353                           | 37.468                                              | 14.555                        | 27.633                          | 2.286                     | 2.714                                 | 1.071                                           | 2.791                                            | 8.092                                          | 16.175                             | 1013.418             |

# Appendix IV : Experiment 5 Autumn Lake Pupuke 21/5/91 - 31/5/91

| Day 10 (31/5/91)      | <i>Peridinium<br/>cinctum</i> | <i>Staurastrum<br/>johnsonii<br/>var. altuis</i> | <i>Fragilaria<br/>crotonensis</i> | <i>Staurastrum<br/>leptocladum<br/>var. insigne</i> | <i>Staurastrum<br/>pinque</i> | <i>Cosmarium<br/>contractum</i> | <i>Achnanthes<br/>sp.</i> | <i>Oocystis<br/>cf.<br/>lacustris</i> | <i>Closterium<br/>acutum var.<br/>variabile</i> | <i>Scenedesmus<br/>bijuga var.<br/>alternans</i> | <i>Cryptomonas<br/>ovata and<br/>marssonii</i> | <i>Trachelomonas<br/>volvicina</i> | TOTAL<br>P.U. (ml-1) |
|-----------------------|-------------------------------|--------------------------------------------------|-----------------------------------|-----------------------------------------------------|-------------------------------|---------------------------------|---------------------------|---------------------------------------|-------------------------------------------------|--------------------------------------------------|------------------------------------------------|------------------------------------|----------------------|
| <b>Exclosure</b>      |                               |                                                  |                                   |                                                     |                               |                                 |                           |                                       |                                                 |                                                  |                                                |                                    |                      |
| P.U. (ml-1)           | 30.25                         | 65.166                                           | 315.459                           | 209.565                                             | 30.553                        | 16.452                          | 10.231                    | 35.116                                | 24.609                                          | 37.463                                           | 4.562                                          | 1.659                              | 781.083              |
| S.D.                  | 4.165                         | 5.738                                            | 46.001                            | 20.975                                              | 5.876                         | 1.383                           | 0.553                     | 2.802                                 | 2.142                                           | 3.507                                            | 3.268                                          | 0.782                              | 64.908               |
| Biomass (mg.m-3)      | 513.274                       | 260.904                                          | 2018.633                          | 123.383                                             | 28.217                        | 82.208                          | 1.8                       | 14.986                                | 3.665                                           | 9.455                                            | 7.418                                          | 8.087                              | 3072.03              |
| <b>Enclosure (1X)</b> |                               |                                                  |                                   |                                                     |                               |                                 |                           |                                       |                                                 |                                                  |                                                |                                    |                      |
| P.U. (ml-1)           | 14.141                        | 6.75                                             | 77.558                            | 29.724                                              | 5.115                         | 21.982                          | 7.88                      | 21.982                                | 12.719                                          | 29.862                                           | 1.659                                          | 1.936                              | 231.308              |
| S.D.                  | 1.58                          | 1.227                                            | 14.636                            | 5.555                                               | 4.023                         | 9.147                           | 1.383                     | 2.405                                 | 4.987                                           | 9.652                                            | 1.277                                          | 0.714                              | 37.394               |
| Biomass (mg.m-3)      | 239.945                       | 27.025                                           | 496.297                           | 17.5                                                | 4.724                         | 109.841                         | 1.386                     | 9.381                                 | 1.894                                           | 7.537                                            | 2.697                                          | 9.435                              | 927.662              |
| <b>Enclosure (2X)</b> |                               |                                                  |                                   |                                                     |                               |                                 |                           |                                       |                                                 |                                                  |                                                |                                    |                      |
| P.U. (ml-1)           | 21.438                        | 28.886                                           | 226.467                           | 54.471                                              | 10.922                        | 27.512                          | 9.263                     | 24.194                                | 12.304                                          | 39.263                                           | 1.659                                          | 3.042                              | 459.419              |
| S.D.                  | 12.346                        | 6.453                                            | 36.675                            | 10.699                                              | 4.786                         | 11.638                          | 2.405                     | 2.647                                 | 5.876                                           | 16.423                                           | 1.355                                          | 3.012                              | 76.846               |
| Biomass (mg.m-3)      | 363.754                       | 115.652                                          | 1449.17                           | 32.07                                               | 10.087                        | 137.473                         | 1.629                     | 10.325                                | 1.833                                           | 9.909                                            | 2.697                                          | 14.827                             | 2149.427             |
| <b>Enclosure (4X)</b> |                               |                                                  |                                   |                                                     |                               |                                 |                           |                                       |                                                 |                                                  |                                                |                                    |                      |
| P.U. (ml-1)           | 11.418                        | 27.908                                           | 140.235                           | 85.403                                              | 13.342                        | 19.096                          | 8.641                     | 44.794                                | 16.142                                          | 47.231                                           | 14.326                                         | 2.713                              | 431.249              |
| S.D.                  | 1.408                         | 16.281                                           | 128.425                           | 24.545                                              | 1.92                          | 10.624                          | 3.747                     | 13.865                                | 13.176                                          | 14.953                                           | 12.212                                         | 1.33                               | 77.467               |
| Biomass (mg.m-3)      | 193.729                       | 111.735                                          | 897.371                           | 50.282                                              | 12.321                        | 95.422                          | 1.52                      | 19.116                                | 2.404                                           | 11.92                                            | 23.293                                         | 13.227                             | 1432.341             |
| <b>Lake</b>           |                               |                                                  |                                   |                                                     |                               |                                 |                           |                                       |                                                 |                                                  |                                                |                                    |                      |
| P.U. (ml-1)           | 16.2                          | 6.278                                            | 54.747                            | 41.199                                              | 9.678                         | 4.977                           | 17.973                    | 12.996                                | 3.595                                           | 8.848                                            | 4.424                                          | 3.595                              | 184.507              |
| S.D.                  | 0.955                         | 1.432                                            | 7.821                             | 1.173                                               | 1.173                         | 1.564                           | 2.737                     | 2.737                                 | 1.173                                           | 1.564                                            | 0                                              | 1.955                              | 4.733                |
| Biomass (mg.m-3)      | 274.877                       | 25.133                                           | 350.328                           | 24.256                                              | 8.938                         | 24.87                           | 3.162                     | 5.546                                 | 0.535                                           | 2.233                                            | 7.193                                          | 17.523                             | 744.594              |



Appendix IV : Experiment 6 Winter Lake Pupuke 23/7/90 - 21/8/90

| Day 0 (23/7/91)       | <i>Peridinium<br/>cinctum</i> | <i>Staurastrum<br/>johnsonii<br/>var. altuis</i> | <i>Fragilaria<br/>crotonensis</i> | <i>Cryptomonas<br/>ovata</i> | <i>Staurastrum<br/>leptocladum<br/>var. insigne</i> | <i>Staurastrum<br/>pinque</i> | <i>Achnanthes<br/>sp.</i> | <i>Oocystis<br/>cf.<br/>lacustris</i> | <i>Closterium<br/>acutum var.<br/>variabile</i> | <i>Scenedesmus<br/>bijuga var.<br/>alternans</i> | <i>Unidenti-<br/>fied<br/>Unicells</i> | TOTAL<br>P.U.(ml-1) |
|-----------------------|-------------------------------|--------------------------------------------------|-----------------------------------|------------------------------|-----------------------------------------------------|-------------------------------|---------------------------|---------------------------------------|-------------------------------------------------|--------------------------------------------------|----------------------------------------|---------------------|
| <b>Exclosure</b>      |                               |                                                  |                                   |                              |                                                     |                               |                           |                                       |                                                 |                                                  |                                        |                     |
| P.U.(ml-1)            | 2.126                         | 0.709                                            | 14.516                            | 3.871                        | 7.466                                               | 2.489                         | 5.53                      | 3.871                                 | 3.18                                            | 2.074                                            | 178.431                                | 224.262             |
| S.D.                  | 0.646                         | 0.485                                            | 3.042                             | 1.498                        | 1.659                                               | 0.958                         | 0.903                     | 2.069                                 | 1.987                                           | 0.944                                            | 48.302                                 | 51.469              |
| Biomass (mg.m-3)      | 36.078                        | 2.838                                            | 92.817                            | 6.294                        | 4.395                                               | 2.298                         | 0.973                     | 1.652                                 | 0.474                                           | 0.523                                            | 12.128                                 | 160.47              |
| <b>Enclosure (1X)</b> |                               |                                                  |                                   |                              |                                                     |                               |                           |                                       |                                                 |                                                  |                                        |                     |
| P.U.(ml-1)            | 3.139                         | 0.81                                             | 14.793                            | 3.318                        | 9.954                                               | 1.383                         | 3.733                     | 2.903                                 | 3.595                                           | 0.968                                            | 150.085                                | 194.679             |
| S.D.                  | 1.287                         | 0.731                                            | 2.904                             | 1.355                        | 1.916                                               | 1.059                         | 1.588                     | 1.226                                 | 2.452                                           | 0.696                                            | 58.354                                 | 57.788              |
| Biomass (mg.m-3)      | 53.257                        | 3.243                                            | 94.585                            | 5.395                        | 5.861                                               | 1.277                         | 0.657                     | 1.239                                 | 0.535                                           | 0.244                                            | 10.201                                 | 176.494             |
| <b>Enclosure (2X)</b> |                               |                                                  |                                   |                              |                                                     |                               |                           |                                       |                                                 |                                                  |                                        |                     |
| P.U.(ml-1)            | 2.734                         | 0.878                                            | 14.24                             | 3.733                        | 8.848                                               | 2.627                         | 7.051                     | 2.074                                 | 3.456                                           | 1.383                                            | 126.645                                | 170.704             |
| S.D.                  | 0.775                         | 0.499                                            | 1.987                             | 0.696                        | 3.884                                               | 0.529                         | 2.76                      | 0.83                                  | 2.229                                           | 1.659                                            | 6.854                                  | 8.146               |
| Biomass (mg.m-3)      | 46.386                        | 3.513                                            | 91.05                             | 6.069                        | 5.209                                               | 2.426                         | 0.895                     | 0.885                                 | 0.515                                           | 0.349                                            | 8.54                                   | 165.836             |
| <b>Enclosure (4X)</b> |                               |                                                  |                                   |                              |                                                     |                               |                           |                                       |                                                 |                                                  |                                        |                     |
| P.U.(ml-1)            | 2.025                         | 0.97                                             | 10.369                            | 1.936                        | 10.507                                              | 1.659                         | 3.43                      | 1.936                                 | 1.936                                           | 2.489                                            | 88.56                                  | 125.815             |
| S.D.                  | 0.652                         | 0.32                                             | 3.508                             | 1.596                        | 0.782                                               | 0.452                         | 1.485                     | 0.714                                 | 0.958                                           | 0.714                                            | 7.88                                   | 6.545               |
| Biomass (mg.m-3)      | 34.36                         | 3.884                                            | 66.298                            | 3.147                        | 6.186                                               | 1.532                         | 0.603                     | 0.826                                 | 0.288                                           | 0.628                                            | 6.019                                  | 123.772             |
| <b>Lake</b>           |                               |                                                  |                                   |                              |                                                     |                               |                           |                                       |                                                 |                                                  |                                        |                     |
| P.U.(ml-1)            | 5.805                         | 0.743                                            | 11.613                            | 1.659                        | 10.784                                              | 2.489                         | 4.424                     | 3.871                                 | 2.212                                           | 0.83                                             | 86.346                                 | 130.774             |
| S.D.                  | 1.146                         | 0.095                                            | 7.039                             | 0                            | 0.391                                               | 0.391                         | 0                         | 1.564                                 | 0.782                                           | 1.173                                            | 6.262                                  | 14.953              |
| Biomass (mg.m-3)      | 98.498                        | 2.973                                            | 74.254                            | 2.697                        | 6.349                                               | 2.298                         | 0.778                     | 1.652                                 | 0.329                                           | 0.209                                            | 5.869                                  | 195.907             |

P.U. (ml-1) and Biomass (mg.m-3) are mean values where n = 4

Appendix IV : Experiment 6 Winter Lake Pupuke 23/7/90 - 21/8/90

| Day 3 (26/7/91)       | <i>Peridinium<br/>cinctum</i> | <i>Staurastrum<br/>johnsonii<br/>var. altuis</i> | <i>Fragilaria<br/>crotonensis</i> | <i>Cryptomonas<br/>ovata</i> | <i>Staurastrum<br/>leptocladum<br/>var. insigne</i> | <i>Staurastrum<br/>pinque</i> | <i>Achnanthes<br/>sp.</i> | <i>Oocystis<br/>cf.<br/>lacustris</i> | <i>Closterium<br/>acutum var.<br/>variabile</i> | <i>Scenedesmus<br/>bijuga var.<br/>alternans</i> | <i>Unidenti-<br/>fied<br/>Unicells</i> | TOTAL<br>P.U.(ml-1) |
|-----------------------|-------------------------------|--------------------------------------------------|-----------------------------------|------------------------------|-----------------------------------------------------|-------------------------------|---------------------------|---------------------------------------|-------------------------------------------------|--------------------------------------------------|----------------------------------------|---------------------|
| <b>Exclosure</b>      |                               |                                                  |                                   |                              |                                                     |                               |                           |                                       |                                                 |                                                  |                                        |                     |
| P.U.(ml-1)            | 5.67                          | 1.519                                            | 91.413                            | 17.696                       | 16.037                                              | 9.125                         | 8.157                     | 9.539                                 | 6.221                                           | 6.498                                            | 219.256                                | 391.131             |
| S.D.                  | 3.181                         | 1.283                                            | 100.388                           | 7.067                        | 12.602                                              | 2.802                         | 2.529                     | 4.123                                 | 2.529                                           | 4.316                                            | 113.765                                | 234.811             |
| Biomass (mg.m-3)      | 96.207                        | 6.081                                            | 584.498                           | 28.772                       | 9.442                                               | 8.427                         | 1.435                     | 4.071                                 | 0.927                                           | 1.64                                             | 14.903                                 | 756.402             |
| <b>Enclosure (1X)</b> |                               |                                                  |                                   |                              |                                                     |                               |                           |                                       |                                                 |                                                  |                                        |                     |
| P.U.(ml-1)            | 6.683                         | 2.7                                              | 75.923                            | 13.963                       | 14.24                                               | 4.701                         | 8.986                     | 7.742                                 | 5.668                                           | 7.742                                            | 369.861                                | 518.209             |
| S.D.                  | 2.07                          | 0.998                                            | 34.753                            | 6.263                        | 6.013                                               | 3.626                         | 5.754                     | 1.195                                 | 1.307                                           | 2.594                                            | 249.109                                | 279.124             |
| Biomass (mg.m-3)      | 113.387                       | 10.81                                            | 485.456                           | 22.703                       | 8.384                                               | 4.341                         | 1.581                     | 3.304                                 | 0.844                                           | 1.954                                            | 25.139                                 | 677.903             |
| <b>Enclosure (2X)</b> |                               |                                                  |                                   |                              |                                                     |                               |                           |                                       |                                                 |                                                  |                                        |                     |
| P.U.(ml-1)            | 5.231                         | 2.498                                            | 87.67                             | 3.733                        | 11.337                                              | 4.286                         | 5.53                      | 10.369                                | 10.092                                          | 5.254                                            | 208.854                                | 354.852             |
| S.D.                  | 1.365                         | 0.357                                            | 58.313                            | 1.14                         | 0.319                                               | 1.383                         | 2.165                     | 6.518                                 | 4.786                                           | 5.352                                            | 58.138                                 | 131.179             |
| Biomass (mg.m-3)      | 88.762                        | 9.999                                            | 560.562                           | 6.069                        | 6.674                                               | 3.958                         | 0.973                     | 4.425                                 | 1.503                                           | 1.326                                            | 14.196                                 | 698.448             |
| <b>Enclosure (4X)</b> |                               |                                                  |                                   |                              |                                                     |                               |                           |                                       |                                                 |                                                  |                                        |                     |
| P.U.(ml-1)            | 5.985                         | 2.228                                            | 48.811                            | 3.456                        | 10.369                                              | 3.871                         | 4.424                     | 11.06                                 | 3.871                                           | 4.009                                            | 250.703                                | 348.787             |
| S.D.                  | 2.671                         | 0.405                                            | 17.397                            | 2.229                        | 2.723                                               | 0.782                         | 1.628                     | 2.069                                 | 3.584                                           | 1.827                                            | 71.228                                 | 74.214              |
| Biomass (mg.m-3)      | 101.552                       | 8.918                                            | 312.098                           | 5.619                        | 6.105                                               | 3.575                         | 0.778                     | 4.72                                  | 0.577                                           | 1.012                                            | 17.04                                  | 461.994             |
| <b>Lake</b>           |                               |                                                  |                                   |                              |                                                     |                               |                           |                                       |                                                 |                                                  |                                        |                     |
| P.U.(ml-1)            | 6.683                         | 1.215                                            | 43.687                            | 8.572                        | 9.954                                               | 4.977                         | 6.636                     | 16.314                                | 6.36                                            | 7.742                                            | 307.962                                | 420.1               |
| S.D.                  | 6.014                         | 0.955                                            | 32.847                            | 1.955                        | 6.256                                               | 5.474                         | 3.91                      | 16.814                                | 8.212                                           | 5.474                                            | 147.466                                | 223.35              |
| Biomass (mg.m-3)      | 113.387                       | 4.864                                            | 279.336                           | 13.936                       | 5.861                                               | 4.596                         | 1.167                     | 6.962                                 | 0.947                                           | 1.954                                            | 20.932                                 | 453.944             |

Appendix IV : Experiment 6 Winter Lake Pupuke 23/7/90 - 21/8/90

| Day 6 (29/7/91)       | <i>Peridinium<br/>cinctum</i> | <i>Staurastrum<br/>johnsonii<br/>var. altuis</i> | <i>Fragilaria<br/>crotonensis</i> | <i>Cryptomonas<br/>ovata</i> | <i>Staurastrum<br/>leptocladum<br/>var. insigne</i> | <i>Staurastrum<br/>pinque</i> | <i>Achnanthes<br/>sp.</i> | <i>Oocystis<br/>cf.<br/>lacustris</i> | <i>Closterium<br/>acutum var.<br/>variabile</i> | <i>Scenedesmus<br/>bijuga var.<br/>alternans</i> | <i>Unidenti-<br/>fied<br/>Unicells</i> | TOTAL<br>P.U.(ml-1) |
|-----------------------|-------------------------------|--------------------------------------------------|-----------------------------------|------------------------------|-----------------------------------------------------|-------------------------------|---------------------------|---------------------------------------|-------------------------------------------------|--------------------------------------------------|----------------------------------------|---------------------|
| <b>Exclosure</b>      |                               |                                                  |                                   |                              |                                                     |                               |                           |                                       |                                                 |                                                  |                                        |                     |
| P.U.(ml-1)            | 4.759                         | 2.396                                            | 138.178                           | 12.028                       | 18.387                                              | 6.913                         | 17.558                    | 14.655                                | 10.092                                          | 10.231                                           | 384.109                                | 619.305             |
| S.D.                  | 1.088                         | 0.767                                            | 91.596                            | 2.274                        | 5.036                                               | 2.324                         | 2.447                     | 6.535                                 | 5.116                                           | 5.861                                            | 116.052                                | 216.432             |
| Biomass (mg.m-3)      | 80.745                        | 9.594                                            | 883.517                           | 19.556                       | 10.826                                              | 6.384                         | 3.089                     | 6.254                                 | 1.503                                           | 2.582                                            | 26.108                                 | 1050.157            |
| <b>Enclosure (1X)</b> |                               |                                                  |                                   |                              |                                                     |                               |                           |                                       |                                                 |                                                  |                                        |                     |
| P.U.(ml-1)            | 7.661                         | 2.126                                            | 70.81                             | 7.327                        | 14.516                                              | 4.839                         | 12.166                    | 15.899                                | 10.507                                          | 11.337                                           | 356.822                                | 514.009             |
| S.D.                  | 3.328                         | 1.036                                            | 36.461                            | 4.221                        | 3.537                                               | 2.088                         | 3.91                      | 9.593                                 | 6.667                                           | 6.066                                            | 200.607                                | 271.279             |
| Biomass (mg.m-3)      | 129.994                       | 8.513                                            | 452.759                           | 11.913                       | 8.547                                               | 4.469                         | 2.14                      | 6.785                                 | 1.565                                           | 2.861                                            | 24.253                                 | 653.799             |
| <b>Enclosure (2X)</b> |                               |                                                  |                                   |                              |                                                     |                               |                           |                                       |                                                 |                                                  |                                        |                     |
| P.U.(ml-1)            | 5.771                         | 2.194                                            | 86.321                            | 2.765                        | 15.622                                              | 4.977                         | 9.689                     | 10.369                                | 7.88                                            | 7.327                                            | 254.096                                | 407.011             |
| S.D.                  | 2.848                         | 0.957                                            | 98.945                            | 2.633                        | 4.85                                                | 3.029                         | 3.662                     | 7.681                                 | 2.833                                           | 5.273                                            | 121.952                                | 174.467             |
| Biomass (mg.m-3)      | 97.925                        | 8.783                                            | 551.937                           | 4.496                        | 9.198                                               | 4.596                         | 1.704                     | 4.425                                 | 1.174                                           | 1.849                                            | 17.271                                 | 703.358             |
| <b>Enclosure (4X)</b> |                               |                                                  |                                   |                              |                                                     |                               |                           |                                       |                                                 |                                                  |                                        |                     |
| P.U.(ml-1)            | 3.038                         | 1.856                                            | 28.341                            | 0.553                        | 9.678                                               | 2.903                         | 6.498                     | 10.231                                | 5.115                                           | 6.083                                            | 163.836                                | 238.131             |
| S.D.                  | 1.452                         | 0.388                                            | 10.29                             | 0.452                        | 1.719                                               | 0.277                         | 2.647                     | 3.541                                 | 4.123                                           | 3.723                                            | 17.433                                 | 37.475              |
| Biomass (mg.m-3)      | 51.539                        | 7.432                                            | 181.215                           | 0.899                        | 5.698                                               | 2.681                         | 1.143                     | 4.366                                 | 0.762                                           | 1.535                                            | 11.136                                 | 268.407             |
| <b>Lake</b>           |                               |                                                  |                                   |                              |                                                     |                               |                           |                                       |                                                 |                                                  |                                        |                     |
| P.U.(ml-1)            | 5.063                         | 0.27                                             | 16.867                            | 3.318                        | 11.06                                               | 1.659                         | 3.871                     | 3.318                                 | 2.212                                           | 1.936                                            | 122.877                                | 172.45              |
| S.D.                  | 0.286                         | 0.191                                            | 5.865                             | 0.782                        | 1.564                                               | 0                             | 1.564                     | 2.346                                 | 1.564                                           | 0.391                                            | 14.09                                  | 12.621              |
| Biomass (mg.m-3)      | 85.899                        | 1.081                                            | 107.845                           | 5.395                        | 6.512                                               | 1.532                         | 0.681                     | 1.416                                 | 0.329                                           | 0.488                                            | 8.352                                  | 219.531             |

Appendix IV : Experiment 6 Winter Lake Pupuke 23/7/90 - 21/8/90

| Day 10 (2/8/91)       | <i>Peridinium<br/>cinctum</i> | <i>Staurastrum<br/>johnsonii<br/>var. altuis</i> | <i>Fragilaria<br/>crotonensis</i> | <i>Cryptomonas<br/>ovata</i> | <i>Staurastrum<br/>leptocladum<br/>var. insigne</i> | <i>Staurastrum<br/>pinque</i> | <i>Achnanthes<br/>sp.</i> | <i>Oocystis<br/>cf.<br/>lacustris</i> | <i>Closterium<br/>acutum var.<br/>variabile</i> | <i>Scenedesmus<br/>bijuga var.<br/>alternans</i> | <i>Unidenti-<br/>fied<br/>Unicells</i> | TOTAL<br>P.U.(ml-1) |
|-----------------------|-------------------------------|--------------------------------------------------|-----------------------------------|------------------------------|-----------------------------------------------------|-------------------------------|---------------------------|---------------------------------------|-------------------------------------------------|--------------------------------------------------|----------------------------------------|---------------------|
| <b>Exclosure</b>      |                               |                                                  |                                   |                              |                                                     |                               |                           |                                       |                                                 |                                                  |                                        |                     |
| P.U.(ml-1)            | 5.13                          | 3.578                                            | 701.16                            | 35.549                       | 34.148                                              | 19.632                        | 13.134                    | 34.563                                | 36.636                                          | 31.936                                           | 470.97                                 | 1386.433            |
| S.D.                  | 0.779                         | 0.628                                            | 118.688                           | 24.733                       | 7.411                                               | 5.685                         | 3.268                     | 6.644                                 | 18.874                                          | 8.355                                            | 94.565                                 | 110.092             |
| Biomass (mg.m-3)      | 87.044                        | 14.323                                           | 4483.242                          | 57.798                       | 20.105                                              | 18.13                         | 2.31                      | 14.75                                 | 5.457                                           | 8.06                                             | 32.012                                 | 4743.232            |
| <b>Enclosure (1X)</b> |                               |                                                  |                                   |                              |                                                     |                               |                           |                                       |                                                 |                                                  |                                        |                     |
| P.U.(ml-1)            | 7.223                         | 3.654                                            | 459.111                           | 12.028                       | 17.696                                              | 10.922                        | 7.327                     | 21.014                                | 16.867                                          | 15.346                                           | 470.415                                | 1041.601            |
| S.D.                  | 3.362                         | 2.439                                            | 265.343                           | 7.073                        | 7.433                                               | 8.76                          | 4.316                     | 9.985                                 | 15.566                                          | 11.337                                           | 116.337                                | 400.581             |
| Biomass (mg.m-3)      | 122.549                       | 14.628                                           | 2935.576                          | 19.556                       | 10.419                                              | 10.087                        | 1.289                     | 8.968                                 | 2.512                                           | 3.873                                            | 31.974                                 | 3161.43             |
| <b>Enclosure (2X)</b> |                               |                                                  |                                   |                              |                                                     |                               |                           |                                       |                                                 |                                                  |                                        |                     |
| P.U.(ml-1)            | 6.953                         | 3.071                                            | 220.124                           | 3.871                        | 16.037                                              | 8.848                         | 7.466                     | 24.056                                | 14.931                                          | 12.857                                           | 503.863                                | 822.075             |
| S.D.                  | 2.004                         | 1.234                                            | 37.617                            | 1.749                        | 8.313                                               | 3.193                         | 2.28                      | 8.679                                 | 11.467                                          | 3.268                                            | 107.594                                | 164.595             |
| Biomass (mg.m-3)      | 117.968                       | 12.296                                           | 1407.478                          | 6.294                        | 9.442                                               | 8.171                         | 1.313                     | 10.266                                | 2.224                                           | 3.245                                            | 34.248                                 | 1612.946            |
| <b>Enclosure (4X)</b> |                               |                                                  |                                   |                              |                                                     |                               |                           |                                       |                                                 |                                                  |                                        |                     |
| P.U.(ml-1)            | 7.999                         | 2.768                                            | 314.745                           | 5.668                        | 12.304                                              | 4.977                         | 4.424                     | 16.175                                | 6.083                                           | 8.019                                            | 307.928                                | 691.089             |
| S.D.                  | 1.852                         | 0.357                                            | 120.838                           | 3.008                        | 1.523                                               | 2.302                         | 1.195                     | 4.657                                 | 2.069                                           | 4.051                                            | 71.727                                 | 147.841             |
| Biomass (mg.m-3)      | 135.721                       | 11.08                                            | 21012.494                         | 9.216                        | 7.244                                               | 4.596                         | 0.778                     | 6.903                                 | 0.906                                           | 2.024                                            | 20.93                                  | 2211.892            |
| <b>Lake</b>           |                               |                                                  |                                   |                              |                                                     |                               |                           |                                       |                                                 |                                                  |                                        |                     |
| P.U.(ml-1)            | 16.996                        | 1.08                                             | 19.079                            | 4.701                        | 9.954                                               | 3.318                         | 5.807                     | 4.148                                 | 3.871                                           | 1.659                                            | 288.638                                | 359.249             |
| S.D.                  | 1.389                         | 0.382                                            | 4.301                             | 1.955                        | 0.782                                               | 2.346                         | 2.737                     | 1.955                                 | 1.564                                           | 0                                                | 31.024                                 | 43.762              |
| Biomass (mg.m-3)      | 288.384                       | 4.324                                            | 121.989                           | 7.642                        | 5.861                                               | 3.064                         | 1.021                     | 1.77                                  | 0.577                                           | 0.419                                            | 19.619                                 | 454.669             |

Appendix IV : Experiment 7 spring Lake Pupuke 8/10/91 - 18/10/91

| Day 0 (8/10/91)       | <i>Peridinium<br/>cinctum</i> | <i>Staurastrum<br/>johnsonii<br/>var. altuis</i> | <i>Fragilaria<br/>crotonensis</i> | <i>Cosmarium<br/>contractum</i> | <i>Staurastrum<br/>leptocladum<br/>var. insigne</i> | <i>Staurastrum<br/>pinque</i> | <i>Achnanthes<br/>sp.</i> | <i>Oocystis<br/>cf.<br/>lacustris</i> | <i>Closterium<br/>acutum var.<br/>variabile</i> | <i>Scenedesmus<br/>bijunga var.<br/>altenans</i> | <i>Unidenti-<br/>fied<br/>Unicells</i> | TOTAL<br>P.U. (ml-1) |
|-----------------------|-------------------------------|--------------------------------------------------|-----------------------------------|---------------------------------|-----------------------------------------------------|-------------------------------|---------------------------|---------------------------------------|-------------------------------------------------|--------------------------------------------------|----------------------------------------|----------------------|
| <b>Exclosure</b>      |                               |                                                  |                                   |                                 |                                                     |                               |                           |                                       |                                                 |                                                  |                                        |                      |
| P.U. (ml-1)           | 51.168                        | 38.727                                           | 113.093                           | 1.521                           | 76.81                                               | 38.295                        | 12.408                    | 92.145                                | 7.88                                            | 18.664                                           | 124.538                                | 575.329              |
| S.D.                  | 3.833                         | 8.306                                            | 24.847                            | 0.696                           | 3.111                                               | 3.537                         | 2.149                     | 12.228                                | 2.319                                           | 2.723                                            | 19.163                                 | 33.538               |
| Biomass (mg.m-3)      | 868.209                       | 155.051                                          | 723.123                           | 7.599                           | 45.269                                              | 35.367                        | 2.183                     | 39.324                                | 1.174                                           | 4.71                                             | 8.465                                  | 1890.474             |
| <b>Enclosure (1X)</b> |                               |                                                  |                                   |                                 |                                                     |                               |                           |                                       |                                                 |                                                  |                                        |                      |
| P.U. (ml-1)           | 34.69                         | 42.294                                           | 110.276                           | 1.383                           | 70.761                                              | 35.807                        | 7.742                     | 69.838                                | 5.115                                           | 20.185                                           | 91.328                                 | 489.417              |
| S.D.                  | 4.719                         | 4.974                                            | 40.786                            | 0.319                           | 7.043                                               | 5.195                         | 5.852                     | 4.934                                 | 2.529                                           | 6.393                                            | 37.108                                 | 40.806               |
| Biomass (mg.m-3)      | 588.615                       | 169.33                                           | 705.108                           | 6.908                           | 41.661                                              | 33.069                        | 1.362                     | 29.804                                | 0.762                                           | 5.094                                            | 6.208                                  | 1587.92              |
| <b>Enclosure (2X)</b> |                               |                                                  |                                   |                                 |                                                     |                               |                           |                                       |                                                 |                                                  |                                        |                      |
| P.U. (ml-1)           | 24.634                        | 53.312                                           | 115.476                           | 1.659                           | 61.723                                              | 30.553                        | 6.636                     | 71.228                                | 3.456                                           | 16.59                                            | 104.612                                | 489.878              |
| S.D.                  | 3.667                         | 8.005                                            | 5.638                             | 1.628                           | 6.033                                               | 2.833                         | 3.696                     | 8.093                                 | 2.229                                           | 5.887                                            | 25.008                                 | 43.199               |
| Biomass (mg.m-3)      | 417.975                       | 213.443                                          | 738.36                            | 8.29                            | 36.34                                               | 28.217                        | 1.167                     | 30.397                                | 0.515                                           | 4.187                                            | 7.11                                   | 1486.001             |
| <b>Enclosure (4X)</b> |                               |                                                  |                                   |                                 |                                                     |                               |                           |                                       |                                                 |                                                  |                                        |                      |
| P.U. (ml-1)           | 30.305                        | 79.64                                            | 126.184                           | 2.489                           | 63.668                                              | 34.424                        | 11.337                    | 87.802                                | 4.701                                           | 14.931                                           | 100.184                                | 555.662              |
| S.D.                  | 4.351                         | 22.81                                            | 58.627                            | 1.392                           | 5.174                                               | 1.454                         | 6.72                      | 33.551                                | 2.324                                           | 6.337                                            | 22.964                                 | 76.852               |
| Biomass (mg.m-3)      | 514.203                       | 318.854                                          | 806.826                           | 12.435                          | 37.485                                              | 31.792                        | 1.994                     | 37.47                                 | 0.7                                             | 3.768                                            | 6.809                                  | 1772.336             |
| <b>Lake</b>           |                               |                                                  |                                   |                                 |                                                     |                               |                           |                                       |                                                 |                                                  |                                        |                      |
| P.U. (ml-1)           | 47.871                        | 32.3                                             | 78.088                            | 1.383                           | 69.604                                              | 35.392                        | 3.042                     | 57.778                                | 3.318                                           | 12.996                                           | 79                                     | 420.77               |
| S.D.                  | 15.597                        | 2.121                                            | 4.684                             | 0.391                           | 2.02                                                | 8.603                         | 2.737                     | 22.274                                | 0.782                                           | 3.519                                            | 44.831                                 | 66.518               |
| Biomass (mg.m-3)      | 812.262                       | 129.32                                           | 499.298                           | 6.908                           | 40.98                                               | 32.686                        | 0.535                     | 24.657                                | 0.494                                           | 3.28                                             | 5.37                                   | 1555.789             |

P.U. (ml-1) and Biomass (mg.m-3) are mean values where n = 4

Appendix IV : Experiment 7 spring Lake Pupuke 8/10/91 - 18/10/91

| Day 3 (11/10/91)      | <i>Peridinium<br/>cinctum</i> | <i>Staurastrum<br/>johnsonii<br/>var. altuis</i> | <i>Fragilaria<br/>crotonensis</i> | <i>Cosmarium<br/>contractum</i> | <i>Staurastrum<br/>leptocladum<br/>var. insigne</i> | <i>Staurastrum<br/>pinque</i> | <i>Achnanthes<br/>sp.</i> | <i>Oocystis<br/>cf.<br/>lacustris</i> | <i>Closterium<br/>acutum var.<br/>variabile</i> | <i>Scenedesmus<br/>bijunga var.<br/>altenans</i> | <i>Unidenti-<br/>fied<br/>Unicells</i> | TOTAL<br>P.U. (ml-1) |
|-----------------------|-------------------------------|--------------------------------------------------|-----------------------------------|---------------------------------|-----------------------------------------------------|-------------------------------|---------------------------|---------------------------------------|-------------------------------------------------|--------------------------------------------------|----------------------------------------|----------------------|
| <b>Exclosure</b>      |                               |                                                  |                                   |                                 |                                                     |                               |                           |                                       |                                                 |                                                  |                                        |                      |
| P.U. (ml-1)           | 90.445                        | 49.652                                           | 134.709                           | 2.074                           | 88.82                                               | 44.517                        | 14.931                    | 124.602                               | 8.157                                           | 29.171                                           | 182.748                                | 744.824              |
| S.D.                  | 33.314                        | 7.451                                            | 22.659                            | 0.529                           | 7.857                                               | 4.703                         | 5.493                     | 19.635                                | 1.383                                           | 2.76                                             | 46.221                                 | 115.832              |
| Biomass (mg.m-3)      | 1534.651                      | 198.791                                          | 861.335                           | 10.362                          | 52.293                                              | 41.113                        | 2.627                     | 53.175                                | 1.215                                           | 7.362                                            | 10.722                                 | 2773.645             |
| <b>Enclosure (1X)</b> |                               |                                                  |                                   |                                 |                                                     |                               |                           |                                       |                                                 |                                                  |                                        |                      |
| P.U. (ml-1)           | 45.673                        | 68.716                                           | 85.227                            | 2.489                           | 81.531                                              | 39.125                        | 5.254                     | 133.603                               | 7.327                                           | 34.977                                           | 142.256                                | 646.17               |
| S.D.                  | 14.815                        | 13.537                                           | 32.017                            | 0.958                           | 5.637                                               | 2.229                         | 1.316                     | 15.14                                 | 1.523                                           | 2.723                                            | 9.629                                  | 72.502               |
| Biomass (mg.m-3)      | 774.967                       | 275.116                                          | 544.946                           | 12.435                          | 48.002                                              | 36.133                        | 0.924                     | 57.017                                | 1.091                                           | 8.828                                            | 9.669                                  | 1769.128             |
| <b>Enclosure (2X)</b> |                               |                                                  |                                   |                                 |                                                     |                               |                           |                                       |                                                 |                                                  |                                        |                      |
| P.U. (ml-1)           | 56.468                        | 98.092                                           | 79.5                              | 2.074                           | 83.019                                              | 41.475                        | 3.595                     | 129.85                                | 4.424                                           | 28.618                                           | 162.176                                | 689.289              |
| S.D.                  | 8.9                           | 5.64                                             | 6.889                             | 0.529                           | 7.379                                               | 3.497                         | 2.324                     | 21.46                                 | 0.452                                           | 7.601                                            | 43.021                                 | 71.904               |
| Biomass (mg.m-3)      | 958.13                        | 392.73                                           | 508.326                           | 10.362                          | 48.878                                              | 38.304                        | 0.632                     | 55.415                                | 0.659                                           | 7.223                                            | 11.023                                 | 2031.682             |
| <b>Enclosure (4X)</b> |                               |                                                  |                                   |                                 |                                                     |                               |                           |                                       |                                                 |                                                  |                                        |                      |
| P.U. (ml-1)           | 46.514                        | 131.453                                          | 71.709                            | 2.489                           | 83.275                                              | 44.517                        | 4.839                     | 152.303                               | 6.36                                            | 21.152                                           | 138.929                                | 703.537              |
| S.D.                  | 8.349                         | 16.389                                           | 28.894                            | 0.958                           | 13.479                                              | 4.874                         | 3.537                     | 50.58                                 | 2.494                                           | 0.944                                            | 30.323                                 | 91.059               |
| Biomass (mg.m-3)      | 789.233                       | 526.296                                          | 458.512                           | 12.435                          | 49.029                                              | 41.113                        | 0.851                     | 64.997                                | 0.947                                           | 5.338                                            | 9.443                                  | 1958.194             |
| <b>Lake</b>           |                               |                                                  |                                   |                                 |                                                     |                               |                           |                                       |                                                 |                                                  |                                        |                      |
| P.U. (ml-1)           | 37.865                        | 41.764                                           | 121.899                           | 1.106                           | 59.814                                              | 34.286                        | 7.189                     | 91                                    | 7.189                                           | 17.143                                           | 130.626                                | 549.88               |
| S.D.                  | 5.013                         | 5.356                                            | 14.412                            | 0.782                           | 3.255                                               | 2.346                         | 0.782                     | 13.576                                | 1.564                                           | 0.782                                            | 9.393                                  | 55.699               |
| Biomass (mg.m-3)      | 642.483                       | 167.209                                          | 779.427                           | 5.527                           | 35.216                                              | 31.664                        | 1.265                     | 38.835                                | 1.071                                           | 4.327                                            | 8.879                                  | 1715.901             |

Appendix IV : Experiment 7 spring Lake Pupuke 8/10/91 - 18/10/91

| Day 6 (14/10/91)      | <i>Peridinium<br/>cinctum</i> | <i>Staurastrum<br/>johnsonii<br/>var. altuis</i> | <i>Fragilaria<br/>crotonensis</i> | <i>Cosmarium<br/>contractum</i> | <i>Staurastrum<br/>leptocladum<br/>var. insigne</i> | <i>Staurastrum<br/>pinque</i> | <i>Achnanthes<br/>sp.</i> | <i>Oocystis<br/>cf.<br/>lacustris</i> | <i>Closterium<br/>acutum var.<br/>variabile</i> | <i>Scenedesmus<br/>bijunga var.<br/>altenans</i> | <i>Unidenti-<br/>fied<br/>Unicells</i> | TOTAL<br>P.U. (ml-1) |
|-----------------------|-------------------------------|--------------------------------------------------|-----------------------------------|---------------------------------|-----------------------------------------------------|-------------------------------|---------------------------|---------------------------------------|-------------------------------------------------|--------------------------------------------------|----------------------------------------|----------------------|
| <b>Exclosure</b>      |                               |                                                  |                                   |                                 |                                                     |                               |                           |                                       |                                                 |                                                  |                                        |                      |
| P.U. (ml-1) (ml-1)    | 91.484                        | 82.781                                           | 148.08                            | 2.627                           | 109.888                                             | 56.607                        | 18.387                    | 177.327                               | 7.189                                           | 31.521                                           | 187.083                                | 912.973              |
| S.D.                  | 27.296                        | 13.715                                           | 17.854                            | 1.226                           | 16.147                                              | 12.009                        | 7.479                     | 7.762                                 | 2.633                                           | 7.281                                            | 8.575                                  | 27.822               |
| Biomass (mg.m-3)      | 1552.267                      | 331.43                                           | 946.826                           | 13.126                          | 64.698                                              | 52.279                        | 3.235                     | 75.676                                | 1.071                                           | 7.955                                            | 12.716                                 | 3061.279             |
| <b>Enclosure (1X)</b> |                               |                                                  |                                   |                                 |                                                     |                               |                           |                                       |                                                 |                                                  |                                        |                      |
| P.U. (ml-1)           | 75.007                        | 81.433                                           | 118.11                            | 1.936                           | 93.931                                              | 53.641                        | 10.507                    | 177.024                               | 4.977                                           | 33.871                                           | 154.98                                 | 805.417              |
| S.D.                  | 40.222                        | 7.971                                            | 12.522                            | 0.714                           | 11.428                                              | 5.323                         | 6.337                     | 34.326                                | 0.452                                           | 5.254                                            | 7.88                                   | 78.215               |
| Biomass (mg.m-3)      | 1272.699                      | 326.033                                          | 755.202                           | 9.671                           | 55.303                                              | 49.54                         | 1.848                     | 75.547                                | 0.741                                           | 8.548                                            | 10.534                                 | 2565.666             |
| <b>Enclosure (2X)</b> |                               |                                                  |                                   |                                 |                                                     |                               |                           |                                       |                                                 |                                                  |                                        |                      |
| P.U. (ml-1)           | 47.097                        | 98.049                                           | 70.294                            | 2.489                           | 95.955                                              | 53.226                        | 4.839                     | 188.709                               | 4.839                                           | 28.065                                           | 128.966                                | 722.526              |
| S.D.                  | 13.945                        | 15.172                                           | 16.002                            | 1.463                           | 20.862                                              | 6.197                         | 2.229                     | 30.591                                | 1.047                                           | 9.389                                            | 26.591                                 | 48.433               |
| Biomass (mg.m-3)      | 799.133                       | 392.558                                          | 449.464                           | 12.435                          | 56.494                                              | 49.157                        | 0.851                     | 80.533                                | 0.721                                           | 7.083                                            | 8.766                                  | 1857.195             |
| <b>Enclosure (4X)</b> |                               |                                                  |                                   |                                 |                                                     |                               |                           |                                       |                                                 |                                                  |                                        |                      |
| P.U. (ml-1)           | 48.431                        | 110.889                                          | 64.981                            | 3.042                           | 79.607                                              | 56.107                        | 3.595                     | 156.757                               | 4.839                                           | 22.258                                           | 114.021                                | 664.526              |
| S.D.                  | 19.08                         | 24.962                                           | 12.299                            | 0.553                           | 7.469                                               | 11.506                        | 1.889                     | 58.116                                | 1.987                                           | 6.808                                            | 20.572                                 | 79.933               |
| Biomass (mg.m-3)      | 821.76                        | 443.967                                          | 415.49                            | 15.198                          | 46.87                                               | 51.817                        | 0.632                     | 66.898                                | 0.721                                           | 5.618                                            | 7.75                                   | 1876.72              |
| <b>Lake</b>           |                               |                                                  |                                   |                                 |                                                     |                               |                           |                                       |                                                 |                                                  |                                        |                      |
| P.U. (ml-1)           | 36.942                        | 39.187                                           | 32.627                            | 1.106                           | 76.29                                               | 39.816                        | 1.936                     | 93.419                                | 7.189                                           | 18.802                                           | 126.198                                | 473.512              |
| S.D.                  | 0.619                         | 7.618                                            | 0.782                             | 0.782                           | 3.521                                               | 1.564                         | 0.391                     | 15.846                                | 0.782                                           | 3.91                                             | 9.393                                  | 24.042               |
| Biomass (mg.m-3)      | 626.822                       | 156.893                                          | 208.618                           | 5.527                           | 44.917                                              | 36.772                        | 0.34                      | 39.867                                | 1.071                                           | 4.745                                            | 8.578                                  | 1134.15              |

Appendix IV : Experiment 7 spring Lake Pupuke 8/10/91 - 18/10/91

| Day 10 (18/10/91)     | <i>Peridinium<br/>cinctum</i> | <i>Staurastrum<br/>johnsonii<br/>var. altuis</i> | <i>Fragilaria<br/>crotonensis</i> | <i>Cosmarium<br/>contractum</i> | <i>Staurastrum<br/>leptocladum<br/>var. insigne</i> | <i>Staurastrum<br/>pinque</i> | <i>Achnanthes<br/>sp.</i> | <i>Oocystis<br/>cf.<br/>lacustris</i> | <i>Closterium<br/>acutum var.<br/>variabile</i> | <i>Scenedesmus<br/>bijunga var.<br/>altenans</i> | <i>Unidenti-<br/>fied<br/>Unicells</i> | TOTAL<br>P.U. (ml-1) |
|-----------------------|-------------------------------|--------------------------------------------------|-----------------------------------|---------------------------------|-----------------------------------------------------|-------------------------------|---------------------------|---------------------------------------|-------------------------------------------------|--------------------------------------------------|----------------------------------------|----------------------|
| <b>Enclosure</b>      |                               |                                                  |                                   |                                 |                                                     |                               |                           |                                       |                                                 |                                                  |                                        |                      |
| P.U. (ml-1)           | 46.879                        | 98.343                                           | 263.324                           | 3.18                            | 142.208                                             | 90.2                          | 27.65                     | 205.336                               | 2.903                                           | 49.079                                           | 170.478                                | 1099.578             |
| S.D.                  | 7.214                         | 25.38                                            | 86.653                            | 1.651                           | 6.654                                               | 4.6                           | 15.171                    | 19.914                                | 1.882                                           | 6.565                                            | 44.317                                 | 145.522              |
| Biomass (mg.m-3)      | 795.426                       | 393.736                                          | 1683.701                          | 15.889                          | 83.726                                              | 83.303                        | 4.864                     | 87.629                                | 0.432                                           | 12.386                                           | 11.587                                 | 3172.68              |
| <b>Enclosure (1X)</b> |                               |                                                  |                                   |                                 |                                                     |                               |                           |                                       |                                                 |                                                  |                                        |                      |
| P.U. (ml-1)           | 53.466                        | 102.231                                          | 93.031                            | 3.733                           | 109.852                                             | 67.303                        | 7.742                     | 170.723                               | 2.903                                           | 56.149                                           | 193.635                                | 860.767              |
| S.D.                  | 12.511                        | 31.969                                           | 48.328                            | 0.529                           | 13.248                                              | 13.332                        | 2.069                     | 41.512                                | 1.14                                            | 12.772                                           | 52.87                                  | 30.298               |
| Biomass (mg.m-3)      | 907.192                       | 409.302                                          | 594.844                           | 18.652                          | 64.676                                              | 62.157                        | 1.362                     | 72.858                                | 0.432                                           | 14.171                                           | 13.161                                 | 2158.808             |
| <b>Enclosure (2X)</b> |                               |                                                  |                                   |                                 |                                                     |                               |                           |                                       |                                                 |                                                  |                                        |                      |
| P.U. (ml-1)           | 43.874                        | 123.146                                          | 87.784                            | 4.286                           | 95.89                                               | 68.431                        | 8.572                     | 225.025                               | 7.466                                           | 37.051                                           | 119.003                                | 820.526              |
| S.D.                  | 11.522                        | 32.076                                           | 48.419                            | 0.529                           | 18.274                                              | 5.469                         | 2.044                     | 37.796                                | 1.719                                           | 8.79                                             | 58.196                                 | 114.937              |
| Biomass (mg.m-3)      | 744.434                       | 493.041                                          | 561.294                           | 21.415                          | 56.456                                              | 63.198                        | 1.508                     | 96.032                                | 1.112                                           | 9.351                                            | 8.089                                  | 2055.93              |
| <b>Enclosure (4X)</b> |                               |                                                  |                                   |                                 |                                                     |                               |                           |                                       |                                                 |                                                  |                                        |                      |
| P.U. (ml-1)           | 42.814                        | 175.799                                          | 67.874                            | 4.562                           | 95.508                                              | 74.341                        | 8.433                     | 253.552                               | 9.954                                           | 30.692                                           | 133.947                                | 897.475              |
| S.D.                  | 10.158                        | 91.72                                            | 37.57                             | 2.76                            | 8.696                                               | 9.415                         | 5.096                     | 13.966                                | 4.447                                           | 9.412                                            | 40.764                                 | 116.788              |
| Biomass (mg.m-3)      | 726.452                       | 703.845                                          | 433.986                           | 22.797                          | 56.231                                              | 68.657                        | 1.483                     | 108.206                               | 1.483                                           | 7.746                                            | 9.104                                  | 2139.991             |
| <b>Lake</b>           |                               |                                                  |                                   |                                 |                                                     |                               |                           |                                       |                                                 |                                                  |                                        |                      |
| P.U. (ml-1)           | 31.43                         | 50.319                                           | 31.798                            | 2.765                           | 76.492                                              | 49.217                        | 2.489                     | 121.678                               | 9.954                                           | 23.503                                           | 154.98                                 | 554.624              |
| S.D.                  | 1.881                         | 1.107                                            | 2.737                             | 0.782                           | 2.133                                               | 1.564                         | 1.955                     | 28.386                                | 0                                               | 1.173                                            | 3.131                                  | 27.432               |
| Biomass (mg.m-3)      | 533.296                       | 201.462                                          | 203.314                           | 13.816                          | 45.035                                              | 45.454                        | 0.438                     | 51.927                                | 1.483                                           | 5.932                                            | 10.534                                 | 1112.691             |



## Appendix IV : Experiment 8 Summer Lake Pupuke 4/2/92 - 14/2/92

| Day O (4/2/92)        | <i>Peridinium<br/>cinctum</i> | <i>Staurastrum<br/>johnsonii<br/>var. altius</i> | <i>Fragilaria<br/>crotonensis</i> | <i>Elakatothrix<br/>gelatinosa</i> | <i>Staurastrum<br/>leptocladum<br/>var. insigne</i> | <i>Staurastrum<br/>pinque</i> | <i>Cosmarium<br/>contractum</i> | <i>Closterium<br/>acutum var.<br/>variabile</i> | <i>Cryptomonas<br/>ovata +<br/>marssonii</i> | <i>Tetraedron<br/>minimum</i> | <i>Trachelomonas<br/>volvicina</i> | <i>Cosmarium<br/>perfissum</i> | Unidenti-<br>fied<br>Unicells | <i>Oocystis<br/>f. lacustris</i> | <i>Scenedesmus<br/>bijuga var.<br/>alternans</i> | Total<br>P.U. (ml-1) |
|-----------------------|-------------------------------|--------------------------------------------------|-----------------------------------|------------------------------------|-----------------------------------------------------|-------------------------------|---------------------------------|-------------------------------------------------|----------------------------------------------|-------------------------------|------------------------------------|--------------------------------|-------------------------------|----------------------------------|--------------------------------------------------|----------------------|
| <b>Exclosure</b>      |                               |                                                  |                                   |                                    |                                                     |                               |                                 |                                                 |                                              |                               |                                    |                                |                               |                                  |                                                  |                      |
| P.U. (ml-1)           | 255.556                       | 104.378                                          | 30.968                            | 243.539                            | 122.873                                             | 65.778                        | 51.987                          | 13.687                                          | 7.189                                        | 3.18                          | 25.991                             | 9.539                          | 63.099                        | 210.884                          | 40.406                                           | 1249.05              |
| S.D.                  | 167.853                       | 34.073                                           | 14.3                              | 65.918                             | 28.12                                               | 16.596                        | 18.223                          | 1.588                                           | 7.01                                         | 2.362                         | 23.362                             | 4.456                          | 18.122                        | 11.343                           | 4.191                                            | 307.17               |
| Biomass (mg.m-3)      | 4336.209                      | 417.898                                          | 198.011                           | 40.091                             | 72.343                                              | 60.748                        | 149.993                         | 2.039                                           | 11.688                                       | 1.239                         | 126.704                            | 54.16                          | 4.289                         | 49.686                           | 10.198                                           | 5535.3               |
| <b>Enclosure (1X)</b> |                               |                                                  |                                   |                                    |                                                     |                               |                                 |                                                 |                                              |                               |                                    |                                |                               |                                  |                                                  |                      |
| P.U. (ml-1)           | 120.442                       | 157.252                                          | 38.71                             | 324.265                            | 131.109                                             | 78.652                        | 73.141                          | 16.175                                          | 3.18                                         | 1.936                         | 4.977                              | 16.314                         | 54.797                        | 202.581                          | 31.55                                            | 1255.08              |
| S.D.                  | 73.124                        | 73.293                                           | 14.887                            | 20.094                             | 16.053                                              | 21.865                        | 20.4                            | 0.529                                           | 2.362                                        | 0.553                         | 3.029                              | 3.541                          | 30.484                        | 6.884                            | 2.12                                             | 162.09               |
| Biomass (mg.m-3)      | 2043.627                      | 629.59                                           | 247.513                           | 53.381                             | 77.192                                              | 72.638                        | 211.024                         | 2.409                                           | 5.17                                         | 0.754                         | 24.262                             | 92.621                         | 3.725                         | 47.73                            | 7.962                                            | 3519.6               |
| <b>Enclosure (2X)</b> |                               |                                                  |                                   |                                    |                                                     |                               |                                 |                                                 |                                              |                               |                                    |                                |                               |                                  |                                                  |                      |
| P.U. (ml-1)           | 122.255                       | 118.23                                           | 23.917                            | 358.841                            | 144.111                                             | 86.964                        | 77.23                           | 14.102                                          | 3.733                                        | 1.797                         | 5.945                              | 14.793                         | 50.369                        | 263.116                          | 33.21                                            | 1318.61              |
| S.D.                  | 75.814                        | 37.02                                            | 10.934                            | 121.439                            | 51.715                                              | 33.611                        | 42.709                          | 1.834                                           | 1.383                                        | 1.226                         | 3.36                               | 10.438                         | 14.838                        | 60.553                           | 1.808                                            | 421.287              |
| Biomass (mg.m-3)      | 2074.39                       | 473.358                                          | 152.928                           | 59.072                             | 84.847                                              | 80.315                        | 222.823                         | 2.1                                             | 6.069                                        | 0.7                           | 28.98                              | 83.987                         | 3.424                         | 61.993                           | 8.382                                            | 3343.37              |
| <b>Enclosure (4X)</b> |                               |                                                  |                                   |                                    |                                                     |                               |                                 |                                                 |                                              |                               |                                    |                                |                               |                                  |                                                  |                      |
| P.U. (ml-1)           | 49.795                        | 96.69                                            | 23.503                            | 246.284                            | 141.78                                              | 64.511                        | 54.5                            | 9.678                                           | 2.489                                        | 2.074                         | 5.115                              | 5.53                           | 43.173                        | 223.061                          | 38.192                                           | 1006.37              |
| S.D.                  | 7.981                         | 20.422                                           | 6.457                             | 25.683                             | 25.231                                              | 8.912                         | 7.099                           | 3.654                                           | 1.463                                        | 0.529                         | 1.047                              | 1.355                          | 8.575                         | 15.798                           | 5.823                                            | 85.588               |
| Biomass (mg.m-3)      | 844.908                       | 387.116                                          | 150.276                           | 40.543                             | 83.474                                              | 59.578                        | 157.242                         | 1.441                                           | 4.046                                        | 0.808                         | 24.936                             | 31.397                         | 2.934                         | 52.555                           | 9.639                                            | 1850.9               |
| <b>Lake</b>           |                               |                                                  |                                   |                                    |                                                     |                               |                                 |                                                 |                                              |                               |                                    |                                |                               |                                  |                                                  |                      |
| P.U. (ml-1)           | 48.848                        | 36.966                                           | 10.784                            | 156.138                            | 84.111                                              | 31.245                        | 22.673                          | 11.06                                           | 2.212                                        | 1.383                         | 7.189                              | 1.383                          | 47.601                        | 214.758                          | 30.996                                           | 707.354              |
| S.D.                  | 18.749                        | 6.285                                            | 3.519                             | 3.448                              | 13.167                                              | 0.391                         | 3.91                            | 3.91                                            | 0.782                                        | 0.391                         | 0                                  | 0.391                          | 10.959                        | 31.311                           | 3.131                                            | 27.204               |
| Biomass (mg.m-3)      | 829.001                       | 148.001                                          | 68.95                             | 25.703                             | 49.521                                              | 28.856                        | 65.416                          | 1.647                                           | 3.596                                        | 0.539                         | 35.046                             | 7.849                          | 3.235                         | 50.599                           | 7.823                                            | 1325.78              |

P.U. (ml-1) and Biomass (mg.m-3) are mean values where n = 4

# Appendix IV : Experiment 8 Summer Lake Pupuke 4/2/92 - 14/2/92

| Day 3 (7/2/92)        | <i>Peridinium<br/>cinctum</i> | <i>Staurastrum<br/>johnsonii<br/>var. altuis</i> | <i>Fragilaria<br/>crotonensis</i> | <i>Elakatothrix<br/>gelatinosa</i> | <i>Staurastrum<br/>leptocladum<br/>var. insigne</i> | <i>Staurastrum<br/>pinque</i> | <i>Cosmarium<br/>contractum</i> | <i>Closterium<br/>acutum var.<br/>variabile</i> | <i>Cryptomonas<br/>ovata +<br/>marssonii</i> | <i>Tetraedron<br/>minimum</i> | <i>Trachelomonas<br/>volvicina</i> | <i>Cosmarium<br/>perfissum</i> | Unidenti-<br>fied<br>Unicells | <i>Oocystis<br/>cf. lacustris</i> | <i>Scenesmus<br/>bijuga var.<br/>alternans</i> | Total<br>P.U. (ml-1) |
|-----------------------|-------------------------------|--------------------------------------------------|-----------------------------------|------------------------------------|-----------------------------------------------------|-------------------------------|---------------------------------|-------------------------------------------------|----------------------------------------------|-------------------------------|------------------------------------|--------------------------------|-------------------------------|-----------------------------------|------------------------------------------------|----------------------|
| <b>Enclosure</b>      |                               |                                                  |                                   |                                    |                                                     |                               |                                 |                                                 |                                              |                               |                                    |                                |                               |                                   |                                                |                      |
| P.U. (ml-1)           | 43.594                        | 85.419                                           | 28.48                             | 441.43                             | 188.753                                             | 59.256                        | 45.045                          | 12.304                                          | 0.277                                        | 2.765                         | 5.53                               | 6.774                          | 49.262                        | 337.868                           | 68.634                                         | 1375.39              |
| S.D.                  | 5.649                         | 29.024                                           | 9.303                             | 83.451                             | 23.159                                              | 7.729                         | 12.971                          | 4.829                                           | 0.553                                        | 1.01                          | 2.346                              | 1.383                          | 25.138                        | 44.348                            | 5.423                                          | 128.68               |
| Biomass (mg.m-3)      | 739.695                       | 341.993                                          | 182.099                           | 72.668                             | 111.13                                              | 54.725                        | 129.963                         | 1.833                                           | 0.45                                         | 1.078                         | 26.958                             | 38.461                         | 3.348                         | 79.605                            | 17.322                                         | 1801.33              |
| <b>Enclosure (1X)</b> |                               |                                                  |                                   |                                    |                                                     |                               |                                 |                                                 |                                              |                               |                                    |                                |                               |                                   |                                                |                      |
| P.U. (ml-1)           | 38.008                        | 87.479                                           | 16.867                            | 595.981                            | 172.969                                             | 79.151                        | 48.664                          | 14.102                                          | 0                                            | 3.18                          | 3.318                              | 9.263                          | 39.299                        | 410.509                           | 58.118                                         | 1576.9               |
| S.D.                  | 3.242                         | 18.14                                            | 6.958                             | 96.805                             | 21.416                                              | 12.39                         | 5.088                           | 4.366                                           | 0                                            | 1.226                         | 1.628                              | 1.307                          | 13.693                        | 76.67                             | 9.629                                          | 116.606              |
| Biomass (mg.m-3)      | 644.901                       | 350.24                                           | 107.845                           | 98.11                              | 101.837                                             | 73.099                        | 140.405                         | 2.1                                             | 0                                            | 1.239                         | 16.175                             | 52.59                          | 2.671                         | 96.72                             | 14.668                                         | 1702.6               |
| <b>Enclosure (2X)</b> |                               |                                                  |                                   |                                    |                                                     |                               |                                 |                                                 |                                              |                               |                                    |                                |                               |                                   |                                                |                      |
| P.U. (ml-1)           | 65.138                        | 108.992                                          | 22.535                            | 728.962                            | 192.74                                              | 70.413                        | 43.687                          | 10.369                                          | 0.415                                        | 2.489                         | 8.71                               | 9.539                          | 30.443                        | 492.788                           | 46.494                                         | 1833.71              |
| S.D.                  | 46.615                        | 38.427                                           | 6.396                             | 76.915                             | 31.151                                              | 10.886                        | 1.498                           | 2.136                                           | 0.529                                        | 0.553                         | 6.343                              | 2.183                          | 6.359                         | 42.168                            | 1.808                                          | 108.112              |
| Biomass (mg.m-3)      | 1105.24                       | 436.371                                          | 144.088                           | 120.002                            | 113.477                                             | 65.029                        | 126.045                         | 1.544                                           | 0.674                                        | 0.97                          | 42.459                             | 54.16                          | 2.069                         | 116.106                           | 11.734                                         | 2339.97              |
| <b>Enclosure (4X)</b> |                               |                                                  |                                   |                                    |                                                     |                               |                                 |                                                 |                                              |                               |                                    |                                |                               |                                   |                                                |                      |
| P.U. (ml-1)           | 72.516                        | 142.065                                          | 25.023                            | 681.59                             | 185.749                                             | 110.054                       | 47.005                          | 10.231                                          | 0.553                                        | 1.106                         | 11.901                             | 10.231                         | 21.033                        | 462.466                           | 38.745                                         | 1820.27              |
| S.D.                  | 34.121                        | 17.344                                           | 8.107                             | 98.948                             | 18.936                                              | 5.236                         | 7.053                           | 4.571                                           | 1.106                                        | 0                             | 3.173                              | 3.626                          | 5.27                          | 60.701                            | 5.572                                          | 192.317              |
| Biomass (mg.m-3)      | 1230.432                      | 568.786                                          | 160                               | 112.203                            | 109.361                                             | 101.639                       | 135.618                         | 1.524                                           | 0.899                                        | 0.431                         | 58.016                             | 58.084                         | 58.084                        | 108.962                           | 9.778                                          | 2657.16              |
| <b>Lake</b>           |                               |                                                  |                                   |                                    |                                                     |                               |                                 |                                                 |                                              |                               |                                    |                                |                               |                                   |                                                |                      |
| P.U. (ml-1)           | 29.45                         | 62.2                                             | 28.48                             | 247.818                            | 139.592                                             | 48.941                        | 29.309                          | 7.742                                           | 0.553                                        | 2.489                         | 1.106                              | 4.424                          | 33.21                         | 317.18                            | 39.852                                         | 992.344              |
| S.D.                  | 0.919                         | 2.167                                            | 5.083                             | 10.208                             | 5.271                                               | 6.648                         | 4.692                           | 3.128                                           | 0.782                                        | 1.173                         | 0                                  | 0.782                          | 9.393                         | 45.508                            | 6.262                                          | 97.683               |
| Biomass (mg.m-3)      | 499.7                         | 249.028                                          | 182.099                           | 40.796                             | 82.186                                              | 45.199                        | 84.562                          | 1.153                                           | 0.899                                        | 0.97                          | 5.392                              | 25.117                         | 2.257                         | 74.731                            | 10.058                                         | 1304.15              |

# Appendix IV : Experiment 8 Summer Lake Pupuke 4/2/92 - 14/2/92

| Day 6 (10/2/92)       | <i>Peridinium<br/>cinctum</i> | <i>Staurastrum<br/>johnsonii<br/>var. altuis</i> | <i>Fragilaria<br/>crotonensis</i> | <i>Elakatothrix<br/>gelatinosa</i> | <i>Staurastrum<br/>leptocladum<br/>var. insigne</i> | <i>Staurastrum<br/>pinque</i> | <i>Cosmarium<br/>contractum</i> | <i>Closterium<br/>acutum var.<br/>variabile</i> | <i>Cryptomonas<br/>ovata +<br/>marssonii</i> | <i>Tetradron<br/>minimum</i> | <i>Trachelomonas<br/>volvicina</i> | <i>Cosmarium<br/>perfisum</i> | Unidenti-<br>fied<br>Unicells | <i>Oocystis<br/>cf. lacustris</i> | <i>Scenesmus<br/>bijuga var.<br/>alternans</i> | Total<br>P.U. (ml-1) |
|-----------------------|-------------------------------|--------------------------------------------------|-----------------------------------|------------------------------------|-----------------------------------------------------|-------------------------------|---------------------------------|-------------------------------------------------|----------------------------------------------|------------------------------|------------------------------------|-------------------------------|-------------------------------|-----------------------------------|------------------------------------------------|----------------------|
| <b>Exclosure</b>      |                               |                                                  |                                   |                                    |                                                     |                               |                                 |                                                 |                                              |                              |                                    |                               |                               |                                   |                                                |                      |
| P.U. (ml-1) (ml-1)    | 39.772                        | 90.132                                           | 56.295                            | 294.421                            | 282.065                                             | 84.967                        | 74.119                          | 12.304                                          | 0.415                                        | 5.392                        | 4.009                              | 13.549                        | 50.922                        | 350.335                           | 66.42                                          | 1425.12              |
| S.D.                  | 11.801                        | 26.225                                           | 14.119                            | 97.014                             | 71.528                                              | 25.809                        | 23.405                          | 2.76                                            | 0.277                                        | 1.936                        | 4.679                              | 1.889                         | 11.144                        | 61.703                            | 13.036                                         | 198.494              |
| Biomass (mg.m-3)      | 674.832                       | 360.861                                          | 359.952                           | 48.468                             | 166.069                                             | 78.47                         | 213.847                         | 1.833                                           | 0.674                                        | 2.101                        | 19.545                             | 76.922                        | 3.461                         | 82.542                            | 16.763                                         | 2106.34              |
| <b>Enclosure (1X)</b> |                               |                                                  |                                   |                                    |                                                     |                               |                                 |                                                 |                                              |                              |                                    |                               |                               |                                   |                                                |                      |
| P.U. (ml-1)           | 36.846                        | 112.761                                          | 35.116                            | 485.272                            | 266.052                                             | 97.621                        | 62.918                          | 16.175                                          | 0.138                                        | 7.051                        | 1.936                              | 17.144                        | 38.745                        | 661.155                           | 84.132                                         | 1923.06              |
| S.D.                  | 7.656                         | 14.609                                           | 1.834                             | 95.433                             | 52.361                                              | 26.737                        | 4.619                           | 1.936                                           | 0.277                                        | 2.088                        | 1.151                              | 2.514                         | 11.07                         | 109.338                           | 25.114                                         | 260.774              |
| Biomass (mg.m-3)      | 625.184                       | 451.459                                          | 224.53                            | 79.885                             | 156.641                                             | 90.156                        | 181.53                          | 2.409                                           | 0.225                                        | 2.748                        | 9.435                              | 97.333                        | 2.633                         | 155.775                           | 21.233                                         | 2101.18              |
| <b>Enclosure (2X)</b> |                               |                                                  |                                   |                                    |                                                     |                               |                                 |                                                 |                                              |                              |                                    |                               |                               |                                   |                                                |                      |
| P.U. (ml-1)           | 43.198                        | 137.404                                          | 56.828                            | 515.554                            | 249.616                                             | 109.489                       | 62.833                          | 14.102                                          | 0.138                                        | 5.495                        | 8.433                              | 18.802                        | 32.103                        | 743.12                            | 79.704                                         | 2076.82              |
| S.D.                  | 8.177                         | 16.081                                           | 9.904                             | 80.028                             | 84.656                                              | 20.876                        | 3.93                            | 4.389                                           | 0.277                                        | 1.794                        | 5.215                              | 3.751                         | 6.884                         | 21.924                            | 13.885                                         | 175.858              |
| Biomass (mg.m-3)      | 732.964                       | 550.122                                          | 363.357                           | 84.87                              | 146.964                                             | 101.117                       | 181.285                         | 2.1                                             | 0.225                                        | 2.142                        | 41.111                             | 106.749                       | 2.182                         | 175.087                           | 20.116                                         | 2510.39              |
| <b>Enclosure (4X)</b> |                               |                                                  |                                   |                                    |                                                     |                               |                                 |                                                 |                                              |                              |                                    |                               |                               |                                   |                                                |                      |
| P.U. (ml-1)           | 33.032                        | 191.856                                          | 63.367                            | 1338.752                           | 401.142                                             | 199.81                        | 57.72                           | 12.719                                          | 0.068                                        | 8.433                        | 6.221                              | 23.364                        | 27.675                        | 840.169                           | 76.937                                         | 3281.26              |
| S.D.                  | 7.532                         | 49.85                                            | 21.991                            | 141.056                            | 86.118                                              | 28.768                        | 8.699                           | 4.692                                           | 0.135                                        | 5.425                        | 3.868                              | 2.229                         | 5.858                         | 157.893                           | 10.126                                         | 391.556              |
| Biomass (mg.m-3)      | 560.47                        | 768.134                                          | 405.168                           | 220.385                            | 236.176                                             | 184.532                       | 166.533                         | 1.894                                           | 0.11                                         | 3.287                        | 30.328                             | 132.652                       | 1.881                         | 197.952                           | 19.417                                         | 2928.92              |
| <b>Lake</b>           |                               |                                                  |                                   |                                    |                                                     |                               |                                 |                                                 |                                              |                              |                                    |                               |                               |                                   |                                                |                      |
| P.U. (ml-1)           | 57.106                        | 56.795                                           | 9.954                             | 308.358                            | 103.254                                             | 48.111                        | 33.733                          | 11.613                                          | 0.277                                        | 1.106                        | 6.913                              | 7.466                         | 13.284                        | 241.301                           | 44.28                                          | 943.549              |
| S.D.                  | 20.939                        | 3.811                                            | 1.564                             | 122.955                            | 1.621                                               | 0.782                         | 6.256                           | 0                                               | 0.391                                        | 0.782                        | 1.955                              | 1.173                         | 6.262                         | 50.062                            | 12.524                                         | 161.245              |
| Biomass (mg.m-3)      | 968.959                       | 227.388                                          | 63.646                            | 50.762                             | 60.792                                              | 44.432                        | 97.326                          | 1.73                                            | 0.45                                         | 0.431                        | 33.698                             | 42.386                        | 0.903                         | 56.853                            | 11.175                                         | 1660.93              |

# Appendix IV : Experiment 8 Summer Lake Pupuke 4/2/92 - 14/2/92

| Day 10 (14/2/92)      | <i>Peridinium<br/>cinctum</i> | <i>Staurastrum<br/>johnsonii<br/>var. altuis</i> | <i>Fragilaria<br/>crotonensis</i> | <i>Elakatothrix<br/>gelatinosa</i> | <i>Staurastrum<br/>leptocladum<br/>var. insigne</i> | <i>Staurastrum<br/>pinque</i> | <i>Cosmarium<br/>contractum</i> | <i>Closterium<br/>acutum var.<br/>variabile</i> | <i>Cryptomonas<br/>ovata +<br/>marssonii</i> | <i>Tetradron<br/>minimum</i> | <i>Trachelomonas<br/>volvicina</i> | <i>Cosmarium<br/>perfissum</i> | Unidenti-<br>fied<br>Unicells | <i>Oocystis<br/>cf. lacustris</i> | <i>Scenesmus<br/>bijuga var.<br/>alternans</i> | Total<br>P.U. (ml-1) |
|-----------------------|-------------------------------|--------------------------------------------------|-----------------------------------|------------------------------------|-----------------------------------------------------|-------------------------------|---------------------------------|-------------------------------------------------|----------------------------------------------|------------------------------|------------------------------------|--------------------------------|-------------------------------|-----------------------------------|------------------------------------------------|----------------------|
| <b>Enclosure</b>      |                               |                                                  |                                   |                                    |                                                     |                               |                                 |                                                 |                                              |                              |                                    |                                |                               |                                   |                                                |                      |
| P.U. (ml-1) (ml-1)    | 18.781                        | 51.015                                           | 45.346                            | 158.588                            | 294.382                                             | 60.925                        | 66.611                          | 8.986                                           | 0.138                                        | 13.963                       | 1.797                              | 18.664                         | 100.737                       | 416.851                           | 99.63                                          | 1356.41              |
| S.D.                  | 5.471                         | 6.81                                             | 18.324                            | 60.125                             | 44.028                                              | 17.748                        | 14.266                          | 4.456                                           | 0.277                                        | 2.362                        | 1.651                              | 11.219                         | 16.419                        | 125.504                           | 48.54                                          | 203.357              |
| Biomass (mg.m-3)      | 318.662                       | 204.25                                           | 289.944                           | 26.107                             | 173.32                                              | 56.266                        | 192.184                         | 1.338                                           | 0.225                                        | 5.442                        | 8.761                              | 105.964                        | 6.847                         | 98.214                            | 25.145                                         | 1512.67              |
| <b>Enclosure (1X)</b> |                               |                                                  |                                   |                                    |                                                     |                               |                                 |                                                 |                                              |                              |                                    |                                |                               |                                   |                                                |                      |
| P.U. (ml-1)           | 40.495                        | 59.418                                           | 51.429                            | 366.86                             | 265.517                                             | 56.269                        | 63.734                          | 16.59                                           | 0                                            | 12.581                       | 4.148                              | 18.249                         | 58.671                        | 701.2                             | 127.859                                        | 1843.02              |
| S.D.                  | 10.111                        | 20.289                                           | 9.131                             | 31.88                              | 35.262                                              | 6.87                          | 8.803                           | 1.862                                           | 0                                            | 3.997                        | 1.719                              | 2.389                          | 16.419                        | 60.169                            | 18.291                                         | 111.549              |
| Biomass (mg.m-3)      | 687.108                       | 237.891                                          | 328.839                           | 60.393                             | 156.326                                             | 51.967                        | 183.885                         | 2.471                                           | 0                                            | 4.903                        | 20.219                             | 103.61                         | 3.988                         | 165.21                            | 32.269                                         | 2039.08              |
| <b>Enclosure (2X)</b> |                               |                                                  |                                   |                                    |                                                     |                               |                                 |                                                 |                                              |                              |                                    |                                |                               |                                   |                                                |                      |
| P.U. (ml-1)           | 29.908                        | 96.247                                           | 74.395                            | 293.688                            | 242.355                                             | 73.996                        | 91.016                          | 12.581                                          | 0                                            | 10.922                       | 6.083                              | 23.917                         | 79.704                        | 811.891                           | 128.412                                        | 1975.11              |
| S.D.                  | 14.891                        | 12.405                                           | 40.832                            | 125.103                            | 51.836                                              | 10.082                        | 25.288                          | 7.244                                           | 0                                            | 2.489                        | 2.258                              | 3.679                          | 29.759                        | 236.91                            | 26.071                                         | 488.092              |
| Biomass (mg.m-3)      | 507.471                       | 385.344                                          | 475.681                           | 48.347                             | 142.689                                             | 68.338                        | 262.598                         | 1.874                                           | 0                                            | 4.257                        | 29.654                             | 135.791                        | 5.417                         | 191.29                            | 32.409                                         | 2291.16              |
| <b>Enclosure (4X)</b> |                               |                                                  |                                   |                                    |                                                     |                               |                                 |                                                 |                                              |                              |                                    |                                |                               |                                   |                                                |                      |
| P.U. (ml-1)           | 20.083                        | 132.83                                           | 66.691                            | 342.821                            | 222.81                                              | 82.979                        | 91.582                          | 7.88                                            | 0                                            | 10.369                       | 4.148                              | 35.807                         | 50.369                        | 968.81                            | 106.165                                        | 2142.34              |
| S.D.                  | 6.488                         | 38.744                                           | 8.824                             | 47.037                             | 43.477                                              | 21.451                        | 14.021                          | 4.679                                           | 0                                            | 2.608                        | 2.494                              | 8.403                          | 17.09                         | 154.044                           | 18.916                                         | 267.806              |
| Biomass (mg.m-3)      | 340.754                       | 531.811                                          | 426.423                           | 56.435                             | 131.181                                             | 76.635                        | 264.231                         | 1.174                                           | 0                                            | 4.041                        | 20.219                             | 203.295                        | 3.424                         | 228.261                           | 26.542                                         | 2314.43              |
| <b>Lake</b>           |                               |                                                  |                                   |                                    |                                                     |                               |                                 |                                                 |                                              |                              |                                    |                                |                               |                                   |                                                |                      |
| P.U. (ml-1)           | 51.737                        | 43.211                                           | 10.784                            | 263.95                             | 100.25                                              | 33.733                        | 27.927                          | 6.913                                           | 0.553                                        | 1.383                        | 4.148                              | 4.424                          | 43.173                        | 181.548                           | 46.494                                         | 820.225              |
| S.D.                  | 3.95                          | 2.546                                            | 1.173                             | 3.233                              | 21.284                                              | 0.782                         | 3.519                           | 3.519                                           | 0.782                                        | 1.173                        | 0.391                              | 1.564                          | 14.09                         | 40.704                            | 0                                              | 10.358               |
| Biomass (mg.m-3)      | 877.859                       | 173.002                                          | 68.95                             | 43.451                             | 59.023                                              | 31.154                        | 80.573                          | 1.03                                            | 0.899                                        | 0.539                        | 20.219                             | 25.117                         | 2.934                         | 42.775                            | 11.734                                         | 1439.26              |

# Appendix V : Experiment 1 Autumn 1/6/90 - 11/6/90 Lake Rotoroa

|                       | Day 0 (1/6/90)     |                     |           | Day 3 (4/6/90)     |                     |           | Day 6 (7/6/90)     |                     |           | Day 10 (11/6/90)   |                     |           |
|-----------------------|--------------------|---------------------|-----------|--------------------|---------------------|-----------|--------------------|---------------------|-----------|--------------------|---------------------|-----------|
|                       | <i>Dinobryon</i>   | <i>Botryococcus</i> | Total     | <i>Dinobryon</i>   | <i>Botryococcus</i> | Total     | <i>Dinobryon</i>   | <i>Botryococcus</i> | Total     | <i>Dinobryon</i>   | <i>Botryococcus</i> | Total     |
|                       | <i>cylindricum</i> | <i>braunii</i>      |           | <i>cylindricum</i> | <i>braunii</i>      |           | <i>cylindricum</i> | <i>braunii</i>      |           | <i>cylindricum</i> | <i>braunii</i>      |           |
| <b>Exclosure</b>      |                    |                     |           |                    |                     |           |                    |                     |           |                    |                     |           |
| P.U. (ml-1)           | 15.3               | 0.407               | 15.707    | 13.394             | 0.542               | 13.936    | 19.547             | 1.237               | 20.784    | 26.902             | 1.877               | 28.778    |
| S.D.                  | 1.697              | 0.192               | 1.505     | 1.83               | 0                   | 1.83      | 2.671              | 0.101               | 2.57      | 7.52               | 0.504               | 8.024     |
| Biomass (mg.m-3)      | 108.477            | 3730.252            | 3838.729  | 94.963             | 4973.669            | 5068.632  | 138.588            | 11346.756           | 11485.344 | 190.732            | 17219.723           | 17410.455 |
| <b>Enclosure (1X)</b> |                    |                     |           |                    |                     |           |                    |                     |           |                    |                     |           |
| P.U. (ml-1)           | 17.35              | 0.949               | 18.299    | 14.044             | 1.084               | 15.128    | 21.669             | 1.549               | 23.217    | 33                 | 2.087               | 35.087    |
| S.D.                  | 0.636              | 0.958               | 0.322     | 0.911              | 0                   | 0.911     | 2.922              | 0.136               | 3.059     | 0                  | 1.715               | 1.715     |
| Biomass (mg.m-3)      | 123.012            | 8703.921            | 8826.932  | 99.572             | 9947.338            | 10046.91  | 153.63             | 14209.827           | 14363.457 | 233.97             | 19151.378           | 19385.348 |
| <b>Enclosure (2X)</b> |                    |                     |           |                    |                     |           |                    |                     |           |                    |                     |           |
| P.U. (ml-1)           | 17.197             | 0.813               | 18.01     | 14.725             | 0.949               | 15.674    | 25.903             | 3.021               | 28.924    | 37.039             | 4.133               | 41.172    |
| S.D.                  | 0.419              | 0.383               | 0.036     | 0.247              | 0.575               | 0.327     | 6.355              | 1.206               | 7.561     | 1.532              | 1.817               | 3.349     |
| Biomass (mg.m-3)      | 121.923            | 7460.503            | 7582.427  | 104.4              | 8703.921            | 8808.321  | 183.649            | 27722.24            | 27905.888 | 262.607            | 37926.52            | 38189.126 |
| <b>Enclosure (4X)</b> |                    |                     |           |                    |                     |           |                    |                     |           |                    |                     |           |
| P.U. (ml-1)           | 17.674             | 1.084               | 18.758    | 20.075             | 2.846               | 22.921    | 29.9               | 4.058               | 33.958    | 35.694             | 2.219               | 37.913    |
| S.D.                  | 3.711              | 0                   | 3.711     | 10.642             | 0.958               | 9.684     | 8.061              | 2.316               | 10.377    | 9.342              | 1.343               | 7.999     |
| Biomass (mg.m-3)      | 125.309            | 9947.338            | 10072.647 | 142.332            | 26111.762           | 26254.094 | 211.991            | 37238.282           | 37450.273 | 253.07             | 20358.09            | 20611.16  |
| <b>Lake</b>           |                    |                     |           |                    |                     |           |                    |                     |           |                    |                     |           |
| P.U. (ml-1)           | 16.48              | 0.949               | 17.429    | 17.394             | 1.22                | 18.613    | 34.548             | 4.257               | 38.805    | 29.831             | 1.504               | 31.334    |
| S.D.                  | 3.366              | 0.192               | 3.557     | 3.826              | 0.192               | 4.018     | 5.872              | 0                   | 5.872     | 1.05               | 1.032               | 0.018     |
| Biomass (mg.m-3)      | 116.843            | 8703.921            | 8820.764  | 123.32             | 11190.755           | 11314.075 | 244.945            | 39064.407           | 39309.353 | 211.498            | 13796.884           | 14008.383 |

P.U. (ml-1) and Biomass (mg.m-3) are mean values where n = 4

Appendix V : Experiment 2 Winter 27/7/90 - 6/8/90 Lake Rotoroa

|                       | Day 0 (27/7/90)<br><i>Botryococcus<br/>braunii</i> | Day 3 (30/7/90)<br><i>Botryococcus<br/>braunii</i> | Day 6 (2/8/90)<br><i>Botryococcus<br/>braunii</i> | Day 10 (6/8/90)<br><i>Botryococcus<br/>braunii</i> |
|-----------------------|----------------------------------------------------|----------------------------------------------------|---------------------------------------------------|----------------------------------------------------|
| <b>Exclosure</b>      |                                                    |                                                    |                                                   |                                                    |
| P.U. (ml-1)           | 1.016                                              | 0.678                                              | 0.474                                             | 0.542                                              |
| S.D.                  | 0.407                                              | 0.645                                              | 0.259                                             | 0.585                                              |
| Biomass (mg.m-3)      | 9325.629                                           | 6217.086                                           | 4351.96                                           | 4973.669                                           |
| <b>Enclosure (1X)</b> | 2.371                                              | 3.32                                               | 1.694                                             | 2.981                                              |
| P.U. (ml-1)           | 1.353                                              | 1.239                                              | 0.559                                             | 0.585                                              |
| S.D.                  | 21759.802                                          | 30463.722                                          | 15542.716                                         | 27355.179                                          |
| Biomass (mg.m-3)      |                                                    |                                                    |                                                   |                                                    |
| <b>Enclosure (2X)</b> |                                                    |                                                    |                                                   |                                                    |
| P.U. (ml-1)           | 2.913                                              | 4.675                                              | 5.827                                             | 6.707                                              |
| S.D.                  | 2.282                                              | 1.158                                              | 1.791                                             | 2.93                                               |
| Biomass (mg.m-3)      | 26733.471                                          | 42897.895                                          | 53466.941                                         | 61549.153                                          |
| <b>Enclosure (4X)</b> |                                                    |                                                    |                                                   |                                                    |
| P.U. (ml-1)           | 1.423                                              | 8.198                                              | 17.073                                            | 12.737                                             |
| S.D.                  | 0.513                                              | 2.593                                              | 6.192                                             | 5.031                                              |
| Biomass (mg.m-3)      | 13055.881                                          | 75226.743                                          | 156670.572                                        | 116881.221                                         |
| <b>Lake</b>           |                                                    |                                                    |                                                   |                                                    |
| P.U. (ml-1)           | 1.897                                              | 2.575                                              | 1.897                                             | 8.266                                              |
| S.D.                  | 1.15                                               | 1.725                                              | 0.383                                             | 4.024                                              |
| Biomass (mg.m-3)      | 17407.841                                          | 23624.928                                          | 17407.841                                         | 75848.452                                          |

# Appendix V : Experiment 5 Autumn 21/5/91 - 31/5/91 Lake Pupuke

|                       | Day 0 (21/5/91)      | Day 3 (24/5/91)      | Day 6 (27/5/91)      | Day 10 (31/5/91)     |
|-----------------------|----------------------|----------------------|----------------------|----------------------|
|                       | <i>Mougeotia sp.</i> | <i>Mougeotia sp.</i> | <i>Mougeotia sp.</i> | <i>Mougeotia sp.</i> |
| <b>Exclosure</b>      |                      |                      |                      |                      |
| P.U. (ml-1)           | 8.522                | 16.025               | 24.646               | 38.922               |
| S.D.                  | 1.196                | 1.357                | 2.705                | 5.384                |
| Biomass (mg.m-3)      | 50.152               | 94.309               | 145.039              | 229.057              |
| <b>Enclosure (1X)</b> |                      |                      |                      |                      |
| P.U. (ml-1)           | 12.048               | 21.89                | 32.906               | 12.893               |
| S.D.                  | 1.612                | 7.567                | 11.731               | 2.046                |
| Biomass (mg.m-3)      | 70.901               | 128.82               | 193.649              | 75.872               |
| <b>Enclosure (2X)</b> |                      |                      |                      |                      |
| P.U. (ml-1)           | 7.493                | 31.371               | 24.396               | 24.153               |
| S.D.                  | 0.752                | 2.241                | 3.08                 | 9.273                |
| Biomass (mg.m-3)      | 44.093               | 184.62               | 143.57               | 142.142              |
| <b>Enclosure (4X)</b> |                      |                      |                      |                      |
| P.U. (ml-1)           | 8.404                | 47.712               | 32.6                 | 177.343              |
| S.D.                  | 1.396                | 23.737               | 18.216               | 151.347              |
| Biomass (mg.m-3)      | 49.456               | 280.782              | 191.851              | 1043.661             |
| <b>Lake</b>           |                      |                      |                      |                      |
| P.U. (ml-1)           | 8.505                | 22.517               | 13.513               | 2.903                |
| S.D.                  | 0.191                | 1.438                | 8.609                | 0.477                |
| Biomass (mg.m-3)      | 50.052               | 132.51               | 79.521               | 17.081               |

# Appendix V : Experiment 6 Winter 23/7/91 - 2/8/91 Lake Pupuke

|                       | Day 0 (23/7/91)         |                   |                  |        | Day 3 (26/7/91)         |                   |                  |        | Day 6 (29/7/91)         |                   |                  |       | Day 10 (2/8/91)         |                   |                  |        |
|-----------------------|-------------------------|-------------------|------------------|--------|-------------------------|-------------------|------------------|--------|-------------------------|-------------------|------------------|-------|-------------------------|-------------------|------------------|--------|
|                       | <i>Fragilaria</i>       | <i>Aulacosira</i> | <i>Mougeotia</i> | Total  | <i>Fragilaria</i>       | <i>Aulacosira</i> | <i>Mougeotia</i> | Total  | <i>Fragilaria</i>       | <i>Aulacosira</i> | <i>Mougeotia</i> | Total | <i>Fragilaria</i>       | <i>Aulacosira</i> | <i>Mougeotia</i> | Total  |
|                       | <i>ulna + granulata</i> | <i>sp.</i>        |                  |        | <i>ulna + granulata</i> | <i>sp.</i>        |                  |        | <i>ulna + granulata</i> | <i>sp.</i>        |                  |       | <i>ulna + granulata</i> | <i>sp.</i>        |                  |        |
|                       | <i>F. u.var.acus</i>    |                   |                  |        | <i>F. u.var.acus</i>    |                   |                  |        | <i>F. u.var.acus</i>    |                   |                  |       | <i>F. u.var.acus</i>    |                   |                  |        |
| <b>Enclosure</b>      |                         |                   |                  |        |                         |                   |                  |        |                         |                   |                  |       |                         |                   |                  |        |
| P.U. (ml-1)           | 0.304                   | 0.844             | 0.304            | 1.451  | 4.151                   | 2.531             | 1.451            | 8.134  | 7.459                   | 1.418             | 1.283            | 10.16 | 33.694                  | 0.675             | 1.08             | 35.449 |
| S.D.                  | 0.129                   | 0.355             | 0.17             | 0.446  | 4.453                   | 2.416             | 1.658            | 6.895  | 4.953                   | 0.783             | 0.523            | 5.225 | 13.048                  | 0.191             | 0.468            | 13.102 |
| Biomass (mg.m-3)      | 0.316                   | 24.473            | 1.788            | 26.577 | 4.321                   | 73.419            | 8.541            | 86.281 | 7.765                   | 41.115            | 7.548            | 56.43 | 35.075                  | 19.578            | 6.356            | 61.01  |
| <b>Enclosure (1X)</b> |                         |                   |                  |        |                         |                   |                  |        |                         |                   |                  |       |                         |                   |                  |        |
| P.U. (ml-1)           | 0.304                   | 0.574             | 0.034            | 0.911  | 1.654                   | 1.856             | 1.485            | 4.995  | 2.835                   | 1.553             | 0.675            | 5.063 | 4.32                    | 1.451             | 4.523            | 10.294 |
| S.D.                  | 0.129                   | 0.17              | 0.068            | 0.256  | 0.805                   | 1.329             | 0.706            | 1.657  | 1.704                   | 0.42              | 0.48             | 2.36  | 3.858                   | 0.203             | 2.61             | 2.903  |
| Biomass (mg.m-3)      | 0.316                   | 16.642            | 0.199            | 17.156 | 1.722                   | 53.841            | 8.739            | 64.301 | 2.951                   | 45.03             | 3.972            | 51.95 | 4.497                   | 42.094            | 26.615           | 73.206 |
| <b>Enclosure (2X)</b> |                         |                   |                  |        |                         |                   |                  |        |                         |                   |                  |       |                         |                   |                  |        |
| P.U. (ml-1)           | 0.371                   | 0.641             | 0.034            | 1.046  | 1.519                   | 2.194             | 1.721            | 5.434  | 1.283                   | 1.384             | 1.586            | 4.253 | 2.194                   | 2.093             | 2.228            | 6.514  |
| S.D.                  | 0.299                   | 0.278             | 0.068            | 0.256  | 0.665                   | 0.555             | 0.963            | 1.189  | 1.06                    | 0.299             | 2.337            | 3.43  | 1.311                   | 1.22              | 0.638            | 2.178  |
| Biomass (mg.m-3)      | 0.386                   | 18.599            | 0.199            | 19.185 | 1.581                   | 63.63             | 10.13            | 75.34  | 1.335                   | 40.136            | 9.335            | 50.81 | 2.284                   | 60.693            | 13.109           | 76.085 |
| <b>Enclosure (4X)</b> |                         |                   |                  |        |                         |                   |                  |        |                         |                   |                  |       |                         |                   |                  |        |
| P.U. (ml-1)           | 0.236                   | 0.608             | 0.169            | 1.013  | 0.473                   | 2.599             | 0.709            | 3.78   | 0.304                   | 1.181             | 0.236            | 1.721 | 0.709                   | 2.16              | 5.771            | 8.64   |
| S.D.                  | 0.17                    | 0.321             | 0.129            | 0.546  | 0.281                   | 0.79              | 0.864            | 1.683  | 0.231                   | 0.587             | 0.388            | 1.115 | 0.231                   | 0.292             | 3.975            | 4.344  |
| Biomass (mg.m-3)      | 0.246                   | 17.621            | 0.993            | 18.86  | 0.492                   | 75.377            | 4.171            | 80.04  | 0.316                   | 34.262            | 1.39             | 35.97 | 0.738                   | 62.651            | 33.964           | 97.351 |
| <b>Lake</b>           |                         |                   |                  |        |                         |                   |                  |        |                         |                   |                  |       |                         |                   |                  |        |
| P.U. (ml-1)           | 0.338                   | 0.473             | 0.135            | 0.945  | 3.645                   | 0.878             | 0.338            | 4.86   | 0.135                   | 0.405             | 0.068            | 0.608 | 1.35                    | 1.148             | 0.068            | 2.565  |
| S.D.                  | 0.095                   | 0.286             | 0                | 0.191  | 3.627                   | 0.668             | 0.095            | 4.391  | 0.191                   | 0.191             | 0.095            | 0.477 | 0                       | 0.668             | 0.095            | 0.764  |
| Biomass (mg.m-3)      | 0.351                   | 13.705            | 0.794            | 14.851 | 3.794                   | 25.452            | 1.986            | 31.233 | 0.141                   | 11.747            | 0.397            | 12.29 | 1.405                   | 33.283            | 0.397            | 35.086 |



Appendix V : Experiment 7 Spring 8/10/91 - 18/10/91 Lake Pupuke

|                       | Day 0 (8/10/91)         |                   |                  |        | Day 3 (11/10/91)        |                   |                  |        | Day 6 (14/10/91)        |                   |                  |       | Day 10 (18/10/91)       |                   |                  |         |
|-----------------------|-------------------------|-------------------|------------------|--------|-------------------------|-------------------|------------------|--------|-------------------------|-------------------|------------------|-------|-------------------------|-------------------|------------------|---------|
|                       | <i>Fragilaria</i>       | <i>Aulacosira</i> | <i>Mougeotia</i> | Total  | <i>Fragilaria</i>       | <i>Aulacosira</i> | <i>Mougeotia</i> | Total  | <i>Fragilaria</i>       | <i>Aulacosira</i> | <i>Mougeotia</i> | Total | <i>Fragilaria</i>       | <i>Aulacosira</i> | <i>Mougeotia</i> | Total   |
|                       | <i>ulna + granulata</i> | <i>sp.</i>        |                  |        | <i>ulna + granulata</i> | <i>sp.</i>        |                  |        | <i>ulna + granulata</i> | <i>sp.</i>        |                  |       | <i>ulna + granulata</i> | <i>sp.</i>        |                  |         |
|                       | <i>F.u.var.acus</i>     |                   |                  |        | <i>F.u.var.acus</i>     |                   |                  |        | <i>F.u.var.acus</i>     |                   |                  |       | <i>F.u.var.acus</i>     |                   |                  |         |
| <b>Enclosure</b>      |                         |                   |                  |        |                         |                   |                  |        |                         |                   |                  |       |                         |                   |                  |         |
| P.U. (ml-1)           | 1.789                   | 2.261             | 12.934           | 16.984 | 2.228                   | 1.114             | 13.642           | 16.983 | 3.611                   | 1.519             | 25.479           | 30.61 | 3.78                    | 1.553             | 35.603           | 40.935  |
| S.D.                  | 0.743                   | 0.459             | 8.362            | 9.28   | 1.127                   | 0.828             | 6.607            | 8.331  | 1.311                   | 0.775             | 22.063           | 23.39 | 1.304                   | 0.647             | 14.516           | 15.018  |
| Biomass (mg.m-3)      | 1.862                   | 65.588            | 76.115           | 143.57 | 2.319                   | 32.304            | 80.28            | 114.9  | 3.759                   | 44.051            | 149.945          | 197.8 | 3.935                   | 45.03             | 209.522          | 258.487 |
| <b>Enclosure (1X)</b> |                         |                   |                  |        |                         |                   |                  |        |                         |                   |                  |       |                         |                   |                  |         |
| P.U. (ml-1)           | 1.148                   | 1.316             | 19.726           | 22.19  | 1.35                    | 2.025             | 9.653            | 13.028 | 1.451                   | 1.721             | 27.894           | 31.07 | 1.485                   | 3.004             | 30.219           | 34.707  |
| S.D.                  | 0.557                   | 0.278             | 13.757           | 14.268 | 0.661                   | 0.779             | 5.147            | 6.439  | 0.878                   | 0.372             | 12.245           | 13.17 | 0.81                    | 2.138             | 26.009           | 28.814  |
| Biomass (mg.m-3)      | 1.195                   | 38.178            | 116.089          | 155.46 | 1.405                   | 58.735            | 56.805           | 116.95 | 1.511                   | 49.925            | 164.153          | 215.6 | 1.546                   | 87.124            | 177.836          | 266.506 |
| <b>Enclosure (2X)</b> |                         |                   |                  |        |                         |                   |                  |        |                         |                   |                  |       |                         |                   |                  |         |
| P.U. (ml-1)           | 1.08                    | 2.295             | 11.762           | 15.137 | 0.81                    | 2.093             | 8.843            | 11.745 | 0.709                   | 1.654             | 10.024           | 12.39 | 1.418                   | 2.565             | 33.239           | 37.221  |
| S.D.                  | 0.382                   | 0.529             | 4.112            | 4.722  | 0.191                   | 0.259             | 5.383            | 5.357  | 0.299                   | 1                 | 0.871            | 0.963 | 1.072                   | 0.98              | 12.477           | 11.995  |
| Biomass (mg.m-3)      | 1.124                   | 66.566            | 69.218           | 136.91 | 0.843                   | 60.693            | 52.038           | 113.57 | 0.738                   | 47.967            | 58.99            | 107.7 | 1.476                   | 74.398            | 195.61           | 271.483 |
| <b>Enclosure (4X)</b> |                         |                   |                  |        |                         |                   |                  |        |                         |                   |                  |       |                         |                   |                  |         |
| P.U. (ml-1)           | 0.945                   | 2.556             | 14.655           | 18.156 | 2.565                   | 0.911             | 18.253           | 21.729 | 0.776                   | 3.409             | 9.686            | 13.87 | 1.283                   | 3.949             | 22.359           | 27.591  |
| S.D.                  | 0.643                   | 1.166             | 5.199            | 6.583  | 2.12                    | 0.338             | 16.177           | 17.986 | 0.319                   | 2.822             | 1.819            | 4.832 | 0.675                   | 1.418             | 10.741           | 12.438  |
| Biomass (mg.m-3)      | 0.984                   | 74.144            | 86.243           | 161.37 | 2.67                    | 26.431            | 107.416          | 136.52 | 0.808                   | 98.871            | 57.004           | 156.7 | 1.335                   | 114.533           | 131.584          | 247.453 |
| <b>Lake</b>           |                         |                   |                  |        |                         |                   |                  |        |                         |                   |                  |       |                         |                   |                  |         |
| P.U. (ml-1)           | 0.743                   | 1.35              | 2.97             | 5.063  | 1.958                   | 0.945             | 7.155            | 10.058 | 3.173                   | 0.608             | 5.198            | 8.978 | 0.675                   | 0.405             | 2.025            | 3.105   |
| S.D.                  | 0.095                   | 1.146             | 0                | 1.241  | 0.095                   | 0.191             | 0.573            | 0.668  | 2.005                   | 0.286             | 1.814            | 4.105 | 0.191                   | 0.191             | 0                | 0       |
| Biomass (mg.m-3)      | 0.773                   | 39.157            | 17.478           | 57.408 | 2.038                   | 27.41             | 42.107           | 71.555 | 3.308                   | 17.621            | 30.587           | 51.51 | 0.703                   | 11.747            | 11.917           | 24.367  |

# Appendix V : Experiment 8 Summer 4/2/92 - 14/2/92 Lake Pupuke

|                       | Day 0 (4/2/92)    |                   |                     |        | Day 3 (7/2/92)    |                   |                     |        | Day 6 (10/2/92)   |                   |                     |       | Day 10 (14/2/92)  |                   |                     |         |
|-----------------------|-------------------|-------------------|---------------------|--------|-------------------|-------------------|---------------------|--------|-------------------|-------------------|---------------------|-------|-------------------|-------------------|---------------------|---------|
|                       | <i>Closterium</i> | <i>Aulacosira</i> | <i>Ceratium</i>     | Total  | <i>Closterium</i> | <i>Aulacosira</i> | <i>Ceratium</i>     | Total  | <i>Closterium</i> | <i>Aulacosira</i> | <i>Ceratium</i>     | Total | <i>Closterium</i> | <i>Aulacosira</i> | <i>Ceratium</i>     | Total   |
|                       | <i>aciculare</i>  | <i>granulata</i>  | <i>hurundinella</i> |        | <i>aciculare</i>  | <i>granulata</i>  | <i>hurundinella</i> |        | <i>aciculare</i>  | <i>granulata</i>  | <i>hurundinella</i> |       | <i>aciculare</i>  | <i>granulata</i>  | <i>hurundinella</i> |         |
| <b>Exclosure</b>      |                   |                   |                     |        |                   |                   |                     |        |                   |                   |                     |       |                   |                   |                     |         |
| P.U. (ml-1)           | 45.087            | 0.135             | 0.54                | 45.762 | 40.254            | 0.068             | 0.236               | 40.558 | 46.9              | 0.068             | 0                   | 46.97 | 56.109            | 0.068             | 0.068               | 56.244  |
| S.D.                  | 13.697            | 0.156             | 0.832               | 13.783 | 8.937             | 0.135             | 0.068               | 8.982  | 8.98              | 0.135             | 0                   | 9.014 | 11.537            | 0.078             | 0.078               | 11.481  |
| Biomass (mg.m-3)      | 94.501            | 3.916             | 22.518              | 120.94 | 84.373            | 1.958             | 9.852               | 96.182 | 98.301            | 1.958             | 0                   | 100.3 | 117.604           | 1.958             | 2.815               | 122.377 |
| <b>Enclosure (1X)</b> |                   |                   |                     |        |                   |                   |                     |        |                   |                   |                     |       |                   |                   |                     |         |
| P.U. (ml-1)           | 44.826            | 0.203             | 1.755               | 46.783 | 49.985            | 0.034             | 0.641               | 50.55  | 74.377            | 0.135             | 0.236               | 74.75 | 79.368            | 0.034             | 0.169               | 79.571  |
| S.D.                  | 5.365             | 0.259             | 1.996               | 6.294  | 2.771             | 0.068             | 0.566               | 2.951  | 13.087            | 0.27              | 0.231               | 13.06 | 14.73             | 0.068             | 0.256               | 14.89   |
| Biomass (mg.m-3)      | 93.955            | 5.874             | 73.184              | 173.01 | 104.769           | 0.979             | 26.74               | 132.49 | 155.894           | 3.916             | 9.852               | 169.7 | 166.355           | 0.979             | 7.037               | 174.371 |
| <b>Enclosure (2X)</b> |                   |                   |                     |        |                   |                   |                     |        |                   |                   |                     |       |                   |                   |                     |         |
| P.U. (ml-1)           | 67.692            | 0                 | 0.506               | 68.198 | 58.573            | 0.236             | 0.135               | 58.944 | 70.354            | 0.034             | 0.608               | 71    | 100.628           | 0.338             | 0.135               | 101.101 |
| S.D.                  | 35.831            | 0                 | 0.403               | 35.88  | 7.978             | 0.473             | 0.156               | 8.174  | 3.199             | 0.068             | 0.259               | 3.376 | 19.415            | 0.281             | 0.191               | 19.258  |
| Biomass (mg.m-3)      | 141.882           | 0                 | 21.111              | 162.99 | 122.768           | 6.852             | 5.63                | 135.25 | 147.463           | 0.979             | 25.333              | 173.8 | 210.916           | 9.789             | 5.63                | 226.335 |
| <b>Enclosure (4X)</b> |                   |                   |                     |        |                   |                   |                     |        |                   |                   |                     |       |                   |                   |                     |         |
| P.U. (ml-1)           | 32.465            | 0.068             | 0.338               | 32.87  | 51.385            | 0.169             | 0.371               | 51.925 | 97.666            | 0.574             | 0.101               | 98.34 | 90.433            | 0.203             | 0.203               | 90.838  |
| S.D.                  | 7.566             | 0.135             | 0.135               | 7.494  | 10.726            | 0.203             | 0.432               | 10.686 | 22.079            | 0.355             | 0.203               | 22.47 | 9.409             | 0.405             | 0.234               | 9.685   |
| Biomass (mg.m-3)      | 68.046            | 1.958             | 14.074              | 84.078 | 107.703           | 4.895             | 15.481              | 128.08 | 204.708           | 16.642            | 4.222               | 225.6 | 189.547           | 5.874             | 8.444               | 203.865 |
| <b>Lake</b>           |                   |                   |                     |        |                   |                   |                     |        |                   |                   |                     |       |                   |                   |                     |         |
| P.U. (ml-1)           | 29.682            | 0                 | 0.405               | 30.087 | 40.183            | 0                 | 0.54                | 40.723 | 34.744            | 0.068             | 0.743               | 35.55 | 39.087            | 0                 | 0.203               | 39.29   |
| S.D.                  | 4.472             | 0                 | 0.191               | 4.281  | 7.592             | 0                 | 0.382               | 7.21   | 6.142             | 0.095             | 1.05                | 5.187 | 0.547             | 0                 | 0.286               | 0.834   |
| Biomass (mg.m-3)      | 62.213            | 0                 | 16.889              | 79.102 | 84.223            | 0                 | 22.518              | 106.74 | 72.823            | 1.958             | 30.962              | 105.7 | 81.926            | 0                 | 8.444               | 90.371  |

**Appendix VI** Size and volume of dominant phytoplankton taxa occurring in the limnocorral experiments (1-4) on Lake Rotoroa.

| Taxa                                                     | GALD<br>( $\mu\text{m}$ ) | SGALD<br>( $\mu\text{m}$ ) | Biovolume<br>( $\mu\text{m}^3$ ) |
|----------------------------------------------------------|---------------------------|----------------------------|----------------------------------|
| <i>Asterionella formosa</i>                              | 80.06                     | 80.06                      | 1,887.80                         |
| <i>Botryococcus braunii</i>                              | 232.60                    | 160.40                     | 9,176,510.98                     |
| <i>Coelastrum reticulatum</i>                            | 23.25<br>26.53            | 23.25<br>24.72             | 5,383.80<br>9,630.85             |
| <i>Cosmarium perfissum</i>                               | 15.24                     | 11.48                      | 602.46                           |
| <i>Cryptomonas marssonii</i><br>+ <i>C. ovata</i>        | 18.78                     | 10.40                      | 1,101.08                         |
| <i>Cyclotella meneghiniana</i><br>+ <i>C. stelligera</i> | 10.86                     | 10.86                      | 480.72                           |
| <i>Cyclotella stelligera</i>                             | 9.81                      | 9.81                       | 244.84                           |
| <i>Dinobryon cylindricum</i>                             | 199.96                    | 81.74                      | 7,090.44                         |
| <i>Elakatothrix gelatinosa</i>                           | 43.70                     | 10.59                      | 141.70                           |
| <i>Fragilaria capucina</i>                               | 58.13                     | 2.56                       | 377.44                           |
| <i>Oocystis</i> cf. <i>lacustris</i>                     | 9.91<br>10.03<br>11.81    | 6.80<br>7.62<br>8.79       | 246.91<br>351.55<br>447.51       |
| <i>Pediastrum tetras</i>                                 | 20.06                     | 20.06                      | 438.38                           |
| <i>Peridinium cinctum</i>                                | 53.76                     | 51.56                      | 26,376.05                        |
| <i>Scenedesmus quadricauda</i><br>+ <i>S. ecornis</i>    | 8.88                      | 7.44                       | 70.63                            |
| <i>Staurastrum leptocladum</i><br>var. <i>insigne</i>    | 54.25                     | 42.94                      | 391.12                           |
| <i>Staurodesmus unicornis</i><br>var. <i>gracilis</i>    | 29.26                     | 24.96                      | 573.59                           |
| <i>Tetrastrum triangulare</i>                            | 5.49                      | 4.39                       | 12.92                            |
| <i>Trachelomonas volvocina</i>                           | 15.32                     | 15.32                      | 2,080.24                         |

**Appendix VI**      Size and volume of dominant phytoplankton taxa occurring in the limnocorral experiments (5-8) on Lake Pupuke.

| Taxa                                                                   | GALD<br>( $\mu\text{m}$ ) | SGALD<br>( $\mu\text{m}$ ) | Biovolume<br>( $\mu\text{m}^3$ ) |
|------------------------------------------------------------------------|---------------------------|----------------------------|----------------------------------|
| <i>Achnanthes</i> sp.                                                  | 16.84                     | 3.20                       | 175.91                           |
| <i>Aulacosira granulata</i><br>+ <i>A. g.</i> var. <i>augustissima</i> | 359.88                    | 9.62                       | 29,005.38                        |
| <i>Ceratium hirundinella</i>                                           | 315.17                    | 60.76                      | 41,700.00                        |
| <i>Closterium acutum</i><br>var. <i>variabile</i>                      | 46.25                     | 6.15                       | 148.94                           |
| <i>Closterium aciculare</i>                                            | 319.12                    | 4.98                       | 2,096.28                         |
| <i>Cosmarium</i> cf. <i>contractum</i>                                 | 27.68<br>38.07            | 16.64<br>18.52             | 2,885.91<br>4,996.90             |
| <i>Cosmarium perfissum</i>                                             | 35.20                     | 23.93                      | 5,677.55                         |
| <i>Cryptomonas marssonii</i><br>+ <i>C. ovata</i>                      | 22.17                     | 11.51                      | 1,625.88                         |
| <i>Elakatothrix gelatinosa</i>                                         | 27.42                     | 3.21                       | 164.62                           |
| <i>Fragilaria ulna</i> +<br><i>F. u.</i> var. <i>acus</i>              | 88.58                     | 4.96                       | 1,040.67                         |
| <i>Fragilaria crotonensis</i>                                          | 56.73                     | 32.90                      | 6,394.04                         |
| <i>Mougeotia</i> sp.                                                   | 304.61                    | 4.96                       | 5,885.16                         |
| <i>Oocystis</i> cf. <i>lacustris</i>                                   | 12.10<br>13.75            | 10.69<br>11.84             | 235.61<br>426.76                 |
| <i>Peridinium cinctum</i>                                              | 47.95                     | 46.09                      | 16,967.73                        |
| <i>Scenedesmus bijuga</i><br>var. <i>alternans</i>                     | 14.55                     | 6.25                       | 252.38                           |
| <i>Staurastrum johnsonii</i><br>var. <i>altuis</i>                     | 65.70                     | 49.48                      | 4,003.70                         |
| <i>Staurastrum leptocladum</i><br>var. <i>insigne</i>                  | 52.06                     | 42.86                      | 588.76                           |
| <i>Staurastrum pingue</i>                                              | 39.97                     | 32.14                      | 923.54                           |
| <i>Tetraedron minimum</i>                                              | 7.47                      | 7.07                       | 389.76                           |
| <i>Trachelomonas volvocina</i>                                         | 16.93                     | 16.93                      | 4,874.92                         |
| Unidentified Unicells<br>sp. A + sp. B                                 | 7.77                      | 3.91                       | 67.97                            |

## Appendix VII Phytoplankton species recorded in Lake Rotoroa during the course of the four seasonal experiments

### Taxon

### Chlorophyta

Euchlorophyceae  
Volvocales  
Volvocaceae

*Pandorina* sp.

Chlorococcales  
Chlorococcaceae

*Tetraedron minimum*

### Oocystaceae

*Ankistrodesmus bibraianus*  
*A. gracilis*  
*Kirchneriella* sp.  
*Monorophidium contortum*  
*M. irregulare*  
*Nephrocytium agardhianum*  
*N. limneticum*  
*Oocystis* cf. *lacustris*  
*O. solitaria*

### Dictyosphaeriaceae

*Botryococcus braunii*

### Scenedesmaceae

*Coelastrum indicum*  
*C. microporum*  
*C. reticulatum*  
*Scenedesmus acuminatus*  
*S. armatus*  
*S. ecornis*  
*S. quadricauda*  
*Tetrastrum triangulare*

### Hydrodictyaceae

*Pediastrum angulosum*  
*P. boryanum*  
*P. duplex*  
*P. tetras*

### Coccomyxaceae

*Elakatothrix gelatinosa*

Ulothricophyceae  
Oedogoniales  
Oedogoniaceae

*Oedogonium* sp.

Zygophyceae  
Zygnematales  
Zygnemataceae

*Mougeotia* sp.

Mesotaeniaceae

*Gonatozygon brebissonii*

Desmidiaceae

*Closterium aciculare*  
*C. acutum* var. *variabile*  
*C. gracile*  
*C. setaceum*  
*Cosmarium perfissum*  
*C. cf. contractum*  
*Cosmarium* sp.  
*Staurostrum leptocladum* var. *insigne*  
*Staurostrum* sp.  
*Staurodesmus unicornis* var. *gracilis*  
*Staurodesmus* sp.

## Chromophyta

Chrysophyceae  
Chromulinales

Dinobryaceae

*Dinobryon cylindricum*

Synyraceae

*Mallomonas akrokomos*  
*Synura* sp.

Xanthophyceae

Mischococcales

Pleurichloridaceae

*Goniochloris pseudogigas*  
*Pseudostaurostrum* sp.

Sciadiaceae

*Centrtractus* sp.

Diatomophyceae

## Coscinodiscales

## Coscinodiscaceae

*Aulacosira distans*  
*A. granulata*  
*Cyclotella meneghiniana*  
*C. stelligera*  
*Melosira varians*

## Diatomales

## Diatomaceae

*Asterionella formosa*  
*Fragilaria capucina*  
*F. ulna*  
*F. ulna* . var. *acus*  
*Tabellaria fenestrata*  
*T. flocculosa*

## Eunotiales

## Eunotiaceae

*Eunotia diodon*  
*E. pectinalis*  
*E. pectinalis* var. *undulata*

## Achnanthales

## Achnanthaceae

*Achnanthes* sp.

## Naviculales

## Naviculaceae

*Cymbella* sp.  
*Frustulia rhomboides* var. *saxonica*  
*Gomphonema acuminatum*  
*G. constrictum*  
*Navicula* sp.  
*Pinnularia* sp.

## Epithemiaceae

*Rhapalodia* sp.

## Surirellaceae

*Surirella* sp.

**Cyanophyta**

Cyanophyceae

Chroococcales

Chroococcaceae

*Chroococcus* sp.  
*Merismopedia* sp.  
*Microcystis aeruginosa*

Nostocales

Nostocaceae

*Anabaena* sp.

Oscillatoriaceae

*Oscillatoria* sp.**Euglenophyta**

Euglenophyceae

Euglenales

Euglenaceae

*Euglena acus*  
*E. oxyuris*  
*Lepocinclis marssonii*  
*Phacus glaber*  
*P. helicoides*  
*P. suecicus*  
*Trachelomonas hispida*  
*T. planctonica*  
*T. playfairi*  
*T. volvicina*

**Pyrrophyta**

Cryptophyceae

Cryptomonadales

Cryptomonadaceae

*Cryptomonas erosa*  
*C. marssonii*  
*C. ovata*

Dinophyceae

Peridiniales

Peridiniaceae



*Peridinium cinctum*  
*P. inconspicuum*

Ceratiaceae

*Ceratium hirundinella*  
*Ceratium h. fa. furcoides*

**Unidentified**

L.R.G.T. (*Chlorella*(?))

**Appendix VII** Phytoplankton species recorded in Lake Pupuke during the course of the four seasonal experiments.

**Taxon**

**Chlorophyta**

Euchlorophyceae

Volvocales

Volvocaceae

*Chlamydomonas* sp.

Chlorococcales

Chlorococcaceae

*Chlorella* sp.

*Nephrocytium agardhianum*

*Tetraedron minimum*

Oocystaceae

*Oocystis* cf. *lacustris*

Scenedesmaceae

*Scenedesmus bijuga* var. *alternans*

Hydrodictyaceae

*Pediastrum boryanum*

Coccomyxaceae

*Elakatothrix gelatinosa*

Zygophyceae

Zygnematales

Zygnemataceae

*Mougeotia* sp.

Desmidiaceae

*Closterium aciculare*

*C. acutum* var. *variabile*

*C. gracile*

*C. parvulum*

*C. setaceum*

*Cosmarium* cf. *contractum*  
*C. perfissum*  
*Cosmarium* sp.  
*Gonatozygon brebissonii* var. *minutum*  
*Mougeotia* sp.  
*Staurastrum leptocladum* var. *insigne*  
*S. johnsonii* var. *altuis*  
*S. pingue*  
*Staurastrum* sp.  
*Staurodesmus* sp.

## Chromophyta

### Chrysophyceae

### Chromulinales

### Dinobryaceae

*Dinobryon cylindricum*

### Synuraceae

*Synura* sp.

### Xanthophyceae

### Mischococcales

### Pleurichloridaceae

*Pseudostaurastrum* sp.

### Sciadiaceae

*Centrtractus* sp.

### Diatomophyceae

### Coscinodiscales

### Coscinodiscaceae

*Aulacosira distans*  
*A. granulata*  
*A. g.* var. *augustissima*  
*Cyclotella meneghiniana*  
*C. stelligera*

### Diatomales

### Diatomaceae

*Asterionella formosa*  
*F. crotonensis*  
*F. ulna*  
*F. u.* var. *acus*  
*Tabellaria fenestrata*  
*T. flocculosa*

## Eunotiales

## Eunotiaceae

*Eunotia pectinalis*  
*Eunotia* sp.

## Achanthales

## Achnanthaceae

*Achnanthes* sp.

*Cocconeis* sp.

## Naviculales

## Naviculaceae

*Amphora* sp.  
*Cymbella* sp.  
*Frustulia rhomboides* var. *saxonica*  
*Gomphonema constrictum*  
*Pinularia* sp.  
*Navicula* sp.  
*Stauroneis* sp.

## Epithemiaceae

*Epithemia* sp.  
*Rhopalodia* sp.

## Nitzschiaceae

*Nitzschia* sp.

## Surirellaceae

*Surirella* sp.

**Cyanophyta**

## Cyanophyceae

## Chroococcales

## Chroococcaceae

*Microcystis aeruginosa*

## Nostocales

## Nostocaceae

*Anabaena circinalis*  
*Anabaena* sp.

## Oscillatoriaceae

*Oscillatoria* sp.

## Euglenophyta

## Euglenophyceae

## Euglenales

## Euglenaceae

*Euglena acus**Euglena* sp.*E. oxyuris**Phacus glaber**P. helicoides**P. suecicus**Trachelomonas lacustris**T. volvocina***Pyrrhophyta**

## Cryptophyceae

## Cryptomonadales

## Cryptomonadaceae

*Cryptomonas erosa**C. marssonii**C. ovata*

## Dinophyceae

## Peridinales

## Peridiniaceae

*Peridinium cinctum**Peridinium* sp.

## Ceratiaceae

*Ceratium hirundinella**Ceratium hirundinella* fa. *furcoides*

## Unidentified Unicells

sp. A

sp. B

**APPENDIX VIII**    Percentage contribution to total phytoplankton biomass made by algal species > 80µm in longest dimension. One standard deviation in parentheses. (n=20)

**Lake Rotoroa**

|              |         |          |
|--------------|---------|----------|
| Experiment 1 | 86.932% | (10.914) |
| Experiment 2 | 84.218% | (15.229) |

**Lake Pupuke**

|              |        |         |
|--------------|--------|---------|
| Experiment 5 | 7.795% | (8.250) |
| Experiment 6 | 8.319% | (3.818) |
| Experiment 7 | 6.816% | (2.530) |
| Experiment 8 | 6.177% | (1.629) |