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SCHOOL OF GRADUATE STUDIES
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**STUDIES ON BENTHIC MACROINVERTEBRATES OF LAKE HAYQ,
ETHIOPIA**

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ABSTRACT

Studies on the benthos of Lake Hayq were carried out at three stations from November, 2008 to April, 2009. Bottom samples were collected by using an Ekman grab (225cm²). Determination of total organic matter of littoral and profundal samples was done using an oven and a muffle furnace. Communities of benthic fauna were reported from the lake in relation to the type of bottom substrates and aquatic macrophytes. The benthic macroinvertebrates of the bottom near to the emergent and submerged vegetation and the vegetation-free region of the lake were identified and their distribution in the lake was recorded in relation to the total organic matter and texture of the bottom sediment. Mollusks were found to be the most numerous of all benthic communities (mean number 52306individual/m⁻²). The Dipetra larvae were next with Chironomidae accounting the highest number. Bottom samples taken from near the vegetated regions of the lake were found to have a silt texture and the vegetation-free zone was sandy in texture. The result shows that near vegetated regions of the lake bottom had higher organic matter content than the bottom of the non-vegetated region. The sub-littoral region had highest richness ($d = 2.13$) while, the highest diversity ($H = 1.8$), evenness ($J (e) = 0.209$) and community density (43673.77 indlm²) were in the littoral region. It was observed that most benthic taxa of Lake Hayq were concentrated in the littoral and sub littoral region in association with macrophytes. The littoral and sub littoral zone can therefore be considered as a site of good habitat and breeding ground for macroinvertebrates. Since there is considerable dependence of many commercial fish species on the invertebrate fauna as food resource, there is need to investigate further the biology and ecology of the benthic organisms and weed beds. It is also important that lake management should maintain the integrity and health of the macrophytes of the lake.

Key words: Benthic macroinvertebrate, Ekman grab, Littoral, Macrophytes, Profoundal, Shannon diversity index, Sub-littoral

1. INTRODUCTION

Lakes offer a diverse range of depths, which supports a range of aquatic flora, and this provides a variety of habitat for macroinvertebrates. There tends to be a diverse range of species living in lakes because of the range of habitats that is present within the water body. Lake ecosystems serve as important nursery habitats for many vertebrate species, including fish and invertebrates, many of which feed on benthic macrofauna (Bazairi *et al.*, 2003). Because of such ecological characteristics, there is a lot of literature on benthic ecology (Mistri *et al.*, 2000; Marzano *et al.*, 2003; Sconfiatti *et al.*, 2003).

Aquatic invertebrates constitute a considerable portion of the total invertebrate taxa. The benthic animals of lakes constitute an extremely diverse assemblage, containing representatives of almost every major group of animals living in fresh water (Hutchinson, 1993). Macroinvertebrates inhabiting freshwater habitats are diverse group of organisms, both functionally and taxonomically. A multitude of classes of several phyla are commonly present at one site, making macroinvertebrates a substantial part of local biodiversity in lakes. Within these taxonomic units, species may be classified into very different functional groups according to their food, feeding habit, locomotion, or which life cycle stages occur in the water (Usseglio-Polatera *et al.*, 2000). This high overall diversity may make it difficult to distinguish general patterns. Other difficulties associated with research on macroinvertebrates are their strongly patchy local distributions and the high seasonal species turnover, which makes accurate sampling difficult and time consuming and also, identifying macroinvertebrates is tedious and time consuming and requires some expertise (Diehl and Kornijow, 1998).

Although there have been extensive studies of benthic fauna mainly in the northern hemisphere since the earliest report by Beudant (1816); cited in Allee *et al.*, (1949), there have been far fewer studies on tropical lakes. Most of the tropical research has been carried out in central Africa (e.g. Munro, 1966; McLachlan, 1974). In East Africa, only few studies have attempted to describe the structure and composition of macroinvertebrates in lake ecosystems. For instance, Mothersill *et al.*, (1980) have attempted to describe benthic macroinvertebrates abundance, distribution, intra-phyletic relationships and relationships between taxa and

selected element concentrations in the lake – bottom sediments of northwestern Lake Victoria. Very little information is available on benthic macro-invertebrates of Ethiopia.

Tilahun Kibret and Harrison (1988) studied the community structure of the benthic and weed-bed faunas of Lake Awasa, Ethiopian Rift Valley in relation to substratum type. According to their study, the weed-bed community consists mainly of Cladocera, Ostracods, Ephemeroptera, Heteroptera, chironomids and pulmonate mollusks. Tudorancea and Harrison (1988) described the benthic fauna of two saline riftvalley lakes (Lake Abijata and Lake Shala). The fauna was found to be dense in both lakes, and the composition varied with depth. The benthos consisted mainly of Ostracoda and Chironomidae in Lake Abijata, whereas mainly of Tubificidae, Ostracoda and Chironomidae in Lake Shala. There were very few Nematoda. Predatory invertebrates were absent and many of the dominant species, notably of the Chironomidae, were different from those of non-saline lakes nearby.

These studies were conducted in the central and northern rift valley lakes of Ethiopia. There is no such kind of research in the northern part of Ethiopia. Because of their distance from Addis Ababa, the Ethiopian high mountain lakes have not been much studied until very recently. They are also not much known to the public like the Rift Lakes and crater Lakes of Ethiopia. And yet, scientists used to visit them since the 1930's and discovered that the lakes support a wealth of biological resources. Therefore, recent information is needed to confirm the benthic fauna of the highland lakes in Ethiopia. Lake Hayq is one of the highland lakes situated in Wollo Province, at 11° 15' N lat, 39° 57' E long, and at an altitude of 2,030 m. Lake Hayq is a freshwater lake, located some 450 km from Addis Ababa, the capital. The earliest limnological studies of this lake were carried out by Italian limnologists during the 1930s (Vatova 1940, 1941; Morandini 1941; Zanon 1942; Cannicci and Almagia 1947 all cited in Baxter and Golobitsch, 1970). Some workers who reported on Lake Hayq include Baxter and Golobitsch (1970) and Elizabeth Kebede *et al.* (1992) and Kebede Alemu (1995). All these studies focused on plankton and fish while the benthos and other invertebrates were not considered in detail.

Recent information on benthic macroinvertebrates of Lake Hayq is lacking. Therefore, the study of these organisms in relation with some of the factors affecting their distribution such as

vegetation, OM, and substrate type, will contribute, to some extent, towards management options for the sustainable use of the lake. Therefore, the purpose of this study was to generate information on distribution and abundance of macrobenthic invertebrates and structure of the bottom substrata in Lake Hayq.

2. OBJECTIVES

2.1. General Objective of the Study:

To generate scientific baseline data on distribution and abundance of benthic macroinvertebrates in the littoral, sub-littoral and profundal zones of Lake Hayq.

2.2. Specific Objectives are

1. To determine composition of benthic taxa on different substrate types in Lake Hayq.
2. To assess abundance of benthic macroinvertebrates in Lake Hayq.
3. To determine the relationship between aquatic vegetation and distribution of benthic macroinvertebrates.
4. To assess relationship between factors such as texture, organic matter content and the benthic macroinvertebrates.
5. To assess the importance of benthos in fisheries and ecology of Lake Hayq and contribute towards sustainable management of the lake.

3. LITERATURE REVIEW

3.1. The Benthic Zone

Lake morphometry affects community structure of both macrophytes and macroinvertebrates (Rasmussen, 1988). While the terminology related to physical structure of lakes is large and varies to some extent (Wetzel, 2001), the depth profile of lakes can most simply be divided into the littoral, sub-littoral and profundal and the bottom zone. Generally, the benthic zone of lakes can be divided along the depth profile into the littoral, sub-littoral, profundal zones and the bottom zone. The littoral zone is defined as the near shore lake bottom areas where emerged macrophytes grow. The sub-littoral zone is defined as the bottom area covered by submerged macrophyte or algal vegetation. The lake bottom area extending deeper is called profundal zone, which consists of exposed fine sediment free of vegetation. Often, empty shells of molluscs are accumulated at its lower end (profundal) and thus form a specific sediment type (Williams and Feltmate, 1992). The bottom zone is below the limnetic zone and down slope from the littoral region we find a community usually termed the bottom. This community consists of faunas far from the living primary producers that support the herbivorous of the open water and the bordering community. They are sustained by the detrital material and its associated bacterial decomposers. Included are various sized fragments of dead plants and animals and faeces from the latter (Williams and Feltmate, 1992). In the present study the three benthic zones; the littoral, sub littoral and profundal benthic zone are considered.

The profundal zone is a deep zone of a body of water, such as an ocean or a lake, located below the range of effective light penetration. This is typically below the thermocline, the vertical zone in the water through which temperature drops rapidly. The lack of light in the profundal zone determines the type of biological community that can live in this region, which is distinctly different from the community in the overlying waters. The profundal regions are inhabited by fewer species.

According to McLachlan (1979) the sediment of profundal zone is not always satisfactory habitat in the tropics where high temperature often induces anaerobic condition because of accelerated oxygen demand of bottom dwelling microorganisms. For example, according to Neuman (1976), the red larvae of *Chironomus spp.* are able to utilize low oxygen tension by means of hemoglobin content and resist concentration of hydrogen sulphide. As lakes become more eutrophic, shifts occur in percentage composition of the two dominant groups of benthic animals of the profundal zone of lakes, reduction in the number of chironomids and other benthic animals and a concurrent increase in oligochaete worm.

A commonly observed community structure in littoral zone consists of a rich fauna with high oxygen demand associated with substratum heterogeneity and species diversity and complex competitive interaction. In contrast, in the profundal zone, the substratum is more homogenous and becomes more so as lakes become more productive with resulting low species diversity.

Benthos is important component of the lake ecosystem. The knowledge of factors affecting their distribution and abundance is essential for the sustainable use of the lake as a whole. For example, in the previous paragraphs, it was established that macrophytes are very important factors which affect the distribution of the benthic macroinvertebrates. Knowledge of the relationship between macrophyte and benthos will help to predict the possible outcomes of loss of macrophytes on the lake ecosystem.

3.2. The Benthos

The benthic region incorporates the entire freshwater environment in contact with land, barring the shallow vegetated shore areas. The benthic region is capable of hosting a large number of organisms, as nutrient and mineral rich sediments are available as food source. Functional feeding groups refer to the feeding mode and approximate food type of macroinvertebrates. Macroinvertebrates were categorized into six functional feeding groups and five habit trait groups according to Merritt and Cummins (1996). Functional feeding groups included

shredders, gatherers, filterers, scrapers, herbivore-piercers, and predators, with feeding characteristics as indicated below.

Functional feeding group	Feeding characteristics
Gatherers	Feed on fine particulate detritus on lake bottom
Filterers	Filter suspended material from water column and often build nets for capturing their food, including small organisms
Herbivore-piercers	Feed on living vascular hydrophytes and algae by piercing and sucking cell and tissue fluids
Predators	Attack other animals and engulf whole prey or suck body fluids
Scrapers	Feed on periphytic algae and associated material on mineral and organic substrates
Shredders	Feed on living or decomposing vascular plant tissue, coarse particulate organic material, by chewing large pieces

Habit trait groups include information on the relative mobility and where food is obtained. Habit trait groups included burrowers, climbers, clingers, sprawlers, and swimmers. There is evidence that the feeding roles of freshwater macroinvertebrates may vary with larval stage, as well as temporally and geographically, and many taxa may be rather omnivorous and highly flexible in their feeding habits (Dangles, 2002).

Aquatic benthic macroinvertebrates are an important component in the freshwater biotic community. First, they are involved in the mineralization and recycling of organic matter produced in the open water above or brought in from external sources. Second, they are important second and third links in trophic sequence of aquatic communities (Boyd, 1970).

According to Gophen *et al.* (1983), many benthic insect larvae form are major food source for demersal fish. Some macroinvertebrates species serve as indicators of environmental disturbances. Community composition, distribution, and abundance of benthic macroinvertebrates appear to be regulated by both abiotic and biotic factors.

Abiotic factors such as pH, dissolved oxygen concentration, conductivity, temperature, area, substrate bottom type, and depth and biotic factors such as presence or absence of aquatic vegetation, predation and competition combine to define the limitations experienced by benthic organisms causing variation in community composition (Cochrane *et al.*, 1998). In this study, presence or absence of aquatic vegetation, substrate (bottom) texture and its organic matter content, were studied to assess the composition, distribution, and abundance of benthic macroinvertebrates.

3.3. Factors Affecting Distribution and Abundance of Benthos

3.3.1. Biological Factors

Biological characteristics comprise the flora and fauna living in the lake system and their interactions (Meybeck and Helmer, 1996). Flora in lake include macrophytes, phytoplankton and periphyton, whereas fauna mainly refers to fish and invertebrates. The development of these biological characteristics is governed by a variety of environmental conditions, which determine selection of species as well as the physiological performance of individual organisms.

3.3.1.1. Predation and Competition

Biological factors such as predation and competition combine to define the limitations experienced by benthic organisms causing variation in community composition (Cochrane *et al.*, 1998). Fish predation, microsporidial and unknown viruses, fungi and bacteria are found to be the most important regulators of some aquatic insects like *Chironomus plumosus* (Swanson, 1983). If spatial dependence is to be found, it should be between fish and semisessile prey (Sih,

1984), because more mobile prey types, such as lake mayflies, may continuously shift their distribution in relation to local predation pressure (Tikkanen *et al.*, 1994). Thus, from the fish point of view mayflies and other mobile invertebrates may form ephemeral prey patches, which disperse as soon as the predator enters a patch. A similar action also happens between stonefly predators and their mayfly prey (Peckarsky and Penton, 1985). Trophic studies have shown that macroinvertebrates such as *Diporeia spp.* and chironomids are important forage for various life stages of many fishes (McNickle *et al.*, 2006).

Benthic organisms are also restricted in their distribution by inter and intra specific competitions. Generally, feeding patterns, aerobic requirements, method of locomotion, body shape and presence or absence of competition restrict the majority of benthos to the upper few centimeters regardless of sediment type (Nalepa and Robertson, 1981). Thut (1969) suggest that the depth distribution of two *chironomus spp* may be determined by competition which, play a role in the spatial distribution of benthic animals. The inverse correlation between numbers of Chironomidae and depth may be due to competitive interaction with Oligochaeta.

3.3.1.2. Phytoplankton and Periphyton

According to Jack and Thorp (2000) there is a poor correlation between benthic and phytoplankton productivity, and between phytoplankton standing crop and benthic macroinvertebrate numbers. Algal food supplies had little impact on the benthic community, which was composed predominately of species that fed mostly on organic detritus.

Elevated nutrient concentrations stimulate dense phytoplankton blooms, which in turn reduce light available for submerged aquatic vegetation (SAV) growth. Under physical conditions that result in low light levels, SAV species, like hydrilla may have a competitive advantage over other more desirable SAV species. Changes in the extent of mud sediments in the littoral zone resulting from changes in nutrient loading and runoff influence potential area available for SAV colonization. When nutrient loads are reduced, density of SAV and emergent vegetation increases. Reduced nutrient loads are expected to reduce and cap mud sediments, and increase areas underlain by sand and peat sediments. Presence of dense SAV and emergent vegetation,

sand and peat sediments, and low nutrient loads will provide habitat that will sustain a more diverse population of macroinvertebrate species (RECOVER, 2006).

Primary and secondary producers serve vital roles in the structure and function of aquatic ecosystems. In lakes, primary production by periphyton is a major food source for higher trophic levels (Thorp and Delong, 2002). Aquatic invertebrates that are secondary producers serve as a direct food source for most fish and strongly influence nutrient cycling and primary productivity (Merritt and Cummins, 1996; Wallace *et al.*, 1996). Periphyton growth may in turn influence water chemistry (dissolved oxygen and pH) and fixed carbon production (dissolved organic carbon). This may impact aquatic habitats and wildlife (benthic macro invertebrates, fish, etc.). Grazers can be very efficient in periphytic communities, and most studies report significant decreases of algal biomass due to grazer activity. Several herbivore types (especially gastropods and trichopteran larvae) can dramatically reduce periphytic biomass, often to only a few percent of the ungrazed biomass (Hillebrand *et al.*, 2000). Excessive periphyton growth can occur in rivers and lakes because of high water temperatures from reduced managed flows or excess nutrient production from human development on the landscape, through releases from wastewater treatment facilities, agricultural operations, deforestation, and soil disturbance. Excessive growth is defined here as growth that is not normal for the system and that causes local or downstream negative impacts such as changes in the organic carbon content, nutrient cycling and oxygen demand. Increases in periphyton growth can change and negatively affect benthic macroinvertebrate abundance and species richness and their functional role in the ecosystem as consumers of organic material and prey to larger invertebrates and vertebrates (Suren *et al.*, 2003).

3.3.1.3. The Littoral and Sub littoral Aquatic Vegetation

Aquatic vegetation is an extremely important component of most freshwater systems. Habitat complexity increases with plant biomass and is well correlated with increased abundance and diversity of aquatic invertebrates (Bell and Westoby, 1986). As a result, plant communities often support a large percentage of the total invertebrate biomass in a system. For example, Watkins *et al.* (1983) found that the number of benthic organisms associated with vegetation in

one Florida Lake was triple that in unvegetated areas, and Wiley *et al.*, (1984) found that macrophytes increased invertebrate abundance by as much as 90% in Illinois ponds. Similarly, Iversen *et al.* (1985) reported that 95% of invertebrates in the River Susa, Denmark, were found in vegetation.

McLachlan (1969) noted that an increase in the abundance, biomass, and variety of benthic macroinvertebrates accompanied an increase in aquatic macrophytes. The effect of floating plants and of rooted macrophytes on the fauna and the habitat offered by the plants themselves is important for the presence of the fauna. According to his observation, the presence of aquatic plants result in an increase in the biomass of the mud fauna and in the appearance of several new species.

Numerous authors (e.g. Smyly, 1952; Straskraba, 1964; Watkins *et al.*, 1983) have demonstrated that a preference exists among benthic macroinvertebrates for a number of aquatic plant species. According to Fryer (1959), vegetation at the littoral regions of lakes is of great importance both from biological point of view and from the point of view of fisheries. Weed beds harbour the majority of shore invertebrates. Aquatic macrophytes in the littoral zone can either be grazed to a large extent by fish (Pullin and McConnel, 1982) or their remains are important constituents of detrital food. Macrophytes can also provide protection from predation, mainly from fish (Hanson, 1990) and lakes with fish may contain different invertebrate communities than those without (Hinden *et al.*, 2005). Although fish species and year-classes vary in their ability to forage for macroinvertebrates among plants, submerged plants and reed beds can also act as a cover and source of food for, particularly, small fish (Okun and Mehner, 2005). While macrophyte cover generally supports greater diversity and abundance of invertebrates than open areas or those dominated by gravel and stones (Watkins *et al.*, 1983), and removal of submerged vegetation generally reduces macroinvertebrate taxa richness (Tolonen *et al.*, 2003)

According to Boyd (1970), most macrophytes are good sources of minerals, carbon, proteins, nitrogen, sulphur and potassium. The amino acid, proteins and caloric contents of vascular aquatic plants were studied by Boyd (1970) and his findings indicated that the amino acid composition of proteins in aquatic macrophytes is relatively constant; for example the protein

level in *Typha latifolia* was found to be 4g/100g dry weight, in *Nymphaea odorata* 14.6, in *Ceratophyllum demersum*, 17.1 and the caloric content of the species ranged from 3,906 to 4,315 calories per gram dry weight.

Macrophytes in littoral zone also provide a surface for egg laying, a protective habitat (Macan, 1976) and nutrition to various invertebrates. The absence of mollusks in Lake Tumba, which lacks macrophytes, suggests strongly that they are an important limiting factor in the distribution and abundance of macro-invertebrates in a lake (Brown, 1980). It can be said therefore that vegetation is important in providing food, shelter and habitat to benthic fauna in lake.

However, some aquatic macrophytes may have a negative influence on the distribution of benthic fauna. According to Hobbs and Molina (1983), the presence of the aquatic fern, *Salvina auriculata* is detrimental to the production of *Anopheles albimanus*. In fact, *Salvinia* had a marked inhibitory effect on anopheline breeding. The plant can be an oviposition barrier to gravid *Anopheles albimanus*. McLachlan (1966) reported that samples taken in association with *Salvina auriculata* mats revealed a total depression of all mud fauna under a permanent mat.

Distinct invertebrate communities are often associated with particular sediment types or macrophytes (Tolonen *et al.*, 2001). Macrophyte and invertebrate communities also vary with depth (Brodersen *et al.*, 1998). During exploratory studies on the invertebrates in Lake McIlwaine, Zimbabwe, Munro (1966) collected along transects running from shallow littoral to profundal water, and samples showed that the greatest abundance of all types of invertebrates occurred in 2-5 meters in the upper sub littoral. Below this the levels of abundance declined.

In Lake Awasa, one of the rift valley lakes of Ethiopia, the majority of invertebrate species sampled were found at the weed bed of the lake (Tilahun Kibret, 1985). In this region, chironomids were found to be among the most dominant benthic forms, and other benthic macroinvertebrates, such as Ephemeroptera, Odonata nymphs, Heteroptera, Coleoptera, Gastropoda snails and some others were mainly found from the macrophyte zone.

Benthic fauna of two saline lakes in the Ethiopian Rift Valley, Lakes Abijata and Shalla, were studied by Tudorancea and Harrison, (1988). The two lakes differ markedly from the non-saline lakes nearby in that they lack any form of aquatic macrophytes. Many benthic forms common in nearby freshwater lakes are absent from the saline lakes; these include all Molluscs, Ephemeroptera such as *Caenis spp.* and the predatory tanypodine chironomids, such as *Procladius brevipetiolatus*. Although Lake Shalla has no macrophytes, it supports dense benthic organisms, which was attributed to the lack of predators in the lake (Tudorancea and Harrison, 1988).

3.3.2. Abiotic Factors

3.3.2.1. Bottom Substrate Texture

Among the factors affecting the distribution and abundance of benthic fauna, substrate characteristics have significance. Mclachlan (1969) reported that the physical properties of substrate particles such as particle size, texture and compaction are of considerable importance and may under certain circumstances be the primary factor affecting benthic fauna presence. For instance, he found that coarse sand was avoided by *Nilodorum brevivucca*, which favored fine particle sediments. Meadows and Campbell (1972) found that the larvae of Mayfly *Hexagenia* could only burrow easily in mud. The association of tube builders, including most chironomids, with substrate particles of particular size is usually related to the tube construction requirements of the species. Mclachlan (1976) has shown that a preference for large pit particles for tube constriction was a factor in restriction of *Glyptotendipes paripes*, a chironomid larva, to a small area near exposed shore of Lake Blaxter in England.

Saunders (1958) explored the relationship between sediment characteristics and trophic-functional adaptation of soft bottom communities. He found that filter-feeding organisms are typical of relatively coarse sediments (high-energy environments), whereas deposit feeders are more abundant in sediments with high percentage of fine particles (low energy environments). His observation has been later confirmed by other studies (Gray *et al.*, 1990 ; Bachelet *et al.*,1996) reported the trophic organization of soft bottom benthic communities using the

relative dominance of different feeding guilds. Trophic organization has usually been related to the nature of the substratum and the organic matter content in sediments (Fresi *et al.*, 1983).

3.3.2.2. Organic Matter Content

Organic matter (OM) is a large reservoir of carbon (Lugo and Brown, 1993). It is also an important source of inorganic nutrients for plant production in natural and managed ecosystems. Moreover, OM governs structural stability and cation exchange capacity of bottom sediments either directly, through its chemical structure and surface properties, or indirectly as a source of energy and nutrients for bottom sediment biota (Zech *et al.*, 1997). According to Lenhard *et al.* (1962), humic acids represent the fractions of soil organic matter, which being highly polymerized end products of metabolic degradation, is rather resistant to further biological degradation. The degree of humification, which is proportion of humic acid in the total organic carbon of soil, is a measure of the extent to which the organic matter in the soil has become stabilized.

According to Wetzel (1975) the structural composition of humic compounds is complex and generally bacterial degradation of phenolic linkage is difficult. Particulate and especially dissolved humic compounds, derived from both autochthonous and largely allochthonous sources, tend to have a long residence time in lake and are mineralized only very slowly. Consequently, when most of the organic matter is in this state, the availability of utilized organic carbon may be very long and limits the profundal benthic fauna. Faunal biomass is positively correlated with the amount of organic carbon in the profundal zone; faunal biomass decreased with increasing depth (McLachlan and McLachlan, 1971). Benthic fauna relies on the “fall - out” of organic matter from the water zone above. All organic matter is soon degraded by bacteria and so benthic organisms are, to a large extent, bacterial feeders. Not all organic matter is easily degraded by bacteria.

Organic matter in sediments is often considered as an important food resource for the sediment community (Mirza and Gray, 1981), however, organic matter composition is known to change according to its concentration (Bordovskiy, 1965), with consequences in degradative and

biogeochemical processes that lead to its use by benthic organisms. Benthic fauna are known to affect both rates and spatial distribution of sediment processes by their feeding, burrowing and ventilation activity (Kristensen *et al.*, 1992). The impacts of benthic macrofauna on sediment mineralization rates depend on both the quality and quantity of the organic matter input and major impacts have been found on organic matter mineralization and nutrient regeneration (Kristensen *et al.*, 1992).

According to Aller (1982), suspension-feeders link the pelagic and the benthic environment, while benthic deposit-feeders redistribute organic matter deposited on the sediment surface by sediment modification, and oxidize the sediment by ventilation. Mineralization is often enhanced significantly. In particular, breakdown of refractory organic matter is stimulated, probably because this material has been buried in anoxic sediment layers. When refractory organic matter is exposed to oxygen during bioturbation, decomposition increase (Kristensen *et al.*, 1995). Benthic fauna also affects nutrient cycling in the sediment. According to Graf (1992), suspension feeders affect nutrient recycling and sedimentation or resuspension of organic particulate matter. When the amount of food filtered by suspension feeders exceeds the needs of the individual, pseudofaeces are produced that incorporate the excess particulate organic matter (POM). The formation of these pseudofaeces facilitates the sedimentation of POM and thus increases the overall sedimentation rate. Biodeposits are also a source of food for benthic organisms such as bacteria, meiofauna and macrofauna. Faeces and pseudofaeces contribute to enhance bacterial activity on a day scale basis, while meiofauna and macrofauna populations rather respond on a week and month scale basis respectively (Graf, 1992). Fauna may either feed directly on the organic matter of the biodeposits or on bacteria, which contributes to secondary production in the benthos but also to increase the turnover of nutrients (Graf, 1992). Kautsky and Evans (1987) argued that the role of suspension feeders in energy transfer may be minimal compared with the role they have in carbon and nutrient cycling in lake ecosystems.

Much of the bottom beyond the littoral zone is covered with mud whose particle size and organic content depends on conditions specific to a lake. The larger inhabitants of this zone are mostly worms, larvae of chironomid flies, and molluscs. In addition, there are numerous

smaller animals like nematode worms and ostracods. Chironomids are very characteristic lakeside inhabitants, typical of many lake insects, with larvae living and growing in the water. The larvae are essential food for many fish and ducks. It was found that survival rates of chironomids decreased with decreasing sediment particle size. Gastropod feeding behavior was also affected significantly by sediment particle size, showing increasing severity of impact with decreasing particle size (Tilahun Kibret, 1985).

Unlike temperate regions, the faunal communities seldom become very dense in the profundus of tropical lakes. McLachlan (1974) attributes this to the greater rate of decomposition in the tropics; this prevents organic matter from accumulating below the mud water interface, so that little food is available for burrowing organisms.

3.3.2.3. Dissolved oxygen (DO)

One of the more important factors that determine the depth at which macroinvertebrates may be found in lakes and reservoirs is the dissolved oxygen content of the water (Jonasson, 1978). Dissolved oxygen determines the abundance, diversity and distribution of benthos and other biotic communities of the freshwater ecosystem (Chapman and Kimstach, 1996). DO in natural waters vary with temperature, salinity, turbulence, the photosynthetic activities of algae and plants and the atmospheric pressure. It declines with increment in temperature and salinity. DO in unpolluted waters are usually close to, but less than 10mg/L. High organic and nutrient load reduces DO concentrations as a result of increased decomposer activities. DO concentrations below 5mg/L may adversely affect the functioning and survival of biological communities (Chapman and Kimstach, 1996). Temperature is another important physical factor determining the integrity of freshwater ecosystem. It is directly related to rate of physiological processes. The microbial respiration responsible for self-purification that occurs in water bodies, for instance, depends on temperature. It also determines the dissolution of gases in water bodies. Temperature in turn can be influenced by the amount of shading, climate and elevation (Allan, 1995).

3.3.2.4. Other Abiotic Factors

pH - Different macroinvertebrates respond differently to different pH values. Fiske (1987) found that crustacean, molluska and Ephemeroptera are the most sensitive taxa to low pH. A pH of 6 was found to be critical to gastropods and fingernail clams in lakes of Norway (Okland and Okland, 1982). Coleopteran and Hemiptera increase in number in low pH, due to their physiological resistance to sodium loss and being able to maintain an internal acid to base balance (Fiske, 1987). The different sensitivity of different macroinvertebrates to different levels of physico-chemical parameters made them suitable for water quality assessment works.

Temperature - Temperature affects both the number and kinds of benthic animals in lakes. Tropical lakes support different species than do temperate lakes, although groups such as Chironomids, Chaoborus, and Oligochaetes are abundant over wide latitudinal ranges. Warm lakes tend to support higher benthic macroinvertebrate densities than do cold lakes. It is known that temperature affects most biological processes such as reproduction, metabolism, etc. of an organism. This effect can be seen by the abundance of chironomid larvae in a lake. *Chironomidae* larvae reached a maximum in summer months and a minimum in winter in Lake Hazar, Turkey (Tellioglu, *et al.*, 2008).

Seasonal variation - Seasonal variation which have a bearing on oxygen distribution (Kugler, 1978), change in temperature and salinity (Swanson, 1983) play a role in benthos abundance and distribution. According to Spence (1983), seasonal variations also affect development of aquatic vegetation and patterns of food availability which may in turn affect individual faunal growth and survival. Environmental factors such as a rise and fall of water level may control the distribution, abundance of some species. This is associated with reduction in oxygen content (McLachlan, 1970).

Climatic factors – Climatic factors, especially wind direction and velocity at time of emergence and oviposition, appeared to be very important in determining the distribution and abundance of aquatic insects in lakes (Hilsonhff, 1967). Oviposition and site selection by adults appears to have little importance upon final distribution of larvae with in a lake. Reproduction behaviour can be seriously affected by wind which disrupts swarming and hence

successful mating, this may also mean that eggs are not laid in suitable sites, although Devis (1976) has shown that wind induced water currents can counteract these effects by leading concentration of eggs within a lakes but also act as dispersal agents for first instar larvae, allowing them to find and settle in more favorable conditions.

Water depth – Shallower zones of lake support larger fauna and this is attributed to appropriate conditions such as better oxygenation, suitable substrate or better food supplies (Demeneer *et al.*, 1978 cited by Tilahun Kibret and Harison, 1988). Swanson (1983) pointed out that the restriction of the habitable zone by meromixis (permanent stratification) with accompanying loss of mobile first and second instars also controls faunal presence. Zone of good habitat that is areas of dense macrophyte or benthic algae growth is seen with high production of invertebrates.

Pollution – According to Saraka and Pasivirta (1972), in the more polluted areas of lakes the macrofauna lives deeper in sediment than in clear parts. It is suggested that here redox potential is less favorable near the surface of the sediment than in deeper layers. The influence of human activities such as agriculture can also affect the distribution and abundance of both macro and meiofauna. Aquatic invertebrates are sensitive to subtle changes in water quality and consequently have been extensively examined as indicators of pollution (Larimore, 1974). Gaufin and Tarzwell (1952) concluded that the quantitative and qualitative composition of an aquatic macroinvertebrate population constitutes a valuable index in delineating zones of pollution in fresh water. Benthic macroinvertebrates are particularly suitable as ecological indicators because their habitat preference and relatively low mobility cause them to be directly affected by substances that enter the environment.

Sediment load by runoff – High levels of fine sediment input to lakes by runoff can significantly alter macroinvertebrate assemblages. Wood and Armitage (1997) identified four ways in which fine sediment can affect macroinvertebrate: (1) by altering substrate composition and changing the suitability of the substrate for some taxa (2) by increasing drift as a result of sediment deposition or substrate instability (3) by resulting low oxygen concentrations associated with fine sediment deposits and (4) by affecting feeding activities by reducing the food value of periphyton and reducing the density of prey items. There is a

generally held view that an increase in fine sediment accumulation leads to changes in macroinvertebrate community composition, by favouring some macroinvertebrate at the expense of others (Wood and Armitage, 1997). Many macroinvertebrate taxa belonging to the Ephemeroptera, Plecoptera and Trichoptera orders, which provide the most productive and available food for freshwater fishes, are particularly affected by sedimentation (Waters, 1995).

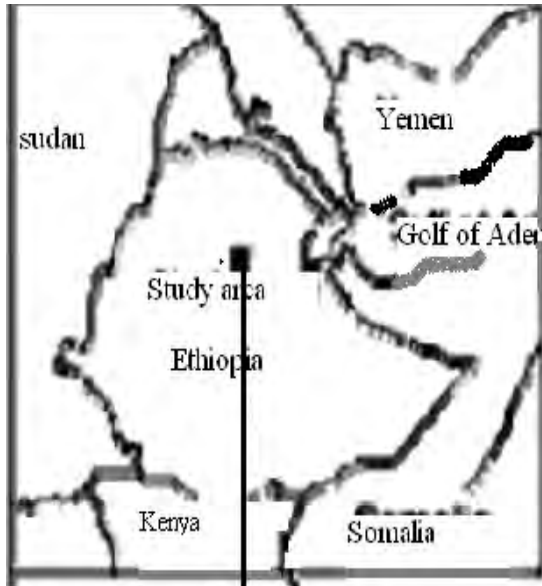
4. DESCRIPTION OF THE STUDY AREA

This study was conducted in Lake Hayq which is one of the highland lakes of Ethiopia located in northern part of Ethiopia, Amhara Regional State, South Wollo Administrative Zone. It is a crater lake with surface area and maximum depth of 22.8 km² and 81 m, respectively (Molla Demilie *et al.*, 2007). The only stream of any size entering the lake is the Anchercah River, which flows to its south east corner. The lake has no visible outlet. Some physico- chemical characteristics of the lake are given in Table 1.

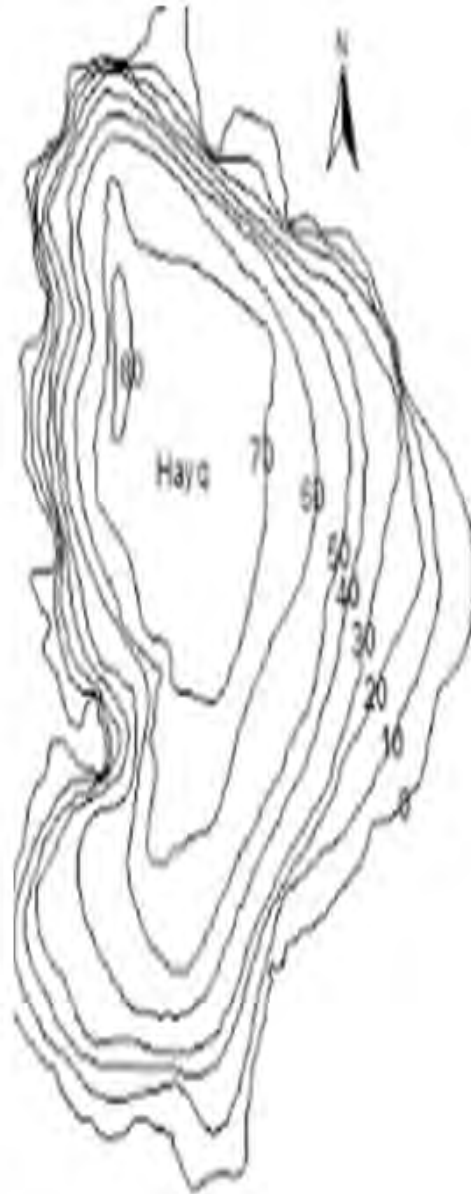
Table1. Morphometry and limnological parameters of Lake Hayq (After Baxter and Golobitsch, 1970; Elizabeth Kebede *et al.*, 1992; Tadesse Fetahi, unpublished data; Esayas Alemayehu, unpublished data)

Parameter	units
Max Length (north-south)	6.7 km
Max width	6.0 m
Perimeter	21.7 km
Mean depth	37.37 m
Volume	0.87 km ³
Average slope of basin	3 ⁰ 45 ¹
Secchi depth	8m
Euphotic depth (Z _{eu})	4.85m
pH	9.1
Conductivity(μscm ⁻¹)	900.6
DO (mg/l)	3.84
DO (%)	53.39
Chlorophyll <i>a</i>	12.5-22.9μgl ⁻¹

a,



c,



b,



Figure 1. a) Location of Lake Hayq in Ethiopia, b) Map and C) Bathymetric profile of Lake Hayq. (from Molla Demlie *et al.*, 2007).

The water level of the lake fluctuates in relation to seasonal variability of rainfall and precipitation and the volume of water increases during the rainy season. The area obtains relatively high rainfall during July and becomes dry during December and January (Fig.2). The water gets colder during January, February, July and November and warmer during April, May, August and September (Kebede Alemu, 1995). Data from the National Meteorological Agency of Ethiopia shows that mean maximum temperature of the area during 2006-2008 was above 24 °C and the mean minimum temperature was below 14 °C (Fig. 3).based on these data, the mean monthly rainfall ranges between 33.7 and 302.5 mm. The area is characterized by a sub-humid tropical climate with average annual rainfall of 1211.4 mm and a mean annual temperature of around 25.9 °C. The average maximum and minimum temperature of the region for the last 20 years, approximately, were 26 and 10.9 °C, respectively.

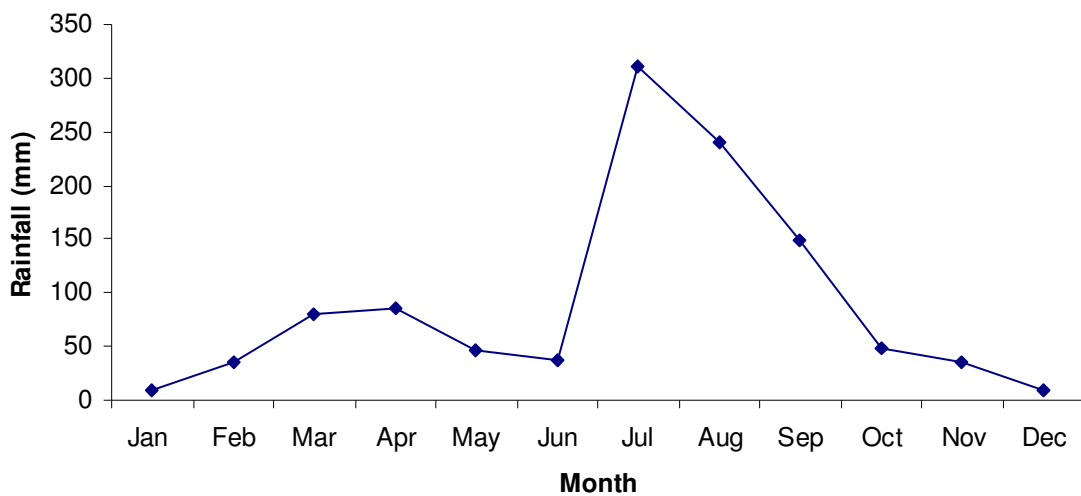


Figure 2. Mean monthly rainfall (mm) of the Lake Hayq area during the years 2006-2008 (Data from the National Metrological Agency of Ethiopia).

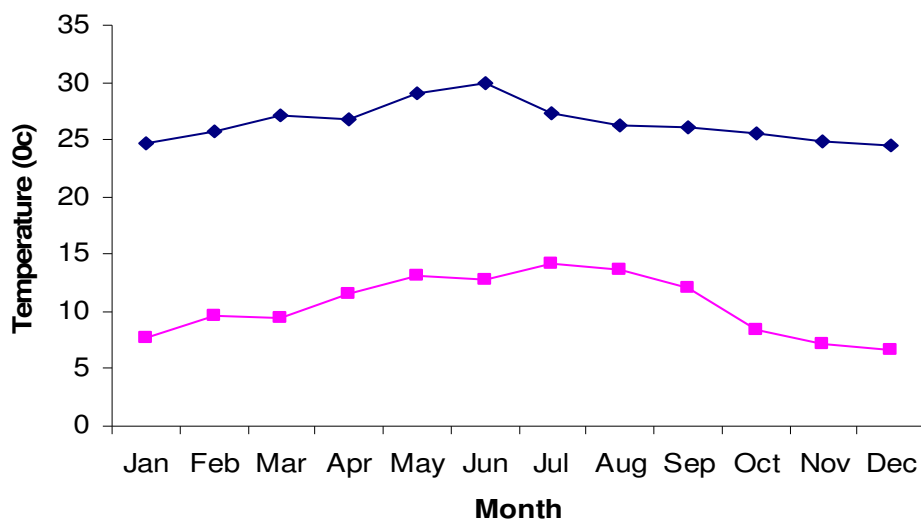


Figure 3. Mean maximum and mean minimum air temperature (°C) of Lake Hayq area during the years 2006-2008 (Data from the National Metrological Agency of Ethiopia).

As reported by Elizabeth Kebede *et al.* (1992), the phytoplankton community is composed of blue green algae, diatoms and others. The dominant species are *Microcystis spp.* which constitutes approximately 90% of the phytoplankton biomass. The fish fauna of Lake Hayq predominantly comprises *Oreochromis niloticus* which was introduced by the Ministry of Agriculture in 1978 (Elizabeth Kebede *et al.*, 1992). The original inhabitant of the lake was catfish, *Clarias gariepinus* (Baxter and Golobitsh, 1970). The other inhabitant of the lake is common carp *Ciprinus caprio* which was introduced into the lake, according to the local people, recently by flooding from a nearby lake, Lake Ardibo. This species has established itself in the lake and now, according to the local people, is increasing in number. *Garra spp.* is also found in the lake. No information is available as to whether the *Garra spp.* is native to the lake or not. A number of factors including overfishing, catchment degradation, encroachment, siltation and water withdrawal threaten the lake (Seyoum Mengistou, 2006). The road construction that is being undertaken currently is a source of concern among stakeholders, as it resulted in the clearing of the surrounding vegetation and restructuring of the slopes surrounding the lake. This situation creates a favorable condition for soil erosion in the rainy season, and the eroded soil would be dumped into the lake.

5. MATERIALS AND METHODS

5.1. Sampling and identification

Bottom sediment samples were taken using an Ekman grab, with an area of 225cm² (15 cm by 15cm), from November 13, 2008 to April 13, 2009 for six months at monthly intervals. Samples were washed in a standard hand net with a mesh size of 0.02 mm.

Three sampling stations were chosen because of their different substrate type and three replicates were taken at each station. The bottom samples were collected from near the region of the lake which was covered by vegetation; emergent vegetation (Graminae) at the littoral region, and submerged vegetation (Potamogetonaceae) at the sub-littoral region and from the region of the lake where no vegetation was found (profundal), at a depth of 1m,3m and 10m, respectively (see figure 1).

The collected samples were then preserved in 5% ethanol and transported in polyethylene plastic bags to Limnology laboratory of Addis Ababa University, Department of Biology. Bigger organisms were sorted out against the white background of enamel dish and then were identified. Smaller ones were analyzed under a dissecting microscope. For detailed identification, a compound microscope was used.

When the samples were large for analysis and counting, sub samplings (Edmondson, 1971), were used for processing and developing data. The sample was poured into a beaker and was thoroughly stirred with a glass rod in an irregular manner to achieve a random distribution of organisms. Stirring was done in such a way as to avoid vortices that serve to concentrate organisms in one portion of the container. While the samples were being stirred, the sub-sample was taken using wide mouthed pipette.

Benthic taxa were identified to the possible lowest taxa. The keys used for identifying the benthic macroinvertebrates include tropical Africa keys (Durand and Leveque, 1981) and temperate keys by (Merritt and Cummins, 1996).

5.2. Sediment organic Matter Content estimation

For the determination of total organic matter in sediment Philip Harris heat oven and an electric Fisher iso muffle furnace were used. Mud sample was dried at 80 °c for 24 hours and the dried samples were burnt in the furnace at 550 °c for 4 hours. Sartorius analytic balance was used for weighing the samples. Total organic matter was calculated from the weight difference of the dried and burnt samples (Tilahun Kibret ,1985) .

$$\text{Organic matter content \%} = \frac{(\text{DW}_{80\text{ }^{\circ}\text{c}} - \text{AshW}_{550\text{ }^{\circ}\text{c}}) * 100}{\text{DW}}$$

Where DW is the dried weight of the mud sample and AshW is the weight of the burnt sample Other physico-chemical parameters were not correlated with the bottom of Lake Hayq because of lack of suitable equipments to take the measures.

5.3. Determination of sediment texture

Sediment samples were taken to the National Soil Testing Center to determine texture. The Bouyoucos method by hydrometer is used to measure the percentage composition of different textures (sand, silt and clay) in the bottom sample taken at each station (Bouyoucos, 1936). 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 to settle out of suspension. Therefore, after 2 hours, it is assumed that only clay-sized particles (<0.002 mm) remain in suspension.

5.4. Ecological Parameters

The abundance of macroinvertebrates in a square meter area was calculated following Jhingran *et al.* (1989) as follows:

$$N = \frac{n}{A}$$

Where,

N= Number of macro-invertebrates in 1 square meter; n= number of macro-invertebrates per sample and A = area of the Ekman grab in square meter (0.0225m²). The relative abundance was calculated by dividing the result from the abundance of macroinvertebrates for each taxa by the total abundance and multiplying it by hundred. The data gathered from monthly samples were pooled in order to determine community structure and the following diversity and evenness indices were applied. Namely:

(1) Diversity (Shannon and Weaver, 1949): $H' = - \sum p_i \ln p_i$

(2) Richness (Margalef, 1958): $d = (S - 1) / \ln N$

(3) Evenness (Pielou, 1966): $J (e) = H' / \ln S$

Where,

$p_i = n_i / N$,

n_i = number of individuals of species i, (in this study individuals of families)

N = the total number of individuals in a sample,

S = total species number. (in this study total family number)

All the Benthic macro invertebrates collected from the lake were identified to family level except Nematodes. Therefore diversity, richness and evenness were done to the number of individuals present in a family.

6. RESULTS

6.1. Sediment Composition and Texture

Particle size analysis showed that sediment sampled from the littoral site (1m depth) was composed of 25% sand, 25 % clay and 50% silt (Table 2). The sediment sampled from the sub-littoral site (3m depth) was 40 % sand, 49% silt and 11% clay, whereas that from the profundal site (10m depth) was 95% sand, 4% silt and 1% clay (Table 2). Thus the texture of the sediment was found to be silt at the two vegetated and shallower sites (littoral and sub-littoral), whereas sand at the non- vegetated and deeper site in the profundal region.

Table 2. Percentage composition of sand, silt and clay in sediment samples taken at the three sites from Lake Hayq

Texture	Site		
	Littoral	Sub-littoral	Profundal
Sand	25	40	95
Silt	50	49	4
Clay	25	11	1
Sediment texture	Silt	Silt	sand

6.2. Organic matter content of sediment

Table 3 shows organic matter content analysis results. The dry weight of organic matter in sediment sampled from the littoral region ranged from 4.2 gm (December) to 6.42 gm (January) with an overall mean of 5.28 gm. Percent organic matter for the same sediment sample was between 48.97% (April) and 74.28% (February) with a mean of about 63%. Dry weight of organic matter in sediment from the sub-littoral region ranged from 3.83 gm

(January) to 5.2 gm (March) with an overall mean of 4.53 gm. Percent organic matter in this sediment ranged from 52.16% (November) to 64.90% (December) and the over all mean was 60.47%. Organic matter content of the sediment from the profundal zone ranged from 1.28 gm (November) to 2.42 gm (March) in dry weight, and from 20.64 % to 38.9% in percentage. The overall mean values were 1.98 gm and 30.72%. Mean percent organic matter content of the sediment from the profundal region was about half of the mean value for sediment from the littoral or the sub-littoral regions. However, the mean percent organic matter of sediment from the littoral and sub-littoral regions was more or less similar (Table 3).

Table 3. Monthly dry weight (gm) and percentage (in brackets) of organic matter in sediment samples taken at the littoral, sub-littoral and profundal sites from Lake Hayq.

Month	Site		
	Littoral	Sub-littoral	Profundal
November(2008)	4.569(63.08%)	3.924(52.16%)	1.2835(20.64%)
December(2008)	4.196(67.24%)	4.8227(64.9%)	2.093(35.44%)
January(2009)	6.418(71.26%)	3.828(59.35%)	2.144(36.68%)
February(2009)	5.4878(74.28%)	4.6776(64.64%)	2.272(37.8%)
March(2009)	5.2449(51.24%)	5.2(59.04%)	2.42(38.9%)
April(2009)	5.7714(48.97%)	4.74(62.72%)	1.68(30.72%)
Grand Mean	5.28(62.70%)	4.53(60.47%)	1.98(30.72%)

6.3. Benthic macroinvertebrates

a) Identified taxa

A systematic list of benthic macroinvertebrate identified is presented in Table 4. Sediment from Lake Hayq contained insects (larvae), nematodes, oligochaetes and molluscs. No live mollusks were collected. Insects were represented by Ephemeroptera, Diptera, Trichoptera and Coleoptera the Diptera belonged to four families, the remaining insects (Trichoptera and Coleoptera) were represented by one family each. The families Naididae, Lumbriculidae and Tubificidae were the oligochaetes identified in sediment samples. The molluscs also belonged to four families: Ceratophyllidae, Planorbidae, Thiaridae and Lymnaeidae. Nematodes were not identified to lower taxa due to lack of expertise.

Thus, the benthic macroinvertebrate fauna of Lake Hayq was composed of nematodes and a total of 15 families belonging to Insecta, Oligochaeta and Mollusca. These contained a total of at least 14 genera and/or species, of these, two genera (*Ablabesmyia* and *Cryptochironomus*) belonged to Chironomidae (Diptera), one genus to Philopotamidae (Trichoptera), and three genera and/or species (*Nais*, *Limbriculus varigatus*, and *Limnodrilus hoffmeisteri*) belonged to different families of Oligochaeta. The remaining genera and/or species belonged to the different families of molluscs identified in this study. Thus, in terms of number of families the Diptera, whereas in terms of number of genera and/or species the Mollusca, were the most diversified benthic macroinvertebrates in Lake Hayq.

Table 4. Systematic list of benthic macroinvertebrates in sediment samples taken at three sites (Littoral, Sub-littoral and Profundal) from Lake Hayq. The presence and absence of organisms at a site is indicated by '+' and '-' signs respectively.

Taxa	Site		
	Littoral	Sub-littoral	Profundal
Insecta			
Ephemeroptera			
Caenidae	-	+	-
Leptophlebiidae	-	+	-
Diptera			
Chironomidae			+
<i>Ablabesmyia</i>	+	+	
<i>Cryptochironomus</i>	+	+	
Chaoboridae	+	+	-
Tipulidae	+	+	-
Tabanidae	+	+	-
Trichoptera			
Philopotamidae	+	+	-
<i>Chimarra sp.</i>	+	+	-
<i>others</i>	+	+	-
Coleoptera			
Elmidae	+	+	-
Nematoda	+	+	-
Oligochaeta			
Naididae			
<i>Nais</i>	+	+	-
Lumbriculidae			
<i>Limbriculus varigatus</i>	+	+	-
Tubificidae			
<i>Limnodrilus hoffmeisteri</i>	+	+	+
Mollusca (shells)			
Ceratophyllidae			
<i>Ceratophallus natalensis</i>	+	+	+
<i>Ceratophallus sp.</i>	+	+	+
Planorbidae			
<i>Bulinus jousseamei</i>	+	+	+
<i>Bulinus sp.</i>	+	+	+

(Cont'd next page)

Table 4(cont'd)

Thiaridae			
<i>Melanoides tuberculata</i>	+	+	+
<i>Cleopatra africana</i>	+	+	+
Lymnaeidae			
<i>Lymnaea natalensis</i>	-	+	+

In addition, there was some site-based difference in benthic macroinvertebrate fauna in Lake Hayq. Thus, all of the above mentioned macroinvertebrate taxa were found in sediment sampled from the sub-littoral region. All the taxa in sediment from the sub-littoral site, except Ephemeroptera and Lymnaeidae (Mollusca), were also encountered in sediment from the littoral site. Thus, the littoral and the sub-littoral samples had a more or less similar benthic macroinvertebrate fauna. On the other hand, sediment from the profundal site contained only the two chironomid genera (*Ablabesmyia* and *Cryptochironomus*) and the molluscs, which were also present in sediment from the other regions.

b) Abundance and density

Benthic macroinvertebrates in the littoral region was the second most abundant of the benthic macroinvertebrates in the three sampling sites having a total of 39348 individuals/m² (Table 5). Mollusks (shells) in this region, accounted for the larger number in abundance than the other families in this region having an abundance of 36999 individuals/m². Next to Mollusks, insect larvae were more abundant in this littoral region, having an abundance of 1860 individuals/m². Insect larvae were dominated by Diptera. Diptera larvae had an abundance of (1637 individuals/m²). Chironomids were found to be more abundant than the other Dipteras, having an abundance of 1037 individual/m². Next to insect larvae, Oligochaetas were more abundant (400 individual/m²). Nematode accounted for the least abundant family, having an abundance of 89 individual/m².

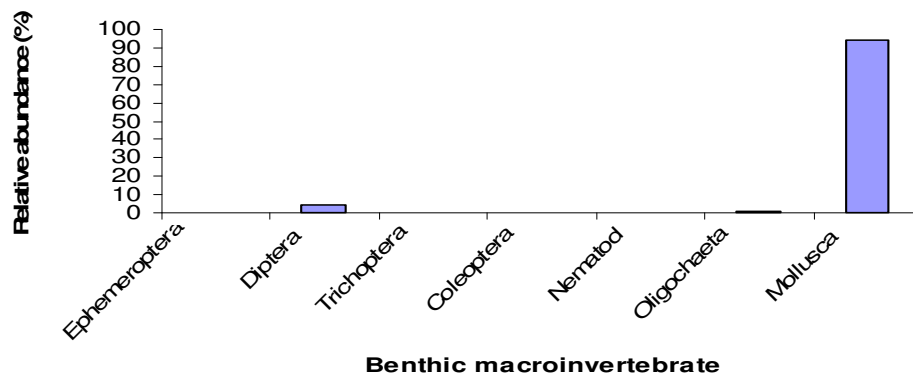
Table 5. Abundance (total individual/m², n=18) of benthic macroinvertebrate in sediment sampled from littoral, sub littoral and profundal zones of lake Hayq. Each number is rounded to the next whole number.

Taxa	Sampling site		
	Littoral	Sub-littoral	Profundal
Insecta	1860	1303	44
Ephemeroptera	0	88	0
Caenidae	0	44	0
Leptophlebiidae	0	44	0
Diptera	1637	1022	44
Chironomidae	1037	622	44
<i>Ablabesmyia sp.</i>	511	222	0
<i>Cryptochironomus sp.</i>	526	400	0
Chaoboridae	22	44	0
Tipulidae	467	289	0
Tabanidae	111	67	0
Trichoptera	67	60	0
Philopotamidae	67	60	0
<i>Chimarra sp.</i>	22	30	0
Others	44	30	0
Coleoptera	156	133	0
Elmidae	156	133	0
Nematoda	89	74	0
Oligochaeta	400	267	22
Naididae	89	67	0
Lumbriculidae	133	111	0
<i>Lumbriculus variegatus</i>	133	111	0
Tubificidae	178	89	22
<i>Limnodrilus hoffmeisteri</i>	178	89	22
Mollusca (shells)	36999	33711	43607
Ceratophyllidae	15052	13015	13089
<i>Ceratophallus sp.</i>	15052	13015	13089
Planorbidae	4444	3548	22437
<i>Bulinus sp</i>	4444	3548	22437
Thiaridae	17503	17059	8037
<i>Melanoides tuberculata</i>	16511	14837	7015
<i>Cleopatra africana</i>	992	2222	1022
Lymnaeidae	0	89	44
<i>Lymnaea natalensis</i>	0	89	44
Total	39348	35355	43673

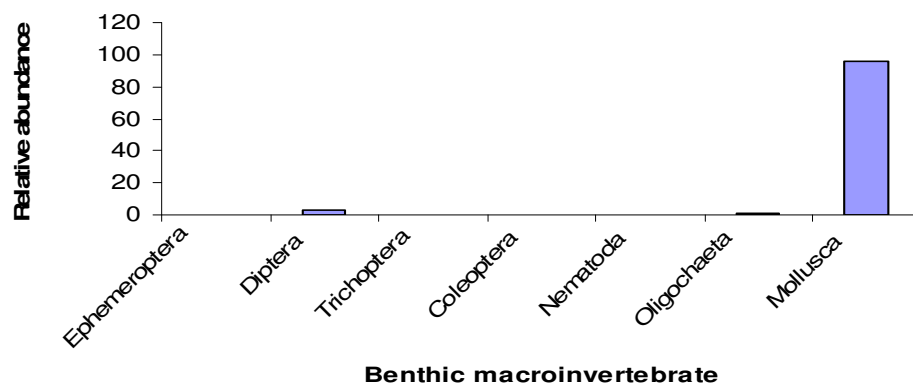
Benthic macro invertebrates in the sub-littoral region were the least abundant of the benthic macroinvertebrates of the three sampling regions, having an abundance of 35355individual/m². As in the littoral region mollusks (shells) were the most abundant benthic macro invertebrate, having an abundance of 33711individual/m². Next to mollusks, insects (larvae) are more abundant in this region. Insect in this region had an abundance of 1303individual/m². Diptera were more abundant than the other insects. Chironomids were found to be more abundant than other Diptera in this region. Chironomids had an abundance of 622individual/m². Next to insects the Oligochaetas were more abundant, having an abundance of 267individual/m². In this region Ephemeroptera and Nematoda were the least abundant benthic macroinvertebrates, having an abundance of 88individual/m² and 74individual/m² respectively. When compared with the littoral region, all the families found in the sub-littoral region were less abundant than similar families found in the littoral region.

The abundance of benthic macroinvertebrates at the profundal region was 43673individual/m². As in the littoral and sub-littoral region mollusks (shells) were the dominant benthic macroinvertebrates in this region. Mollusks (shells) at this region had an abundance of 43607individual/m². Thus this region had more abundance of mollusks than the littoral and sub-littoral regions. On the other hand, Insects and Oligochaets accounted for the least abundance in this region, having an abundance of 44individual/m² and 22individual/m², respectively. The difference in the abundance of the benthic macroinvertebrate found in the three sampling regions can be clearly seen in Figure 4 and Figure 5, which shows the densities and relative abundance of each benthic macroinvertebrate in diagram.

a) Littoral



b) Sub-littoral



c) Profundal

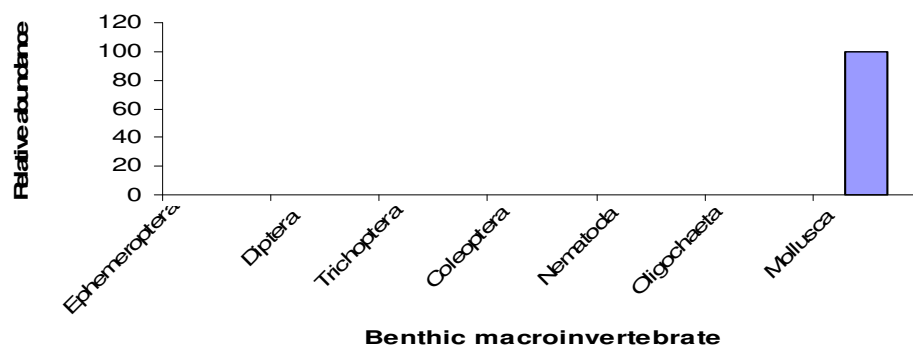
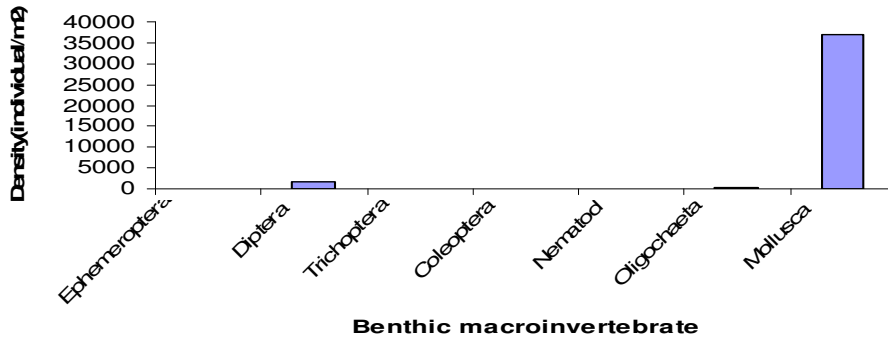
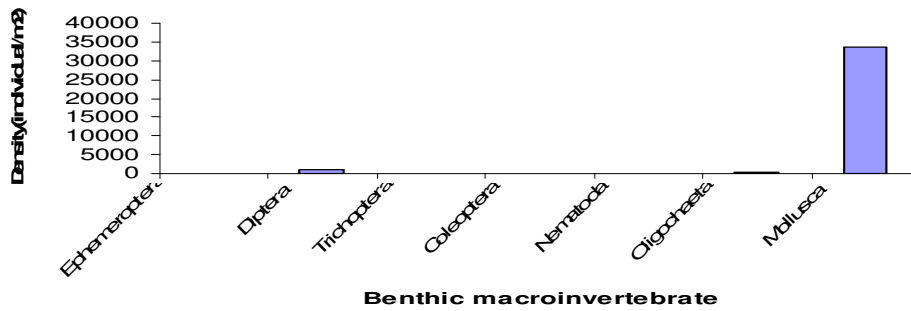


Figure 4. Relative abundance (%) of benthic macroinvertebrate at a) littoral b) sub-littoral and c) profundal zones of Lake Hayq.

a) Littoral



b) Sub-littoral



c) Profundal

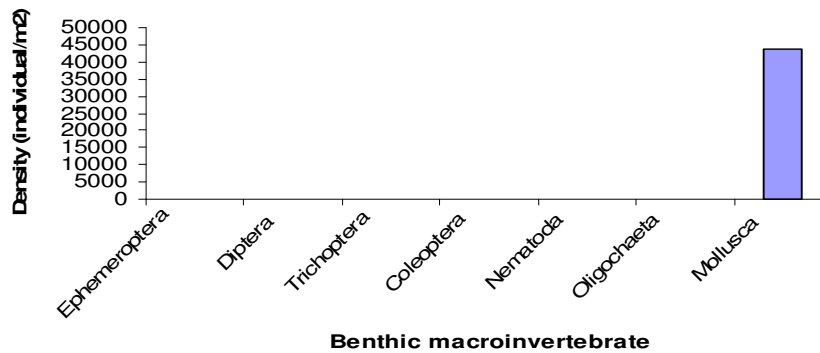


Figure 5. Density (individual/m²) of benthic macroinvertebrates at a) littoral b) sub-littoral and c) profundal zones of Lake Hayq

c) Indices of diversity, Evenness and Richness

The estimated indices of diversity, evenness and richness, based on macroinvertebrate families, are presented in Table 6. The littoral region had the largest value of Shannon diversity index ($H=1.8$) followed by the sub-littoral ($H=1.4$) and the profundal ($H=1.1$) regions. Evenness value was also largest for the littoral region ($J(e)=0.73$) and lowest for the profundal ($J(e)=0.42$). On the other hand, richness index value was largest for the sub-littoral region ($d=1.34$). Richness index value was 1.04 and 0.47 for the littoral and the profundal regions, respectively.

Table 6. Shannon diversity index, evenness and richness done for the three sampling sites of Lake Hayq: the littoral, sub-littoral and profundal regions. Each number is rounded to the second decimal digits.

Index	Site		
	Littoral	Sub-littoral	Profundal
Shannon diversity (H)	1.80	1.40	1.10
Evenness (J (e))	0.73	0.52	0.42
Richness (d)	1.04	1.34	0.47

7. DISCUSSION

Higher richness and diversity of macro invertebrates were found in the bottom of vegetated (littoral and sub-littoral) than non-vegetated (profundal) habitat of Lake Hayq. In accordance with many studies (Connolly, 1997; Diehl and Kornijow, 1998; Mistri *et al.*, 2000; Hedgel and Kriwoken, 2001) higher richness and diversity of macroinvertebrates are found in the littoral and sub-littoral regions of a lake, where aquatic vegetations are found. The presence of aquatic vegetation in Lake Hayq had an effect on the diversity and richness of macroinvertebrates. For most lakes the number of benthic taxa is highest in the littoral zone and decreases as the depth increases (Salmoiraghi *et al.*, 2001). In Lake Hayq too, distribution of the benthic macro invertebrates was mainly determined by the presence of aquatic vegetation which was also determined by the depth. The station with the highest richness was in the sub littoral region, the highest diversity and evenness was reported in the littoral region.

Tilahun Kibret and Harrison (1988) has also shown that littoral regions adjacent to the macrophyte zone of Lake Awasa, which extend out to the 4 m , are rich in benthic macroinvertebrate, while no benthic animals were present in the mud of the profundal region where no vegetation occur. The fauna of aquatic vegetation habitat has been studied In manmade Lake Kariba (McLachlan, 1969) and as well as in natural situations such as the Amazon basin and Lake Chad in North Africa (Dejoux and Saint-Jean, 1972 cited in McLachlan, 1976), as in temperate waters, the bottom of aquatic vegetation habitat clearly supports rich benthic community .

Plants release oxygen as the waste product of photosynthesis. Recent studies have shown that areas with concentrated plant growth have significantly higher levels of dissolved oxygen than areas without aquatic plants (Findlay, 2006). Tadese Fetahi's unpublished data supports this in Lake Hayq. Higher dissolved oxygen levels are able to support the more sensitive macroinvertebrates as well as the low-oxygen tolerant ones producing a wider array of species. This was the reason for the bottom samples taken near the two vegetated regions in Lake Hayq having more sensitive macroinvertebrates such as, Trichoptera and Ephemeroptera, as well as

the low-oxygen tolerant ones such as, chironomids and oligochaetes, producing a wider array of species, while the non -vegetated region was reported to have only few of the low-oxygen tolerant taxa. Although Eggleton (1931) noted that the profundal region supported fewer numbers and variety of benthic macro invertebrates than littoral habitats, in this study the profundal region supported larger numbers and less variety of benthic macroinvertebrates than the littoral and sub littoral region. According to Findlay, (2006) the profundal zone is distinguished by a few hardly forms that tolerate low levels of oxygen. A typical macroscopic assemblage would include bright red midge larvae of the Genus *Chironomus*; a few species of oligochaete worms, *Limnodrilus* being a common genus and mollusks. Marshall (1978) observed a similar situation in Lake Mcllwaine (Zimbabwe) where most of the benthos was restricted to 8m. Below 8m depth no animals were found but individuals of mollusks were present. In Lake Hayq at the profundal region few chironomid and oligochaetes, and mollusks (shells) were present.

Although the submerged vegetation region was deeper than the emergent region, this difference seems not to be determinant for benthic fauna, since light always reached the bottom at both areas and both areas were covered with aquatic vegetation. The sediments were also similar at both areas in texture and organic matter content. Therefore, the presence of different macrophyte types is the most acceptable reason to expect two different benthic communities at the littoral and sub littoral regions. According to Scheffer *et al.*, (1984), the penetrability of vegetation and physical and chemical conditions within the plant stands may be important factors affecting the distribution of macroinvertebrates in their habitats.

For instance, compared to the bottom of emergent vegetation (Graminae), the number of chironomids supported by the bottom of submerged vegetation (Potamogetonaceae) was smaller. Ephemeroptera species were also only found under the submerged vegetation type, although number of most insect larvae and mollusk increased at the bottom of emergent vegetation in the lake. Differences in benthic macroinvertebrate density among plants of varying architecture have been reported for several macrophyte taxa (Cattaneo and Kalff, 1980). According to Scheffer *et al.*, (1984), vegetation pattern is probably the main factor in

determining the spatial distribution of macroinvertebrates. In lakes, different vegetation types differed considerably in total faunal density.

It was clearly seen that most benthic taxa of Lake Hayq were mostly concentrated in littoral region in association with the presence of macrophytes. The bottom of Macrophyte zone can therefore be considered as a site of good habitat for macroinvertebrates in Lake Hayq. This increase in the diversity of macroinvertebrate benthos was shown by an increase in the Shannon diversity index when compared to the vegetation free region.

Almost continuous presence of vegetation should lead to a reduced grain size of sediment and to an increased content of organic matter (Nichols and Allen, 1981). This is the case in Lake Hayq too, where plants are present; the soil particle size is reduced and has an increased amount of organic matter of bottom substrata, which in turn enhanced the richness of macroinvertebrate benthos. Distribution patterns of organic matter were influenced by factors such as particle sizes, and depth. Such factors were also used to determine habitat types. Similar distribution patterns of organic matter in response to these physical variables have been reported by others (Lancaster and Hildrew, 1993). Macroinvertebrate communities also exhibited distinct faunal patterns among habitat types. Research, which has examined invertebrate communities with respect to a broader range of particle sizes, supports the findings of this study that invertebrate communities differ with substratum type (Wallace *et al.*, 1992). These findings suggest that substrata of visually distinguishable size fractions do influence the functional composition of invertebrate communities.

According to McLachlan (1969), the physical properties of substrate particles themselves are of considerable importance and may under certain circumstances be the primary factor affecting substrate selection of benthic macroinvertebrates. In Lake Hayq, the profundal region where there is no vegetation coverage had a bottom of larger particle sized substrate and the less organic matter content compared to the vegetated region of the lake. This region supported only six of the families reported. The overriding influence of substrate composition in the distribution and abundance of benthic fauna (McLachlan and McLachlan, 1971) can explain the significantly lower benthic densities in the profundal region, the macrophyte-free zone.

According to Reice and Wohlenberg (1993), sediment organic matter tends to increase as the clay content increases. This increase depends on two mechanisms. First, bonds between surface of clay particles and organic matter slow down the decomposition process. Second, sediments with higher clay content increases the potential for aggregate formation. Macroaggregates physically protect the organic matter molecules from further mineralization caused by microbial attack. In Lake Hayq, at the littoral and sub-littoral regions the bottom texture was found to be silt, with increased clay content compared to the bottom of the non vegetated region. Organic matter content was also found to be higher at the bottom of the two vegetated regions (littoral and sub-littoral) than in the non vegetated region (profundal).

The dominant benthic macroinvertebrate were the mollusks (shells) at all the sampling regions in Lake Hayq. Mollusks prevail in the littoral, sub-littoral region and profundal, in this study. Mollusks (shells) were present in large number at the bottom of all the three sites. Similarly Lake Chivero was dominated by *Molluscs* (especially *Melanooides tuberculoid*).

Next to mollusk shells, insect larvae were dominant. The dominant insect larvae were found to be larva of Diptera. The presence of macrophytes and decomposition of accumulated plant materials provided the right conditions for higher density of Diptera in the vegetated regions of the lake (littoral and sub-littoral regions) than the vegetation free region (profundal region). The dominating Diptera larvae were found to be chironomid larvae. Association between chironomid larvae, organic matter and particle size have been demonstrated by (Wene, 1940 other workers; Cummins and Lauf, 1969). Chironomidae were also found in all the three regions, although in a very few numbers in the profundal region. Chironomidae can tolerate large gradient of depth and oxygen concentration, thus they are able to live in littoral, sub-littoral and profundal zones. Chironomidae have particular adaptation: some species (Chironominae sub-family) have haemoglobin in the hemolymph and can survive low oxygen concentration in profundal habitats.

According to a concurrently conducted study (Esayas Alemayehu, unpublished data), benthic invertebrates were found in the diet of *Clarias gariepinus* of Lake Hayq mainly the insect larvae such as Chironomids and Ephemeroptera. In a study done on Lake Langeno it was also noted that insect food items of *C.gariepinus* were composed of Trichoptera larvae, Ephemeroptera nymphs, Diptera larvae such as chironomidae, Coleopteran larvae and also Nematode (Leul Teku, 2001). Chironomide larvae were also noted in the stomach of *C.gariepinus* in a study done on Lake Awasa (Elias Dadebo, 2000) and in the stomach of *O. niloticus* in Lake Awasa (Tudorancea and Harrison, 1988). In Lake Chamo, nematodes and Chironomid larva were noted in the stomach of *O. niloticus* (Yirgaw Teferi *et al.*, 2000). The cyprinid large Labeobarbus (*Labeobarbus intermedius*) feeds on insects such as chironomidae larvae, ephemeroptera nymphs, Trichoptera larvae and pupae, Coleoptera and mollusks such as *Bulinus sp.* (Demeke Admassu and Elias Dadebo, 1997). A study done in Lake Nabugabo, Uganda also shows that Chironomids dominated food for the haplochromines, percentage occurrence exceeding 50%. As for the Tilapiines, percentage occurrence for chironomids exceeded 50% which indicated some kind of food specialization or preference on this prey species (Kateyo, 2006).

Fisheries biologists who have worked on the food and feeding habits of various species of fish of Lake Victoria have found that benthic fauna play a very significant role in the diet of many fish (Ogutu-Ohwayo, 1984). Not only do they contribute to the diet of many fish but also form an important trophic link in the food-web of the lake's ecosystem and enhance the release of nutrients required for primary production through their activities. The organisms convert organic material into animal protein for use by other organisms at higher trophic levels including fish. They therefore contribute to the recycling of energy flow in the aquatic ecosystem

There was no sign of degradation noticed. From the result and the discussion it is clear most of the different benthic taxa were found near at bottom of the two vegetated regions of the lake and it was also observed that fish population increases around the vegetated region of the lake (personal observation).

Therefore the three major factors, presence of macrophytes, bottom texture and organic matter content have an effect on the distribution and abundance of the benthic macroinvertebrates in Lake Hayq.

8. CONCLUSION AND RECOMMENDATIONS

In this study, the distribution of benthic macroinvertebrates of Lake Hayq was studied. The lake harbours most of its benthic macroinvertebrate taxa under the bottom of the littoral zone adjacent to the macrophytes. The macrophytes appeared to be the most important sites of interactions among the benthos. Mollusks dominated at all sampling regions, although all the mollusks present were shells. Insect larvae were found in larger numbers than the other benthic macroinvertebrates. The profundal zone, however, contained fewer taxa, which are oxygen tolerant benthic macroinvertebrates, such as chironomids and mollusks. Therefore, vegetation coverage, organic matter content and silt bottom texture and dissolved oxygen influence the distribution of benthic macroinvertebrates in Lake Hayq.

The road construction that is being undertaken currently is a source of concern among stakeholders, as it resulted in the clearing of the surrounding vegetation and restructuring of the slopes surrounding the lake. This situation creates a favorable condition for soil erosion in the rainy season and the washed soil is dumped directly into the lake. High levels of sediment input to lakes by runoff can significantly alter macroinvertebrate assemblages. Therefore, all who are associated with the road construction project must do their part to control erosion. Maintenance of erosion and sediment control should be done.

The littoral zone, with macrophytes, which fringe the lake, not only provide habitats to the many invertebrate taxa and young fish but also serve as important food source for the different fauna of the lake. It has also been apparent that most of the benthic invertebrates of the lake are important sources of food for fish. Therefore it is important that care should be taken to maintain the integrity and health of the macrophytes, otherwise the lake may probably be unproductive in macrobenthos and fish fauna. In view of the above changes and the considerable dependence of many commercial fish species on the invertebrate fauna as a resource base, there is need to investigate further the biology and ecology of the benthic organisms and weed beds. This will be useful for the lake ecosystem as well as fisheries management.

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DECLARATION

I, the undersigned, hereby declare that this thesis is my original work and that all sources of material used for the thesis have been duly acknowledged.

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