# ADDIS ABABA UNIVERSITY

# SCHOOL OF GRADUATE

# STUDIES

**ZOOPLANKTON COMMUNITY GRAZING RATES STUDY ON THE NATURAL PHYTOPLANKTON ASSEMBLAGES IN LAKE ARSEDI (BETEMENGIST)**

By

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## Abstract

Zooplankton community grazing rates as percentage of algae cleared per day (%G/d) were determined in Lake Arsedi by ***in-situ*** feeding experiments (with changes in chlorophyll ***a*** concentration method) using 1 l incubation clear glass bottles at two sampling sites (Littoral and open water). In replicated treatments, zooplankton and phytoplankton size fractionation experiments were done and the results indicate that invariably the larger zooplankton had higher % G/d than the smaller-sized ones, and the smaller-sized phytoplankton were easily removed by zooplankton than the larger-sized ones. Observations and experiments revealed that zooplankton community composition; abundance and food density were important factors determining grazing rates in this lake. Monthly variation in % G/d was caused by changes in zooplankton and phytoplankton community structures. During October 2005-February 2006 massive blooms of the cyanobacteria, especially ***Microcystis aeruginosa*** reduced grazing impact, whereas during March-April 2006, diatoms and small flagellates dominated the phytoplankton and were highly vulnerable to grazing by both cylopoid and calanoid copepods, although calanoid copepods had much stronger effect. Increased copepod grazing during this period resulted in low phytoplankton biomass (the clear –water period). These results suggest that variation in the strength of grazing in eutrophic lakes such as Hora (Arsedi) result from changes in zooplankton and phytoplankton densities and community structure. The findings of this study are believed to lay a basis for further research and consequently to solve the problem of eutrophication by reducing external nutrient loading and controlling internal ecological processes.

# 1. Introduction

Fresh waters such as lakes, rivers and reservoirs are one of humanity's most important resources, especially in the tropics, where they are often viewed as highly productive biological systems. They provide water for consumption, fishing, irrigation, and power generation, transportation, recreation, disposal of waste and a variety of other domestic, agricultural and industrial purposes. In spite of the fact that freshwater bodies are very limited and sensitive resources that need proper care and management, they are probably the most abused of resources. Therefore, accelerated eutrophication of lakes because of human activity is a concern throughout the world. However, most research on this problem has been done in the temperate zone, and there is little information from tropical Africa, especially Ethiopia (Zinabu Gebre-Mariam, 2002).

In modern times both surface and subsurface waters are becoming increasingly affected by human activities leading to the development of a number of adverse phenomena that call for ecological emergencies (Lang, 1979). During the past centuries, increased urbanization and sewage disposal, regulation of wetlands and streams and more intensive farming practice have increased the nutrient loading to many shallow lakes world wide, not least in the industrialized part of the world. This has resulted in major changes in the biological structure and dynamics of the lakes and often in a shift from clear to turbid states. Common problems that occupied much of the limnological effect of the last four decades

are excessive growth of algae and large aquatic plants (Lazzaro ***et al***, 1992), which are a major indication of eutrophication. Eutrophication of lakes and reservoirs is enrichment with plant nutrient, mainly phosphorus and nitrogen, which enter as solute and bind to organic and inorganic particles. Enhanced growth and increased abundance of aquatic plants often results in reduction of water quality.

Man has tried to combat the problem of accelerated eutrophication for a long time ago. Lake restoration has long been considered to be primarily a matter of chemistry and engineering techniques to lower nutrient concentration or remove sediments and rooted plants or diversion of silt and nutrients. These approaches, however, usually ignore the biological interaction within the lake, interaction which themselves may be responsible for low water transparency and high internal nutrient release. Now a days, there is an alternative approach (in order to avoid high economic associated costs and /or common irrelevance of more conventional approaches), which consists of flexible ecological shifting of trophic state balance. At present, extensive literature is devoted to the feasibility of biomanipulation approaches to restore lakes and reservoirs (Shapiro and Wright, 1984; Lazzaro, 1988). “Biomanipulation” includes lake management procedures that alter the food web to favor grazing on algae by zooplankton, or that eliminate fish species that recycle nutrients. Biomanipulation involves eliminating certain fish species or restructuring the fish community to favor the dominance of piscivorous fish instead of planktivorous fish.

Bendorff (1988) proposed integration of two strategies to have a better water quality and lower cost /benefit ratio in the management of water resources. These are: 1) strategy of reducing the external load of nutrients, toxic substances, organic matter or acid precipitation 2) The strategy of controlling internal ecological processes. If one consider the second solution, it is clear that zooplankton grazing is one of the internal dynamics regulating water clarity.

Grazing refers to the predator-prey interactions in water where algae, bacteria, detritus and protozoans are the prey organisms. The importance of grazing by herbivorous zooplankton on the development of phytoplankton populations became recognized in the 1970s. Demonstration that grazing was directly involved in the clear water phase provided available field support for this concept (Lampert, 1978). The clear water phase describes the very regular occurrence of a minimum density of phytoplankton in the middle of the growth period, most frequently in meso-and eutrophic lakes. During the clear water phase, phytoplankton has their highest rate of specific photosynthesis (photosynthesis /biomass), indicating that at least the dominant algal species have high rates of reproduction. Thus, the decline in the phytoplankton densities can only be attributed to higher mortality. The clear water phase also corresponds to the time of the yearly maximum of herbivorous zooplankton, implicating zooplankton grazing as the major cause of phytoplankton mortality. Recently, there is direct evidence that the feeding rates of the zooplankton during the clear water phase exceed the production rates of the phytoplankton (Sommer and Lampert, 1997).

Zooplankton plays an important role in lake ecosystem, transferring energy from primary producers to predators and suppressing the abundance of phytoplankton. When their grazing is intense, zooplankton can substantially reduce total phytoplankton biomass and productivity, producing clear water phase, when Phytoplankton's are extremely scarce (Lampert ***et al.,*** 1986). Zooplankton also can affect the relative abundance of phytoplankton species, both by direct grazing (top-down) and by nutrient recycling (bottom-up) processes. The enrichment of algal growth by nutrients and the resulting enhanced production of grazing zooplankton, predatory invertebrates and fish is called "bottom-up control" because nutrients flow from the base of the food chain up through the trophic levels. However, the alternative regulation of algal abundance and primary production can come from "top-down control". When grazing zooplankton is abundant, algal biomass can be suppressed by consumption even when nutrient concentration is high. Large –bodied and abundant zooplankton occur in lakes that have relatively low number of zooplanktivorous fish density (Brooks and Dodson, 1965). And low zooplanktivorous fish density is found in lakes with high number of piscivorous fish. Thus, an alternative to reducing phosphorus input as a means of regulating the abundance of algae is to increase the density of stocked piscivorous fish. Managing fisheries has become a tool for controlling phytoplankton biomass in lakes (Carpenter and Kitchell, 1993). In natural lakes, both bottom-up and top-down processes operate. Their relative importance may vary among lakes or can change seasonally within a lake.

The zooplankton community in lakes consists of a variety of organisms with different feeding abilities, which exploit a wide diversity of food available in the environment. Based on their size, the zooplankton communities in lakes are divided into three groups. These are 1) Micro-zooplankton (rotifers and protozoans especially ciliates) 2) Meso-zooplankton -cladocerans and copepods (calanoid, cyclopoid and harpacticoid) and 3) Macro-zooplankton–insects (mostly larvae such as ***Chaoborus),*** shrimps (***Mysis, Gammarus***).

Analyses on large data sets have indicated that grazing rate measured in different communities vary with zooplankton taxonomic composition (Cyr and Pace, 1992), as well as with the body size of grazers (Lampert, 1988). It is already a well-known pattern that communities of large –bodied zooplankton (e.g. ***Daphnia)*** can graze more intensively on phytoplankton than communities of smaller species (e.g. Rotifers and ***Bosmina***) (Cyr and Pace, 1992). Substantial evidences for this review come from biomanipulated lakes, where the increase in individual crustacean size and zooplankton mass has resulted in higher grazing activity, often exceeding phytoplankton growth rates (Gulati, 1995). The success of biomanipulation depends on the efficacy of zooplankton grazing, which in turn depends on species composition, body size and biomass of zooplankton (Carpenter ***et al***., 1985).

Several studies have indicated that zooplankton community structure in lakes is affected by many factors. Some of these are: size selective predation by fish (Jeppesen ***et al***., 1996) together with resource partitioning because of different feeding modes and selectivity of zooplankton (Pourriot, 1977; Gilbert and

Bodgon, 1984; DeMott, 1986) in environment with fluctuating resources availability. The abundance and biomass of planktivorous fish increase with increasing productivity of lake ecosystem, which consequently lead to intensive predation on zooplankton communities.

The trophic status of lakes as explained by earlier workers (Gulati ***et al***., 1982; Shapiro and Wright, 1984) and recently by the trophic cascade interaction theory (Carpenter ***et al***., 1985; Vanni and Findlay, 1990) depends on zooplankton grazing capacity to a large extent. The basis of this fact is the size efficiency hypothesis proposed by Brooks and Dodson (1965). According to this theory planktivores and piscivores can be called “food selectors” because they continuously make choices in large part on the basis of size whereas herbivorous zooplankton are named “food collectors” because the size range of their food is more or less automatically determined. The ecological implication of size-dependent predation upon the planktonic food collectors (i.e. herbivorous zooplankters) were outlined in what Brooks and Dodson 9165) called the “size – efficiency hypothesis”. The premises of this hypothesis are:

a) Plankton herbivores all compete for the fine particulate matter (1-15μm) of the open water but large zooplankter does so more efficiently and can also take large particles;

b) When predation is of low intensity the small planktonic herbivores will be competitively eliminated by larger forms (dominance of large cladocera and calanoid Copepods);

c) When predation is intense, size-dependent predation will eliminate the larger forms, allowing the small zooplankter (rotifers, small cladocera) that escape predation to become dominant; and

d) When predation is of moderate intensity, it will, by falling more heavily up on the larger species keep the population of these more effective herbivores sufficiently low so that slightly smaller competitors are not eliminated.

The probable reason given for the greater effectiveness of the larger zooplankters in collecting the non-seston is the fact that in related species (with especially identical food collecting apparatus) the food-collecting surface are proportional to the square of some characteristic linear dimension, such as body length. Accordingly, whenever predation by planktivores is intense, the standing crop of small algae will be high because of relatively inefficient utilization by small planktonic herbivores, and that of large algae will also be high since the small herbivores cannot graze them. In other words, the biomass of both small and large algae depends on the abundance of the larger zooplankters. Carpenter ***et al***., (1985) reviewed case studies with consistent conclusions: these studies show that removal of planktivorous fishes from lakes results in greater densities of larger zooplankton, which impose greater grazing pressure on the phytoplankton, reduce chlorophyll ***a*** (Chl ***a***) concentration and total algal densities, increase Secchi disc transparency and reduce total nutrient concentration in the epilimnion. In shallow eutrophic lakes, smaller-bodied individuals and species of rotifers, cladocerans and cyclopoid copepods often dominate in the zooplankton community (Haberman, 1988). Also the habitat of

shallow lakes with large population of inedible filamentous phytoplankton and large population of bacteria favor development of protists and small zooplankton (Gulati, 1990; Jeppenes ***et al***., 2000).

Zooplankton grazing activity can be determined by several methods based on measuring the variation of a tracer in the food as a function of time. The three main methods are; bottle incubations, gut fluorescence, and the use of radiotracers. The incubation method is based on the decrease of phytoplankton numbers (or chlorophyll ***a***) with time and is thus essentially an indirect method (Harris, 1994). Another indirect method is based on the production of fecal pellets. The gut fluorescence method Peterson ***et al***., 1990) is based on the calculation of the grazing rates from the increase or decrease of chlorophyll and phaeopigments in the gut, for example, copepods. The $^{14}C$ method uses the uptake of this radio-tracers by the zooplankton after incubation with $^{14}C$ labeled phytoplankton (Daro, 1978). This method is so sensitive that relatively few zooplankton individuals are required (10-20 individuals, Gulati ***et al***., 1985). The advantage of using radiolabelled material in the gut- fluorescence and $^{14}C$ methods are measurement performed in the zooplankton itself, and are therefore, direct methods, they can also be used when food is available in surplus. A disadvantage of both the incubation method and the gut- fluorescence method is that a considerable number of copepods is necessary for each measurement in time (up to 200 for copepods <500µm), as the sensitivity of these methods is relatively low (Bautista and Harris, 1992). Furthermore,

pigments are susceptible to denaturation due to light and temperature effects (Morales ***et al***., 1991)

There is an overwhelming literature concerning zooplankton-grazing rate in temperate lakes Example includes: Heart lake, Canada (Haney, 1973); Great lakes, North America (Ross and Munawar, 1987); Lake St. George in Ontario (Mazumder ***et al***., 1990), and 16 lakes in three states in North America, New York (Cyr and Pace, 1992). However, very little information is available on zooplankton grazing pressure in tropical lakes and reservoirs (e.g. Hart, 1988).

Ethiopia is one of the tropical countries, which is gifted with a variety of aquatic ecosystems, especially a number of lakes that are of great scientific interest and economic importance. The total area of inland waters in Ethiopia is 8800 square kilometer, representing 0.72 % of the total surface area of the country (Greboval ***et al.,*** 1994). The Ethiopian Rift Valley lakes and the Bishoftu crater lakes are among the most studied water bodies in Ethiopia with respect to their morphmetric, planktonic communities, physical and chemical features and primary productivity (Wood and Talling, 1988; Tudorancea ***et al***., 1989; Seyoum Mengistou and Fernando, 1991).

In tropical African countries like Ethiopia, human factors in combination with the natural conditions of climate and geology strongly influence water quality. Although Ethiopia does not have the industry that flourished in the developed countries and pollutants are not produced in large quantity, materials resulting from human activities such as land use modification and other activities

associated with rapid population increase have caused or accelerated many changes in the lakes such as nutrient loading (Zinabu Gebre Mariam, 2002). The result of increased nutrient loading is eutrophication. Such events have already been reported in some of the Ethiopian Rift -Valley lakes. Fish kills, algal blooms and associated death of wild life in Lake Chamo (Amha Belay and Wood, 1982) and Abijata (Kassahun Wodajo, 1982) are attributed to the human impact in the catchment areas of these lakes.

There are some indications that the Bishoftu crater lakes have undergone changes in their limnological features during the last three decades, as a result of human interference and / or natural causes (Zinabu Gebremariam, 2002). These lakes are a group of volcanic explosion craters in the vicinity of an emerging city, Bishoftu. The impacts of this fast growing city on these lakes in recent years have also accelerated many changes in these aquatic bodies. Lake Hora- Arsedi, the present study lake is no exception. The major changes in this lake have been increase in plankton biomass that is the major symptom of eutrophication, which has resulted in reduced water clarity and oxygen level, taste and odor problem. Though such problems are identified in this lake, so far no scientific study has been done to protect, conserve, and restore the lake condition. Thus, the present study attempts to assess the effect of zooplankton community grazing on phytoplankton and its possibilities as one of the interventions to the eutrophication problem in Lake Hora-Arsedi.

## *2. Objectives of the study*

**General Objectives:**

The general objective of this study is to measure the daily grazing impact of the zooplankton community on phytoplankton in Lake Hora-Arsedi in order to

examine whether they are responsible for cropping a significant fraction of the daily primary production.

**Specific Objectives:**

1) To estimate zooplankton grazing rates on biomass of natural phytoplankton assemblages in Lake Hora-Arsedi;

2) To determine which size fraction of the zooplankton community are more effective in controlling the abundance of phytoplankton;

3) To determine which size fraction of phytoplankton are removed most by the zooplankton;

4) To see the simultaneous effect of food and grazer density changes in experimental incubation (in ***situ)***; and

5) To assess the contribution of zooplankton grazing to water quality improvement and/ or fisheries enhancement in Lake Hora-Arsedi.

## 3.Description of the study area

Lake Hora-Arsedi, the present study lake, is one of the Bishoftu crater lakes formed due to volcanic action ~7000 years ago (Mohr, 1961). It is located at Bishoftu about 47 Km southeast of Addis Ababa at 1850 m altitude ( $8^{o}$ 50 and,

39$^{o}$ E) as shown in Fig 1. Unlike other crater lakes, Lake Hora-Arsedi is made of juxtaposition of two twin craters. Its bathymetry and limnology were investigated in detail by Wood ***et al*** (1984). Some morphometric characteristics of Lake Hora-Arsedi is described in Table 1 below.

Table 1: Some morphometric Characteristics of Lake Hora-Arsedi (From Prosser ***et al.***

1968)

| | |
|---|---|
| Location | 8$^{o}$ 50' N, 39$^{o}$ E |
| Altitude | 1850 m |
| Surface area | 1.03 Km$^{2}$ |
| Maximum depth | 38 m N.crater and 31 m S.crater |
| Mean depth | 17.5 m |
| Volume | 0.018 Km$^{2}$ |

The region around the lake is characterized by moderate rainfall, varying around about 850 mm per annum (Rippey and Wood, 1985), high incident solar radiation and low relative humidity. The region has two rainy periods, the minor one extending roughly from February to April and the major one beginning in June and ending in September.

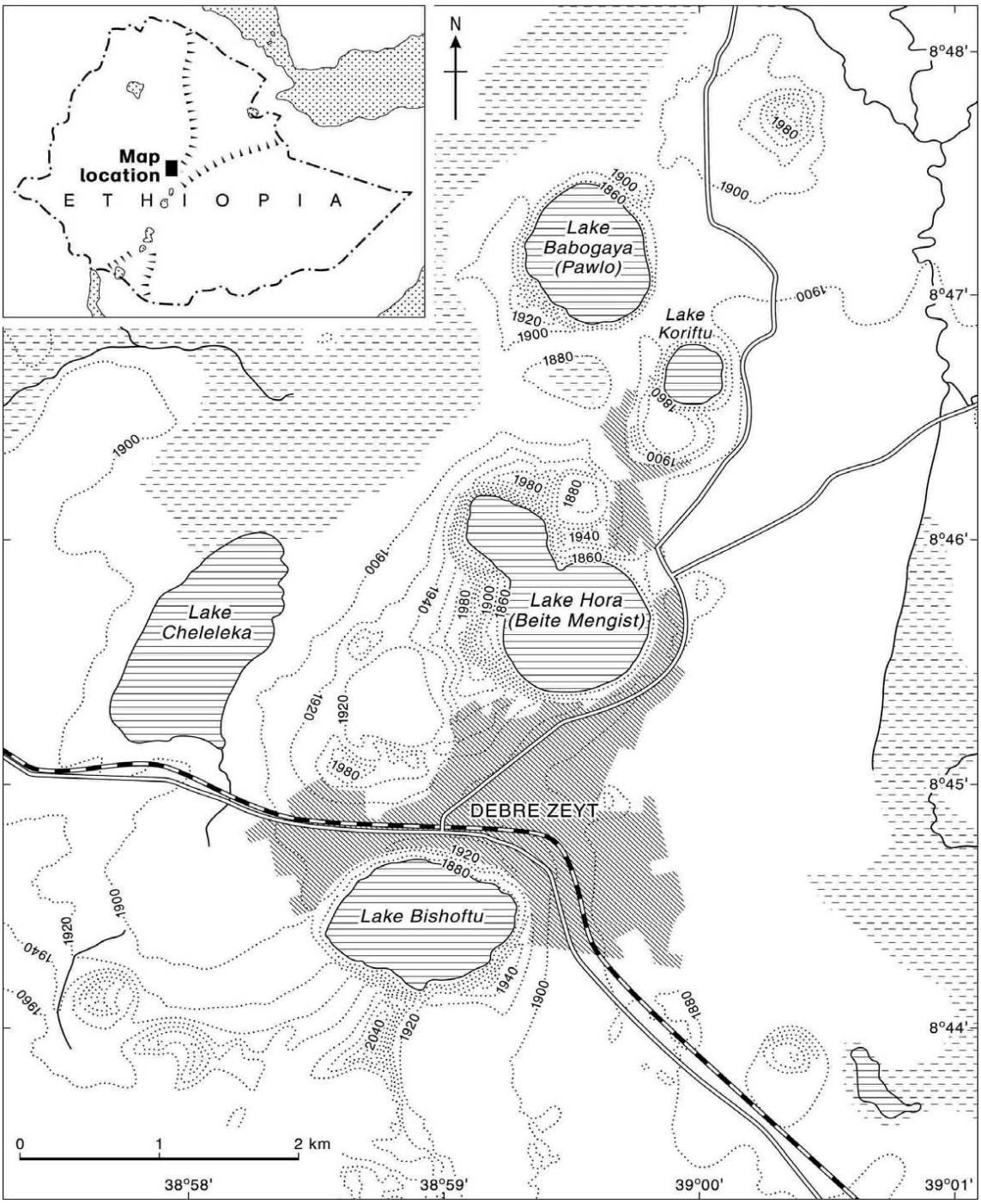


Fig.1 Location map of Lake Hora- Arsedi (Beite Mengist)

The temperature of its surface water was frequently found to be about 22 $^{0}$C with a maximum of 24.5 $^{0}$C and minimum of 19.2 $^{0}$C, while the bottom temperature was almost constant (19.2 $^{0}$C-19.4 $^{0}$C) (Wood ***et al.,*** 1976). Its seasonal cycle of stratification, mixing and hydrochemical properties resemble to that of the nearby Lake Babogaya (Pawlo), which it most resembles hydrochemically. It stratifies during the February-October wet season, and mixes as a result of heat loss to clear night skies during the dry season (Lamb ***et al.,*** in press). Through their studies over extended periods, Baxter ***et al.*** (1965) and Wood ***et al.*** (1976) have shown the frequent occurrence of pronounced and deep-seated thermal stratification with a consequent stratification of various chemical species in Lake Hora-Arsedi.

Lake Hora-Arsedi is a dilute lake with $Na^{+}$ as the dominant cation and carbonate-bicarbonate as the dominant anion. The water is alkaline, with the erosion of basaltic and hyper-alkaline rocks surrounding the lake playing an important role in increasing the alkalinity of the water (Baxter ***et al***., 1965). A good deal of summary concerning the chemical and algal relationships of Ethiopian inland waters was compiled in Wood and Talling (1988). The study showed that Lake Hora-Arsedi had a rather low salinity (2.57ppt) probably due to its subterranean spring inflow but the salt concentration of the inflowing spring is not reported. Lake Hora-Arsedi is a closed-basin type lake. The persistence of this lake requires the annual water inflow should equal the annual evaporation loss minus

direct rainfall on the lake. However; this water budget is sometimes distorted by underground inflow, outflow, or seepage. The chemical composition of this lake depends on its drainage characterstics. That is apart from the internal regeneration of elements, an input from the external environment also affects the chemical concentration of this lake. In Ethiopian lake, the time variation of salinity is dominated by the alteration of wet and dry seasons. That is conductivity increases during the dry season and decrease during the wet seasons. These situations are forced by the evaporative concentration and dilution by the incoming water respectively, as it is theoretically known. Lake Hora-Arsedi follows the usual trend proposed by Wood and Talling (1988). High salinity is not accompanied by high conductivity in Lake Hora-Arsedi. This could be for the fact that alkalinity increases as solubility of calcium carbonate increases (Wood and Talling, 1988). Therefore, solubility of calcium carbonate may be higher in Lake Hora-Arsedi. Some of the chemical characteristics of the lake are listed below (Table 2).

Table 2. Chemical Composition of the water of Lake Hora-Arsedi (After Prosser ***et al***., 1968; Wood and Talling, 1988)

| Chemical Feature | Na (meq/l) | K (meq/l) | Mg (meq/l) | Total Cations (meq/l) | Total Anions (meq/l) | Conductiviy (µS/cm) | Saliniy (ppt) | Alkalinity (meq/l) | pH | $Cl_2$ (meq/l) | $SO_4$ (meq/l) | $SiO_2$ (meq/l) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Value | 23.9 | 1.31 | 3.94 | 29.5 | 32.9 | 2200 | 2.57 | 26.8 | 9.2 | 5.67 | 0.4 | 55 |

The immediate surrounding of the lake is semi urban in character, with many planted and invasive exotics (e.g. ***Eucalyptus***, ***Casuarina***, ***Schinus*** and ***Opuntia***).

Cereal cultivation has entirely replaced the natural vegetation of the surrounding landscape.

The phytoplankton community of Lake Hora-Arsedi was reported to be dominated by ***Microcystis aeruginosa*** (Baxter and Wood, 1965; Wood and Talling, 1988). Lake Hora-Arsedi had chlorophyll ***a*** concentration which varied between 1-54µgl$^{-1}$ during 1964-66 and 1980 (Wood and Talling 1988) and 28-49 µgl$^{-1}$ during 1990-92 (Zinabu Gebremariam, 1994). On the other hand the low shoreline development value implies the littoral region cannot harbor rich macrophyte growth, as is the case with Lake Hora-Arsedi. There are some floating macrophytes and emergent macrophytes ***Typha*** and ***Juncus*** that are present in wide areas in the shore sites.

The zooplankton community of Lake Hora-Arsedi as reported by Seyoum Mengistou and Green (1991) is dominated by the rotifer ***Brachionus dimidiatus*** (see Table 3***).*** Little information is available on the crustacean zooplankton.

The fish fauna of Lake Hora-Arsedi consists only of ***Oreochromis niloticus,*** which was introduced to this lake around 1943. At present no commercial fishing exists in the lake; although a few tones of fish are caught for consumption by people who have the sole right to fish in this lake (Shibru Tedla, 1973).

Table 3. Zooplankton composition in Lake Hora-Arsedi at different times (Seyoum Mengistou and Green, 1991; Seyoum Mengistou, unpublished data) (+ indicates abundant)

| Group | 1983 Zooplankton data | 2004 Zooplankton data |
|---|---|---|
| Rotifera | ***Brachionus angularis*** **+**<br>***B.urceolaris***<br>***B.dimidiatus***<br>***B.calyciflorus*** **+**<br>***Asplancha brightwelli***<br>***A.Seiboldi***<br>***Philodina.sp.***<br>***Marcochaetus collini*** | ***B.angularis***<br>***B. Calyciflorus***<br>***B.pilicatilis***<br>***B.quadridentatus*** **+**<br>***Asplancha brightwelli*** + |
| Cylopoida | ***Thermocyclops crassus*** + | ***Thermocyclops.sp*** |
| Cladocera | None | None |
| Ostracoda | None | None |
| Insecta | ***Ephemeroptera (Mayflies)***<br>***Hydractina (water mites)***<br>***Odonata (dragon and damsel***-flies)<br>***Chironomidae*** (midges) | Absent<br>Absent<br>Damsel flies present +<br>Present |

# *4. Materials and Methods*

## 4.1. Field Sampling Methods and Experimental design

***Plankton samples were collected from two sites in Lake Hora-Arsedi, which were designated as the central zone (open water) and littoral zone of the lake. The sampling sites were 450m far apart from each other .The approximated depth of the central and littoral sampling sites were 36m and 9m, respectively. At each site, grazing incubation experiments were conducted twice a month.***

Zooplankton samples were collected by means of vertical net hauls (open water) and using horizontal and vertical hauls at the littoral site. Vertically hauled net samples were taken at the fixed central sampling stations from 3m depth using No 25 (67 µm mesh) plankton net with a mouth diameter of ca 31 cm. After concentrating, the samples were transferred to incubation bottles (transparent bottles with wide – mouth screw caps). Samples for zooplankton enumeration were taken from each incubation bottle and preserved in 5- 7% formalin solution.

Phytoplankton samples were collected from the littoral and open water of the lake using plankton net and Ruttner sampler and transferred to incubation bottles after concentrating. On the other hand, plankton samples for initial bottles were collected from the two sampling sites and filtered through a sieve that removed zooplankton but allowed only the phytoplankton to pass. It was then immediately filtered with GF/C paper and designated as initial (Co). In the same way, another plankton sample free of zooplankton was prepared and added to grazing bottles for incubation and designated as control bottle (Cp).
Phytoplankton sample for determining food concentration were collected from each grazing bottle before incubation and preserved immediately at the sampling site by adding Lugol Iodine solution at the ratio of 1:100 (Vollenweider, 1969). Incubation of bottles for grazing experiment was done at each site for about 5- 24 hrs, after which the bottles were retrieved from the lake and filtered for chlorophyll ***a*** analysis.

## 4.2. Zooplankton Enumeration and Identification

200 ml of sub sample was taken from each incubation bottle with zooplankton (Cz) and a sub sample of 20 ml was drawn using a wide–mouthed glass tube for the analysis of zooplankton abundance. The sub samples were poured into a tray (grided counting chamber) with 15 grids and counted under a WILD stereoscopic microscope (40 x magnification) according to the method recommended in Edmondson and Winberg (1971). Three grids were counted and extrapolated as

zooplankton densities from the counts as individual per liter (ind/l$^{-}$). Total zooplankton densities were calculated as the sum of rotifers, cladocerans, and copepods densities. The dominant zooplankton in the lake was determined according to their numerical abundance based on the method recommended in Seyoum Mengistou (1989). Species were identified using keys of Defaye (1988), Dussart and Fernando (1988); Fernando ***et al***., (2001).

### *4.3. Phytoplankton Enumeration and Identification*

Phytoplankton enumeration was done according to the method of Hotzel and Croome (1999) using a Sedgwick-Rafter chamber. Microscopic cell count was made to estimate the algal densities (cells/ml). 50 ml of phytoplankton sample was taken from each incubation bottle and settled in graduated cylinder for three days. Excess water was gently removed using syringe to leave a 10 ml of the sample water in the graduated cylinder. From the concentrated sample, 1 ml sub-sample was taken with a pipette then run into the chamber at one corner with the cover slip lying at an angle across the chamber (APHA, 1995). Once the chamber is filled, the cover slip was moved to cover the whole chamber and the sample was left to settle for 30 minutes. To prevent formation of air bubbles due to evaporation of sample water during counting, distilled water was added to the edge of the cover slip from time to time.

The cells were counted on the bottom of the chamber using an inverted microscope. Most often the sample was counted at more than one magnification

depending on the size of the phytoplankton present. Large cells or colonies were counted at 100x. If picoplankton was present in considerable numbers, a count at 400x were performed. Viewing at 1000 x was used for identification only as in McAlice (1971).

The cell concentration (Co), expressed as the number of units permilititer was calculated according to:

$$\text{Co (Cells/ml)} = \frac{N \otimes 1000 mm^3}{A \otimes D \otimes F} \otimes \frac{1}{5}$$

Where: N = number of cells or units counted

A =Area of field ($mm^2$)

D = Depth of a field (Sedgwick –Rafter chamber)

F = Number of fields counted and 1/5 is a concentration factor

For colonial taxa, the count units were multiplied by the average number of cells per units. To obtain an accurate count, the numbers of cells per filament or colony were enumerated in each sample, since the size of these algal units can vary greatly. For example, ***Anabaena*** filaments may contains between five and several hundred cells and the size of a ***Microcystis*** colony can range from fewer than 10 to several thousands cells. The dominant phytoplankton taxa were identified using keys of Komarek and Crenberg (2001) and Hindak (2000).

4.4. Measurement of chlorophyll ***a*** concentration

(as phytoplankton biomass indicator)

**200 ml of the water samples from each incubated bottle was filtered through a glass fiber filter (GF/C) to recover the phytoplankton. Pigments were extracted from the phytoplankton with cold 96% Methanol. The extract is centrifuged at 3000 rpm for 10 minutes. Pigment extract is decanted into a volumetric flask (20ml) and made up to the mark with methanol. The flask is overturned several times before the extract is transferred to a 1cm spectrophotometer cell (cuvette). The absorbance of the pigment extract at 665 and 750 nm (absorbance peaks of Chlorophyll "a "is measured in the spectrophotometer SP6-350 model. The concentration of chlorophyll" a" is calculated according to Talling and Driver (1963).**

$$Chla(\mu g / l) = \frac{13.9(E_{665} - E_{750})Ve}{Vsf \otimes PL}$$

***Where*** ***$E_{665}$ =extinction at 665 nm***

$E_{750}$ = extinction at 750 nm

Ve = Volume of extract (in ml)

Vsf = Volume of sample flittered (in liters)

PL = path length of the cuvette (1cm)

## *4.5. Calculation of Zooplankton Community Grazing Rates*

The measurement of zooplankton community grazing rate was done by changes in chlorophyll ***a*** concentration method, which involves incubating zooplankton in bottles with food for a fixed length of time, measuring the decrease in food concentration compared to that in control and initial bottles with no grazers, and thus calculating the clearance rate. The goal is to incubate zooplankton under conditions, which mimic the natural environment as closely as possible. This approach is the simplest method and the one longest in use (Gauld, 1951; Paffenhofer, 1988). Zooplankton grazing activities in this study were expressed as grazing rate, clearance rate and ingestion rate. Clearance rate is defined as the volume of water containing food particles filtered by an individual organism per day (ml/ind/day), grazing rate is the filtering activity of groups of organisms per day (Haney, 1973). Daily community grazing rate was calculated based on whole zooplankton community filtering activity and exposure time to the food in the chamber (bottles).

Clearance rate was measured by monitoring changes in chlorophyll ***a*** concentration. Zooplankton grazing rate as percentage per day was calculated as in Marin ***et al***., (1986) assuming that chlorophyll a loss is attributed only to grazing. This is based on the assumption that the experiments were conducted in such a way that net cell growth in the grazing bottles to be 0 or cell death was absent during the experiment. These could happen when the experiment time is

reduced and if initial chlorophyll concentration (Co) is equal to chlorophyll concentration in control bottle (Cp). T-test was done to check whether there is statistical difference between the two treatments and the result showed that there is no statistically significant difference (t-test, p= 0.91)(see Appendix XII). Therefore, I did not consider Cp in the calculation of %G/d.

**The Clearance rate (F) can then be calculated from**

$$F = \frac{Vg}{N}$$

**Where F = Clearance rate (ml/ind/d)**

**V = Volume of the experimental container (ml)**

**N = number of herbivores in the container**

**g = grazing coefficient ($d^{-1}$)**

**The grazing coefficient (g) of herbivore zooplankton is calculated as**

$$g = \frac{\ln(Ci / Ct)}{t}$$

**Where Ci = initial chl a concentration in experimental container (µg/L)**

**Ct = chlorophyll a concentration at time t in experimental**

**Container (µg/L)**

**t = duration of the experiment ($d^{-1}$)**

**g = grazing coefficient (d)**

**The Ingestion rate (I) can be calculated using the formula**

**I = F (Co)**

**Where I = ingestion rate (cells/ind/d)**

**F = Clearance rate (ml/ind/d)**

**Co =initial food concentration in experimental container (Cells/ml)**

**Percentage grazing rate per day (%G/d) was calculated with a modified formula as:**

$$\%G/d = \frac{I}{Co} \otimes 100$$

Where %G/d = Percentage of grazing per day

Co = initial cell (food) concentration in experimental container (Cells/ml)

I = cells removed during grazing time (cells/ind/d)

## 4.6. Manipulated Zooplankton Grazing Rates

Zooplankton grazing studies was done under manipulated conditions i.e. by altering their natural density or fractionating food and grazers into different size groups. This was done to detect if there is any difference in percentage grazing rate due to zooplankton size and density gradient.

Zooplankton density was manipulated in relative units. When zooplankton were concentrated from 3-meter vertical depth by hauling the net once it was designated as one times (1x), when twice, (2x) and when four times, (4x). In each case the concentrated zooplankton was added into a grazing chamber that contains filtered lake water of the same food concentration. The grazing bottle was then incubated in the natural water for the time period determined to allow grazing (5- 24 hrs).

Phytoplankton was concentrated from three-meter depth using plankton net accordingly by hauling the net once (Cp1x), twice (Cp2x) and four times (Cp4x). The concentrated samples were first filtered through a sieve with 80µm mesh before adding into grazing bottles. The objective was to prepare a sample of water free of zooplankton, while at the same time allowing the phytoplankton to pass through. Then, the concentrated phytoplankton was added into grazing bottles that contain known volume of water (half of the grazing bottles) with grazers to be incubated.

The method is based on the assumption that filters or meshes of different porosity can separate the consumer from their prey (algae) quantitatively. Grazing rates are then calculated by comparing the difference in phytoplankton biomass in the presence and absence of predators.

Zooplankton size fractionations were obtained by filtering lake water using sieves of different mesh sizes based on the assumption that it can separate the consumer from their prey quantitatively. For example, when zooplankton size less than 250 µm were required, 500 ml of lake water is passed through 25 µm mesh sieve and added directly into the grazing bottle that contains known volume of water (500 ml in this study) with phytoplankton food. When zooplankton size greater than 250 µm and less than 450 is required, first the water is passed through 450-µm-mesh sieve and then the filtered water is again passed through 250 µm mesh sieve. The larger zooplankton (>250 and <450µm) were washed out from the surface of the sieve gently at the air –water interface at a minimum time possible to reduce stress or deaths due to exposure out of water and then poured into a grazing bottle that contains a known volume of water (500ml) with phytoplankton. When zooplankton size greater than 450 µm is required, the water is passed through 450 µm mesh size sieve and then the larger -sized zooplankton were immediately washed out from the surface of the sieve gently and poured into the grazing chamber with food for incubation.

Phytoplankton size fractionations were obtained by collecting samples from three-meter depth using Ruttner sampler and filtering it with different-size nylon sieves. For example, when phytoplankton sizes less than 10 µm were required, the water is passed through 10 µm mesh size and added directly into the grazing bottle. When phytoplankton size less than 20 µm is required, the water is passed through 20-µm-mesh size sieve and the filtered samples were added directly into

the grazing bottle with zooplankton predators for incubation. Whereas, phytoplankton size less than 63 µm were collected by passing the lake water through 63 µm mesh size sieve and mixing the filtered sample into a known volume of water that contains zooplankton predators. The <10 µm algae are present in all three size-groups and <20 µm algae are found in both<20 µm and <63 µm size groups.

## 4.7. Statistical Analysis and Calculation of Trophic Status

A simple t-test was performed to determine if changes in percentage grazing rates per day (%G/d) were statistically different between sampling stations and whether there is a difference between initial chlorophyll concentration (Co) and chlorophyll concentration in the control bottle (Cp). In all cases, the result was considered statistically significant when the p value associated with the t-test was, 0.05. Statistical analyses were performed using statistical package MINITAB. In addition to this, regression analysis was performed to determine the relations of percentage grazing and other variable (chlorophyll ***a*** biomass) for both sampling sites through time.

The trophic status of the lake was calculated according to the method recommended in Carlson (1977). Individual TSI values can be calculated from the following equations:

Total phosphorus TSI (TSIP) = 14.42*[ln (TP average)] + 4.15

Chlorophyll-***a*** TSI (TSIC) = 9.81*[ln (Chlorophyll-***a*** average)] + 30.6

Secchi disk TSI (TSIS) = 60 - (14.41*[ln(Secchi average)])

However, in this study the trophic status of Lake Hora-Arsedi was determined only from the equation of chlorophyll ***a*** biomass.

## 5. Results and Discussion

### 5.1. Phytoplankton abundance and biomass

Blue-greens, green algae, and diatoms make up the greatest proportion of the phytoplankton in Lake Hora-Arsedi. The list of the taxa identified is presented in Table 4.The blue-greens were observed to persist in appreciable numbers for a relatively longer period (October 2005 to February 2006) in this lake while green algae and diatoms were relatively scarce during these months. The blue-green algae, especially ***Microcystis*** species made relatively very large proportion of the algal community in Lake Hora-Arsedi and this corresponds with the high chlorophyll ***a*** (Chl ***a***) biomass during the same period. In Lake Hora-Arsedi, there appears to be a high proportion of green algae and diatoms during the period of low algal biomass (August-September2005 and March April 2006 sampling date) i.e. because of complete replacement of ***Microcystis*** species by green algae and diatoms during this period.

Table 4. List of the dominant phytoplankton taxa in Lake Hora-Arsedi

| Phytoplankton Group | Phytoplankton species |
|---|---|

| | |
|---|---|
| Cyanophyceae | a***) Microcystis aeruginosa (***Kütz.) Kütz<br>b) ***Anabaena raciborskii (***Woloszynska)<br>c) ***Cylindrospermosis africana (***Komarek and Kling)<br>***d) Cylindrospermosis sp***<br>e) ***Planktolyngbya sp*** |
| Bacilariophyceae | ***a)Fragilaria crotonensis***<br>***b)Synedra nana***<br>***c) Nitzschia*** sp***.(kutzingiana)***<br>***c) Cyclotella*** sp. |
| Chlorophyceae | a) ***Pediastrum simplex (Meyen)***<br>b) ***Scenedesmus diamoiphus (***Turp) Brebisson)<br>c) ***Scenedesmus quadricauda*** (Turp) Brebisson)<br>d) ***Scenedesmus obliqus*** (Turp) Brebisson)<br>e) ***Chlamydomonas pisiforms*** (Dill)<br>f***) Phacatus lenticularis***<br>g***) Staurastrum chaetoceras*** (Shrod) Smith) |
| Euglenophyceae | a) ***Phacus longicauda*** (Her.) Dujardin<br>b) ***Phacus orbicularis (Hubner )*** |
| Cryptophyceae | ***Cryptomonas*** ovata ***(Ehro)*** |

The present data also indicate and give some information on the monthly distribution of the net algal groups in Lake Hora-Arsedi. Diatoms and chlorophytes were generally more abundant during August –September 2005 and March –April 2006 than in October 2005-January 2006. Prior to September 2005, Lake Hora-Arsedi experienced high rainfall and flush was very high (Ripple

and Wood, 1985). This high flow rate may have flushed the cyanobacteria out for some time. Hawkins and Griffiths (1993) noticed an increase in diatoms after intense rainfall and increased flushing led to shifts of the phytoplankton communities from cyanobacteria to eutrophic algae in a small Australian reservoir. The large contribution of green algae and diatoms in Lake Hora-Arsedi in September 2005 suggests that the cyanobacteria had been flushed out from the lake for some time.

Chlorophyll ***a*** concentration was generally moderate to high in Lake Hora-Arsedi during the study period. The maximum value of Chlorophyll ***a*** biomass measured is about 58.38µg/l during October at the central site and 57.28 µg/l at the littoral site (Table 6). During the early months of the study period from August 2005 to the end of October 2005, chlorophyll ***a*** concentrations were relatively low and then increased during December 2005 –January 2006. The lowest record of chlorophyll ***a*** concentration was recorded during March and April of 2006. The possible reason for the decline in the concentration of chlorophyll a between August-October 2005 and later between March-April 2006 is due to zooplankton grazing. The present data shows that efficient grazers particularly by the calanoid copepods and the abundance of algae which are susceptible to zooplankton grazing (Green algae, cryptomonads and diatoms) were found abundantly during this period (see Table 8 below). The highest community grazing rates was also recorded when the abundance of efficient grazers were at its peak.

Phytoplankton biomass measured in this study is higher than results recorded in the previous studies. Table 5 shows the comparison of the variation of the phytoplankton biomass of Lake Hora-Arsedi in the past. Previous studies based on time series of Chlorophyll ***a*** (Chl ***a***) analysis speculated that Lake Hora-Arsedi shows a mesotrophy status (Habte Jebessa, 1994), but the result of the present study shows a different trend. It shows a progressive trend towards eutrophy.

Table 5. A comparison of the phytoplankton biomass of Lake Hora-Arsedi during 1964-2006

| | Date | Chlorophyll a (µg/l) |
|---|---|---|
| Wood and Talling (1988) | 1964-1966 | 1-54 |
| Zinabu GebreMariam (1994) | 1990-1992 | 28-49 |
| Habte Jebesa (1994) | 1993 | 5 |
| Present Study (2006) | 2005-2006) | Open water 14.43-58.38<br>Littoral 23.57-55.6 |

The increase in the mean chlorophyll ***a*** concentration from 5 µg/l (Habte Jebessa, 1994) to 35.85µg/l (the present study) may be an increase in the productivity of the lake that can be attributed to human activities in the watershed. High chlorophyll biomass is associated with high production status of a lake (Edmondson and Winberg, 1971; Cansfield and Bachmann, 1981).

Table 6.Comparison of the variation in phytoplankton biomass in the two sampling

sites of Lake Hora-Arsedi during the study period (Chlorophyll a (µg/l)

| Sampling Date | Chlorophyll a (µg/l) | |
|---|---|---|
| | Center | Littoral |
| 21 August 2005 | 15.56 | - |
| 3 September 2005 | 25.57 | 37.25 |
| 21 September 2005 | 21.5 | 57.28 |
| 15 October 2005 | 16.77 | 23.57 |
| 29 October 2005 | 58.38 | - |
| 18 November 2005 | 55.6 | - |
| 14 December 2005 | 52.1 | 52.2 |
| 8 January 2006 | 50.04 | 54 |
| 22 January 2006 | 55.6 | 52.8 |
| 5 February 2006 | 50.04 | 55.6 |
| 2 March 2006 | 14.43 | - |
| 25 March 2006 | 14.58 | - |
| Mean | 35.85 | 47.53 |

## 5.2. Zooplankton Composition and Abundance

The zooplankton community in Lake Hora-Arsedi is composed of rotifers, and cyclopoid and calanoid copepods, whereas cladocerans were rarely observed during the study period. One interesting result in this study was the appearance of ***Diaphnosoma***, which was not reported in this lake before. The list of the zooplankton taxa identified and their relative abundance is presented in Table 7.

Table 7. Numerically dominant zooplankton taxa in Lake Hora-Arsedi during the study period (+ indicates dominance)

| Rotifera | Copepods | Cladocera |
|---|---|---|
| ***Brachionus calyciflorus*** | Cyclopoida | ***Diaphanosoma*** |
| ***B.quadridentatus*** | ***Thermocyclops consimilis*** | ***excisum*** |
| ***B.bidentata*** +++ | Calanoida ++ | (Rare) |
| ***B.dimidiatus*** | ***Paradiaptomus (Lovenula) africana*** | |

An interestingly shift in time in the percentage of zooplankton groups was seen in Lake Hora-Arsedi. Over the study period zooplankton abundance showed a clear variation over the months. Calanoids and cylopoids were relatively high during August –October 2005 and then gradually decreased in the following months. Copepods showed maximum abundance in March (Table 8). Rotifers made up the largest component of the zooplankton numbers during most of the sampling dates, but their numbers decreased in March 2006. The genus ***Brachionus*** dominated the Rotifera. Peak numbers of rotifers were observed in November 2005 –January 2006. However this proportion decreased with declining ***Microcystis*** abundance. On the other hand, copepod density increased with decreasing ***Microcystis*** spp. abundance.

Table8. Monthly changes in the zooplankton abundance (in %) in Lake Hora-Arsedi

during the study period

| Sampling Date | Rotifers | | Copepod | | Cladocera | |
|---|---|---|---|---|---|---|
| | Open | Littoral | Open | Littoral | Open | Littoral |
| Aug- 21 | 51.4 | - | 48.6 | - | - | - |
| Sep-3 | 48.5 | 66.7 | 47.1 | 33.1 | 4.4 | - |
| Sep-21 | 65.2 | 70 | 34.5 | 30 | - | - |
| Oct-15 | 80 | 83.3 | 20 | 16.7 | - | - |
| Oct-29 | 66.7 | - | 33.3 | - | - | - |
| Nov-18 | 71.4 | - | 28.6 | - | - | - |
| Dec-14 | 75.9 | 79.5 | 24.1 | 20.5 | - | - |
| Jan-8 | 74.4 | 81.25 | 22.6 | 18.75 | - | - |
| Jan-22 | 72 | 77.8 | 28 | 22.2 | - | - |
| Feb-5 | 63.6 | 75 | 36.4 | 25 | - | - |
| Mar-2 | 16.7 | - | 83.3 | - | - | - |
| Mar-25 | 18.8 | - | 75.0 | - | 6.2 | - |

The zooplankton species composition of Lake Hora-Arsedi is characterized by low number of crustaceans zooplankton. The crustacean zooplankton of Lake Hora-Arsedi is composed of cyclopoid copepods especially the ***Thermocyclops cansimilis*** and the calanoid copepods particularly ***Paradiaptomus*** (***Lovenula) africana.*** However, cladocerans were rarely seen during the study period***.***

The zooplankton in Lake Hora-Arsedi also exhibited monthly fluctuations in population size. There were clear monthly patterns in the abundance of adult

copepods. Copepods were present abundantly at the beginning of the sampling time (August, 2005) i.e. towards the end of the rainy season and they sharply declined until February 2006 and attained maximum density during March 2006 (Table 6). On the other hand, rotifers characteristically attained maximum during October 2005–February 2006) when the copepods declined and attain minimum between March and April 2006 with the emergence of the copepods. Rotifer and copepod densities appeared to be negatively correlated with each other and when the copepods were abundant rotifers were found in low numbers. This may have been due to competition or even predation by the copepods on the small rotifers. Copepod densities appeared to be negatively affected by the cyanobacteria. Copepods had been exposed to high concentration of cyanobacteria in the months prior to January 2006, which could have depleted their numbers during these months. Colonial and filament interference may have caused the larger, more herbivorous calanoid copepods to decline in number. After February 2006 cyanobacteria were not detected and the copepod population started to increase in number. The large nauplii numbers observed in February 2006 probably grew to the large adult copepods recorded in March – April 2006.

***Brachionus calyciflorus, B.bidentata and B quadridentatus,*** were dominant when cyanobacteria densities were highest (Oct 2005-Jan 2006). They may have fed on smaller, more nutritious algae or they may have gained some nutrition from the ***Microcystis. Brachionus*** can ingest ***Microcystis*** with few adverse effects

(Fulton and Paerl, 1988), so this ability could have allowed these rotifers to survive in a low –nutrition seston dominated by ***Microcystis***.

## 5.3. Natural Zooplankton Community Grazing Rates

Natural zooplankton community grazing rates ranging from 24 -173 %G/d was obtained at the central site whereas 19-59 % G/d was recorded in the littoral site in Lake Hora-Arsedi (Fig 2). Although, a higher %G/d was recorded at the central than the littoral site the difference between the two sampling sites, was not significant (t-test P=0.054)(See Appendix IX). The reason for this could be due to the smaller number of samples (n=7) taken from the littoral site (see Appendix I and II) and relatively high standard error of the mean observed in the grazing impact at the open water (see Appendix X).

Slight monthly variations in grazing rates were observed in the littoral sampling site whereas large variation in grazing rates was observed in the open water. On several occasions, the observations in this lake had shown that plankton at the littoral sampling location differ greatly from that of the central site. The plankton at the littoral site were usually dominated by rotifers and covered by scum of cyanobacterium bloom for a long period of time. These largely reduce and inhibit the filtering capacity of the dominant grazers (rotifers) in this site. On the other hand, the abundance of zooplankton groups varies greatly over the study period in the open water than in the littoral site. Large and efficient grazers (calanoid copepods) were abundant during August-September 2005 and March 2006 whereas the rotifers were dominant in the rest of months; this accounts for the

higher variation in the grazing impact of zooplankton on the phytoplankton population at this site.

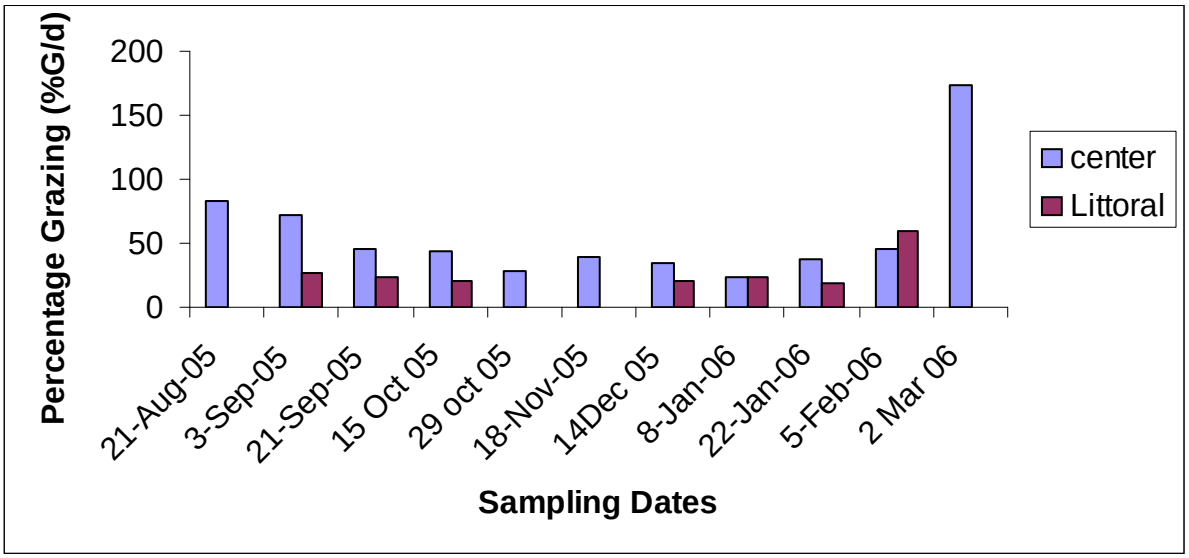


Fig. 2. Monthly variations of zooplankton community grazing rates at the central and littoral sites of Lake Hora-Arsedi (Aug 2005-March 2006)

To test the relationship between chlorophyll ***a*** biomass and %G/d a simple regression was performed for both sampling sites and the result show that there is a strong association between these variables in the central site ($r^2$ =0.42, P= 0.030) but no association between them in the littoral site ($r^2$ =0.081, p = 0.536). This is due to the fact that the quality and quantity of food source and the type and size of grazers in the lake are the major factors that influence grazing activity (Cyr and Pace, 1992). In this study it was also observed that the smaller bodied rotifers and large population of colonial and filamentous algae dominated the littoral site as compared to the open water. High concentration of seston particles

including colonial algae known to negatively affect food collection process and result in lower grazing activity. Therefore, this might be the reason for the lack of association between chlorophyll ***a*** biomass and %G/d in the littoral site (see Appendix X and XI).

Earlier studies in Lake Hora-Arsedi showed substantially higher grazing rates on phytoplankton with different methods (radioactive and chlorophyll ***a*** concentration change) (Habte Jebessa, 1994). In 1993, the average grazing rate was 75% whereas the result obtained in this study is 53.6 %. The difference could be due to advantage of using isotope-labeling technique in the previous study. Isotope labeling allows feeding to be observed within individual zooplankter, thereby allowing the determination of relative and absolute grazing rate. Usually, radiolabelling method is more sensitive than changes in chlorophyll ***a*** concentration (Peters, 1984). Therefore, the low zooplankton grazing in this study may be the result of underestimation with the chlorophyll method. Secondly, the result of the previous study was analyzed on a smaller data (n=4) and a different result might have been obtained if studies were made on large-data basis, when environmental conditions and plankton assemblage differed monthly. Lastly, the trophic status of the lake has changed over time. It was described as mesotrophic by Habte Jebesa (1994), but the results of the present study have shown that, it has gradually changed to the eutrophic end spectrum.

Low grazing intensity on phytoplankton was measured in this lake as compared to some values reported in the literature. The natural zooplankton community

grazing rate studies in Lake Hora-Arsedi indicate that grazer effect (both in the littoral and open water site) is relatively high in comparison with lakes in the temperate regions. This is evident from Cyr and Pace (1992) who plotted frequency distribution of published measurements versus %G/d and found that 51% out of 365 observations were less than 25%G/d. Few of the temperate community grazing rates are higher than the present measurements and this is notable (Haney, 1973; Gulati ***et al.,*** 1982). However; comparison of tropical zooplankton grazing rate values with those of temperate result is misleading for various reasons. First, whenever we think about temperate zooplankton, cladocerans are usually mentioned, especially ***Daphnia;*** secondly there is a great difference in temperature as well as mixing patterns. It is also possible that high temperature may result in higher grazing rate, for respiration rate increases more rapidly at higher temperatures. Finally, zooplankton grazing rate studies are highly concentrated in temperate regions but there is scarce literature in the field in tropical Africa.

The grazing results observed in this work are less than that measured in subtropical and tropical African lakes (e.g. Jarvis, 1986; Habte Jebessa, 1994). Several reasons account for such differences. Usually radiolabeling method is applied in studying zooplankton-grazing rate, and this is more sensitive than change in chlorophyll ***a*** (chl a) method. The use of chlorophyll as estimator of phytoplankton biomass could introduce various types of errors into the calculations of phytoplankton growth and zooplankton grazing rates. Chlorophyll from phytoplankton cells, which are dead but intact, or incompletely digested by

zooplankton (Head and Harris, 1992), could affect biomass estimates. Furthermore, the relative chlorophyll contents of phytoplankton cells may vary accordingly to physiological condition or taxonomic composition (Riemann ***et al.***, 1989). Another reason is the trophic state of the study lake. The pattern of zooplankton effects on phytoplankton observed in this experiment supports certain views of the nature of algal-grazer interaction as a function of lake trophic status. This can be comparable with the result found in the literature. The impact of macrozooplankton are weak in ultr-oligotrophic systems (Carney and Elser, 1990), reflecting extreme food limitation of crustaceans in unproductive systems that prevent them from reaching sufficient densities to control their prey (the algae) or to be important in nutrient processing. Experimental studies performed in moderately productive, nutrient-limited meso-oligotrophic systems showed a strong direct and indirect effect of grazers on phytoplankton (Bergquist and Carpenter, 1986; Vanni, 1987, Elser and Mackay, 1989). In such systems nutrients are relatively scarce and larger cells are at a competitive disadvantage. Thus, algae may face a tradeoff between the advantage of large size as a defense against grazing and its disadvantages in nutrient acquisition and as a result algal communities in such nutrient –limited systems reflect the impact of both zooplankton grazing and nutrient regeneration. Finally, the weak efforts of grazers on the large-sized, cyanbacteria-dominated algal assemblage confirm the view that grazer impacts should weaken in eutrophic and hypereutrophic systems (McQueen ***et al.,*** 1986; Sommer ***et al***., 1986; Carney and Elser, 1990).

In such nutrient rich systems, colonial and other large algal taxa can dominate, lessening the ability of crustacean zooplankton to graze them significantly.

Based on Carlson (1977) trophic state index scale, the level of productivity of Lake Hora-Arsedi as measured by chlorophyll ***a*** is categorized as eutrophic. Apart from elevated chlorophyll ***a*** biomass, eutrophic lakes are characterized by increasing incidence of nuisance algal blooms (Stephen ***et al***., 1989). These conditions were also usually observed in this lake during the study period (Personal observation). Since grazing rate decreased with increasing food concentration (Gulati ***et al***., 1982; James and Forsyth, 1990; Cyr and Pace, 1992), this observation is in agreement with theoretical expectations. Generally, the results of this study indicate a similar trend and comparable grazing impact of zooplankton on the natural phytoplankton assemblage to that of tropical and subtropical lakes (Crisman ***et al***., (1995); Cichra ***et al***., (1995); Moriarity e***t al.,*** (1973); Saunders and Lewis, 1988; Fernando, 1994; Magadza, 1994). All of these studies reached the conclusion that zooplankton are unable to utilize colonial algal species that develop in such nutrient –rich tropical environments.

Various reasons should be given for the low grazing impact of zooplankton on the natural phytoplankton assemblages in Lake Hora-Arsedi. In Lake Hora-Arsedi as in the other lowland tropical lakes mentioned above, it appears that the considerable overlap in size between large cyanobacteria dominated phytoplankton and the smaller herbivorous zooplankton is responsible for the reduction of top-down control. As in temperate lakes (Schoenberg and Carlson,

1984; Elser and Mackay, 1989), the small zooplankton cannot effectively control phytoplankton biomass when it is dominated by cyanobacteria.

Furthermore, both the qualitative and quantitative aspects of food sources are the major factors shaping the composition and abundance of zooplankton assemblages (Rothhaupt, 1990a, Cordova ***et al***., 2001), which in turn influence the grazing activity (Cyr and Pace, 1992). That might also be the reason for low grazing activity recorded in Lake Hora-Arsedi, where the seston concentration and phytoplankton biomass were considerably higher and Cyanobacteria contribute much of the total phytoplankton biomass. If cyanobacteria are driving zooplankton diversity, certain species may have been favored not only by their size but also by their mode of feeding and ecological adaptation. The ability of rotifers to withstand cyanobacteria colony makes them dominate over a long period in this lake.

Micro-zooplankton grazing was higher at high densities of cyanobacteria. This suggests that these cyanobacteria did not inhibit micrograzers and may even have provided them an advantage over larger grazers at high cyanobacteria concentration. There may have been competitive or even predation pressure on rotifers, from large zooplankton. Copepods, can actively feed on rotifers (Burns and Shallenberg, 2001). Since micro-zooplankton grazing was greater when cyanobacteria density was higher, competition and predation were probably negligible on the smaller zooplankton size fraction at this time, resulting in higher

micro-zooplankton densities and suggesting negative impacts of the cyanobacteria on larger grazers.

The importance of top-down control is also influenced by the strength of bottom-up factors and thus seems stronger in deep lakes than shallow lakes because shallow lakes are typically fully mixed throughout the year whereas most deep lakes are stratified. This affects nutrient availability for the phytoplankton due to nutrient loss to the hypoliminion through sedimentation. However cyanobacteria are S-strategies and have low specific settling rates, among other reasons, because of high buoyancy (Reynolds, 1984). This makes them competitive in stratified system where loss by sedimentation is critical because, as discussed above, the nutrient do not immediately return to the epilimnion. Therefore, the majority of deep lakes are dominated by cyanobacteria (Sas, 1989). This might be the case for the dominance of ***Microcysts*** in Lake Hora-Arsedi, which is a deep lake with a maximum depth of 38m, and mean depth of 17.5m.

Although fish predation seems to be the main cause for decrease in zooplankton grazing pressure in mesotrophic to eutrophic lakes, larger and in particular filamentous algae can also have a negative impact on grazing capacity and thereby weaken the top-down control of phytoplankton. This is particularly the case with cyanobacteria in freshwater lakes (Bernardi and Giussani, 1990). Thus large cyanobacteria may affect the filtration capacity of zooplankton by interference and being less edible, less nutritious and sometimes toxic (Bernerdi and Giussani, 1990). This might be also the case in Lake Hora-Arsedi for the

weakening of the grazer impact on the phytoplankton community between October 2005–January 2006. Genera such as ***Microcystis (which*** consists of colonies of small cells) and ***Cylindrospermosis*** are the most common form of cyanobacteria found in Lake Hora-Arsedi and it may be a relatively inefficient food source.

The daily ***in situ*** community grazing rates tracked the zooplankton abundance. In Lake Hora-Arsedi the highest community grazing rates were recorded when efficient grazers abundance (such as calanoids) was at its peak. These highest grazing rates, which amounted to 173%, were also concomitant with the period of clear water phase, which is comparable to temperate lakes. A spring peak of zooplankton coinciding with a period of very clear water is frequently reported in the literature for temperate lakes (Lampert, 1985; Sommer ***et al***., 1986).

The coincidence of clear water phase and the macrozooplankton maximum, may be, is not proof that zooplankton are responsible for the removal of particles. The decline of algal populations could be consequences of nutrient limitation, sedimentation and the zooplankton maximum may occur during the clear water phase as a time –delayed response to good food conditions. There is even a possibility that the zooplankton maximum could be a consequence of algal break down, if the zooplankter feed on the increased number of bacteria decomposing the algal material. On the other hand, calculation of the loss budget of algal population (Reynolds ***et al***.1982 and Sommer 1983) and direct estimation of

zooplankton grazing rates (Lampert and Schober, 1978; Gulati ***et al.,*** 1982) indicate that grazing losses can at times exceed primary production.

Through observation of monthly variation of zooplankton and phytoplankton groups, manipulating zooplankton in the grazing bottles and comparison of the daily percentage grazing results obtained during the study period, I have provided multiple evidences that grazing by zooplankton caused the clear water phase in Lake Hora-Arsedi. The literature survey also shows that the impact of grazers on phytoplankton can be tested directly by manipulation of zooplankton densities in experimental enclosures (Porter, 1972; McCauley and Brand 1979). The work of Lampert ***et al***.,(1986) clearly demonstrates that even in relatively large lakes zooplankton can cause phase of extreme clear water. It also shows that two conditions must be met to produce clear water phase: the algal standing stock must consist of small" edible cells "and the density of filter feeding zooplankton must reach high level. Since these conditions were evident in March and April 2006, this may explain and is evidence for the fact that the impact of efficient grazers on the natural phytoplankton is the cause for the appearance of clear water phase in Lake Hora-Arsedi at this time of the year.

## 5.4. Manipulated Zooplankton Grazing Rates

### 5.4.1. Zooplankton density gradient grazing rates

Zooplankton grazing rates showed inverse relationship with grazer density in all cases of the sampling dates and at both sampling sites in Lake Hora-Arsedi. That is, increase in zooplankton density beyond the ambient level (1x) decreased

percentage grazing per day (see Fig 3 and 4). The result of this study seems not in agreement with some literature, which shows that as the zooplankton density increase, chlorophyll concentration decreased (James and Forsyth, 1990) and a threshold reached where no more grazing rates increases after which it decreases because of shortage of food. The main reason for the decrease in grazing rates as the zooplankton density increase in this study was primarily the interference of large filamentous and colonial algae. Generally, zooplankton exert much stronger effect on phytoplankton biomass, when phytoplankton species susceptible to zooplankton grazing tend to be more abundant and relatively resistant species are less common (Vanni and Temot, 1990). In this study, blooms of blue-green algae especially ***Microcystis aeruginosa*** dominated over the study period. It is known that such large sized algae are actively rejected by herbivorous zooplankton (Stangenberg, 1968; Peters, 1984). Thus the increase in zooplankton density contributes to competition for other few available edible algae, causing %G/d to decrease. Therefore, increase of ambient zooplankton density has no strong negative effect on phytoplankton biomass in Lake Hora-Arsedi. This problem is still a challenge to biomanipulartion. That is when phytoplankton under consideration is inedible by the zooplankton of that system; no solution can be found (Bendorf, 1988). Considering the living and feeding condition for zooplankton, Lake Hora-Arsedi seems to be an unfavorable environment with a higher density of seston particles and large inedible phytoplankton. The inhibiting effect as well as the low nutritional values of seston and colonial cyanobacteria may cause food limitation to large efficient grazers.

Another reason why grazing rates decreased as the zooplankton density increased was low filtering capacity of grazers. In Lake Hora-Arsedi the dominant grazers observed in these months were the rotifers, which have small filtering apparatus as compared to the larger efficient grazers.

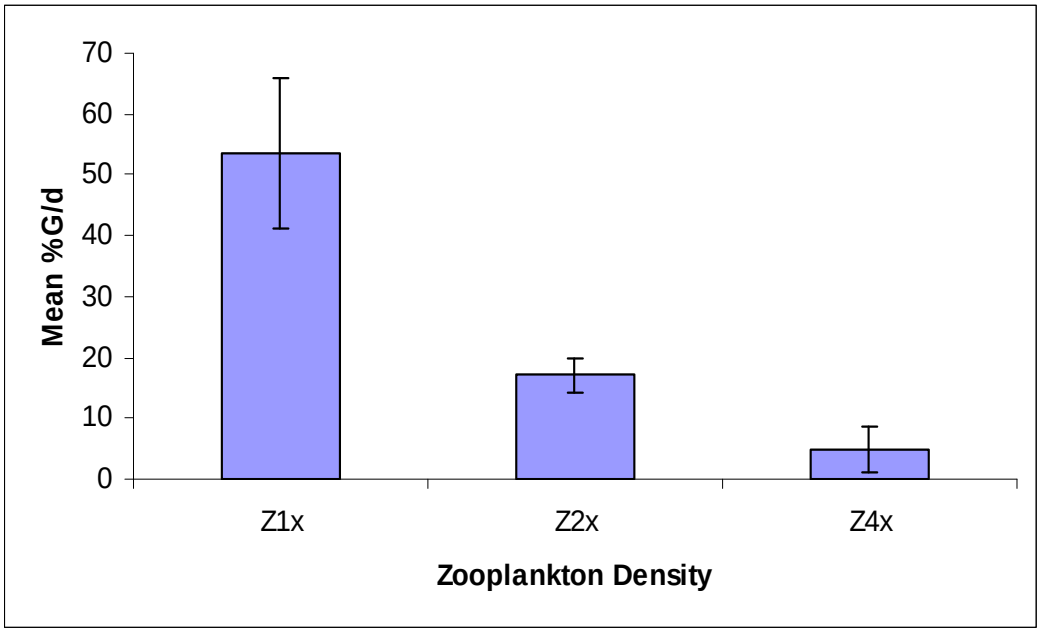


Fig.3. Zooplankton density gradient grazing rates in the central site of Lake Hora-Arsedi

(Mean of 33 incubations). Error bars indicate standard error of the mean.

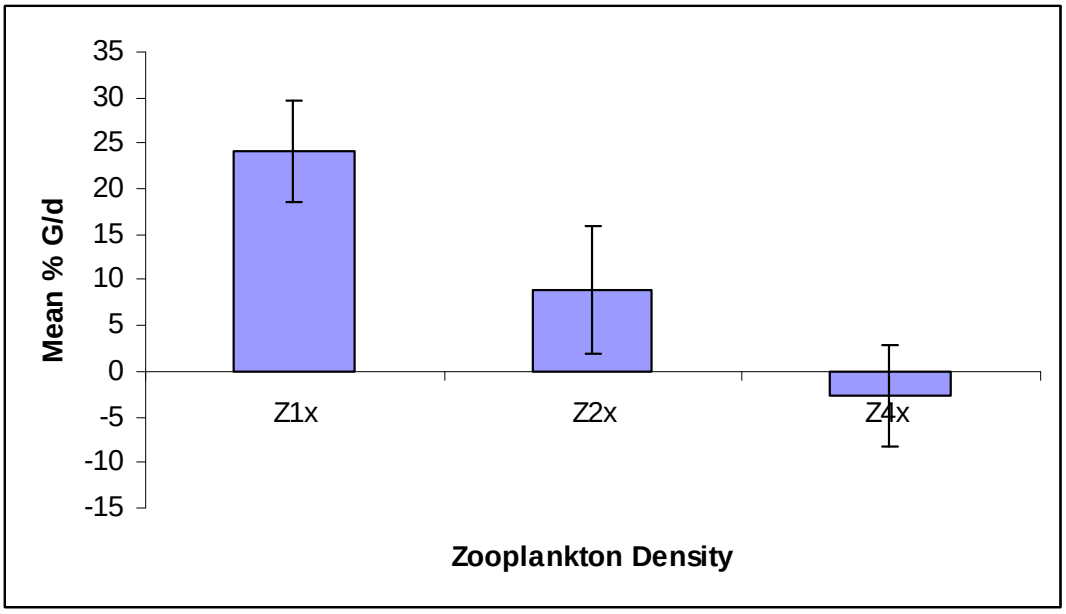


Fig. 4.Zooplankton density gradient grazing rates at the littoral sampling station in Lake Hora-Arsedi (Mean of 21incubations). Error bars indicate standard error of the mean.

It is known that large zooplankton may be disadvantaged during blooms of cyanobacteria and replaced by smaller species (Zankai and Ponyi, 1986). In this study; the rotifers contributed the largest portion of herbivorous zooplankton during the dominance of cyanbacteria. This indicates the rotifers may be temporarily even more important grazers than the available large zooplankton at this time in this lake but rotifers as a group cannot be considered as efficient grazers on phytoplankton. Therefore, differences in zooplankton size structure and taxonomic composition are expected to result in different grazing impact on algae being consumed. This might be one reason that increasing zooplankton density cannot increase grazing rates in Lake Hora-Arsedi. Altogether the combined effect of unfavorable large colonies of ***Microcystis*** food available in the

lake; low filtering capacity of the dominant zooplankton (rotifers) and food depletion were the main reason for decreasing grazing rates observed with respect to the experiment on increasing zooplankton density.

The implication of this result for biomanipulation is that in order to attain the required water quality, there should be a desired number of herbivorous zooplankton. In other words the density value of zooplankton needed to clear the daily primary production in each lake of different trophic status should be known (Gulati, 1990). In this respect Lake Hora-Arsedi zooplankton, especially the calanoids, are effective grazers in controlling the phytoplankton biomass and to create a clear water phase during their dominance. Thus, the application of bimanipulation is promising in this lake when the calanoids are dominant whereas during the time rotifers are dominant, it is unthinkable.

In this study a negative mean percentage grazing rates was recorded in the littoral site at high zooplankton density (Z4x), which is not observed in the central site (see Appendix I and II). The main reason for this difference is due to the aggregation of ***Microcystis*** into larger colonies in the littoral site that interfere with the grazing activity of rotifers and limit the development of larger efficient grazers. Large zooplankton are disadvantaged during blooms of cyanbacteria and replaced by smaller species. Several observations in this lake show that the dominant zooplankton group in this site over the study period was the rotifers. Small zooplankton cannot effectively control phytoplankton biomass when the lake is dominated by cyanobacteria (Elser and Mackay, 1989). Therefore, the

negative grazing rates measured in the littoral site at high zooplankton density was due to the interference of large colonial algae in the filtering activity of rotifers plus the absence of large-efficient grazers in this site.

With regard to dual zooplankton and phytoplankton density -gradient grazing rate experiment, the result obtained show similar trend in all cases i.e. grazing rate decrease as the zooplankton and phytoplankton density increase simultaneously (Fig 5 and Appendix 7). Thus, from this observation one should come to the conclusion that increasing the zooplankton and phytoplankton density beyond ambient concentration cannot increase grazing rate. This is because of the fact that food concentration was naturally above the incipient limiting level and the dominant phytoplankton group was cyanobacteria, which are inedible, and therefore, further increase leads to crowding. On the other hand the dominant zooplankton groups during the study period were the rotifers, which are not efficient grazers on the available algae.

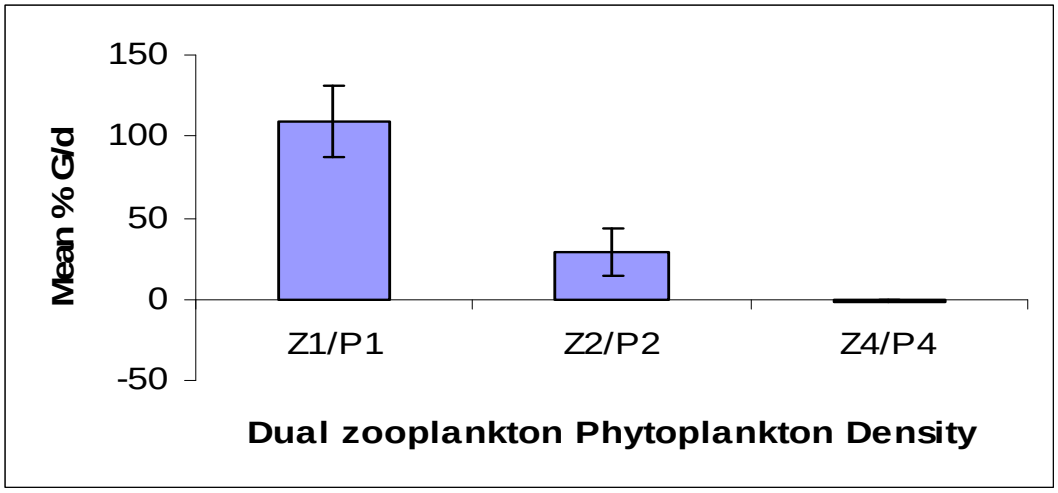


Fig 5. Simultaneous zooplankton and phytoplankton density gradient grazing rates

(Mean of six incubations). Error bars indicate standard error of the mean

### 5.4.2. Phytoplankton Density Gradient Grazing Rates

Over the study period the zooplankton community was exposed to different densities of food in the grazing bottles at both sampling stations of Lake Hora-Arsedi. The result obtained show that zooplankton community grazing rate generally decrease as the food density increases(Fig 6 and 7) . This trend was the same for both the open water and the littoral site (See Appendix III and IV). Food concentration is one of the various factors affecting the grazing rates of the zooplankton (Dhert, 1996; Navarro, 1999). Food concentration affects feeding by determining the rate at which a grazer encounters food items (Begon ***et al***., 1986). This study examined the effect of ambient concentration of the food (the natural phytoplankton community in Lake Hora-Arsedi) as a prey source for the zooplankton community in the lake.

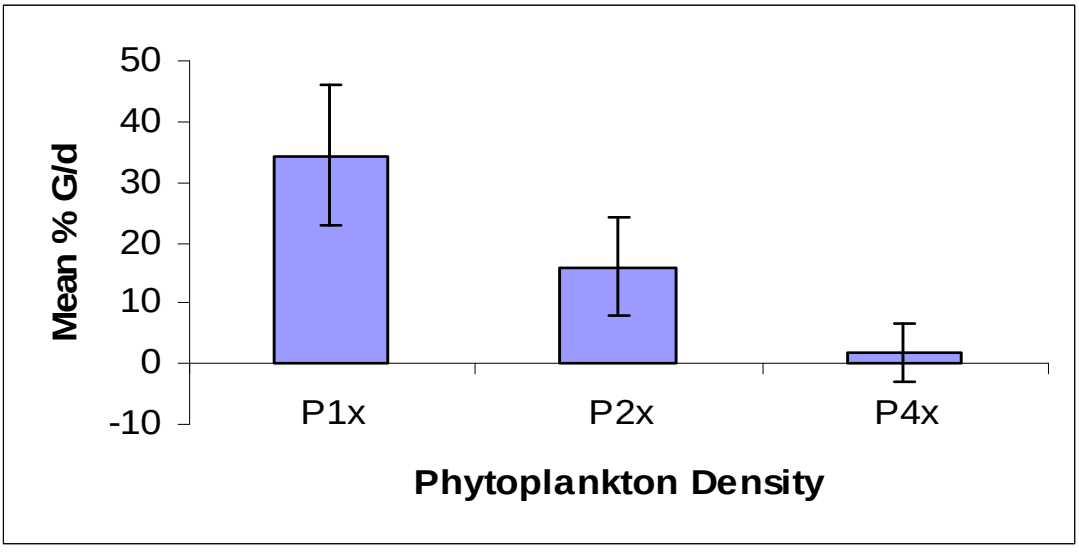

Fig .6. Zooplankton grazing rates on different phytoplankton density at the central site of Lake Hora-Arsedi (Mean of twelve incubations). Error bars indicate standard error of the mean).

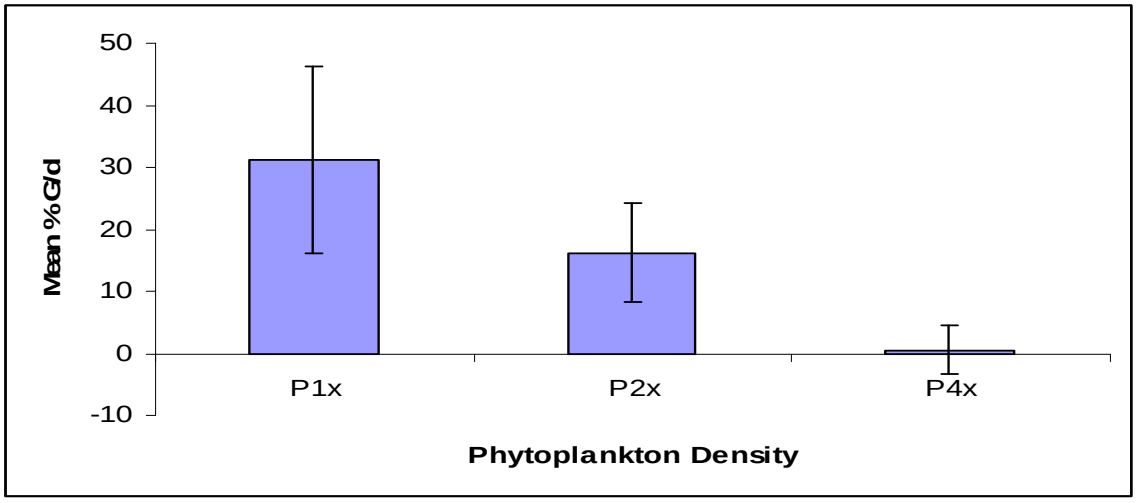


Fig. 7. Zooplankton grazing rates on different phytoplankton density at the littoral site in Lake Hora-Arsedi (Mean of twelve incubations).Error bars indicate standard

error of the mean.

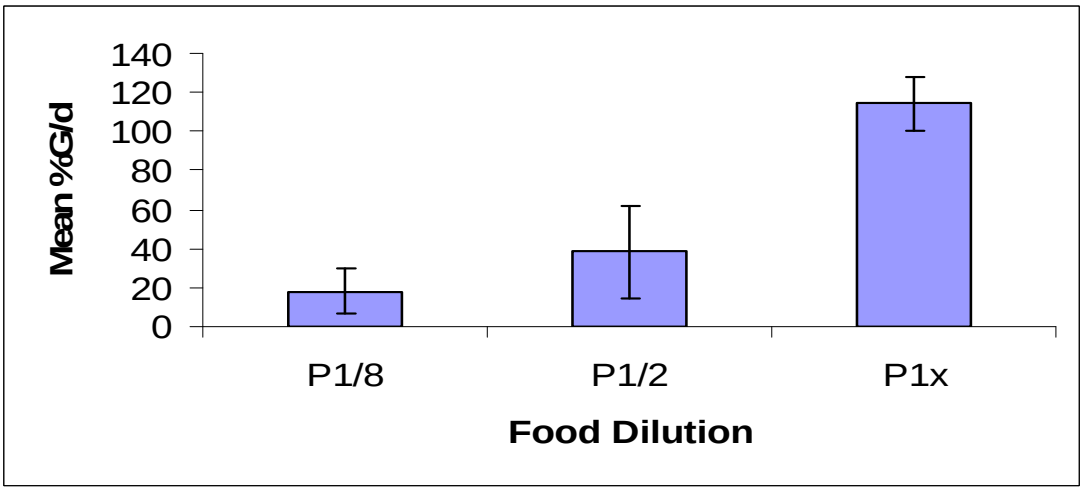

Fig 8. Zooplankton grazing rates at lower food dilution levels (Mean of nine Incubations). Error bars indicate standard error of the mean.

The present results indicate that zooplankton-grazing rates in Lake Hora-Arsedi decrease in response to increasing food concentration; which is consistent with the literature. High food concentration decrease grazing rates because the food level may lead to superfluous feeding, above the incipient limiting level i.e. the point where grazing becomes asymptotic with increasing food concentration (Rothhaupt, 1990b). The assimilation rate reaches a plateau and thus there is no more increase in grazing rate (Gulati ***et al***., 1982). Filtering rate decreases as the concentration of food increase above incipient level and above this point, an increase in prey does not raise ingestion rate. Observation from other studies on ***Brachionus pilicatilis***, fed various prey species indicated that grazing rate increase with increasing food concentration until a plateau is reached (Korstad ***et al***., 1989; Hansen ***et al***., 1997; Navarro, 1999). Thus, most likely why grazing rates decreased with food concentration in Lake Hora-Arsedi is because the ambient food concentration is already above the incipient limiting level.

From the physiological point of view, the food particles can be ingested only after falling from a feeding current onto the sieve –like second maxillae in the case of filter feeding copepods. Ingestion rate of such a feeder increases in direct proportion to increase in concentration of food up to a saturation point above which ingestion may be determined by the passage rate of food through the alimentary canal (Frost, 1972). In a laboratory experiment, Varsechi and Jacobs

(1994) also found a highly significant and steep negative correlation in adult copepods of ***Lovenula africana*** between algal concentration and grazing rate. They claimed saturation or clogging effect at higher concentration as the main reason.

Although the present data appear to agree reasonably well with those in the literature, there are caveats that require recognizing. First, feeding rate can vary with food quality (Doohon, 1973 and cell types and size (Starkweather, 1980; Rothhaupt, 1990b; Hansen ***et al.,*** 1997; Navarro, 1999). Second, incubation time of the zooplankton community to the experimental condition may not be sufficient to alter their physiology substantially. The present data, thus, represents the grazing of the zooplankton community that has entered an environment with a new food concentration for a relatively short period. Finally, the trophic status of the study lake may affect the grazing activity of the grazer. As mentioned above, the present study showed that Lake Hora-Arsedi is being in the eutrophic state; ambient food concentration was above the incipient limiting level; cyanbacterium blooms were dominant; these may result interference with the filtering impact of the zooplankton in this lake.

On the other hand, the dilution experiment conducted on three occasions indicated that grazing rates declined at lower food concentration and reached peak when ambient food concentration is reached (i.e. P1/8,P1/2 and P1x) (Fig 8). Food less than 1x could be below the threshold value. Therefore, under natural condition, where cyanbacteria blooms are abundant, the zooplankton community may not be food limited. However, the dominant zooplankton group

during this period was rotifers, which are not efficient grazers on the available food and have low filtering ability. Even the rotifers population overfeeds on the available food, overfeeding leads to food particles being ingested but not digested (Doohan, 1973; Galkovskaja, 1987), probably resulting in poor water quality (Dhert, 1996). Therefore, this result showed ambient food concentration in Lake Hora-Arsedi is optimal that is why grazing rates decrease above or below natural food concentration.

Generally, food concentration has a marked influence on both feeding and grazing rate. According to Frost three models describes feeding rate as a function of food concentration (Frost, 1972). These are: a) The rectilinear model, which implies a constant grazing rate below the incipient limiting food concentration .b) The curvi linear model, which implies a decelerating grazing rate as food concentration increase c) Ivlev model, which permit a reduction in grazing rates at very low food concentration. Therefore, the observation in this study indicates the grazing rates for the zooplankton of Lake Hora-Arsedi follows the curvilinear model at high food concentration as in Fig 6 and 7 and Ivlev model at low food concentration as in Fig 8.

### 5.4.3. Zooplankton Size Gradient Grazing Rate

Zooplankton size fractionation studies were done in Lake Hora-Arsedi from December 14 2005 to March 2, 2006. To distinguish the grazing rates of the various grazer size- classes on the natural phytoplankton community in the open

water, the zooplankton communities were fractionated into <250 µm, <450µm and >450µm and the result obtained is listed in Appendix V. The smaller zooplankton size -class (<250 µm) was dominated by rotifers, and the size class>250 µm and <450µm was dominated by copepod nauplli, copepodites, rotifers and small copepods. The size- class >450µm groups were dominated by large cyclopoid and calanoid copepods. A comparison of the effect of the various grazer size- classes on the natural phytoplankton community showed that zooplankton community-grazing rate generally increases as the size of the grazers increased (Fig 9). Low grazing rates are obtained for zooplankton size fraction less than 250 µm and moderate rates for <450 µm. Zooplankton with-size class greater than 450 µm showed more than 100 percentages grazing rates per day (see Fig 9).

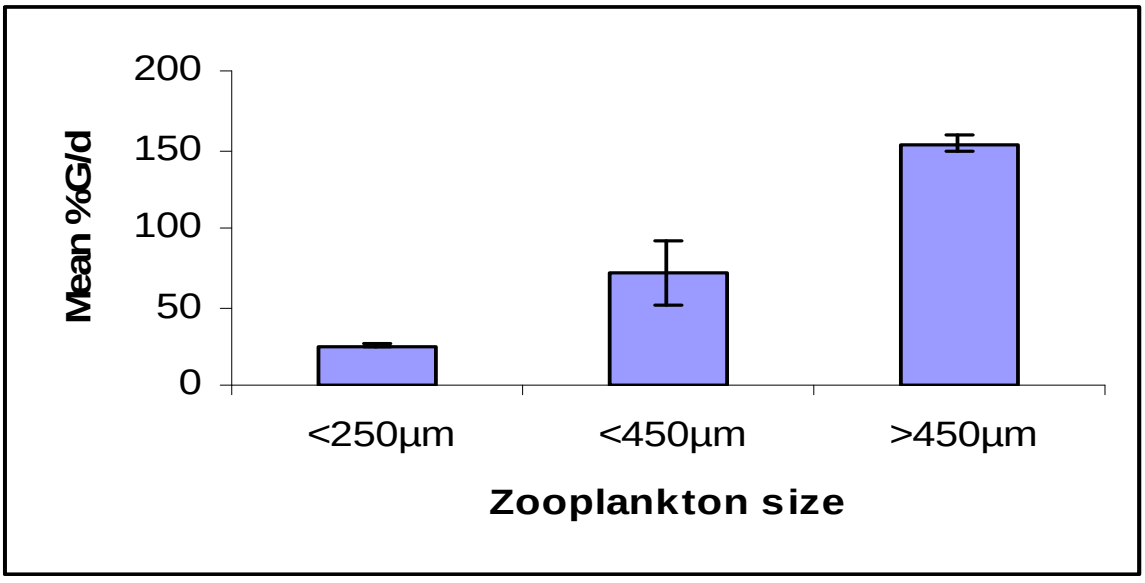


Fig 9. Zooplankton size gradient grazing rates in Lake Hora-Arsedi (Mean of eighteen incubations). Error bars indicate standard error of the mean.

The result of this study is consistent with the reports in the literature. Whenever the zooplankton size- fractionation grazing rate studies were performed, usually the larger size zooplankter showed higher grazing rates than the smaller size classes. Larger zooplanktons are able to consume a wider range of algal types compared to smaller zooplankton (Cooke, 1986) and filter large volume of water.

Burns and Rigler (1967) showed that clearance rates of zooplankton increase with increasing body length. This idea corresponds to the size efficiency hypothesis for the filtering apparatus possesses an area equivalent to the square of the body length of that specific species. So the bigger the organism the larger the filtering apparatus and thus filtering large volume of water is possible according to this theory. Larger sized zooplanktons are the most desirable in terms of algal filtration.

This idea is also supported by the size efficiency hypothesis proposed by Brooks and Dodson (1965). The size efficiency hypothesis assumes that all freshwater zooplankton can utilize cells in the 1-15µm ranges, that large zooplankton can eat much larger cells, and that there in relationships between zooplankton size and the minimal size of ingestible cells. The assumption of this hypothesis indicate that large and small zooplankton should compete for similar- sized food and that large zooplankton should out -compete small zooplankton when these resources become limiting, both because of their ability to utilize large as well as small cells and because of their ability to exist at lower food levels.

### 5.4.4. Phytoplankton Size Gradient Grazing Rates

Size selection consumption of prey has been a key issue in aquatic ecology ever since the classical work of Brooks and Dodson (1965) and is fundamental to predator-prey interactions as well as the food- web concept (Carpenter ***et al***., 1985; Carpenter, 1988). Different aspect of size- selective herbivory on various prey organism have been widely studied in temperate freshwater systems (McCauley and Downing, 1985; Pace ***et al.,*** 1990), but the potential impact of tropical zooplankton on algal populations has been less studied.

In this study a combination of descriptive field study was done to focus on the effect of dominant grazers on the three size -classes of food organisms (phytoplankton) ranging from nanoplankton (<20 µm) to microplankton (>20µm) and categorized as <10µm, <20µm, and <63µm size-classes. In Lake Hora-Arsedi, algal microplankton (>20 µm) contributed most to phytoplankton biomass, while nanoplankton dominated numerically (See Appendix VI). In the grazing studies on the three-phytoplankton size- classes, all the grazer groups (copepods and rotifers) had a negative impact on algal abundance. Algal composition of all fractions was analyzed and associated zooplankton community grazing activity was recorded and the result show that all phytoplankton size- class is removed by herbivorous zooplankton almost equally, although the size class < 63 µm were removed relatively less than the other size classes. (Fig 10).

Numerous studies have found that algae suppressed by zooplankton grazing comprises mostly small, easily digested species including ***Cryptomonas,***

***Cyclotella, Rhodomonas, Astereonela, Oocysitis, Chlamidomonas, Scenedesmus*** (Breteler ***et al***., 1999;Tang ***et al.,*** 2001). There are some algae which are unaffected by grazing. This group consists of species that are seldom grazed by zooplankton, either because they are too large or because they have anti-predator defense such as large spines or bad taste. e.g. ***Cosmarium, Peridinium ,Ceratium ,Anabaena*** and ***Cylindrospermosis .***

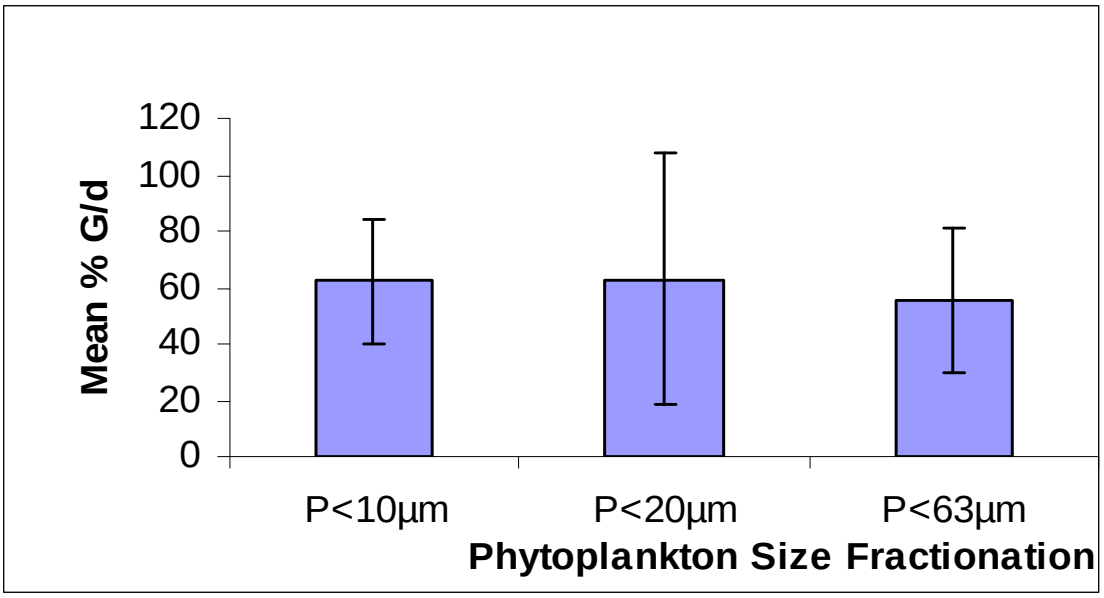


Fig10. Phytoplankton size- gradient grazing rates in Lake Hora-Arsedi (Mean of 21

Incubations). Error bars indicate standard error of the mean.

The result obtained in this study showed that almost all phytoplankton size-classes were grazed equally, which is a different trend as compared to the literature. Since more zooplankton species are able to consume prey organisms at the lower end of the size spectrum than at the higher end (Burns, 1968) smaller prey organisms generally suffer from a higher grazing rate pressure than

the larger ones (Gliwicz, 1977). Better performance of a smaller species of zooplankton in the nanoplankton and of large species in the microplankton are in agreement with the accepted idea that the size limit of ingested particles by herbivores depends on the body size and the mesh size of the filtering setae (Geller and Muller, 1981).

Various reasons could be pointed out why grazing rates are not so different on the three size-classes of algae in Lake Hora-Arsedi over the study period. First, the food size spectrum of zooplankton is quite wide (McCauley and Downing, 1985). Any sharp edibility limit is arbitrary. The knowledge on interaction between algal assemblage and herbivores is critical for generalization in applying lab data to field. The distribution of zooplankton grazing rates on algae of different sizes could either be described with a negative relationship or a simple threshold, but either of these provides an absolute measure of algal edibility. Different algal taxa within a given size range varied widely in their response to grazing, from complete depletion to enhanced net growth. Other studies have also reported large variability in the response of different algal taxa to zooplankton grazing (Elser, 1992). This variability suggests that factors other than algal size are at least as important in determining the intensity of grazing on different algal taxa. Laboratory studies in simplified assemblages of one or a few algal species and one zooplankton species have shown that many factors other than algal size affect food selectivity by zooplankton (e.g. shape, hardness, taste, motility, nutrient content, surface characteristics, toxity (Vanderpoeg, 1990). It is unclear, however, whether these factors are as important in more complex natural

communities. In the communities of Lake Hora-Arsedi, grazing rates on the three size-classes did not show variation (Fig 10). Although many factors other than algal size are known to reduce their edibility in this study there are no quantitative model available to predict which algal taxa are grazed more in the natural communities.

Secondly, the size range of grazed algae varied greatly with the size structure and taxonomic composition of zooplankton. Different zooplankton taxa feed differently on the various assemblages of algal communities and may not be expected to follow the same relationship. The taxonomic composition of zooplankton communities appears to be as important as their size structure in determining the range of algal size they graze. Filter feeding predators consume prey about 40-50 times smaller than themselves, whereas raptorial predators feed on relatively larger prey between 5-20 times smaller than themselves (Hansen ***et al***., 1994). Among zooplankton, Daphnidae ***(Daphnia*** and ***Ceriodaphnia)*** and Sididae ***(Diaphnosoma*** and ***Holopedium***) are filter feeders, while Bosminidae (***Bosmina*** and ***Eubosmina***) and Chydoridae are dual-mode feeders, which combine raptorial and filter feeding. Copepods (the common crustaceans in Lake Hora-Arsedi) are generally thought to feed on larger particles than cladocerans (Peters and Downing, 1984; Horn, 1985). Calanoids use a mixture of passive and active collection for small and large particles respectively (Vanderploeg, 1990) and Cyclopoid are omnivorous and raptorial feeders (Zankai and Ponyi, 1986; Adraion and Frost, 1992).

The major part of the phytoplankton taxa dominated in Lake Hora-Arsedi during the study period was the blue-greens whereas the dominant zooplankton species was the rotifers (Table 7). Rotifers feed on small particles (Pourriot, 1977) and are not expected to affect the size ranges of algae. On the other hand, calanoid and cyclopoid copepods were also observed in this period, although at a lower density. Calanoids are expected to graze on both the smaller and larger-sized algae and the raptorial cyclopoid are thought to select larger food particles. Therefore, the combination of different size structure and taxonomic composition of the zooplankton community in Lake Hora-Arsedi resulted a similar impact on the three-size fraction of the natural phytoplankton groups.

The third reason may be comparable with Lake Monte Alegre i.e. the problem of contamination of the algal fraction due to experimental artifacts (Acrifa ***et al***., 1998). In studies of natural food for herbivores, numerous criteria have been used to separate the phytoplankton assemblages into size classes. Commonly, however, algal size classes are obtained by filtering phytoplankton through nets, which results in the contamination of a given fraction by algae of other fraction (Zureck and Bucka, 1994). Therefore, it is important, if possible to identify the organism present in the algal fraction offered as food to zooplankton. Actually, the use of nylon cloth to fractionate phytoplankton did not prevent contamination. Small algae can be entangled in the larger one during the filtration procedure, whereas large but narrow species can pass throughout the net pores. Thus, both the larger and the smaller phytoplankton group contaminated to some extent, depending on the lake seston composition.

Three phytoplankton fractions were offered to the natural zooplankton community in Lake Hora-Arsedi, The sestons were separated by filtration through a <10µm, <20µm and <63µm Nylon cloth. Observation of the phytoplankton community in this study also revealed that, contamination by large algae occurred in the smaller groups. Even so, a larger relative contribution of large algae to the smaller algae size class compared with the smaller one. In this study, it might be the case that the net (nylon cloth) was not so efficient in preventing the larger alga to contaminate to the smaller fraction. Therefore, contamination may result the proportion of edible algae to be similar in all size fractionation class. Zureck and Bucka (1994) stated that the relatively easy procedure of fractionating seston by filtering water through a net, used in limnological studies should be considered. Most studies do not identify the organism in different phytoplankton size class, which is a shortcoming in studies of phytoplankton –zooplankton interaction.

Finally, duplication of the smaller size classes of phytoplankton in all size fractions probably result proportional distribution of the edible portion of algae. This condition may be the case for similar grazer impact on the three- size classes of phytoplankton in Lake Hora-Arsedi.

Generally, the results of the present study show that the assumptions many ecologists have made regarding the ability of zooplankton to feed on the various size fraction of the phytoplankton are compatible. Attempt to categorize or predict

the diet of zooplankton by its size or major taxonomic groups is unlikely to be realistic, due to the aforementioned reasons.

On the other hand, the result obtained in the simultaneous effect of the three size- classes of zooplankton and phytoplankton groups have shown the same general trend, with the exception of the smallest size classes of zooplankton. Higher grazing rates were recorded for zooplankton size class greater than 450µm exposed to the phytoplankton size -class less than 20 µm (see Appendix VIII). Community dominated by small zooplankton (<250 µm) had low grazing rates of 2.9-13 %G/d, because algal biomass increased with increasing zooplankton and phytoplankton size. These grazing rates were measured due to the fact that smaller-sized zooplankton groups (rotifers) were very rare during this time of sampling (25March 2006). Whereas intermediate grazing rates (34-70 %G/d) were measured by zooplankton size- class <450 µm which is dominated by copepod nauplli and small cyclopoids. The grazer community in size class > 450 µm, (calanoids) grazed all algal size group at high rates between 131-145 %G/d. Calanoids are generally expected to feed selectively on large algae (Peters and Dowening, 1984), but can also graze passively on small particles (Vanderpleg, 1990). The result of this study thus suggests that differences in the size rage of algae grazed by different types of zooplankton communities could result in large differences in their impact on phytoplankton. It was found that both zooplankton size and taxonomic composition affect their grazing impact. Calanoid-dominated communities grazed the widest range of algae. In contrast

communities dominated by small zooplankton (rotifers) grazed a much narrower size range.

## 6. Conclusions and Recommendation

Lake Hora-Arsedi, the study lake, is one of the Bishoftu crater lakes in the vicinity of an emerging city, Debre-Zeit. The impact of this fast growing city on this lake in recent years and the extent to which the lake has changed in the last three decades as a result of human interference and /or natural causes have been recently studied (Zinabu Gebre Mariam, 2002). The catchment area of this lake is a dynamic resource system, providing opportunities for agricultural, residential, recreational and livestock grazing and watering. Thus the trophic status of this lake is probably a reflection of such intervention whereby the integrated effects of these anthropogenic activities is driving this lake towards eutrophic condition. While flood inputs silt, it also adds fertilizers leaching from the farmland in the catchments and accelerates the growth of algae. In the face of the growing population, intensified land use and the associated water quality changes, immediate action have to be taken to change the present approach of water utilization and management. Unless corrective measure for reducing degradation of the lake is worked out, and the existing problems are tackled soon, severe ecological crises are inevitable.

The strategies of reducing the external load of nutrient and controlling internal ecological process are the two important techniques proposed to have a better water quality intervention. However, the control of internal ecological dynamics is

recently advocated as the most approachable strategy. The applicability of this strategy depends on zooplankton community grazing rates at large. That is, if zooplankton-grazing rates are high, biomanipulation is certainly a choice of preference. However, if zooplankton community grazing rates in a given lake are low, nutrient control may be more important.

Although, grazing rates are moderately high in Lake Hora-Arsedi as compared to temperate lakes, they are low with respect to other tropical lakes. Nevertheless; under eutrophic condition, high grazing rate has little effect on phytoplankton biomass. Furthermore, Lake Hora-Arsedi is dominated by blue-green algae, which are not edible either because of their large size or toxicity. It is clear that grazing rate is only important wherever edible algae are dominant. This is true because during the month March-April 2006, Lake Hora-Arsedi phytoplankton was almost exclusively dominated by diatoms, green algae and cryptomonads, which are edible. It was during these months that high grazing rate was recorded in this study.

From the present study it is clear that increase in the density of zooplankton has no positive impact on phytoplankton biomass removal. Increasing rotifer (dominant zooplankton in Lake Hora-Arsedi) does not bring much change in removing phytoplankton. Although control of internal ecological dynamics is an important factor, management of external nutrient input cannot be ruled out to control eutrophication. It is also important to note that the type of zooplankton and phytoplankton species determines the application of biomanipulation. However, it is also necessary to know that high grazing rates do not mean water

clarity since high grazing rates may have no effect on eutrophic lakes like Lake Hora-Arsedi. Based on the grazing rates measured, it seems that biomanipulation alone is not effective in Lake Hora-Arsedi. Current restoration trend that may improve the reliability of biomanipulation is its integration with nutrient management. Controlling nutrient levels along with food-web manipulation has the potential to create long lasting results because neither food-web interactions nor nutrients are the sole regulators of phytoplankton (Kitchell, 1992). Nutrient management techniques tend to work best in deep lake environments since nutrient loading is not a major factor (Moss, 1991). Therefore, based on findings of the current study and relating to other available information, the following major conclusions and recommendations are forwarded:

1. Conclusions

    i. The impact of zooplankton community grazing rates per day in Lake Hora-Arsedi is relatively high when compared with temperate but lower than other tropical measured values.

    ii. Increasing zooplankton density has no considerable effect on the phytoplankton biomass.

    iii. Increasing or decreasing in phytoplankton density beyond the ambient concentration decrease grazing rates.

    iv. Large size zooplankton group showed higher grazing rates than the smaller size- class.

V.The impact of the dominant zooplankton in the lake is more or less the same on the three size-classes of algae

2. Recommendations:

a. Biomanipulation is promising to control the problem of eutrophication in Lake Hora-Arsedi as far as the larger efficient grazers(calanoids) are available
b. It is also recommended to strengthen the management of external nutrient input in order to control the phytoplankton community at a considerably lower biomass.

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***APPENDICES***

**The Following Abbreviations used in the text works only for Appendix I- VIII**

SD = Sampling dates

IT = Incubation time (Day)

N = Zooplankton density

Co = Food Concentration (Cells/ml)

g= Grazing coefficient (d)

F= Clearance rate (ml/ind/d)

I = Ingestion rate (cells/ind/d)

%G/d =Percentage grazing per day

Appendix I. Zooplankton density- gradient grazing rate at the central site

| SD | IT | PB (µg/l) | N | Co | g | F | I | %G/d |
|---|---|---|---|---|---|---|---|---|
| 21/08/05 | 0.2 | Z1=7.24 | 4625 | 127120 | 3.85 | 0.83 | 105509.6 | 83 |
| | | Z2=13.21 | 6125 | 116280 | 0.85 | 0.14 | 16279.2 | 14 |
| | | Z4=14.54 | 8625 | 115040 | 0.4 | 0.046 | 5291.84 | 4.6 |
| 3/9/2005 | 0.25 | Z1=17.34 | 2125 | 159720 | 1.52 | 0.72 | 114998.4 | 72 |
| | | Z2=24.4 | 2625 | 160680 | 0.2 | 0.076 | 12211.68 | 7.6 |
| | | Z4=26.13 | 3125 | 145040 | 0.08 | 0.03 | 4351.2 | -3 |
| 21/09/05 | 0.2 | Z1=16 | 2875 | 126840 | 1.3 | 0.45 | 58806 | 45 |
| | | Z2=18.3 | 3200 | 144300 | 0.85 | 0.23 | 33189 | 23 |
| | | Z4=20.4 | 5375 | 136400 | 0.25 | 0.05 | 6820 | 5 |
| 15/1005 | 0.29 | Z1=12.15 | 2500 | 126840 | 1.1 | 0.44 | 55809.6 | 44 |
| | | Z2=14.37 | 3200 | 110240 | 0.55 | 0.17 | 18740.8 | 17 |
| | | Z4=16.1 | 5375 | 122840 | 0.13 | 0.02 | 2456.8 | 2 |
| 29/10/05 | 0.75 | Z1=36.23 | 2250 | 63920 | 0.62 | 0.28 | 17897.6 | 28 |
| | | Z2=55.3 | 4280 | 70840 | 0.08 | 0.02 | 1416.8 | 2 |
| | | Z4=56.87 | 6125 | 65000 | 0.04 | 0.006 | 390 | 0.6 |
| 18/11/05 | 0.25 | Z1=39.7 | 3500 | 317880 | 1.36 | 0.39 | 123973.2 | 39 |
| | | Z2=44.55 | 5750 | 305560 | 0.88 | 0.15 | 45834 | 15 |
| | | Z4=56 | 12500 | 299040 | -0.4 | 0.032 | 9569.28 | -3.2 |
| 14/12/05 | 0.2 | Z1=39.8 | 3625 | 302000 | 1.3 | 0.35 | 105700 | 35 |
| | | Z2=42 | 4125 | 301280 | 0.9 | 0.22 | 66281.6 | 22 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Z4=51.8 | 10500 | 301640 | 0.025 | 0.002 | 603.28 | 0.2 |
| 8-Jan | 0.25 | Z1=39.8 | 3875 | 308440 | 0.92 | 0.24 | 74025.6 | 24 |
| | | Z2=41.14 | 5125 | 319000 | 0.72 | 0.14 | 44660 | 14 |
| | | Z4=51.4 | 10400 | 334240 | -0.12 | 0.01 | 3342.4 | 1 |
| 22/1/06 | 0.25 | Z1=41.92 | 3125 | 300960 | 1.16 | 0.37 | 111352 | 37 |
| | | Z2=44.48 | 6375 | 325440 | 0.88 | 0.13 | 42307.2 | 13 |
| | | Z4=53.6 | 10000 | 301800 | 0.16 | 0.016 | 4828.8 | 41.6 |
| 5/2/2006 | 0.25 | Z1=36.14 | 2750 | 330840 | 1.28 | 0.46 | 152186.4 | 46 |
| | | Z2=42.8 | 4000 | 329800 | 0.64 | 0.16 | 5276 | 16 |
| | | Z4=48.9 | 6375 | 328160 | 0.08 | 0.012 | 3937.92 | 1.2 |
| 2/3/2006 | 0.79 | Z1=5.2 | 750 | 51160 | 1.3 | 1.73 | 88506.8 | 173 |
| | | Z2=12.3 | 800 | 52200 | 1.25 | 1.56 | 81432 | 156 |
| | | Z4=14.08 | 1050 | 57040 | 1.59 | 1.51 | 86130.4 | 151 |

Appendix II. Zooplankton density-gradient grazing rates at the littoral site

| SD | IT | PB (µg/l) | N | Co | g | F | I | %G/d |
|---|---|---|---|---|---|---|---|---|
| 3/9/2005 | 0.25 | Z1=31.13 | 2625 | 180200 | 0.72 | 0.27 | 48654 | 27 |
| | | Z2=33.92 | 4000 | 170920 | 0.34 | 0.085 | 14528.2 | 8.5 |
| | | Z4=40.58 | 6375 | 175200 | 0.33 | 0.05 | 8760 | -5 |
| 21/09/05 | 0.2 | Z1=47.26 | 3750 | 241840 | 0.9 | 0.24 | 58041.6 | 24 |
| | | Z2=54.9 | 7625 | 336120 | 0.195 | 0.026 | 87391.2 | 2.6 |
| | | Z4=59.1 | 14250 | 312240 | 0.2 | 0.014 | 4371.36 | -1.4 |
| 15/10/05 | 0.29 | Z1=18.9 | 3000 | 169240 | 0.62 | 0.2 | 33848 | 20 |
| | | Z2=20.13 | 6500 | 173560 | 0.55 | 0.085 | 14752.6 | 8.5 |
| | | Z4=23.6 | 11375 | 154000 | 0.03 | 0.003 | 462 | -0.03 |
| 14/12/05 | 0.25 | Z1=39.4 | 4875 | 334600 | 1.04 | 0.21 | 70266 | 21 |
| | | Z2=43.9 | 3025 | 289800 | 0.68 | 0.19 | 5506.2 | 19 |
| | | Z4=60.6 | 5625 | 339360 | 0.56 | 0.099 | 33596.6 | -0.9 |
| 8/1/2006 | 0.25 | Z1=42.36 | 4000 | 330240 | 0.92 | 0.23 | 75955.2 | 23 |
| | | Z2=48.2 | 3375 | 355040 | 0.11 | 0.032 | 113601.28 | 3.2 |
| | | Z4=55.2 | 4600 | 290600 | -0.02 | 0.004 | 1162.4 | -0.4 |
| 1/22/2006 | | Z1=48 | 2250 | 305360 | 0.38 | 0.193 | 58018.4 | 19 |
| | | Z2=51.7 | 2625 | 318240 | 0.08 | 0.03 | 9547.2 | 3 |
| | | Z4=64.5 | 5625 | 299200 | -0.8 | -0.14 | 41888 | -14 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 5//2/06 | 0.25 | Z1=39.0 | 1875 | 313920 | 0.68 | 0.35 | 109872 | 35 |
| | | Z2=47.7 | 3525 | 311080 | 0.64 | 0.18 | 55994.4 | 18 |
| | | Z4=53.9 | 4500 | 326760 | 0.12 | 0.027 | 8822.52 | 2.7 |

Appendix III.Zooplankton grazing rates on different phytoplankton density at the central site

| SD | IT | PB (µg/l) | N | Co | g | F | I | %G/d |
|---|---|---|---|---|---|---|---|---|
| 18/1/05 | 0.25 | P1=34.67 | 4500 | 329720 | 1.88 | 0.42 | 138482.4 | 42 |
| | | P2=46.2 | 3650 | 386480 | 0.72 | 0.2 | 77296 | 20 |
| | | P4=50.4 | 3800 | 456480 | 0.36 | 0.09 | 41023.2 | 9 |
| 14/12/05 | 0.2 | P1=38.9 | 3258 | 219400 | 1.3 | 0.4 | 55760 | 40 |
| | | P2=41.2 | 4750 | 229240 | 1.15 | 0.24 | 55017.6 | 24 |
| | | P4=51.8 | 5125 | 389680 | 0.03 | 0.006 | 1618.08 | 0.6 |
| 8/1/2006 | 0.25 | P1=43.35 | 3375 | 314800 | 0.56 | 0.17 | 53516 | 17 |
| | | P2=49.8 | 4000 | 390240 | 0.02 | 0.05 | 19512 | 5 |
| | | P4=51.0 | 3875 | 502640 | 0.08 | 0.02 | 10452.8 | -2 |
| 22/1/06 | 0.2 | P1=42.48 | 3600 | 325080 | 1.35 | 0.375 | 325079.92 | 37.5 |
| | | P2=48.6 | 4250 | 397560 | 0.65 | 0.15 | 59634 | 15 |
| | | P4=55.9 | 3125 | 447760 | -0.01 | 0.0032 | 1432.83 | 0.3 |
| 5/2/2006 | 0.25 | P1/8=45.6 | 4250 | 32400 | 0.37 | 0.087 | 2818.8 | 8.7 |
| | | P1/2=43.9 | 3500 | 164880 | 0.52 | 0.15 | 24732 | 15 |
| | | P1=37.8 | 3875 | 249800 | 4.4 | 1.14 | 284772 | 114 |
| 2/3/2006 | 0.79 | P1/8=11.96 | 750 | 19640 | 0.23 | 0.31 | 5530.4 | 31 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | P1/2=10.6 | 625 | 118880 | 0.39 | 0.62 | 73705.6 | 62 |
| | | P1=7.9 | 750 | 326520 | 0.76 | 1.01 | 329785.2 | 101 |
| 25/3/06 | 0.75 | P1/8=13.7 | 575 | 18680 | 0.08 | 0.14 | 2615.2 | 14 |
| | | P1/2=12.5 | 550 | 92120 | 0.21 | 0.38 | 35005.6 | 38 |
| | | P1=10.2 | 375 | 328320 | 0.48 | 1.28 | 420249.6 | 128 |

Appendix IV. Zooplankton grazing rates on different phytoplankton density at the littoral site

| SD | IT | PB (µg/l) | N | Co | g | F | I | %G/d |
|---|---|---|---|---|---|---|---|---|
| 14/12/05 | 0.25 | P1=39.6 | 3375 | 3320 | 1.12 | 0.33 | 10929.6 | 33 |
| | | P2=40.2 | 3750 | 251840 | 1 | 0.27 | 67996.8 | 27 |
| | | P4=55 | 3625 | 508040 | 0.2 | 0.05 | 254002 | -5 |
| 8/1/2006 | 0.25 | P1=49.6 | 3600 | 336240 | 0.36 | 0.1 | 33624 | 10 |
| | | P2=51.2 | 3125 | 333440 | 0.24 | 0.077 | 29356.8 | 7.7 |
| | | P4=53.2 | 3750 | 528120 | 0.08 | 0.02 | 10562.4 | 2 |
| 22/1/06 | 0.2 | P1=44.8 | 1875 | 331160 | 0.85 | 0.45 | 149022 | 45 |
| | | P2=49.3 | 2250 | 390960 | 0.34 | 0.15 | 58644 | 15 |
| | | P4=50.48 | 2625 | 4827400 | 0.49 | 0.019 | 91720.6 | 1.9 |
| 2/5/2006 | | P1=44.5 | 2875 | 305920 | 0.88 | 0.37 | 113190.4 | 37 |
| | | P2 = 50.04 | 2625 | 42960 | 0.38 | 0.15 | 6444 | 15 |
| | | P4 = 54.6 | 2375 | 14120 | 0.08 | 0.034 | 480.08 | 3.4 |

Appendix V.Zooplankton size-gradient grazing rates

| SD | IT | PB (µg/l) | N | Co | g | F | I | %G/d |
|---|---|---|---|---|---|---|---|---|
| 14/12/05 | 0.2 | <250=42.8 | 2875 | 300600 | 0.9 | 0.3 | 90180 | 30 |
| | | >250=40.3 | 2500 | 304960 | 1.25 | 0.5 | 152480 | 50 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 8/1/2006 | 0.25 | <250=44.7 | 1625 | 314200 | 0.44 | 0.27 | 84834 | 27 |
| | | >250=40.7 | 2000 | 308240 | 0.8 | 0.4 | 123296 | 40 |
| 22/1/06 | 0.2 | <250=47.26 | 1625 | 327600 | 0.85 | 0.52 | 170352 | 52 |
| | | >250=42.81 | 2375 | 324560 | 1.3 | 0.55 | 178508 | 55 |
| 5/2/2006 | 0.25 | <250 =42.3 | 2250 | 315360 | 0.66 | 0.29 | 91454.4 | 29 |
| | | >250 =44.5 | 3000 | 296520 | 0.44 | 0.15 | 4447.8 | 15 |
| 2/3/2006 | 0.79 | <250=12.79 | 575 | 273880 | 0.15 | 0.26 | 71208.8 | 26 |
| | | <450 =10.3 | 750 | 290280 | 0.43 | 0.57 | 165459.6 | 57 |
| | | >450=7.03 | 850 | 305920 | 0.91 | 1.58 | 483353.6 | 158 |
| 19/4/06 | 0.29 | <250=13.42 | 375 | 71680 | 0.09 | 0.24 | 17203.2 | 24 |
| | | <450 =11.5 | 1000 | 90440 | 0.86 | 0.86 | 77778.4 | 86 |
| | | >450 =7.67 | 1500 | 94660 | 2.27 | 1.5 | 141996 | 150 |

## Appendix VI. Phytoplankton size gradient- grazing rates

| SD | IT | PB (µg/l) | N | Co | g | F | I | %G/d |
|---|---|---|---|---|---|---|---|---|
| 18/11/05 | 0.25 | <10 =39.46 | 1750 | 3040 | 1.36 | 0.78 | 2371.2 | 78 |
| | | <20 =37.2 | 2000 | 9480 | 1.6 | 0.8 | 7584 | 80 |
| | | <63 =50.04 | 2125 | 284520 | 0.38 | 0.18 | 51213.6 | 18 |
| 14/12/05 | 0.2 | <10 =35.7 | 3000 | 51880 | 1.9 | 0.63 | 32684.4 | 63 |
| | | <20 =41.9 | 3500 | 80040 | 1.1 | 0.31 | 24812.4 | 31 |
| | | <63 =39.6 | 3750 | 242160 | 1.4 | 0.37 | 89599.2 | 37 |
| 8/1/2006 | 0.25 | <10 =44.02 | 1500 | 5160 | 0.52 | 0.34 | 51600 | 34 |
| | | <20 =40.5 | 1750 | 10240 | 0.84 | 0.48 | 4915.2 | 48 |
| | | <63 =36.8 | 2125 | 235000 | 1.2 | 0.56 | 131600 | 56 |
| 22/1/06 | 0.2 | <10 =42.8 | 2625 | 6720 | 1.3 | 0.49 | 3292.8 | 49 |
| | | <20 =48.4 | 1875 | 17480 | 0.7 | 0.37 | 6467.6 | 37 |
| | | <63 =44.4 | 2125 | 284360 | 1.1 | 0.52 | 147867.2 | 52 |
| 5/2/2006 | 0.25 | <10 =34.69 | 2750 | 5760 | 1.44 | 0.52 | 2995.2 | 52 |
| | | <20 =32.8 | 2870 | 8040 | 1.62 | 0.56 | 4502.4 | 56 |
| | | <63 =30.6 | 3000 | 209840 | 2 | 0.67 | 140592.8 | 67 |
| 2/3/2006 | 0.79 | <10 =10.6 | 675 | 2240 | 0.39 | 0.58 | 1299.2 | 58 |
| | | <20 =12.3 | 625 | 7040 | 0.2 | 0.32 | 2252.8 | 32 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | <63 =10.2 | 750 | 104120 | 0.43 | 0.57 | 59348.4 | 57 |
| 19/4/06 | | 0.29 | <10 =9.11 | 1000 | 268 | 1.1 | 1.1 | 2948 | 101 |
| | | | <20 =6.23 | 1250 | 5440 | 1.96 | 1.57 | 8540.8 | 157 |
| | | | <63 =9.59 | 1375 | 90060 | 1.38 | 1 | 80060 | 100 |

Appendix VII. Simultaneous zooplankton and phytoplankton density-gradient Grazing rates

| SD | IT | PB (µg/l) | N | Co | g | F | I | %G/d |
|---|---|---|---|---|---|---|---|---|
| 2/3/2006 | 0.79 | Z1/P1=8.3 | 750 | 119040 | 0.7 | 0.93 | 17707.2 | 93 |
| | | Z2/P2 =12.3 | 1075 | 148840 | 0.2 | 0.19 | 28279.6 | 19 |
| | | Z4/P4=15.8 | 2875 | 156680 | 0.12 | 0,042 | 6580.56 | -4.2 |
| 25/3/06 | 0.75 | Z1/P1=9.03 | 500 | 106360 | 0.62 | 1.24 | 131886.4 | 124 |
| | | Z2/P2=11.8 | 750 | 187520 | 0.29 | 0.39 | 73132.8 | 39 |
| | | Z4/P4=14.6 | 1625 | 311240 | 0.013 | 0.008 | 2489.92 | -0.8 |

Appendix VIII. Simultaneous zooplankton and phytoplankton size-gradient grazing rates

| SD | IT | PB (µg/l) | N | Co | g | F | I | %G/d |
|---|---|---|---|---|---|---|---|---|
| 25/03/06 | 0.75 | <250/10=14.2 | 375 | 83520 | 0.04 | 0.11 | 9187.2 | 11 |
| | | <250/20=14.5 | 450 | 102920 | 0.013 | 0.029 | 2984.68 | 13 |
| | | <250/63=13.95 | 500 | 110000 | 0.065 | 0.13 | 14300 | 2.9 |
| | | <450/10=12.5 | 625 | 91840 | 0.21 | 0.34 | 31225.6 | 34 |
| | | <450/20=10.3 | 550 | 110480 | 0.47 | 0.85 | 93908 | 85 |
| | | <450/63=10.1 | 700 | 112640 | 0.49 | 0.7 | 78848 | 70 |
| | | >450/10=9.3 | 450 | 93120 | 0.6 | 1.33 | 123849.6 | 133 |
| | | >450/20=8.25 | 525 | 109880 | 0.76 | 1.45 | 159326 | 145 |
| | | >450/63=10.5 | 375 | 189240 | 0.49 | 1.31 | 247904.4 | 131 |

Appendix IX. Two Sample T-Test and Confidence Interval (comparison of percentage grazing rate at the central and littoral sites)

Two sample T for Center vs. Littoral

| | N | Mean | St Dev | SE Mean |
|---|---|---|---|---|
| Center | 11 | 56.9 | 42.3 | 13 |
| Littoral | 7 | 27.6 | 14.1 | 5.3 |

95% CI for mu Center - mu Littoral: (-1, 59.2)

T-Test mu Center = mu Littoral (vs. not =): T = 2.12 P = 0.054 DF = 13

## Appendix X. Regression (Central Site)

| | | | | |
|---|---|---|---|---|
| Constant | 54.064 | 7.752 | 6.97 | 0.000 |
| %G | -0.2861 | 0.1111 | -2.58 | 0.030 |

S = 14.88, R-Sq = 42.4%, R-Sq (adj) = 36.0%

Analysis of Variance

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Regression | 1 | 1467.9 | 1467.9 | 6.63 | 0.030 |
| Residual Error | 9 | 1991.8 | 221.3 | | |
| Total | 10 | 3459.6 | | | |

## Appendix XI. Regression (Littoral Site)

| Constant | 40.60 | 11.54 | 3.52 | 0.017 |
|---|---|---|---|---|
| %G | 0.2514 | 0.3783 | 0.66 | 0.536 |

S = 13.08, R-Sq = 8.1%, R-Sq (adj) = 0.0%

Analysis of Variance

| Source | DF | SS | MS | F | P |
|---|---|---|---|---|---|
| Regression | 1 | 75.6 | 75.6 | 0.44 | 0.536 |
| Residual Error | 5 | 855.8 | 171.2 | | |
| Total | 6 | 931.4 | | | |

Appendix XII.Two Sample T-Test and Confidence Interval

Two sample T for Co vs. Cp

| | N | Mean | St Dev | SE Mean |
|---|---|---|---|---|
| Co | 12 | 35.7 | 17.9 | 5.2 |
| Cp | 12 | 34.9 | 17.9 | 5.2 |

95% CI for mu Co - mu Cp: (-14.4, 16.0)

T-Test mu Co = mu Cp (vs. not =): T = 0.11, P = 0.91, DF = 21

Appendix XIII.

(a) Phytoplankton biomass (µg/l) in the intial (Ci) and control (Cp) bottles at the central sampling site

| Dates | Ci | Cp |
|---|---|---|
| 21/8/05 | 15.56 | 14.85 |
| 3/9/05 | 25.57 | 25.01 |
| 21/9/05 | 21.5 | 20.45 |
| 15/10/05 | 16.77 | 16.78 |
| 29/10/05 | 58.38 | 57.19 |
| 18/11/05 | 55.6 | 55.14 |
| 14/12/05 | 52.1 | - |
| 8/01/06 | 50.04 | - |
| 22/1/06 | 55.6 | - |
| 5/2/06 | 50.04 | 50.01 |
| 2/3/06 | 14.43 | 14.54 |

b) Phytoplankton biomass (µg/l) in the intial (Ci) and control (Cp) bottles at the littoral sampling site

| Dates | Ci | Cp |
|---|---|---|
| 18/11/05 | 37.25 | 35.54 |
| 14/12/05 | 57.28 | 56.23 |
| 8/1/06 | 23.57 | 21.08 |
| 22/1/06 | 52.2 | 52 |
| 5/2/06 | 54 | - |
| 2/3/06 | 52.8 | - |
| 25/3/06 | 55.6 | - |