**Addis Ababa University**
**School of Graduate Studies**

# Ecological Assessment of Lake Hora, Ethiopia, Using Benthic and Weed-bed Fauna

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# TABLE OF CONTENTS

**Contents** **Pages**

# LIST OF FIGURES

# LIST OF TABLES

# LIST OF APPENDICES

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*ABSTRACT*

*The purpose of this study was ecological assessment of Lake Hora using benthic and weed-bed faunas. Samples of benthic and weed-bed were collected monthly from September 2009 to March 2010 at 3 sampling stations (A, B and C). Stations A and B were faced with human disturbance and station C was free from human interaction. Station A is in front of Ras Hotel, station B is place of Irecha and station C was to the south crater of the lake. Bottom samples were taken to determine sediment texture and total organic matter of the lake. The result obtained showed that the weed-bed had sandy loam texture and the profundal had loamy soil. Generally, total organic matter content of station C was lower than A and B (with an average of 8.3, 20.8 and 18.0, respectively). The benthic and weed-bed fauna of Lake Hora included a total of 6958 belonging to 27 taxa with principally Copepod (2812), Chironomidae (1460) and Ecdyonuridae (735). A high number of organisms were observed mainly at stations B and A (3198 and 2342, respectively) and lower numbers were observed at station C (1419). As compared to stations A and B, station C was cooler in its water temperature but its dissolved oxygen content was not higher. Correlation between macroinvertebrates and temperature and total organic matter was insignificant ($P>0.01$). The correlation result verified that oxygen showed strong relation to benthic and weed bed fauna distribution and abundance. There were high number of individuals, taxa diversity, evenness and great number of rare taxa of benthic and weed-bed fauna at stations of A and B, but these stations were human influenced areas and affected by the community around the lake area for different reasons (for example washing clothes, boat parking and others). The FBI index for all the sampling stations was 7.55, according to Hilsenhoff Family Biotic Index this value is between* 7.26 and 10.00 *and indicating likely severe organic pollution and very poor water quality throughout the study lake*

# CHAPTER 1: INTRODUCTION

## 1.1. Background and Justification

Human activities in drainage areas are potential causes of pollution of lakes. Even without human interference, lakes change over time because natural factors, such as soil erosion, sediment loading, deposition of animal and plant debris, solution of minerals in the basin, and so on, are always at work. Human activities like land use and modification greatly accelerate some of these changes.

Clearing of forests, animal grazing, and other reductions in the vegetation of the catchment areas of the Ethiopian lakes, which have expanded considerably during recent years, increases the silt and nutrient load of the water. The present level of deforestation in Ethiopia results from the usage of wood for fuel and construction and from the population-driven need to increase cultivable land, forest clearing currently poses a serious problem. Most of the factors that encourage soil erosion (depleted forest, inadequate plant cover, organically poor soils, improper farming methods, etc.) are very common in Ethiopia, and some of its lakes have suffered from the consequences of the linked processes of plant cover removal, erosion, and sedimentation. When erosion takes place, the torrents, carrying soil particles, usually rich in nutrients, may end up in lakes. The result of such increased nutrient loading is eutrophication. This phenomenon in turn can lead to fish-kills caused by decreased oxygen concentrations, algal blooms, and other interrelated consequences such as destruction of benthic habitats. Such events have already been reported in some of the Ethiopian rift-valley lakes.

Urbanization and human settlement in close proximity to the Ethiopian lakes are among the greatest potential causes of changes in water quality and quantity.

The drastic changes introduced into one of the Bishoftu crater lakes (Kilole) best exemplify this phenomenon (Prosser *et al.*, 1968). Although there is very little indication of acute cultural pollution in the Ethiopian lakes at the moment, the potential problems deserve some attention here. Most of the fast-growing cities, like Zwai, Awassa, and Arbaminch, are in the neighborhood of the rift-valley lakes, and the Bishoftu crater lakes are in the vicinity of the flourishing city of Debre-Zeit. The growing population and industrialization of these cities can have potentially serious consequences on the lakes. It is possible that domestic and industrial wastes may find ways into the lakes.

Diversion of the inflows for irrigation purposes and flushing from deforested and heavily grazed catchment may also have contributed to the decrease in the water level and the increase in the concentrations of ions (Zinabu Gebre-Mariam and Elias Dadebo, 1989). Although the changes in salinity can take place due to evapotranspiration and/or solute inputs, the intensity of the human activity in their catchments must have contributed to the contrasting trends in their salinity. In the catchment areas of the lakes that have become more saline, human activity has been much more intense than in those that have not. Thus it is possible to conclude that human interference in the lake basins is a major cause of water quality changes in the Ethiopian lakes.

Certain human activities, like building resort areas, washing cars and clothes, gutting and filleting of fish caught from the lake, etc., tend to be concentrated on the shores of lakes. The effects of using detergents for washing clothes at lakeshores, for example, may look very insignificant. However, given the number of people that live near the shores or go to the lakes to wash clothes and do other cleaning activities, the impacts can be significant indeed. Harrison and Hynes (1988) reported that such human activities were possibly responsible for the elimination of freshwater crabs and the reduction in numbers of some fresh water insects from Ethiopian water bodies. This indicates that destruction of the catchment area will impact the benthic community of the lake.

The major Ethiopian rift lakes have been studied for various purposes in the last few decades. However, crater lakes situated elsewhere in the country are some of the poorly understood hydrobiologic systems (Seifu Kebede *et al.,* 2001). Zinabu Gebre-Mariam (1994) and Zinabu Gebre-Mariam *et al.,* (2002) have noted that the Ethiopian rift valley and crater lakes have been undergoing changes in their liminological features during the last two decades or so. The Bishoftu crater lakes are inside or in the vicinity of fast growing city, Debre Zeit, and their shores are currently used for washing clothes, watering livestock and recreation (eg. Lake Hora). Shoreline modifications made for various purposes (eg. for the construction of hotels in the catchments of Lake Kuriftu and Bishoftu) also introduce enormous amounts of particulate materials, which form suspensions in the water column there by reducing light penetration at least in the near-shore regions of the lakes (Zinabu Gebre-Mariam, 1998). This activity leads to eutrophication of the lake and disturbance of the benthic fauna (bioindicators) and the fish food.

Most extensively studied are the effects of organic pollution and eutrophication (Pearson & Rosenberg, 1978). A variety of techniques are in use to assess the pollution effects on communities and to separate these effects from natural environmental variability. It is well documented that pollution often leads to structural changes in benthic communities, as revealed by diversity measurements (Pearson & Rosenberg, 1978). A few tolerant or opportunistic species will become relatively more numerous and will dominate the community, while many less tolerant species will become increasingly rare or disappear (Brage, 1985).

At the present day, most of the biological method for lake monitoring is based on their trophic level definition through analyses of nutrient concentrations and/or pelagic primary producers or through analyses of consumer communities (Oligochaeta, Diptera Chironomidae, and Fishes) whose characteristics are then considered as a trophic level result (Saether (1979), Wiederholm (1980)).

It appears that there is a need of new biological methods offering more syntheticall descriptors able to reflect the ecological status of lakes and not only their tophic level (Verneaux, *et al.,* 2004).

Community structure or species composition of benthic invertebrates has frequently been used in environmental monitoring and assessment of aquatic systems. In the past few years considerable advances have been made by applying multivariate statistical techniques to large data matrices and relating benthic community structure to key environmental variables. This suggests that environmental criteria and objectives can be established based on biological variables as opposed to the more traditional chemical approach. Measurement of ecosystem health using functional attributes of benthic invertebrates is generally in the development stage in Africa and Ethiopia.

## 1.2. Benthic and Weed-bed Invertebrates for Ecological Assessment of Water Bodies

The organisms associated with the lake bottom (also called benthic organisms) are referred to collectively as benthos. These include all forms found in or on submerged substrates, regardless of whether they are in the littoral or profundal zone. The littoral zone shows large daily as well as seasonal variations of physical and chemical factors. In contrast, the profundal zone is below the thermocline and is physically and chemically uniform. Diversity, density and productivity are high in the well mixed, shallow littoral zone. On the other hand, the community structure of the profundal zone of lakes is relatively simple with only few groups of macroinvertebrates. Benthic invertebrate communities serve as food source for some adult fish species and almost all-juvenile fish in lakes. As a result they are important in trophic interactions and transfer of energy in aquatic environments. Benthic macroinvertebrates are moderately long-lived and are in constant contact with lake sediments. Contamination and toxicity of sediments will therefore affect those benthic organisms which are sensitive to them. Acidification of lakes is accompanied by shifts in the composition of benthic assemblages to dominance by species tolerant of acidic conditions. Benthic macroinvertebrates are present year-round and are often abundant, yet not very motile (Dereje Tewabe, 2009).

Monitoring biological communities can provide a good estimate of ecosystem integrity (i.e. chemical, physical, and biological integrity) in aquatic environments (Plafkin, *et al.,* 1989). Biological communities are sensitive to stressors (i.e. domestic waste, agricultural runoff, and sedimentation) that pollute water bodies.

Among biological communities, benthic macroinvertebrates are thought to be very important, pertaining to their responses to ecological changes. Benthic macroinvertebrates are lake-inhabiting organisms, mostly easily viewed with the naked eye. Since these invertebrates inhabit the lake bottom, any modification of the lake weed-bed by pollutants, deposited sediment and watershed degradation, will most likely have a profound effect upon the benthic invertebrate community. These make macroinvertebrates attractive water quality study subjects, with advantages over other community members.

Indices derived from biological data are increasingly used to measure the ecological health of lakes. The indices consist of a collection of metrics that summarize information from population, community, and ecosystem levels into a single number through bioassessment. Metrics are measurable components of biological systems used to describe communities. They show predictable change in value along a gradient of human disturbance. Metric categories include community composition, richness, and habitat tolerance measurements. A multimetric index approach to bioassessment encompasses all these types of descriptors in biological communities. Multimetric indexes quantify the biological effects of a broad array of human activities because they are sensitive to water quality, habitat structure, flow regime, energy source and biotic interactions (Karr and Chu, 1999).

Biological monitoring, or bioassessment, is the use of biological responses to assess changes in the environment, generally changes due to anthropogenic causes. Bioassessment programs may be qualitative, semi-quantitative, or quantitative. Bioassessment is a valuable assessment tool that is receiving increased use in water quality monitoring programs of all types. Another advantage of biological monitoring is it's relatively low cost when compared with chemical and toxicity tests.

Bioassessment involves the use of indicators, indicator species or indicator communities. Generally benthic and weed bed invertebrates, fish, and/or algae are used. Certain aquatic plants have also been used as indicator species for pollutants including nutrient enrichment. There are advantages and disadvantages to each method of taxa used. Benthic and weed bed invertebrates are most frequently used (Rosenberg and Resh, 1993). These organisms are the most reliable indicators of human stress. Biochemical, genetic, morphological, and physiological changes in certain organisms have been noted as being related to particular environmental stressors and can be used as indicators.

## 1.3. Advantages and Disadvantages of Benthic and Weed-bed Fauna in Biomonitoring Practice

According to Plafkin *et al.,* (1989), Barbour *et al*., (1999) and SWCSMH, (2006) the advantages of using benthic and weed bed fauna for bio-assessment purpose are:-

- Benthic and weed-bed fauna are found in most aquatic habitats. so they are affected by perturbations in many different habitats,

- There are a large number of species, and different stresses produce different benthic and weed-bed fauna communities.
- Benthic and weed-bed fauna generally have limited mobility. Thus they are indicators of localized environmental conditions.
- Since benthic and weed-bed fauna retain (bioaccumulations) toxic substances, chemical analysis will allow detection in them where levels are undetectable in the water resource.
- A biologist experienced in benthic and weed-bed fauna identification will, be able to determine relatively quickly whether the environment has been degraded by identifying changes in the benthic community structure of the water resource.
- Benthic and weed-bed fauna are small enough to be easily identified.
- Benthic and weed-bed fauna are the primary food source for recreationally and commercially important fish. An impact on benthic and weed-bed fauna impacts the food web and designated uses of the water resource.
- They are sedentary, so they stay put, which allows determination of the spatial extent of a perturbation.
- They are long-lived, which allows temporal changes in abundance and age structure to be followed.
- They integrate conditions temporally, so like any biotic group, they provide evidence of conditions over long periods of time
- In the food webs of lakes, benthic invertebrates have an intermediate position between primary producers and detritus on one side, and higher trophic levels (as fish) on the other side. Hence, they play an essential role in key ecosystem processes (food chain dynamics, productivity, nutrient cycling and decomposition).
- As benthic invertebrates respond sensitively not only to pollution, but also to a number of other human impacts (hydro-logical, climatological, morphological, navigational, recreational, and others), they could potentially be used for a holistic indication system for lake ecosystem

health. Their ubiquitous presence and their relative longevity may be seen as strong points recommending them for use in an indication system.

- Benthic invertebrates show considerable spatial variation with lake depth, across habitats, and across lakes.
- Unlike fish, benthos cannot move around much so they are less able to escape the effects of sediment and other pollutants that diminish water quality. Therefore, benthos can give us reliable information on stream and lake water quality. Their long life cycles allow studies conducted by aquatic ecologists to determine any decline in environmental quality.
- Benthos represents an extremely diverse group of aquatic animals, and the large number of species possesses a wide range of responses to stressors such as organic pollutants, sediments, and toxicants.

- Many benthic and weed-bed fauna are long-lived, allowing detection of past pollution events such as pesticide spills and illegal dumping.
- Benthic and weed-bed fauna respond to short-term environmental disturbances and degraded conditions can be detected through taxa identification.
- Long term effects of stress can be seen through changes in community structure

According to Plafkin (1989) and Barbour *et al*., (1999) the disadvantages of using benthic and weed bed fauna for bio-assessment purpose are:-

- The distribution and abundance of benthic and weed-bed fauna may be affected by factors in addition to the perturbation.
- The distribution and abundance of benthic and weed-bed fauna vary seasonally.
- Benthic and weed-bed fauna do not respond to all impacts.

- Drifting may bring benthic and weed-bed fauna into waters in which they would not normally occur. Knowledge of drifting behavior of certain species can alleviate this disadvantage.
- Certain groups are difficult to identify to the species level.

Within this range of knowledge, lake ecologists should study the environmental impact of deforestation and human expansion on the living organisms in the water and should provide recommendations for laws, policies and guidelines for future development and expansion. The identification of the reference status for a specific lake type based on benthic invertebrates is complicated by the facts that the composition of benthic invertebrate communities exhibits natural variation due to season, lake depth, meso-scale habitat structure, and also due to biotic effects (competition and predation). Clear seasonal changes in community structure can be observed which are primarily due to the life cycles of aquatic insects, but may be influenced by seasonal changes in habitat conditions, too.

Lake morphometry affects community structure of both macrophytes and benthic and weed-bed fauna (Rasmussen, 1988). While the terminology related to physical structure of lakes is large and varies to some extent (Ruttner, 1953; Hutchinson, 1957; Wetzel, 2001). The benthic zone of lakes can be divided along the depth profile into the littoral, sub-littoral and profundal zones. The littoral zone is defined as the nearshore lake bottom areas where emerged macrophytes grow. The sub-littoral zone is defined as the bottom area covered by submerged macrophyte or algal vegetation. Often, empty shells of molluscs are accumulated at its lower end (littoriprofundal) and thus form a specific sediment type. The lake bottom area extending deeper is called profundal zone, which consists of exposed fine sediment free of vegetation. It would be expected that nutrient enrichment affects those zones in different ways. It has been known for a long time that profundal invertebrate communities are strongly influenced by the trophic state of a lake (Naumann 1921, Lenz 1925, Lundbeck

1936, Thienemann 1954, Brundin 1956, Saether, 1979, Wiederholm, 1981; Aagaard, 1986). In contrast, hydromorphological alterations will affect most strongly the littoral zone, but the sub-littoral to a much lower extent. The profundal is probably hardly affected. The study of benthic invertebrates in lakes is traditionally segregated by depth zone: littoral, sub-littoral and profundal, as these zones are generally colonized by distinct communities, which also respond in different ways to specific impacts on lakes.

## 1.4. Status of Using Biomonitoring Program in Ethiopia

Infrastructure development, e.g., the building of roads, bridges, and airports, is already in progress. In addition to these activities, changes in lifestyle, such as the proliferation of consumer products that generate significant wastes and effluents, have begun to produce environmental impacts. Therefore, the factors that brought about changes in the waters of developed countries are already at hand and serious problems are just around the corner. The fact that many well-intended development projects have adverse repercussions, including eutrophication and disruption of freshwater ecosystems, presents conflicts that need to be handled with care. It is clear that many environmental problems arise from the process of development itself. Therefore, although all the development programs that the country is planning to carry out appear to be indispensable, their ecological impacts should be considered before any of the development programs are launched; and their negative impacts should be minimized where and when possible. Increased emphasis should be placed on preventive planning based on environmental impact assessment (Tamiru Gebre, 2006).

As a case in point the destruction of Ethiopia's once beautiful Lake Koka can be cited. Lake Koka provided habitat for fish and wildlife, outstanding recreational and business opportunities, and much of the scenic beauty that makes Southern Ethiopia such a wonderful place. The water from the lake was also used to generate electricity. Today however, Lake Koka is so heavily polluted that the water glows a toxic green and most of the fish are dead (http://lakekoka.ning.com).

Information on distribution and abundance of macroinvertebrates in relation to abiotic factors (temperature, dissolved oxygen, pH and ionic concentration) and biotic factors (competitive abilities and predators) is available in the temperate regions of the world (Oliver, 1971; Peterson, 1975; Beck, 1977; McAuliffe, 1984; Harvey; 1986). However, there have been far fewer studies on tropical lakes. In East Africa, only few studies have attempted to describe the structure and composition of macroinvertebrates in lotic systems. For instance in Kenya, Mathoko (2002) looked at the colonization of artificial substrates by aquatic insects in Naro-Moru River, Barnard & Biggs (1988) studied macroinvetebrates in the catchments streams of Lake Naivasha while Kinyua & Pacini (1991) surveyed macroinvertebrates of Nairobi River. Tumiwesigye *et al.,* (2000) investigated the structure, taxonomic composition and the temporal distribution of benthic macroinvertebrates in Nyamweru River in Uganda. In Ethiopia, very limited information is available on benthos macroinvertebrates of streams and lakes (Hynes, 1955; Harrison, 1987; Harrison and Hynes, 1988). The majority of these studies have been conducted in the central and northern rift valley lakes of Ethiopia.

In Ethiopia and to larger extent the whole of Africa, the use of macroinvertebrate characteristics for assessment and monitoring of lake conditions is less common. However, a South Africa Scoring System for rapid bioassessment of water quality in rivers is being used in a National Biomonitoring Programme in South Africa (Dallas, 1997). In Ethiopia also Baye Sitotaw (2006) has done research on the Assessment of Benthic-Macroinvertabrate structure in relation to Environmental Degradation in some Ethiopian Rivers. Tilahun Kebret and Harrison (1989) had studied benthic and weed bed fauna of Lake Awasa. However no study was done in crater lakes of Ethiopia using macroinvertebrates as an assessment method. The purpose of this project was, therefore, to do ecological assessment of Lake Hora using benthic and weed-bed fauna.

**Research questions**

1. What factors determine the distribution and abundance of benthic and weed bed fauna in Lake Hora? (Physicochemical factors, temperature and oxygen and also total organic matter, texture, etc).
2. What does diversity and abundance of macroinvertebrate indicate about ecological integrity of Lake Hora?

## 1.5. General Objective

General objective of this study was to assess ecological quality of Lake Hora using the distribution, composition and abundance of benthic fauna in relation to the type of bottom sediment organic pollution and vegetation.

### 1.5.1. Specific Objectives

-To determine the relations of benthic and weed bed fauna to the physico-chemical limnology of the lake.
-To assess the distribution of benthic fauna in relation to aquatic macrophytes, sediment texture and total organic matter.
- Assess ecological integrity of the lake using Hilsenhoff Family Biotic Index (H-FBI) and diversity indices

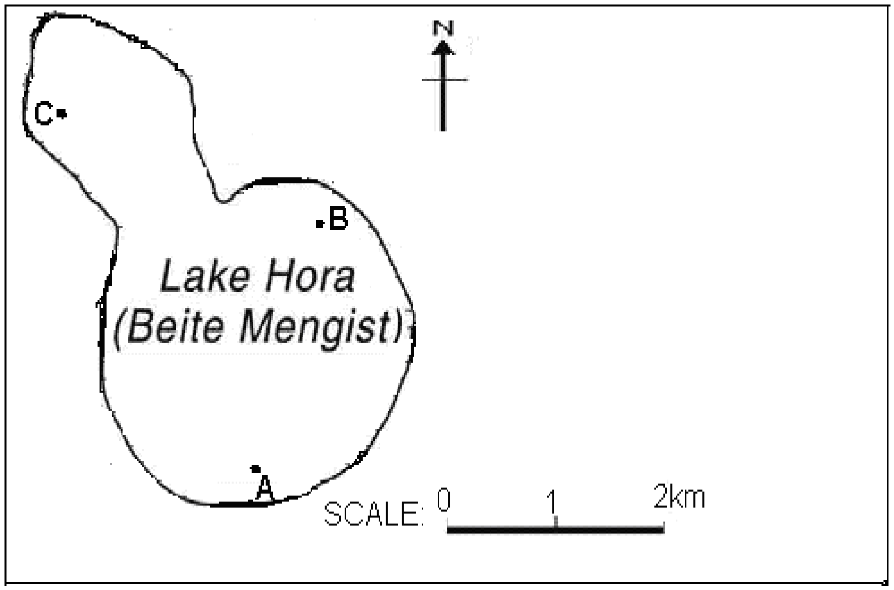
# CHAPTER 2: MATERIALS AND METHODS

## 2.1. Description of the Study Area

Lake Hora is a small (1.03 $Km^2$) lake and It is a double crater with a maximum depth (in meters) of 38 (North crater) and 31 (South crater) and a mean depth of 17.5 m (Figure 1). Like all the other volcanic crater lakes in this area, Hora is a closed system, surrounded by very steep and rocky hills and cliffs. Mohr (1961), estimated the age of Lake Hora along with other Bishoftu crater lakes as early Holocene (≈ 7000 years). The catchment of the lake is formed from volcanic rocks of basalt, rhyolite and tuff. Some morphometric and physico-chemical features of the present study lake are given in Table 1.

Previous limnological studies on Lake Hora described bathymetry (Prosser *et al*., 1968), water chemistry (Prosser *et al.,* 1968; Wood *et al*., 1984; Rippey and Wood, 1985; Zinabu Gebre-Mariam *et al*., 2002, Abebaw Wondie, 2007), thermal stratification and mixing (Baxter and Wood, 1965; Wood *et al.,* 1976), chlorophyll "a" and phytoplankton (Wood and Talling, 1988; Abebaw Wondie, 2006), community structure of Rotifera and taxonomic composition and grazing by zooplankton (Tamiru Gebre, 2006).

Figure-1: Map of Lake Hora shows locations of stations A, B and C. Station A was In front of Ras hotel, station B was around Irecha place (Traditional celebration of Oromo culture) and station C was Hora ilmo the South crater of the lake.




The lake has no surface outflows and receives water primarily from rainfall falling directly on its surface and run-off from its small catchments. The annual variation in depth of this lake is less than a meter, which suggests the maintenance of water level by seepage to and from the water table. Groundwater inflow represents about forty per cent of the total water inflow to Lake Hora, but only about three percent of its water loss, the remainder being lost by evaporation (Baxter and Wood, 1965).

The immediate surroundings of the lake are semi-urban in character, with many planted and invasive exotic species (e.g. *Eucalyptus, Casuarina, Schinus and Optunia spp*). 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.

Table-1: Some limnological features of Lake Hora [Source: Chemical data from Baxter (2002) and Morphometric data from Prosser, *et al.,* (1968) unless otherwise indicated].

| **Parameters** | **Measured values** |
|---|---|
| Surface area ($Km^2$) | 1.03 |
| Maximum depth (m) | 38 |
| Mean Depth (m) | 17.5 |
| Volume ($km^3$) | 0.018 |
| Conductivity (µS $cm^{-1}$) | 2350 |
| Salinity (g $l^{-1}$) | 2.57 |
| Alkalinity (meq $l^{-1}$) | 26.5 |
| $_P$H | 9.2 |
| $NO_3$-N (µg $l^{-1}$) | 10 – 20* |
| $PO_4$–P (µg $l^{-1}$) | 16.86 - 69.50* |
| $SiO_2$ (mg $l^{-1}$) | 17.48 to 46.96* |
| Sum of cations (meq $l^{-1}$) | 29.5 |
| Sum of anions (meq $l^{-1}$ ) | 32.9 |
| $Na^+$ (meq $l^{-1}$) | 23.9 |
| $Cl^-$ (meq $l^{-1}$) | 5.7 |
| Chlorophyll " a"(µg $l^{-1}$) | 19.1 - 47.6* |

* Abebaw Wondie (2007) for a central station

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). The lake stratifies during the February-October wet season, and mixes as a result of heat loss to clear night skies during the dry season (Rippey and Wood, 1985). Through their studies over extended periods, Baxter *and* Wood *(*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 (Wood *et al.,* 1984).

The phytoplankton community is dominated by the colonial cyanobacterium *Microcystis aeruginosa* (Kütz,) (Wood and Tallinig, 1988). The zooplankton community of Lake Hora includes the rotifers *Asplanchna sieboldi* Leydig*, Brachionus calyciflorus* Pallas*, and B. dimidiatus* Bryce*, B. urceolaris* Müller and *Hexarthra jenkinae* de Beauchamp (Tamiru Gebre, 2006). The Lake supports a piscifauna, which is exclusively composed of Tilapia (*Oreocromis niloticus* Linnaeus), *Tilapia zilli* although not much fishing is done (Baxter and Wood, 1965). Hora has bird community of Little Grebe, Pelican, Malachite Kingfisher, Little Bee-eater, Black-billed Barbet, African Paradise Flycatcher, Masked weaver and Starlings (Tamiru Gebre, 2006).

The sample stations selected for this study were: In front of Ras hotel (station A), around Irecha place (Traditional celebration of Oromo culture) (station B) and Hora ilmo the South crater of the lake (station C). These sites were chosen to represent the littoral and profundal zones of the lake and also sites that were impacted by human activities (A and B) and station C was relatively free from human influence.

## 2.2. Benthic and Weed bed Fauna Sampling Processing And Identification

Samples of benthic and weed-bed were collected for 5 months September, October, December (2009), February and March (2010) at 3 sampling stations (A, B, C). Station A and B has wide macrophyte zone and weed bed area with littoral and sublittoral zones as compared to station C. Station C has sloppy hillside not accessible for human interference and less nutrient input from the catchments.

Stations A and B were faced with human disturbance and station C was free from human interaction. Because station A is in front of Ras Hotel, local people use it for entertainment (refreshment), fishing and boat parking purposes. Station B is place of Irecha (place of traditional Oromo people celebration). Stations (A and B) were not free from human interference and the lake gets nutrients from these two stations. Samples were taken from each station and date at 3 depths (0-1, 1-3, 3-5). However station C was very steep and had no sublittoral zone, so this site was sampled only at 2 sampling depths (0-1, 4-11). Samples were taken with 3 replicates at each sampling point. Weed bed samples were taken using hand net. Bottom samples and benthic fauna were sampled with a standard Ekman grab, (15cm x 15cm) area and sub sampling method was used. Samples were transferred to the plastic bags and preserved immediately in 5% formalin and then washed in a nitex net with 0.20mm mesh. Larger organisms were picked out and sorted in a white enamel dish; smaller ones were counted in a small plexiglass dish under a dissecting microscope. A compound microscope was used for detailed identification.

The benthic and weed bed fauna was identified in the laboratory to the family level using different keys from literature (Michael, 2006 and www.xerces.org). Macrophytes of the three stations were identified at Addis Ababa University National Herbarium.

## 2.3. Biological parameters

Diversity of the benthic and weed bed fauna was calculated using Simpson's Diversity and Shannon Weaver index. Pielou’s index (J) of evenness was also applied to calculate the relative diversity for each station. The Modified Family Biotic Index (FBI) was used to compare organic pollution between stations and the whole lake generally.

### 2.3.1. Species Richness

The species richness *S* is simply the number of species present in an ecosystem. This index makes no use of relative abundances. In practice, measuring the total species richness in an ecosystem is impossible. The observed number of species in the system is a biased estimator of the true species richness in the system, and the observed species number increases non-linearly with sampling effort. Thus *S*, if indicating the observed species richness in an ecosystem, is usually referred to as species density. The more species present in a sample, the 'richer' the sample. Species richness as a measure on its own takes no account of the number of individuals of each species present. It gives as much weight to those species which have very few individuals as to those which have many individuals.

### 2.3.2. Simpson's Index of Diversity (D)

Also known as species diversity index is one of a number of diversity indices, used to measure diversity. In ecology, it is often used to quantify the biodiversity of a habitat. It takes into account the number of species present, as well as the relative abundance of each species. D therefore ranges from 0 to 1, with 0 representing infinite diversity and 1 representing no diversity. The formula for the Simpson index is:

$$D = 1 - \frac{\sum_{i=1}^{S} n_i(n_i - 1)}{N(N-1)},$$

Where: $S$= is the number of species

ni= the total number of organisms of a particular species

N = the total number of organisms of all species

### 2.3.3. Shannon Weaver Index

Shannon index is a measure of community structure defined by the relationship between the number of distinct taxa and their relative abundance. The Shannon index has been the most widely used in community ecology. The higher the number, the greater the diversity (Shannon and Weaver, 1963).

$Hs = \sum Ni/NLog2Ni/N$ (Shannon weaver, 1963)

Where:

Hs = Shannon weaver index

N = total number of individual in the sample

Ni = the number of individuals of species in the sample.

### 2.3.4. Evenness index

Evenness is a measure of the relative abundance of the different species making up the richness of an area. As species richness and evenness increase, so diversity increases. When there are similar proportions of all subspecies or species equally present in the habitat then evenness is one but when the abundances are very dissimilar (some rare and some common species) then the value increases. Pielou's index measures how evenly the species are distributed in a sample community. It is expressed as:

$J = Hs/Hmax$

Where: J = diversity evenness

H = Diversity Index (Shannon weaver)

$Hmax = Log_2S$

### 2.3.5. Hilsenhoff Family Biotic Index (H-FBI)

The Hilsenhoff Family Biotic Index (H-FBI) indicates organic and nutrient pollution and provides an estimate of water quality for each site using established pollution tolerance values for each taxon. Table 2 shows how water quality is evaluated using the Family Biotic Index and the index value increase as water quality decreases. Tolerance values range from 0 to 10 for families, taxa assigned a 0 or 1, on a scale from 0-10, were considered to be intolerant taxa. The index was developed by Hilsenhoff (Hilsenhoff, 1988) to summarize the various tolerances of the benthic arthropod community with a single value. The Modified Family Biotic Index (FBI) was developed to detect organic pollution and is based on the original species-level index (BI) of Hilsenhoff. The formula for calculating the Family Biotic Index is:

$$FBI = \Sigma(x_i * t_i)/(n)$$

Where, $x_i$ is number of individuals within a taxon, $t_i$ is tolerance value of a taxon and n is total number of organisms in the sample.

Table-2: Evaluation of water quality using the family-level biotic index (Hilsenhoff, 1988).

| **Family Biotic Index** | **Water Quality** | **Degree of Organic Pollution** |
|---|---|---|
| 0.00-3.75 | Excellent | Organic pollution unlikely |
| 3.76-4.25 | Very good | Possible slight organic pollution |
| 4.26-5.00 | Good | Some organic pollution probable |
| 5.01-5.75 | Fair | Fairly substantial pollution likely |
| 5.76-6.50 | Fairly poor | Substantial pollution likely |
| 6.51-7.25 | Poor | Very substantial pollution likely |
| 7.26-10.00 | Very poor | Severe organic pollution likely |

### 2.3.6. Statistical and Computational Data Analysis

Data collected for the environmental parameters and benthic macroinvertabrates were subjected to statistical analysis using Analysis of variance (ANOVA) and correlation to determine variations at stations and months and correlations between different factors and macroinvertebrates.

## 2.4. Physicochemical Parameters

*In situ* measurements of temperature and dissolved oxygen were made in the field with oxygen-temperature probe (model Co-411) on each sampling date.

### 2.4.1. Organic Matter Determination of the Sediment

Sediment samples were taken from the littoral, sublittoral and profundal zones of the 2 stations (A and B) and only littoral and profundal zones of C for the determination of organic matter at each station in of each month. Total organic matter in the sediment was determined in the laboratory by drying the mud in a drying oven at 80°C to constant weight; and then incinerated the dried samples in a muffle furnace at 500°C. The organic matter content of the samples was determined by loss of weight on ignition.

### 2.4.2. Sediment Texture Identification

To determine soil texture of Lake Hora, sediment samples were taken from the littoral, sublittoral and profundal zones of the 3 stations using Ekman grab. Samples were transferred to the plastic bags without preservation and analysis was done at the National Soil Testing Center in Addis Ababa. The sediment texture (grain size) was determined according to Bouyoucos hydrometer method. A hydrometer measures the density in (g/l) of the suspension at the hydrometer's center of buoyancy. Bouyoucos (1936) found that sand-sized particles (2.0 to 0.05 mm) settle out of suspension in 40 seconds, whereas silt-sized particles (0.5 to 0.002 mm) require approximately 2 hours settling out of suspension. Therefore, after 2 hours, it is assumed that only clay-sized particles (<0.002 mm) remain in suspension.

# CHAPTER 3: RESULT AND DISCUSSION

## 3.1. Biological Parameters

### 3.1.1. Macrophytes

*Typha latifolia* and *Schoenoplectus carymbosus* were present in some areas in the shore sites of stations A and B. Station C was low in vegetation and only *Oxytenanthera abyssinica* was observed. The weed-bed (vegetation) communities of this lake varied between seasons and depths in species composition. Table 3 shows macrophytes of Lake Hora.

There were fluctuation of water level in the lake and macrophytes were reduced during dry season and sublittoral macrophytes were totally absent during March. Water level fluctuation was also shown to reduce the diversity, or alter the composition of littoral habitats (Baxter, 1977; Hellsten *et al.,* 1996; Hill & Keddy, 1992), and affected the littoral food chain through the loss of macrophytes as a food resource (Hill *et al.,* 1998; Wilcox & Meeker, 1991).

Table-3: Distribution of macrophytes in Lake Hora

| **List of taxa** | **Stations** | | |
|---|---|---|---|
| | **A** | **B** | **C** |
| Typhaceae | | | |
| *Typha latifolia* | p | p | a |
| Cyperaceae | | | |
| *Schoenoplectus carymbosus* | p | p | a |
| Poacceae | | | |
| *Oxytenanthera abyssinica* | a | a | p |
| p=present, a=absent, | | | |

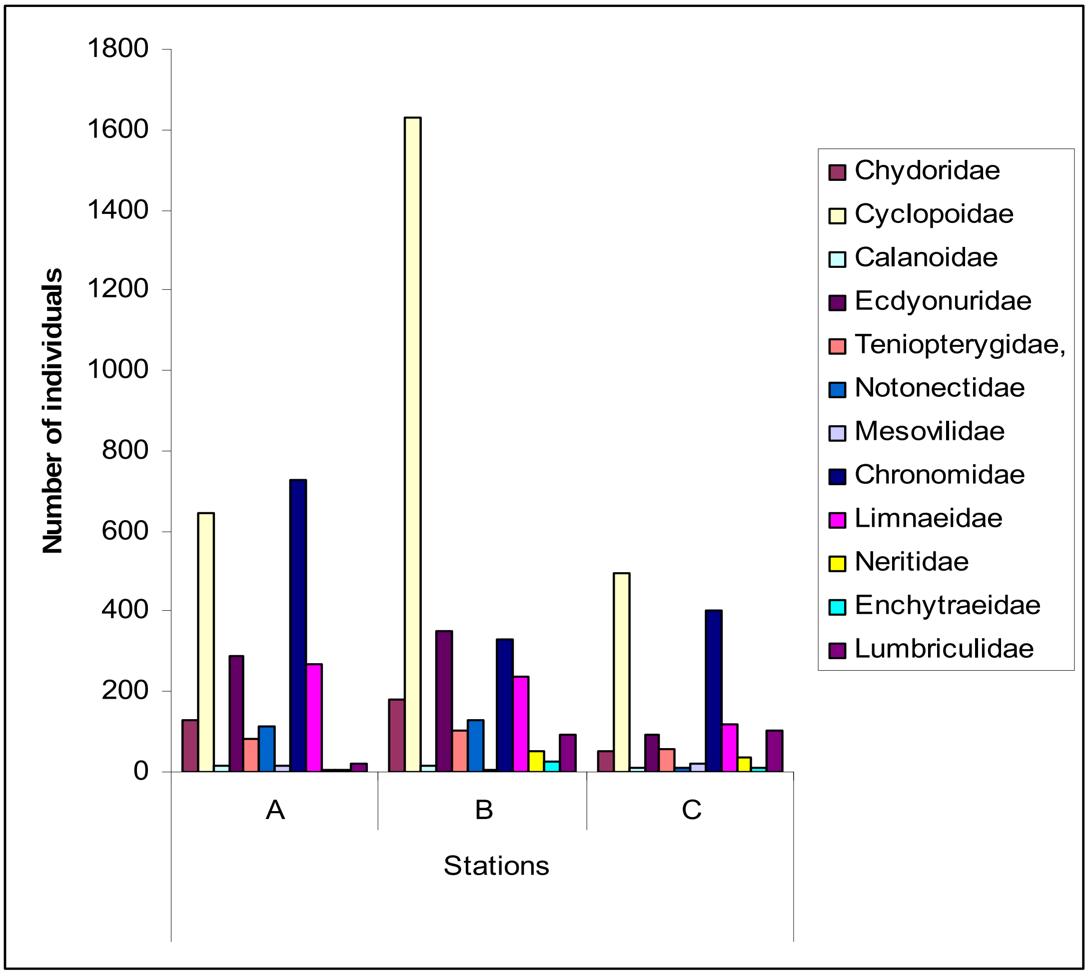
### 3.1.2. Distribution of Benthic and Weed-bed Fauna in Relation to Stations' Water Depth and Sediments

Benthic and weed-bed fauna of Lake Hora included a total of 6958 specimens within 27 taxa belonging principally to Copepod (2812), Chironomidae (1460) and Ecdyonuridae (735). A high number of organisms were observed mainly at stations B and A (3198 and 2342 respectively) and lower taxa numbers were observed at station C (1419), where there was low content of total organic mater, concentration of dissolved oxygen and cooler temperature, although this fact may be related to low macrophyte zonation and its sloppy geographical setting. Taxa richness at the stations ranged from 15 (station, C) to 21 (station, B). Among the 27 families collected, 12 were common and the rest 16 were rare. The bathymetric distribution of taxa showed higher species richness in the weed-bed (0-2m) and it decreased as depth increased. There was high number of benthic and weed bed organisms in October (3835) and their number were reduced in March (638), and also taxa richness was higher in September (21) and lower in March (9). Station C was cooler in temperature but its oxygen content was not higher except in September and the recorded number of organisms was smaller than other stations. Oxygen showed positive relations to the number of organisms exactly and to the number of taxa relatively. For example during October there was high concentration of oxygen in relation to this the number of organisms recorded was similarly higher and also in other months oxygen concentration was lower and relatively similar and the number of organisms.

In general, distribution and abundance of macroinvertabrates increase with substrate stability and the presence of organic detritus in stations of A and B. Other factors which appear to play a role include the mean particle size of mineral substrates, the variety of sizes, and surface texture, although it is difficult to generalize about their effects.

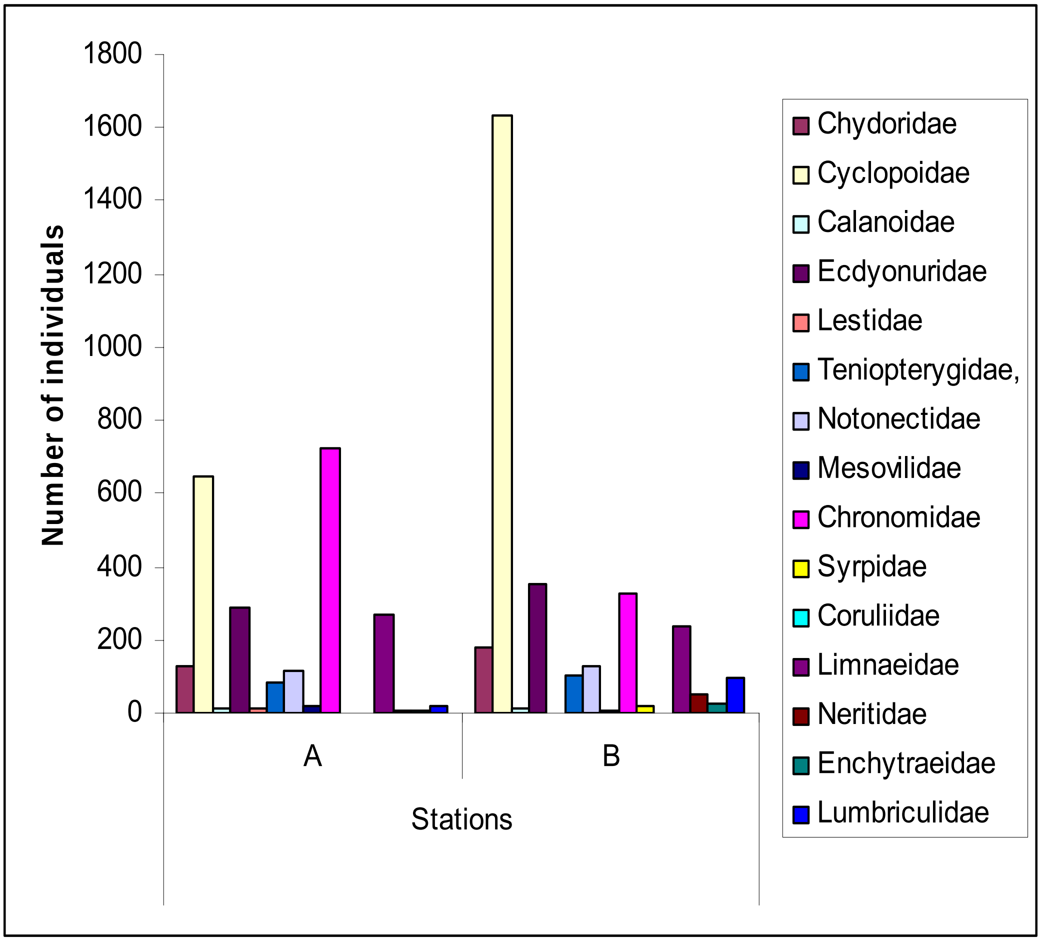
Figure 2 shows recorded taxa common for the three stations. Most of the rare families were collected from stations A and B. Family Cyclopidae has recorded high number at stations B and C.  At station A Chironomidae was the highest in number. Nertidae, Mesovelidae and Enchytraeidae were small in number at the three stations (A, B and C respectively).

Figure-2: Common families for the three stations.




Stations A and B show similarity in their recorded families and 16 families were present in both of these stations. Figure 3 shows families of Lake Hora shared by A and B stations.

Figure-3: Common families for the two stations (A and B).




### 3.1.2.1. Benthic Fauna

11 families were collected from the benthic sediment and these had a mean total of 288 individuals. Table 4 lists the fauna of the bottom mud down to a depth of 3-11m the Ekman grab brought up a community consisting mainly of Lymnidae, Chironomidae and Lumbriculidae. Lymnidae were about 42.7% of this, most of them were *Myxas glitunosa* and a small number of *Lymnaea ovata*. The Chironomids were about 31.6% and Lumbriculidae were about 14.8% of the total benthic fauna.

Table-4: Benthic Fauna of Lake Hora

| Taxa list | Mean No (n=5) | % Total |
|---|---|---|
| **Odonata (damselflies and dragonflies)** | | |
| Lestidae | 1 | <0.1 |
| **Hemiptera** | | |
| Notonectidae | * | <0.1 |
| Mesovilidae | 4 | 1.4 |
| **Diptera (trueflies)** | | |
| Chironomidae | 92 | 31.6 |
| Syphyridae | 3 | 1.03 |
| **Anisoptera** | | |
| Coruliidae | * | <0.1 |
| **Gastropod (snails)** | | |
| Lymnidae | 124 | 42.7 |
| Neritidae | 18 | 6.24 |
| Ancylidae | * | <0.1 |
| **Oligochaeta** | | |
| Enchytraeidae | 3 | 1.03 |
| Lumbriculidae | 43 | 14.80 |
| **Total mean** | 288 | 100 |
| *= their total abundance is less than 5 | | |

### 3.1.2.2. Weed-Bed Fauna

5522 organisms were identified from 25 families from the hand net samples making a mean of 1099 organisms per sample with standard error of 1325.68

(Table 5). Crustacean mainly Copepoda, were quantitatively predominant in all stations, followed by Chironomidae and Ecdyonuridae. Several other groups such as Chedoridae, Notonectidae and Teniopterygidae were present in comparatively low percentages. Copepoda reached very high abundance at all stations B, A, C (1632, 647, 493 respectively) dominant species were *Cyclops sp.* typical Cyclopods of weed-bed zone.

Table-5: Weed-bed fauna of Lake Hora

| **Taxa list** | **Mean No (n=5)** | **% Total** |
|---|---|---|
| **Cladocera (water fleas)** | | |
| Chydoridae | 72 | 6.48 |
| **Copepod** | | |
| Cyclopoidae | 554 | 49.86 |
| Calanoidae | 8 | 0.72 |
| **Ephemeroptera (mayflies)** | | |
| Ecdyonuridae | 147 | 13.23 |
| Ephemeridae | * | <0.1 |
| **Odonata (damselflies and dragonflies)** | | |
| Coenagriidae | * | <0.1 |
| Lestidae | 2 | 0.18 |
| **Plecoptera** | | |
| Isoperlidae | 4 | 0.36 |
| Teniopterygidae, | 49 | 4.41 |
| **Hemiptera** | | |
| Notonectidae | 51 | 4.56 |
| Mesoveliidae | 4 | 0.36 |
| **Trichoptera (caddisflies)** | | |

| | | |
|---|---|---|
| Rhyacophillidae | * | <0.1 |
| Hydroptilidae | * | <0.1 |
| **Coleoptera (beetles)** | | |
| Dytiscidae | 1 | <0.1 |
| Lycidae | * | <0.1 |
| **Diptera(trueflies)** | | |
| Chironomidae | 200 | 18 |
| Syphyridae | 1 | <0.1 |
| Stratiomyidae | * | <0.1 |
| Corethrellidae? | * | <0.1 |
| **Anisoptera** | | |
| Gampidae? | * | <0.1 |
| Coruliidae | * | <0.1 |
| **Gastropod (snails)** | | |
| Neritidae | 1 | <0.1 |
| **Arachinda** | | <0.1 |
| Argyronetidae? | * | <0.1 |
| **Oligochaeta** | | |
| Enchytraeidae | 5 | 0.45 |
| Lumbriculidae | 1 | <0.1 |
| **Total mean** | 1099 | 100 |
| *= their total abundance is less than 5<br>?=not confirmed | | |

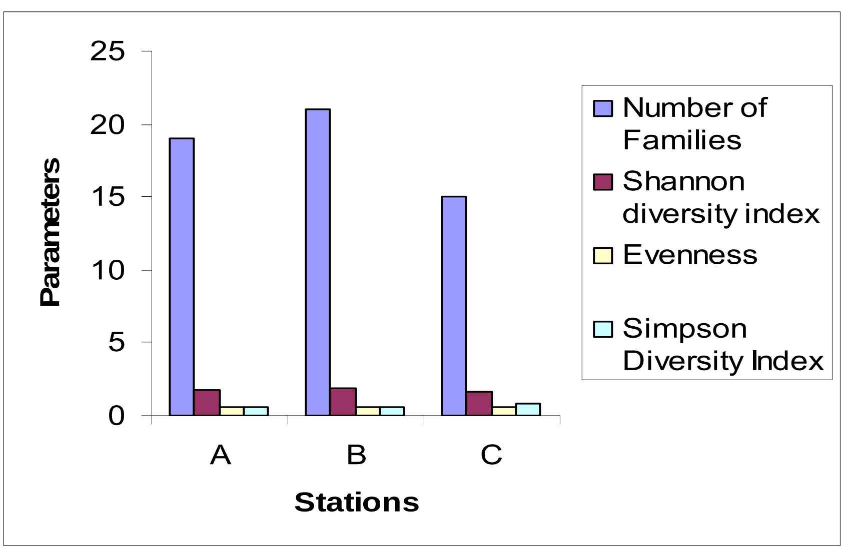
Among insects Chironomidae constituted the most abundant group although with moderate percentage. Other insects showed low percentage, for example, Ecdyonuridae with high number of *Ecdyonurus sp.*

## 3.2. Ecological Integrity of Lake Hora in Relation to Diversity Indices and Hilsenhoff Family Biotic Index

### 3.2.1. Spatial diversity

Comparison of the benthic and weed bed fauna communities in the 3 stations (Figure 4) showed that their values of species richness, diversity and evenness were not very different. However species-richness was lowest at station C, where there was low content of total organic mater, low concentration of dissolved oxygen and cooler temperature. This may be related to low macrophyte zonation and presence of low microhabitat of macrophytes and steepness of the profundal. Species-richness remained 15 at station C, only reaching 20 at station A and 21 at station B. It is clear that benthic and weed bed fauna richness are considerably higher at stations B and A, and this is believed to reflect the higher content of total organic matter at station B and A, coupled with quantitative increases in the levels of organic inputs.

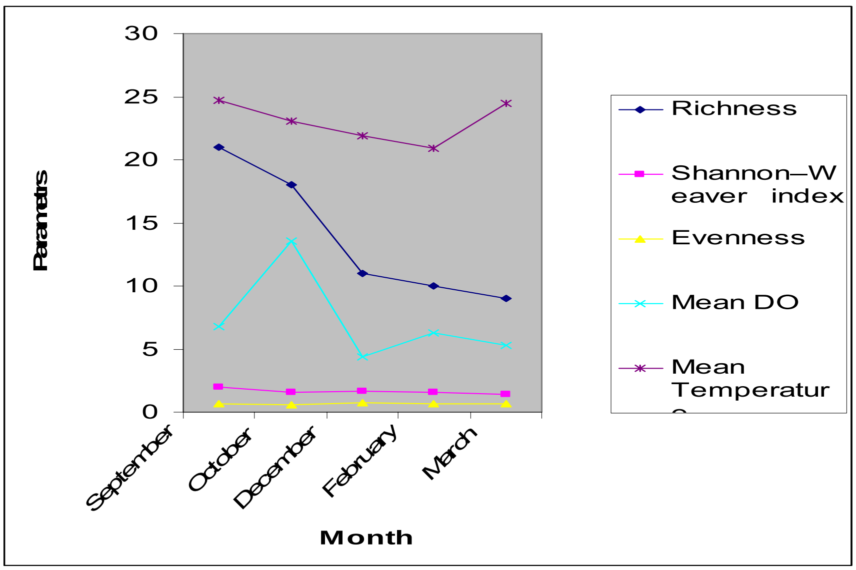
Figure-4: Spatial diversity indices of the three stations.



### 3.2.2. Seasonal diversity

There was high number of benthic and weed bed organisms in October (3835) and their number were reduced in March (638). As figure 5 indicates, family richness was high in September (21) and it was reduced in March (9). Highest diversity was recorded in September and the smallest in March and it varied between these months. Equitability of the recorded families was high in December but it was lower in October. Temperature was highest in September and March and also continuous reduction from September to February. Dissolved oxygen showed was higher in October.

Figure-5: Monthly diversity indices.




### 3.2.3. Hilsenhoff Family Biotic Index

The Hilsenhoff family biotic index is a weighted measure of the individuals in a population. Table 6 below provides the FBI values of the 3 stations and this table indicates that stations A and B were much poorer than that of station C. As a whole, the H-FBI value for all of the sampling stations was 7.55, indicating likely severe organic pollution and very poor water quality throughout the study area. This H-FBI value was calculated using family tolerance value, abundance of benthic and weed-bed fauna and evaluation of water quality using the family-level biotic index (Table 2). The increasing H-FBI values found within the study area are a result of the increasing pollution tolerant Chironomids and their higher tolerance values.

Table-6: Hilsenhoff Family Biotic Index values of the three stations (A, B and C).

| Stations | FBI |
|---|---|
| A | 7.60 |
| B | 7.63 |
| C | 7.43 |

## 3.3. Correlation between Macroinvertebrates and Physicochemical Parameters

Correlation between macroinvertebrates and temperature and total organic matter was insignificant (P>0.01). The correlation result (Table 7) indicates that oxygen showed strong relation to benthic and weed bed fauna distribution and abundence.

Table-7: Correlations of macroinvertebrates to oxygen temperature and total organic matter. MI=macroinvertebrates, T=temperature, DO=disolved oxygen, OM=organic matter

**Correlations**

| | | MI | T | DO | OM |
|---|---|---|---|---|---|
| MI | Pearson Correlatio | 1 | .095 | .707** | .376 |
| | Sig. (2-tailed) | | .737 | .003 | .167 |
| | N | 15 | 15 | 15 | 15 |
| T | Pearson Correlatio | .095 | 1 | -.042 | -.224 |
| | Sig. (2-tailed) | .737 | | .882 | .421 |
| | N | 15 | 15 | 15 | 15 |
| DO | Pearson Correlatio | .707** | -.042 | 1 | .477 |
| | Sig. (2-tailed) | .003 | .882 | | .072 |
| | N | 15 | 15 | 15 | 15 |
| OM | Pearson Correlatio | .376 | -.224 | .477 | 1 |
| | Sig. (2-tailed) | .167 | .421 | .072 | |
| | N | 15 | 15 | 15 | 15 |

**. Correlation is significant at the 0.01 level (2-tailed).

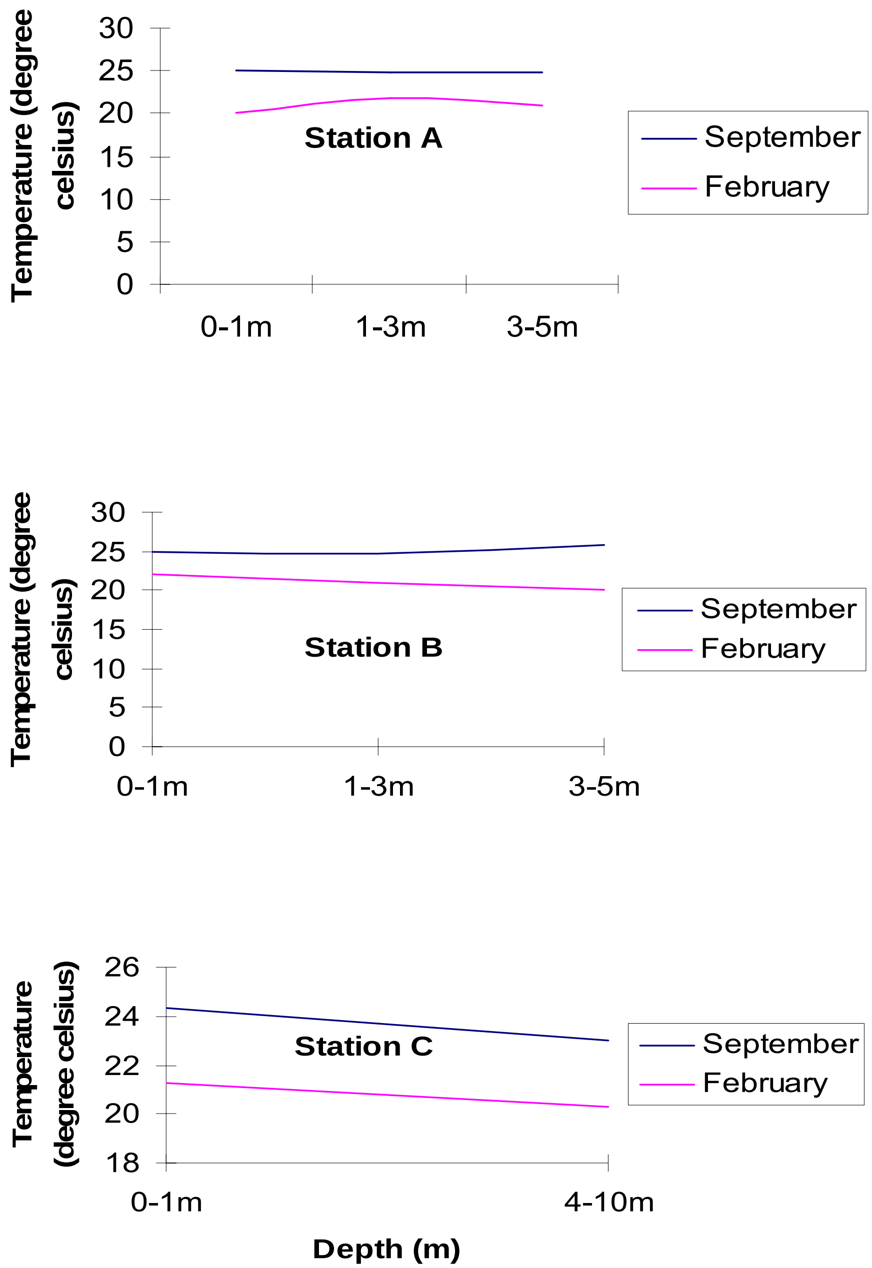
## 3.4. Physicochemical Parameters

Summary of physicochemical data from each station on each month are given in Appendices 3 and 4, respectively.

### 3.4.1. Temperature

Surface water temperature of the lake varied between stations from 21.3$^0$C (February) at station C to 26$^0$C (March) at station A and from 20$^0$C (February) at station B to 25.8$^0$C (September) profundal waters of station A. There was often little temperature difference between littoral and sublittoral zones of the lake. Temperature of the lake decreased when we go deep from the littoral zone but sometimes higher temperature was recorded such as that for 25.8$^0$C September 2009 at station B of the profundal zone. Figure 6 indicates temperature variation of the three stations at different depths of the lake on selected months of September and February.

Figure-6: Temperature variations of September and February at three stations (A, B and C).

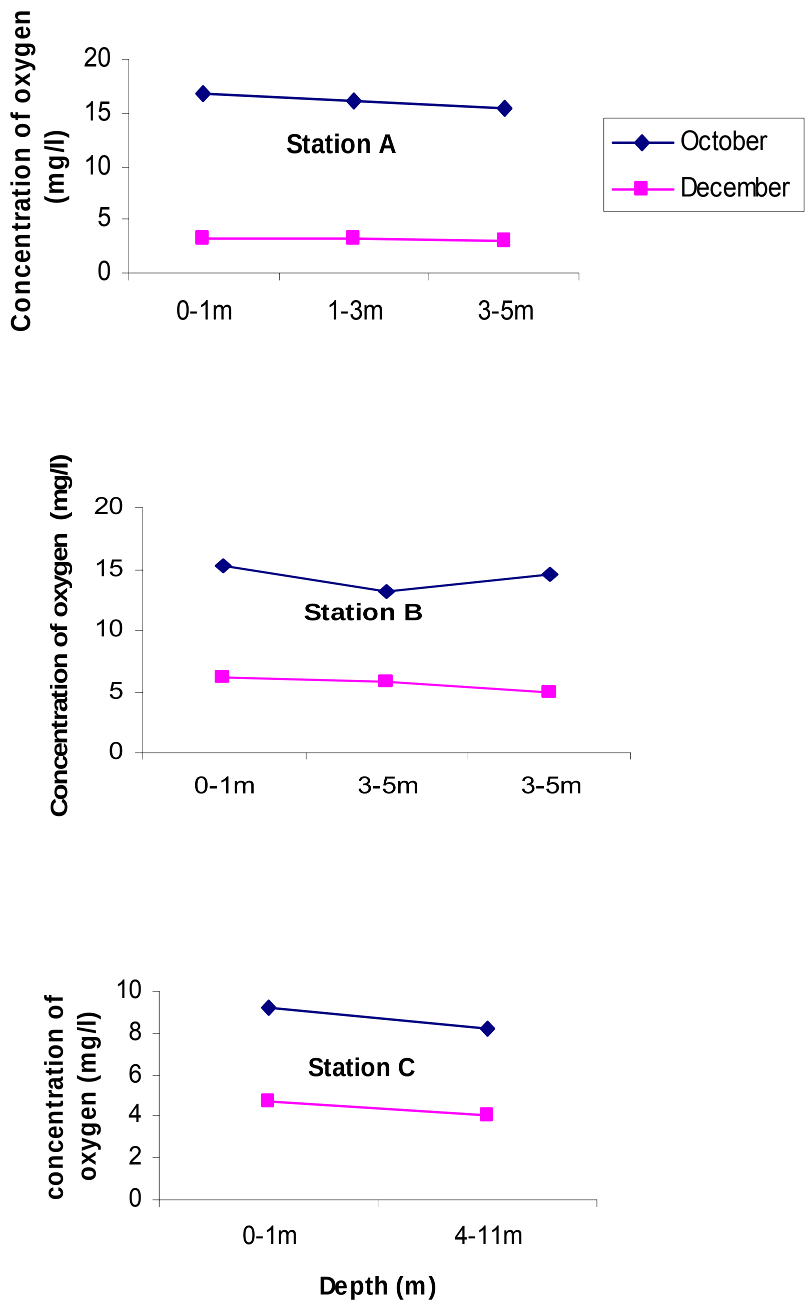


### 3.4.2. Dissolved Oxygen

There was high concentration of dissolved oxygen (16.7mg/l) (October) in the weed-bed and 15.3mg/l in the profundal. Concentration of dissolved oxygen decreased in December in the weed-bed and profundal (3.21mg/l and 3mg/l, respectively). As compared to stations A and B, station C was cooler in its water temperature but its dissolved oxygen content was not higher opposed to the principle that warmer water has a lower saturation point for DO than cooler water (Vant and Smith, 2004), except in September. The concentration of oxygen was higher in October and lower in December, and it showed similarity during September, February and March. Figure 7 shows concentration of dissolved oxygen at three stations of the lake on selected months of October and December.

Dissolved oxygen (DO) is vital for the survival of fish, aquatic invertebrates and amphibians (Boulton & Brock, 1999). Boulton & Brock (1999) state that dissolved oxygen levels in waterways depend on the physical, chemical and biological activities that are occurring in the water body (Abbott and Marshman, 2003). So the concentration of dissolved oxygen in Lake Hora was good indicator for macroinvertabrate distribution and abundance.

Figure-7: Concentration of oxygen in mg/l at three stations (A, B, C) of Lake Hora.



### 3.4.3. Organic matter determination of the sediment

Analysis of sediment samples taken at various depths in Lake Hora show that the organic matter at the weed-bed ranged from 2.3% (March) of station C to 31% (March) at station B and at the profundal it ranged from 3.3% (March) at station C and 23% (March) of station A (Table 8). Result of this study indicates that total organic matter content of the 3 stations increased from littoral to the profundal zone of the lake but sometimes higher organic mater content were recorded such as that for 23.5% during October, 2009 at station C of the profundal zone. And it showed monthly reduction from October to March with few exceptions of the three stations. Generally total organic matter content of station C was lower than A and B.

Table-8: Total organic matter taken from different zones at 3 stations of Lake Hora.

| **Stations** | **Zone** | **Month** | | | |
|---|---|---|---|---|---|
| | | **October** | | **March** | |
| | | **Total organic Matter (g)** | **% d-w** | **Total organic matter(g)** | **% d-w** |
| **A** | 0-1m | 1.2 | 24 | 5.57 | 27.8 |
| | 1-3m | 4.44 | 22.2 | 1.15 | 10.7 |
| | 3-5m | 5.29 | 17.6 | 1.2 | 23 |
| **B** | 0-1m | 2 | 16.6 | 1.12 | 31 |
| | 1-3m | 2.77 | 19.7 | 2.85 | 14.2 |
| | 3-5m | 3.42 | 11.4 | 3.13 | 15.6 |
| **C** | 0-1m | 1.32 | 4.4 | 1.31 | 2.3 |
| | 4-11 | 1.6 | 23.5 | 1 | 3.3 |

### 3.4.4. Sediment Texture Determination

The result obtained showed that sand dominated across the weed bed which revealed sandy loam texture. The profundal of the lake was loam soil. A loam soil is a mixture of sand, silt and clay that exhibits the properties of that separate in about equal proportions (Brady and Weil, 1999). Loam soils often contain a good amount of organic matter. Table 9 below shows the sediment texture of Lake Hora.

Table-9: Sediment texture of Lake Hora

| **Depth** | **Sand %** | **Silt %** | **Clay %** | **Class** |
|---|---|---|---|---|
| 0-3 | 75 | 14 | 11 | Sandy loam |
| 4-11 | 47 | 38 | 15 | Loam |

# CONCLUSION

As compared to stations A and B, station C was cooler in its water temperature but its dissolved oxygen content was not higher opposed to the principle that warmer water has a lower saturation point for DO than cooler water (Vant and Smith, 2004), except during September. However oxygen shows strong relation to benthic and weed bed fauna distribution and abundence.

The result obtained showed that sandy loam dominated across the weed bed and the profundal was loamy. Generally total organic matter content of station C was lower than A and B.

Associated to the weed-bed, Copepoda, Chironomidae and Ecdyonuridae were quantitatively dominant in all stations and the profundal zone of the lake was dominated by Lymnidae, Chironomidae and Lumbriculidae.

The benthic and weed bed fauna analysis of the 3 stations sampled showed that there was a difference in the distribution, diversity and abundance of benthic and weed bed invertebrates and these were much higher at stations A and B. The Family Biotic Index result indicates that the water quality at stations A and B, was of poor quality than that of station C, and also the whole lake water quality was very poor with an average H-FBI value of 7.55.

The benthic and weed bed community identified within Lake Hora included invertebrates from 27 families, and generally resembled species commonly associated with polluted water or stressed environmental conditions (stations A and B). All sampling stations were dominated by Cyclopidae and Chironomidae with a number of pollution tolerant forms present.

It is well documented that pollution often leads to structural changes in benthic communities, as revealed by diversity measurements (Pearson & Rosenberg, 1978). A few tolerant or opportunistic species will become relatively more numerous and will dominate the community, while many less tolerant species will become increasingly rare or disappear (Brage, 1985). In Lake Hora, there were high number of individuals, taxa diversity, evenness and great number of rare taxa of benthic and weed bed fauna were recorded at stations of A and B and this were human influenced areas affected by the community around the lake area, used by different purposes (for example washing clothes, boat parking and others) these activities could; influence the benthos at stations A and B. However low density and abundance of macroinvertabrates at station C could be due to:

1, low organic matter load at station C which was free of human interactions,

2, steep and slope geographical setting of the profundal and its catchment; and

3, low vegetation cover.

It has been shown that there are a number of hydromorphological and physicochemical alterations that may impair ecological status of lakes. As benthic invertebrates are much less mobile than fish, and exhibit a much higher dependence on littoral habitat types, shoreline developments would be expected to have considerably more severe impacts on invertebrate communities.

# RECOMMENDATION

In general there is a need for further investigation of the benthic and weed bed fauna indicator value for lake-types (including consideration of indicator variability) of benthic and weed-bed fauna communities from different lake zones (littoral, sublittoral and profundal) and to understand their sensitivity to various pressures. Result of this study indicates poor water quality of the lake, so further investigation should be done with large number of sampling stations.

Recreational use of lake shores has – to our knowledge – never been examined regarding its effects on littoral macroinvertebrates. In the future, functional measures of ecosystem health, such as chronic measures of toxicity or stress, should be incorporated into any assessment process in addition to using benthos for bioassessment purpose. Further investigation is needed to understand the distribution of littoral invertebrates and their relationship to nutrients and hydromorphological modifications.

Lake Hora is impacted by human activity and has poor biological integrity. Further ecological deterioration should be prevented through proper management plans and mitigation actions. Use of benthic and weed bed fauna as bioindicators can assist in bio-assessments of intensive and extensive sampling can be done.

# REFERENCES

Aagaard, K. (1986). The chronomid fauna of north Norwegian lakes. With a discussion on methods of community classification. *Halarect. Ecol.* **9.**

Abbott L. and Marshman P. (2003). Macroinvertebrate analysis, comparing streams of varying water quality, with in the Manlay Dam Catchment. “In: Fresh Water Ecology Report 2003, Department of Environmental Sciences, University of Technology, Sydney.”

Abebaw Wondie (2007). Temporal dynamics of biomass and primary production of Phytoplankton in relation to some physico-chemical variables in Lake Hora-Arsedi, Ethiopia. M.Sc. Thesis, School of Graduate Studies, Addis Ababa University, Addis Ababa.

Barnard & Biggs (1988). Macroinvertabrates in the catchment streams of Lake Naivasha, Kenya. Rev. *Hydrobiol*. *Trop*. **21**:127-133.

Barbour M T, Gerritsen J, Snyder B D and Stribling J B (1999). Revision to rapid bioassessment protocols for use in streams and rivers: periphyton, benthic macroinvertebrates and fish. 2nd edition. EPA 841-B-99-002. US Environmental Protection Agency: Office of Water, Washington DC.

Baxter, R. M. (1977) Environmental effects of dams and impoundments. *Annual Review of Ecology and Systematics.* **8**: 255-283.

Baxter, R. (2002). Lake morphometry and chemistry. In: *Ethiopian Rift Valley lakes*, Tudorancea, C. and Taylor, W.D. (eds.), pp. 45-60, Backhuys Publishers. Leiden, *The Netherlands*.

Baxter, R. and Wood, R. (1965). Studies on stratification in the Bishoftu crater lakes. *J. Appl. Ecol*., **2**: 416.

Baye Sitotaw (2006). Macroinvertebrate assemblage structure in relation to and use types and pollution in some Ethiopian rivers. M.Sc. Thesis, School of Graduate Studies, Addis Ababa University, Addis Ababa.

Beck, W. M. J. (1977). Environmental requirement and pollution tolerance of common fresh water chironomidae. EPA 600/4-77-024. US Environment Protect, Agency. Cincinati. p.261.

Bode, R.W., Novak, M.A., and Abele, L.E. (1996). Quality Assurance Work plan for Biological Stream Monitoring in New York State. NYS Department of Environmental Conservation, Albany, NY.

Boulton and Brock, (1999). Freshwater ecology: a scientific introduction. p.38.

Bouyoucos G.J. (1936). Directions for Making Mechanical Analysis of Soils by the Hydrometer Method. *Soil Sci.* 42pp

Brady, N.C and Weil, R.R. (1999). The nature and properties of soils. Prentice Hall, New Jersey

Brage, R.Y. (1985). Effect of sediment copper on benthic fauna. Vol. **25**: 83-89, Norway.

Brundin, H. (1956). The Chironomidae: biology and ecology of non-biting midges pp 48.

Dallas, H.F. (1997). A preliminary evaluation of aspects of SASS (South Africa Scoring System) for rapid bioassessment of water quality in rivers. *S. Afr. J. Aquat. Sci.* **23**: 79–94.

Dereje Tewabe, (2009). Distribution and Abundance of Macro-benthic and Weed-bed Faunas in The Northern Part of Lake Tana, Ethiopia. Proceedings of the First Annual Conference of EFASA. pp 99.

Harrison, A.D. (1987). Chronomidae of five Central Ethiopian Rift Valley lakes. *Ent. Scand Suppl* **29**: 39-43.

Harrison, A. D. and Hynes, H. (1988). Benthic fauna of Ethiopian mountain streams and rivers. *Hydrobiologia* **1**:1-36.

Harvey, H. H. and MCArdle, J.M (1986). Composition of the benthos in relation to pH in the Locloche Lakes, Water, Air, Soil Pollute. **30**:529-536.

Hellsten, S. Marttunen, M.  Palomaki, R. Riihimaki, J. & Alasaarela, E. (1996). Towards an ecologically based regulation practice in Finnish hydroelectric lakes. Regulated Rivers-Research & Management. **12**: 535-545.

Hill, N. M. & P. A. Keddy (1992). Prediction of rarities from habitat variables: Coastal plain plants on Nova Scotian lakeshores. *Ecology* 73: 1852-1859.

Hill, N. M., P. A. Keddy & I. C. Wisheu (1998). A hydrological model for predicting the effects of dams on the shoreline vegetation of lakes and reservoirs. *Environmental Management*. **22**: 723-736.

Hilsenhoff, W. L. (1988). Rapid bioassesment of organic pollution with a family level biothic index. *J. North Am. Benthol. Soc.* **7**(1): 65-68

Hutchinson, G.E. (1957). *A Treatise on Limnology*, I. Geography, Physics and Chemistry. John Wiley and Sons, New York.

Hynes, H. B. N. (1955). Biological notes on some East African Aquatic Heterotero. *Proc. Entomal Soc. Lond*. (A) **30**: 43-54.

Karr J R and Chu E W (1999). Restoring life in running waters: better biological monitoring. Island, Covelo, California, USA.

Kinyua, A. M. and Pacini, N. (1991). The impact of pollution on the Ecology of the Nairobi-Athi River system in Kenya. *J. Biochem. Phys.* **1**: 5−7.

Lenz, F., (1925). Chironomiden und Seetypenlehre. Die Naturwissenschaften **13**: 5-10

Lundbeck, K. (1936). Untersuchungen über die Bodenbesiedlung der Alpenrandseen. *Arch. Hydrobiol*. **10:** 207-358.

McAuliffe, J.R. (1984). Composition for space, disturbance, and the structure of a benthic stream community. *Ecology*, **65**: 894-908.

Mackie, G. L. (2001). Applied Aquatic Ecosystem Concepts. Kendall/Hunt Publishing Company. 744pp. ISBN 0-7872-7490-9

Mathoko, J. M. (2002). The sizes, maturity stages and biomass of mayfly assemblages colonizing disturbed streambed patches in Central Kenya. *Afri. J. Ecol.* **40**:84−93.

Michael R. (2006). Freshwater Macroinvertebrates from Streams in Western Washington and Western Oregon. A laminate field guide.

Mohr, P. A. (1961). The geology, structure and origin of the Bishoftu explosion craters, Shoa, Ethiopia. *Bull. Geophys. Obs., Addis Ababa, 2*: 65-101.

Naumann, G. (1921). Einige Grundlinien der regionalen liminologie. Lunds Univ. Arsskr. N.F. **17**:1-21

Oliver, D. R. (1971). Life history of the chironomidae. *Ann. Rev. Ent.* **16**: 211-230.

Pearson,T. H. & Rosenberg.R. (1978). Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. *Ocenogr. Mar. Biol. Ann. Rev.* **16**: 229-311.

Peterson, C. H. (1975). Stability of species and of community for the benthos of two lagoons. *Ecology*, **56**: 958-963.

Plafkin, J. L., Barbour, M.T., Porter, K.D., Gross, S.K. and Hughes, R.M. (1989). *Rapid bioassessment protocols for use in streams and rivers: benthic macroinvertebrates and fish.* EPA/444/4-89-001. U.S. Environmental Protection Agency, Office of Water, Washington.

Prosser, M., Wood, R. and Baxter, R. (1968). The Bishoftu Cater Lakes: a bathymetric and chemical study. *Arch. fur hydrobiol.,* **65**:309-324.

Rippey, B. and Wood, R. B. (1985). Trend in major ion composition of five Bishoftu crater lakes.*Sinet: Ethiop. J .Sci*., **8**:9-29.

Rosenberg D. M. and Resh V. H. (Eds) (1993). Freshwater biomonitoring and benthic macroinvertebrates. Chapman & Hall, London and New York.

Rasmussen, J. B. (1988). Littoral zoobenthic biomass in lakes, and its relationship to physical, chemical and trophic factors'. – *Canadian Journal of Fisheries and Aquatic Science.* **45**:1436-1447.

Ruttner, F (1953). *Fundamentals of Limnology.* University of Toronto Press. pp295.

Saether, O. A. (1979). Chironomid communities as water quality indicators. *Holarct. Ecol.* **2**: 65–74.

Seifu Kebede,Tenalem Ayenew and Mohammed Umer (2001). Application of isotopes and water balance approaches for the study of the hydrogeological regime of the Bishoftu crater lakes, Ethiopia. *SINET: Ethiop. J. Sci*., **24**(2) pp. 151-166

Shannon, D. E. and Weaver, W. (1963). *The Mathematical Theory of Communication.* Urbana, Illinois: University of Illinois Press.

Soil & Water Conservation Society of Metro Halifax (SWCSMH), (2006). Freshwater Benthic Ecology and Aquatic Entomology. *J. Soil and Wat. Conser.*

Tamiru Gebre, (2006). Zooplankton Community Grazing Rates Study on the Natural Phytoplankton Assemblages in Lake Arsedi (Betemengist). M.Sc. Thesis, School of Graduate Studies, Addis Ababa University, Addis Ababa.

Thienemann, A. (1954). Chironomus Leben Verbreitung und wirtschaftliche Bedeutung der Chironomiden. Die Binnengewässer, Bd. 20, Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, 834 pp.

Tilahun Kibret and Harrison, D. (1989). The benthic and wed-bed faunas of Lake Awasa (Rift Valley, Ethiopia). *Hydrobiologia*.**174**, 1-15.

Tumiwesigye C. Yesuf, S.K. Makanga, B. (2000). Structure and composition of benthic macroinvertebrate of a tropical forest stream, River Nyamweru, western Uganda. *Afri. J. Ecol.* **38**:72-77

Vant, B. and Smith, P. (2004). *Trends in River Water Quality in the Waikato Region, 1987-2002*. Environment Waikato Technical Report, 2004/02.

Verneaux, V. Verneaux, J. Schmitt, A. Lovy C. and Lambert C. (2004). The Lake Biotic Index (LBI): an applied method for assessing the biological quality of lakes using macrobenthos; the Lake Châlain (French Jura) as an example *Ann. Limnol. - Int. J. Lim*., **40** (1), 1-9

Wetzel, R. G. (2001). *Limnology*: *Lakes and rivers ecosystems*, 3rd ed. Academic press, San Diago San Francisco New York.

Wilcox, D. A. & Meeker, J. E. (1991). Disturbance effects on aquatic vegetation in regulated and unregulated lakes in northern Minnesota. *Canadian Journal of Botany*. **69**: 1542-1551.

Wiederholm, T. 1980. Use of benthos in lake monitoring. *Journal of the Water Pollution Control Federation.* **52**:537-547

Wiederholm, T. (1981). Associations of lake- living chronomidae. A cluster analysiss of Brundin's and recent data from Swedish lakes. Schweiz. Z. Hydrol./Rev. Hydrol./Suisse J. *Hydrol.* **43**: 140-141.

Wood, R., Baxter, R. and Prosser, M. (1984). Seasonal and comparative aspects of chemical stratification in some tropical crater lakes, Ethiopia. *Freshwat. Biol.,* **14**: 551-573.

Wood, R. B. Prosser, M. V. and Baxter, R. M. (1976). The seasonal pattern of thermal characteristics of four Bishoftu cater lakes, Ethiopia. *Freshwat. Biol.,* **.6**: 519-530.

Wood, R. B. and Talling, J. F. (1988). Chemical and algal relationships in a salinity-series of Ethiopian inland waters. *Hydrobiologia*, **15**:29-67.

Zinabu Gebre-Mariam (1994). Long-term changes in indices of chemical and productivity status of a group of tropical Ethiopian lakes with differing exposure to human influence. *Arch. Hydrobiol*., **132(**1): 115-125.

Zinabu Gebre-Mariam (1998). Human Interactions and Water Quality in the Horn of Africa, Science in Africa Emerging Water Management Issues, AAAS, Philadelphia, Symposium Proceedings.

Zinabu Gebre-Mariam, Elizabeth Kebede-Westhead and Zerihun Desta (2002). Long-term changes in chemical features of waters of seven Ethiopian Rift Valley lakes. *Hydrobiologia*, **477**: 81-91.

Zinabu Gebre-Mariam and Elias Dadebo (1989). Water resources and fisheries management in the Ethiopian rift valley lakes. *SINET: Ethiop.J.Sc*.**12** (2): 95-109.

**List of websites**

www.xerces.org.

http://lakekoka.ning.com

# LIST OF APPENDICES

**Appendix-1.** Benthic and weed-bed fauna of Lake Hora and their seasonal variation

| **Taxa list** | **Stations** | | | | | | | | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | | | | | B | | | | | C | | | | | |
| | S | O | D | F | M | S | O | D | F | M | S | O | D | F | M | |
| **Cladocera (waterfleas)** | | | | | | | | | | | | | | | | |
| Chydoridae<br>*Eurycerus lamelatus*<br>*Chydorus sphaericus* | 0 | 128 | 2 | 0 | 0 | 0 | 160 | 12 | 10 | 0 | 0 | 50 | 0 | 0 | 0 | 362 |
| **Copepod** | | | | | | | | | | | | | | | | |
| Cyclopoidae<br>*Cyclops sp* | 70 | 210 | 159 | 208 | 0 | 143 | 1225 | 180 | 77 | 7 | 1 | 470 | 3 | 19 | 0 | 2772 |
| Calanoidae<br>*Diaptomus sp* | 15 | 0 | 0 | 0 | 0 | 4 | 9 | 0 | 0 | 0 | 0 | 12 | 0 | 0 | 0 | 40 |
| **Ephemeroptera (mayflies)** | | | | | | | | | | | | | | | | |
| Ecdyonuridae | 61 | 20 | 90 | 81 | 38 | 19 | 318 | 0 | 11 | 2 | 2 | 80 | 8 | 0 | 5 | 735 |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Ecdyonurus sp*<br>*Heptagenia sp*<br>*Rhithrogena sp* | | | | | | | | | | | | | | | | |
| Ephemeridae<br>*Ephemera vulgata* | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| **Odonata(damsel and dragonflies)** | | | | | | | | | | | | | | | | |
| Coenagriidae<br>*Coenagriion sp* | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Lestidae<br>*Lestes sp* | 8 | 4 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 13 |
| **Plecoptera** | | | | | | | | | | | | | | | | |
| Isoperlidae<br>*Isoperla sp* | 0 | 0 | 0 | 0 | 0 | 22 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 22 |
| Teniopterygidae,<br>*Teniopteryx nabulosa*<br>*Brachyptera sp* | 0 | 6 | 71 | 7 | 0 | 0 | 80 | 18 | 0 | 4 | 0 | 58 | 0 | 0 | 0 | 244 |
| **Hemiptera** | | | | | | | | | | | | | | | | |
| Notonectidae | 8 | 1 | 13 | 35 | 57 | | 51 | 10 | 57 | 13 | | 3 | | | 7 | 255 |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Notoneta sp* | | | | | | | | | | | | | | | | |
| Mesovelidae<br>*Mesovelia forcata* | 1 | 1 | 2 | 1 | 12 | 2 | 1 | 1 | | 1 | | 1 | | 19 | | 42 |
| **Trichoptera (caddisflies)** | | | | | | | | | | | | | | | | |
| Rhyacophillidae | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Hydroptilidae | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| **Coleoptera (beetles)** | | | | | | | | | | | | | | | | |
| Dytiscidae | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 6 |
| Lycidae | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 2 |
| **Diptera (Trueflies)** | | | | | | | | | | | | | | | | |
| Chironomidae<br>*chironomus sp* | 74 | 336 | 8 | 138 | 171 | 61 | 63 | 48 | 46 | 111 | 1 | 252 | 35 | 43 | 73 | 1460 |
| Syphyridae | 0 | 1 | 0 | 0 | 0 | 0 | 17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 18 |
| Stratiomyidae | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Corethrellidae? | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| **Anisoptera** | | | | | | | | | | | | | | | | |
| Gampidae | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Coruliidae | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| **Gastropod (snails)** | | | | | | | | | | | | | | | | |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lymnidae<br>*Limnaea ovata*<br>*Myxas glutinosa* | 20 | 67 | 32 | 92 | 55 | 17 | 50 | 138 | 17 | 14 | 46 | 28 | 20 | 13 | 12 | 621 |
| Neritidae<br>*Theodoxus danubialis* | 4 | 0 | 0 | 0 | 0 | 52 | 0 | 1 | 0 | 0 | 38 | 0 | 0 | 0 | 0 | 95 |
| Ancylidae | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| **Arachinda** | | | | | | | | | | | | | | | | |
| Argyronetidae? | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| **Oligochaeta** | | | | | | | | | | | | | | | | |
| Enchytraeidae<br>*Ancylastrum fluviatila* | 1 | 2 | 1 | 2 | 0 | 0 | 13 | 7 | 1 | 4 | 0 | 8 | 0 | 0 | 0 | 40 |
| Lumbriculidae<br>*Lumbriculus varigatus* | 1 | 1 | 0 | 20 | 0 | 30 | 0 | 8 | 4 | 52 | 0 | 103 | 2 | 0 | 0 | 221 |
| **Total** | 268 | 777 | 380 | 584 | 333 | 352 | 1992 | 423 | 223 | 208 | 95 | 1065 | 68 | 94 | 97 | 6958 |
| **Grand Total** | **6958** | | | | | | | | | | | | | | | |
| **S=September, O=October, D=December, F=February, M=March**<br>**?=not confirmed** | | | | | | | | | | | | | | | | |

**Appendix-2.** Abundance of benthic and weed-bed fauna at 3 stations of Lake Hora

| Taxa list | Stations | | | | | |
|---|---|---|---|---|---|---|
| | A | | B | | C | |
| | Abundance | %total | Abundance | %total | Abundance | %total |
| **Cladocera (water fleas)** | | | | | | |
| Chydoridae | 130 | 5.55 | 182 | 5.69 | 50 | 3.52 |
| **Copepoda** | | | | | | |
| Cyclopoidae | 647 | 27.62 | 1632 | 51.03 | 493 | 34.7 |
| Calanoidae | 15 | 0.64 | 13 | 0.40 | 12 | 0.84 |
| **Ephemeroptera (mayflies)** | | | | | | |
| Ecdyonuridae | 290 | 12.38 | 350 | 10.94 | 95 | 6.69 |
| Ephemeridae | 1 | 0.04 | | | | |
| **Odonata (damsel and dragonflies)** | | | | | | |
| Coenagridae | 0 | | 1 | 0.03 | 0 | |
| Lestidae | 12 | 0.51 | 1 | 0.03 | | |
| **Plecoptera** | | | | | | |
| Isoperlidae | 0 | | 11 | 0.34 | 0 | |
| Teniopterygidae | 84 | 3.58 | 102 | 3.18 | 58 | 4.08 |
| **Hemiptera** | | | | | | |
| Notonectidae | 114 | 4.86 | 131 | 4.09 | 10 | 0.70 |
| Mesovilidae | 17 | 0.72 | 5 | 0.15 | 20 | 1.40 |
| **Trichoptera(caddisflies)** | | | | | | |
| Rhyacophillidae | 0 | | 1 | 0.03 | 0 | |

| | | | | | | |
|---|---|---|---|---|---|---|
| Hydroptilidae | 1 | 0.04 | 0 | | 0 | |
| **Coleoptera (beetles)** | | | | | | |
| Dytiscidae | 2 | 0.085 | 0 | | 4 | 0.28 |
| Lycidae | | | | | 2 | 0.14 |
| **Diptera (trueflies)** | | | | | | |
| Chironomidae | 727 | 31.04 | 329 | 10.27 | 404 | 28.47 |
| Syphyridae | 1 | 0.04 | 17 | 0.53 | 0 | |
| Stratiomyidae | 0 | | 1 | 0.03 | 0 | |
| Corethrellidae? | 0 | | 1 | 0.03 | 0 | |
| **Anisoptera** | | | | | | |
| Gampidae | 0 | | 1 | 0.03 | 0 | |
| Coruliidae | 1 | 0.04 | 1 | 0.03 | | |
| **Gastropod (snails)** | | | | | | |
| Lymnidae | 266 | 11.35 | 236 | 7.37 | 119 | 8.38 |
| Neritidae | 4 | 0.17 | 53 | 1.65 | 38 | 2.67 |
| Ancylidae | 1 | 0.04 | 0 | | 0 | |
| **Arachinda** | | | | | | |
| Argyronetidae? | 0 | | 0 | | 1 | 0.07 |
| **Oligochaeta** | | | | | | |
| Enchytraeidae | 6 | 0.25 | 25 | 0.78 | 8 | 0.56 |
| Lumbriculidae | 22 | 0.94 | 94 | 2.93 | 105 | 7.4 |
| **Total** | **2341** | | **3198** | | **1419** | |

?=not confirmed

**Appendix-3.** Recorded value of temperature at three stations

| Stations | Zones (m) | Month | | | | |
|---|---|---|---|---|---|---|
| | | September | October | December | February | March |
| A | 0-1 | 25.1 | 22.4 | 21.7 | 20 | 26.8 |
| | 1-3 | 24.9 | 22.1 | 21.5 | 21.9 | 24.2 |
| | 3-5 | 24.8 | 22 | 21.3 | 21 | 23 |
| B | 0-1 | 25 | 24.2 | 23 | 22.1 | 25 |
| | 1-3 | 24.8 | 24.7 | 22.5 | 21 | 24.8 |
| | 3-5 | 25.8 | 22.5 | 21.5 | 20 | 24 |
| C | 0-1 | 24.3 | 23.4 | 22.3 | 21.3 | 24.8 |
| | 4-11 | 23 | 23.2 | 21.4 | 20.3 | 23 |

**Appendix-4.** Recorded value of oxygen in (mg/l) at three stations

| Stations | Zones(m) | Month | | | | |
|---|---|---|---|---|---|---|
| | | September | October | December | February | March |
| A | 0-1 | 6.91 | 16.7 | 3.22 | 6.5 | 6 |
| | 1-3 | 6.1 | 16 | 3.2 | 5 | 5 |
| | 3-5 | 5.6 | 15.3 | 3 | 7 | 4.3 |
| B | 0-1 | 7.1 | 15.3 | 6.2 | 6 | 4 |
| | 1-3 | 7 | 13.2 | 5.8 | 6.5 | 5 |
| | 3-5 | 6.8 | 14.6 | 4.9 | 7 | 6 |
| C | 0-1 | 7.7 | 9.2 | 4.7 | 5.6 | 6 |
| | 4-11 | 7 | 8.2 | 4 | 6.9 | 6.3 |

**Appendix-5**: Tolerance Values for macroinvertebrates for application in the Modified Family Biotic Index and other metrics (Barbour *et al*., 1999; Bode *et al*., 1996; Hilsenhoff, 1988; Plafkin *et.al*., 1989)

| **Taxa** | **Taxa tolerance value** | **Taxa** | **Taxa tolerance value** |
|---|---|---|---|
| **Cladocera(water fleas)** | | **Coleoptera (beetles)** | |
| Chydoridae | 8 | Dytiscidae | 5 |
| **Copepoda** | | Lycidae | Not known |
| Cyclopoidae | 8 | **Diptera (trueflies)** | |
| Calanoidae | 8 | Chironomidae | 8 |
| **Ephemeroptera (mayflies)** | | Syphyridae | 10 |
| Ecdyonuridae | 10 | Stratiomyidae | 7 |
| Ephemeridae | 3 | Corethrellidae? | Not known |
| **Odonata (damsel and dragonflies)** | | **Anisoptera** | |
| Coenagridae | 6 | Gampidae | 3 |
| Lestidae | 6 | Coruliidae | 2 |
| **Plecoptera** | | **Gastropod (snails)** | |
| Isoperlidae | 10 | Lymnidae | 7 |
| Teniopterygidae, | 2 | Neritidae | 7 |
| **Hemiptera** | | Ancylidae | 7 |
| Notonectidae | 3 | **Arachinda** | |
| Mesovilidae | 5 | Argyronetidae? | Not known |
| **Trichoptera (caddisflies)** | | **Oligochaeta** | |
| Rhyacophillidae | 1 | Enchytraeidae | 10 |
| Hydroptilidae | 4 | Lumbriculidae | 5 |

**PLATES**

1, Station A

2, Station B

3, Station C