THE EFFECTS OF NUTRIENT INPUT ON ALGAL PERIPHYTON IN NYANGORES TRIBUTARY OF THE MARA RIVER IN KENYA

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DECLARATION AND RECOMMENDATION

DECLARATION

This thesis is my original work and has not been submitted or presented for examination in any other institution.

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RECOMMENDATION

This thesis has been submitted for examination with our recommendation and approval as University Supervisors.

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DEDICATION

To my late parents George and Debora Mbao, grandmother Nyahero (the late), brother George (the late) for your spirits made me press on.

To my brothers Ben, Douglas, Frank, Tony and Mark; sisters Emily, Teresa and Rhodah for their inspiration and tireless moral support throughout my study period.

To my compassionate Mercy, Esther and Cloe for enduring long period of my absence.

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ABSTRACT

The potential of using algal component of periphyton as indicator of nutrient pollution was investigated in Nyangores tributary of Mara River in Kenya. The river suffers impacts of agricultural pollutants from the farms in its upper course and inorganic, organic pollutants as well as solid wastes deposited into the lower course of the stream as a result of anthropogenic activities. These pollutants are a major threat to the health of this river, affecting quality of the water and the growth of biota. Algal periphyton were sampled twice a month from February 2012 to May 2012, at eight sampling sites to determine the effects of these pollutants on their growth, through biomass and community composition. The algal periphyton community structure and primary productivity determined and related to the physical and chemical variables of the stream such as water temperature, electrical conductivity, discharge, total suspended solids, pH, dissolved oxygen, concentration of the nutrients including ammonium, nitrate, nitrite, soluble reactive phosphorus and total phosphorous. The data collected was statistically analyzed using JMP version 10, a product of SAS^{inc}:- Statistical Analysis System developed in 1989 by John Sall: Statistical Discovery^{TM} to determine if there were significant differences between the periphyton community structures with temporal nutrient variation as well as comparison of different physical and chemical parameters between sampling sites in different months. The results showed that nutrients had a strong positive correlation with periphyton biomass and productivity. Nutrients concentrations significantly increased downstream and correlated with discharge. In total nine algal taxa were found, with forested site having the least number of species. The periphyton community structure was dominated by the diatoms (67%). Algal periphyton species diversity was lower at forested site (H=1.77) compared to farmland (H=2.14). Algal periphyton productivity was low with the highest value of 2.85×10^{-6} mgCm^{-2}day^{-1} observed at forested site upstream and the lowest was in May at the rangeland site 1.77×10^{-6} mgCm^{-2}day^{-1}. Algal periphyton growth and community structure was influenced by nutrients washed into the river especially during peak discharge in April and May.

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DO	Dissolved oxygen
NH_4-N	Ammonium nitrogen
NO_2-N	Nitrite nitrogen
NO_3-N	Nitrate nitrogen
SRP	Soluble reactive phosphorus
TP	Total Phosphorus
TSS	Total Suspended Solids
MMNR	Masaai Mara National Reserve
MRB	Mara River Basin

CHAPTER ONE

INTRODUCTION

1.1 Background information

Growth and community composition of aquatic biota in any ecosystem is dependent on both the physical and chemical characteristics of the system together with the interaction between these variables and the general biota found (Oliveira *et al.*, 2004). In a lotic system, there are normally found a group of primary producers called the Periphyton. This are important component of biofilm and include algae, bacteria as well as macroinvertebrate. The algal periphyton refers to the photosynthetic organisms attached to sediment, rock, and on each other at the bottom and edges of water-bodies as well as on sessile plants. These organisms form an important component of aquatic biota, providing food for invertebrates, as well as fish (Finlay *et al.*, 2002). Their growth is influenced by various factors that include light (Kiffney and Bull, 2000) nutrients (Cascallar *et al.* 2003) and temperature (Francoeur *et al.*, 1999). These factors may limit growth when inadequately supplied various water bodies. Therefore, periphyton can deplete water bodies of nutrients, if there are no additional inputs. Periphyton community structure can also vary in relation to the nutrient concentrations (Marinelarena and Di Giorgi, 2001). Excessive periphyton growth can occur in rivers and lakes as a result of high nutrient input from human development, through release of wastewater from treatment facilities, agricultural activities, and deforestation. They can also serve as ecological indicator of these changes in these variables (Bojsen and Jacobsen, 2003). Changes in their community structure and biomass may act as clue to changes in environmental conditions making them appropriate indicators of ecological condition.

The Mara river has its source in the Mau Forest in Kenya at an altitude of about 3000 m above sea level and flows across different landscapes through Masai Mara National Reserve (MMNR) in Kenya and Serengeti National Park (SNP) in Tanzania before finally draining into Lake Victoria at Musoma Bay. The Nyangores and Amala sub-basins form the upstream part of the Mara River Basin (MRB) and are its main sources of water throughout the year (Mango *et al.*, 2011). The basin vegetation types range from forested areas to savanna grassland in which large numbers of animals, mainly the large herbivorous mammals such as the wildebeests migrate within the Serengeti-Masai Mara Ecosystems (SMME) a phenomenon documented by UNESCO as the seventh wonder of the world (Gereta *et al*., 2002). This river has a high ecological profile as the only source of surface water throughout the year for these two renowned conservation areas, the Masai Mara National Reserve and Serengeti National Park (Gereta *et al*., 2002). The biodiversity of the MRB is however threatened by habitat modification and fragmentation, reduction in vegetation cover through over-exploitation of forest resources, and competition from invasive species, mainly as a consequence of human impacts (Gereta *et al*., 2002; Mati *et al*., 2005). Such changes in the basin are bound to promote soil erosion in the catchment area thereby increasing nutrient inputs into the river which may eventually stimulate periphyton growth in the river. increased nutrient input into water bodies, termed 'eutrophication', results in a high periphyton biomass production which when it eventually dies and decompose, make the water devoid of oxygen through microbial activities thereby affecting the survival of aquatic organisms. Sources of nutrients flowing into rivers may include point sources such as sewage disposal from hotels or residential areas and non-point sources from agricultural lands through run-offs. Such negative characteristics caused by nutrients influx may be observed in the Mara River since it runs through a large forested area, agricultural land, small urban centres and pastoral lands, with varied anthropogenic activities causing eutrophication in some sections of the river (Mango *et al*., 2011).

Anthropogenic threats to rivers have been reviewed by a number of authors (Dudgeon *et al*. 2006, Strayer 2006). Such threats include human settlements along riparian zone of rivers, water abstraction for irrigation and farming along the river course. According to FAO bulletin (2008), human activities that harm river ecosystems showed an upward trend throughout the 20th century even though some aspects of pollution have ameliorated in recent years. Other pressures, including species invasions and climate change impacts, are expected to worsen in future. The impact of climate variations in East African Rivers and their catchment such as Mara River (UNEP, 2008) is reflected by the observed low and sometimes high water levels during certain months of the year. According to Mati *et al.*, (2005) the influx of cash crop farming within the Mau catchment has enhanced the use of both organic and inorganic fertilizers that subsequently get washed into the Mara River. This entry of nutrients into the river is thought to have triggered periodic blooms of periphyton (Cascallar *et al.* 2003). The de-gazettement and subsequent excision of some part of forest in the Mau escarpment coupled with irrigated farming extracting water from the Mara River upstream has had a negative ecological impact to the ecosystem.

Currently, WWW has increased its effort in urging the communities living near the Mara River to save the river by planting more trees. Other organizations that are promoting conservation of the river include Lake Victoria Basis Commission (LVBC), Mara Flows, Ministry of Environment and Natural Resource, Kenya Wildlife Service and community forest associations among others. They help the local communities in establishing tree nurseries for growing trees for riparian restoration. They also plant trees along Mara River to prevent siltation into the river (WWF 2006)

Local communities in the Mara River Basin are increasingly facing water shortages as well as poor water quality due to these environmental degradations upstream. This hinders activities focused on alleviating poverty and improving health care, food security, economic development and conservation of natural resources. The main competing interests for water resources include the numerous small-scale irrigation farms (presently water permits have been issued to pump water for the Mara up to a maximum rate of 0.1-45 $m^3 s^{-1}$ to irrigate 520 hectares of mechanized farms in Loita Plains (J. Anakeya, pers. com) on the Kenyan side of the Masai Mara and Serengeti wildlife protected areas. In addition, there is small-scale farmers and pastoralists on both sides of the basin, the mining industry in Tanzania, small-scale fishing activities, urban and rural domestic water supplies. Additional environmental problems include the loss of forest cover in the upper catchments and along rivers, pollution threats from urban settlements, and deforestation (WWF 2006).

The water quality assessment provides information on the present characteristics of the river and considers the influences of discharge fluctuations on the presence and concentration of compounds that could be harmful to humans and aquatic life. Water quality is defined as the physical, chemical, biological and aesthetic qualities of water that determine its fitness for human use as well as for maintenance of a healthy ecosystem (Mokaya *et al.*, 2004). The influence of discharge levels were considered in relation to the physico-chemical parameters and how they affect the growth and composition of the algal periphyton. In order to evaluate the overall water quality in the basin and identify potential threats, a water quality survey in relation to the growth of the algal periphyton was undertaken at different sites based on dominant land use along the Nyangores tributary of the Mara River between February to May, 2012.

1.2 Statement of the problem

Improper agricultural practices upstream, deforestation of the river catchment, the cutting of riparian vegetation and the discharge of wastes from the settlements into the river have resulted in increased nutrients load into the Mara River from its tributaries such as the Nyangores. Land use changes in the upper Mara basin from previous dominance of forested area to agricultural landscape and poor farming practices result into excess nutrients such as phosphorus and nitrogen being washed into the river thereby enhancing eutrophic conditions that results into massive growth of algal periphyton. Algal periphyton development is important in water quality monitoring since they are sensitive to changes in environmental conditions usually due to anthropogenic activities. The extent to which such human activities have impacted on the Nyangores' river water quality, focusing on nutrient loading and consequently to the periphyton community structure, diversity, biomass and its contribution to primary production of the river was the main subject of this study. The findings from this study may be used in creating awareness to the population living along the river on the need to safeguard the river, it will also contribute to MRB data base on conservation of Mara river and may be used to formulate policy briefs for policy makers.

1.3 Objectives

1.3.1 General objective

The main objective of this study was to investigate the effect of changes in nutrient input and physicochemical parameters on the algal periphyton community structure and productivity along the Nyangores tributary of the Mara River.

1.3.2 Specific objectives

To determine the:

- i. temporal and spatial variations in nutrient concentrations in the Nyangores tributary.
- ii. algal periphyton community structure in the Nyangores tributary and how it changes with variations in nutrients levels.
- iii. algal periphyton primary production in the Nyangores tributary of the Mara River.

1.4 Hypotheses

- i. There is no variation in temporal nutrient concentrations along the Nyangores tributary.
- ii. Algal periphyton community structure and biomass in the Nyangores tributary is not influenced by changes in nutrient concentrations along the river channel.
- iii. Algal periphyton primary production in Nyangores tributary does not vary overtime along the river channel.

1.5 Justification

The Mara River is ecologically, economically and socially important to the communities living within the Mara basin. Changes in water quality in the river affects the growth of periphyton and its composition. For ecological functioning and ecosystem support, there is need to establish the dynamics of the physical and chemical variables particularly nutrients in this river and how they influence the biota in the river with special reference to periphyton. The algal periphyton has been used as water quality indicator in many rivers in the world but not in the Mara River. Therefore there is need to adopt the use of algal periphyton as a biomonitoring tool in this important river. The knowledge obtained of using changes in algal periphyton as a bioindicator for water quality will advance knowledge which may be applied in the proper and integrated management of this important water body for its sustainable use. The results from this study will contribute to the ecological knowledge database that would inform policy decisions and ecosystem management in the Mara basin.

1.6 Limitation and scope of the study

This study did not address other factors which would influence development of periphyton in river systems but only focused on nutrients and physico-chemical parameters in Nyangores tributary of the Mara River. Data on nutrients was used to show the effects of catchment land use on the river's algal periphyton community. Although rainfall pattern in the catchment was considered as having a direct influence on the water flow in the rivers emanating from these catchments, its measurement, micro-nutrients, heavy metals and heterotrophic nanoflagellates were not included in this study. In addition the study was carried out within a limited timeframe within an MSc research work plan.

CHAPTER TWO

LITERATURE REVIEW

2.1 Water quality in rivers

Rivers and streams are terms used to describe natural and man-made bodies of flowing water. Rivers are larger than streams and empty into large water bodies such as oceans and lakes. River and stream systems consist of numerous tributaries joined together to form a main channel (Leinster and White 2006). The tributaries are identified by their stream order, denoted by its position in the system. There are three main types of streams; Ephemeral streams which regularly exist for short periods of time, usually during a rainy period, and may have defined channels even when they are dry, the intermittent streams which flow at different times of the year, or seasonally, when there is enough water from either rainfall, springs, or other surface sources such as melting snow or even discharge from a wastewater treatment facility, and the perennial streams which flow year-round (DCR. 2007). The conditions of river and stream water vary greatly with season, weather changes, and solar intensity. Water characteristics affected by these outside influences include conductivity, temperature, turbidity, and chemical composition such as dissolved nutrient concentrations (Winter and Duthie, 1998). Interactions between air and water give rise to changes in surface agitation and gas exchange of oxygen and carbon-dioxide (Walsh *et al* 2004). Land-water interactions relate to erosion, nutrient influxes, and channel alteration. The constant stirring of the channel bottom by underwater currents also affect erosion, nutrient flow, and turbidity.

The benthic habitat of lotic environments is found in the streambed, which is comprised of various physical and organic materials where erosion and/or deposition are a continuous characteristic. Erosion and deposition may occur simultaneously and alternately at different locations in the same streambed. Where channels are exceptionally deep and taper slowly to meet the relatively flattened streambed, habitats may form on the slopes of the channel (Havens *et al* 1996). These habitats are referred to as littoral habitats. Shallow channels may dry up periodically in accordance with weather changes. The streambed is then exposed to open air and may take on the characteristics of a wetland.

Silt and organic materials settle and accumulate in the streambed of slowly flowing rivers and streams. These materials decay and become the primary food resource for the invertebrates inhabiting the streambed. Productivity in this habitat depends upon the breakdown of these organic materials by microorganisms into inorganic nutrients. Not all organic materials are used by bottom dwelling organisms; a substantial amount becomes part of the streambed in the form of peat (James *et al.*, 2000).

In faster moving rivers and streams, organic materials do not accumulate easily. Primary production occurs in a different type of habitat found in the riffle regions where there are shoals and rocky regions for organisms to adhere to. Therefore, plants that can attach themselves into the streambed dominate these regions (James *et al.*, 2000). These plants are mostly attached algae known as periphyton, often microscopic and filamentous, that can cover rocks and debris that have settled into the streambed.

Although the filamentous algae seems well anchored, strong currents can easily slough it off from the streambed and carry it downstream where it becomes a food resource for low level consumers. One factor that greatly influences the productivity of a river or stream is the width of the channel; a direct relationship exists between stream width and richness of bottom organisms (Rosemond *et al.*, 2000). Bottom dwelling organisms are very important to the ecosystem as they provide food for other, larger benthic animals through consuming detritus (Jansson *et al.*, 2000).

Rivers are recipients of the effects of watershed activities such as crop farming and hence their characteristics reflect the conditions prevailing in the catchment areas. High population densities, coupled with multiple industrial and agricultural activities expose most hydrological basins close to large urban centers to environmental degradation, especially pollution through disposal of both domestic and industrial wastes (Mokaya *et al.*, 2004). Such changes in land-use and runoff patterns may increase nutrient loads discharged into rivers (Gergel *et al.*, 2002). The impact of such discharge depend on a combination of factors, such as the volume and load of effluents and discharge level of the receiving water body. Approaches to water quality assessment are divided in two main categories: based on physical and chemical methods, and the other considering biological communities evaluation (Lobo *et al.*, 2004). Physical and chemical monitoring reflect only instantaneous measurements, restraining the knowledge of water conditions to the moment when the measurements were performed. Biotic parameters on the other hand provide information on environmental changes, because community development integrates a period of time reflecting conditions that might not be any more present at the time of sampling (Borduqui *et al.*, 2008). Long-term ecological impacts are important since conservation of aquatic life is the ultimate goal in a well-functioning ecosystem. The adverse effects of chemical variables become even more serious when the object of study is a lotic system where water currents promote continuous mixing of the water at each site. Therefore both biological and chemical studies are important for holistic assessment of the quality of running waters (Lobo *et al.*, 2004). Different biological communities have been used for the evaluation of water quality. Among which, periphyton growth and community structure are recognized as potential indicators of pollution and eutrophication of aquatic ecosystems (Biggs , 2000).

2.2 Nutrients loading into rivers

Stream networks are important not only for delivery of nutrients to downstream systems, but they are also sites of significant nutrient removal through uptake by autotrophic organisms in the streams (Peterson 1996). The magnitude and efficiency of this removal is influenced by biotic, physical structures and processes occurring in the rivers all of which vary at multiple spatial and temporal scales. Little is known about how spatial and temporal variation in flow, channel geometry, and biotic activity influence nutrient dynamics (Ndiritu *et al.*, 2003). There are several sources of nutrients in rivers such as the natural sources, but many stem from human activities (Kelly and Whitton 1998). Nutrients sources may reach the river either from point or/ and non-point or diffuse sources.

2.2.1 Non-point sources of nutrients

Non-point sources of nutrients are external diffuse sources such as land runoff and atmospheric deposition as well as sub-surface flow or groundwater seepage. Nutrients are present naturally in rivers, being washed from the catchment through runoffs (Mathooko *et al*., 2009). Soil and rocks are the primary natural sources of phosphorus, usually in the form of phosphates. Natural sources of nitrogen include organic debris from riparian vegetation. Such debri decompose and release nutrients. The Mau Forest is an important source of organic debris in form of falling leaves and twigs washed into the river from the forest and other riparian vegetation (UNEP 2008).

The use of fertilizers is considered as a major source of both phosphorus and nitrogen that flow into aquatic systems. Such fertilizer not used by the plants finally end up being washed into the streams through runoffs from farmlands. This problem has been confounded by the high demand for farm lands due to high demand for food to feed the high population increase in Kenya. This has a direct link to the quality of the aquatic environment due to increase in chemical pollution by fertilizers, pesticides, as well as pollution from animal wastes (Novotny, 1999). Generally there has been a trend of increase in fertilizer use worldwide (Zehnder *et al*., 2003). The annual worldwide nitrogen fertilizer application which stood at 87 million tonnes in 2000 may increase to 135 million tonnes in the year 2020, while phosphorus input may increase from the 2000 estimate of 34.3 million tonnes to 47.6 million tonnes in 2020 (Zehnder *et al*., 2003). In Kenya, fertilizer application amounted to 500,000 metric tonnes in 2008 and this figure is expected to double by 2015 (Ariga *et al*., 2008). Other than farm lands, run-off from the riparian settlements and grazed pastures drain into rivers and are also potential sources of nitrogen, ammonia and phosphorus (Vlok and Engelbrecht, 2000). Depending on the composition of the soil in an area, coupled with the amount of rainfall, nutrients not utilized by crops either run off from the land into lakes and rivers, or build up in the soil, or seep down into groundwater. Groundwater seepage into a river can therefore be a source of nutrients (Vlok and Engelbrecht, 2000). The use of manure in farmlands is another source of nutrient input in lakes and rivers. If manure from rangeland, is not properly managed, it can be washed into rivers through runoffs or from direct deposition by animals in the water, particularly during watering visits (Koning *et al*., 2000).

2.2.2 Point-sources of nutrients

Refers to effluents that originate from a particular source such as municipality sewage effluents and industrial wastes that are released into the water bodies. Wastewater (or sewage) treatment plants are point sources of nutrients mainly nitrogen and phosphorus species which are discharged directly into rivers (Puckett, 1994). In the past, household detergents were the main source of high loads of phosphorus into the treatment plants, which then were discharged with the effluent. However, at present wastes from households are rich in both nitrogen and phosphorus species. While in the developed world, laws restricting the phosphorus content of detergents have produced markedly reduced phosphate levels (Puckett, 1994), in developing countries river water is used directly for washing vehicles, clothes and bathing which result into high phosphorus content in the water (Mathooko *et al*., 2009) thus enriching these water bodies with nutrients.

2.3 Periphyton communities in rivers

Periphyton community refers to the attached plants, algae, fungi bacteria, small invertebrates and other microorganisms growing on rocks, logs of wood and other hard surfaces in water bodies. Periphyton play an important role in influencing water quality in a river by absorbing nutrients during growth and releasing them as they die off. In addition, algal periphyton contribute to decrease in nutrient levels in a river system through bio-uptake from the water column (Borchardt, 1996). It has been documented that their ability to use nutrients from the sediment may deplete nutrients in the water column (Stevenson, 1996). Other than nutrients concentration in the water and sediments, other factors influencing periphyton growth, biomass and productivity include high frequency of flooding, light climate availability in the water and substrate stability especially where there is increased flooding frequency (Biggs, 1996; Biggs *et al.*, 1998; Peterson, 1996; Müllner and Schagerl, 2003; Velasco *et al.*, 2003). During flooding, periphyton may be dislodged from their substrate by the current or damaged by particles contained in the current. Deficiencies in nutrient and light limitation are known to reduce periphyton abundance (Denicola and McIntire, 1990; Stevenson and Peterson 1991; Wellnitz *et al.*, 1996). Further, grazing pressure by invertebrates also limits periphyton abundance (Kjeldsen, 1996; Steinman, 1996).

The algal periphyton communities in rivers include diatoms (Bacillariophyta), species of green algae (Chlorophyta) and Cyanobacteria among others. Some have complex three-diamensional morphologies made up of frustules and microfrustules (Passy, 2002). Algal periphyton community are known to require different environmental conditions for their growth which therefore make them potential indicators of environmental conditions prevailing in a habitat. Some species of periphytic algae such as *Fragilaria ulna* (diatom) usually thrive in polluted habitats (Biggs *et al.*, 1998) hence used as water quality indicators. The use of periphyton as water quality indicator has a long history (Richardson and Host 1994). Anton and Abdullah (1982) recorded a decrease in periphytic algal species in the downstream stations due to heavy siltation in the Langat River, Selangor in Malaysia. Periphyton composition changed in response to the addition of both NO_3-N and PO_4-P in the Ulu Langat River, Selangor in Malaysia (Anton and Abdullah 1982), and Cyanophyta was dominant when nitrogen was the limiting factor. Mansor and Lidun (1992) reported the presence of several species of filamentous algae and a high nutrient concentration in the Pulau Pinang Rivers. Maznah and Mansor (1999) studied diatom diversity and its relation to river pollution and concluded that diversity values could be related to changes in water quality as influenced by nutrients concentrations. In a related study, Wan Maznah and Mansor (2000) reported the occurrence of various diatom species in clean, polluted and brackish waters. The diatoms were collected from artificial substrates (glass slides) along the Pinang River Basin, Pulau Pinang and its tributaries. The differences in the specific sensitivity of certain diatom species to pollution have been used as a means of assessing the degree of pollution in the Pinang River system, but the diversity of diatoms could not be directly related to water quality (Wan Maznah and Mansor 2000).

Increased pollution due to urban development and land use types in catchment areas impacts on periphyton species diversity. This change in biodiversity has been attributed to many factors including changes in water chemistry, turbidity, channelization of rivers and water abstraction (Passy 2002). High nutrients concentration and lower turbidity levels as well as adequate light in water favors periphyton growth. This has been observed in many urban rivers, where periphyton does not appear to be nutrient limited (Passy 2002). However, the shifting nature of bed sediments in rivers, frequent bed disturbance through erosion and deposition and high turbidity may limit periphyton accumulation and lower their primary production in the water. Several periphyton species are also known to be sensitive to presence of metals in water, while invertebrate grazers regulate diatoms abundance (Feminella and Hawkins, 1995; Kohler and Wiley, 1997; Olguin *et al.*, 2000).

2.4 The relationship between nutrient concentration and periphyton community

In-stream nutrient concentrations have been correlated to human activity in many river basins (Gergel *et al.*, 2002). As ambient nutrient concentrations increase, with favorable light and temperature conditions, the algal periphyton growth increases and certain species dominates the community structure and other species may disappear (Morgan *et al.*, 2006). Periphyton biomass accumulation and the development of nuisance algae have been shown to be strongly associated with nutrient enrichment in streams (Lohman *et al.*, 1992). Many studies have linked ambient nutrient concentrations to periphyton biomass (Tank and Dodds, 2003; Stevenson *et al.*, 2008) and shown that both N and P can co-limit their growth (Biggs, 2000).

Many studies have documented effects of nutrients on periphyton (Biggs, 2000). In addition, such data obtained from many regional studies predict effects of specific nutrient on periphyton community within a specific river (Biggs, 2000).

Measuring the variables that govern periphyton biomass requires consideration of ambient conditions such as temperature, pH, dissolved oxygen, electrical conductivity, discharge, light availability and nutrient concentrations (Hill and Knight, 1988). These variables have been measured and correlated individually to algal periphyton growth (Stevenson *et al.*, 2008) hence considered essential for growth and development of algal periphyton. In order to understand these relationships, it is necessary to measure levels of nutrient availability in situ across a gradient of selected conditions while accounting for variations in biomass accumulation due to secondary factors such as light availability, temperature, discharge, substrate, anthropogenic impacts, and losses due to scour and grazers (Hill and Fanta, 2008).

Periphyton biomass on both rocks and plant surfaces varies greatly during colonization after storm disturbances (Passy 2002). Areas with patchy growths of periphyton make sampling difficult to assess their biomass both within reaches and riffles. The phyla and growth forms of periphyton (i.e., functional group) vary seasonally from diatoms to filamentous green and blue-green algae (Borduqui *et al.*, 2008) depending on the changing environmental conditions.

2.5 Periphyton primary production in rivers

Periphyton in streams and rivers are an important component of aquatic ecosystems, providing food for invertebrates, as well as fish (Finlay *et al.*, 2002). This energy provision occurs through the accumulation of their biomass through the process of their primary production (Rosemond *et al.*, 2000). Anthropogenic disturbance affecting rivers such as increased soil erosion and nutrient leaching, do alter their algal periphyton productivity (Rosemond *et al.*, 2000). The importance of algal periphyton as a high turnover production base for river food webs and main source of fixed carbon for many fish taxa is well documented (Shineni and Ramadhani, 2005).

Lack of nutrients often limits algal periphyton production in streams (Chaloner *et al.*, 2002). The specific nutrient limiting algal periphton production often varies and several studies have applied nitrate and phosphorus experimentally in stream systems to determine which nutrient is most limiting to algal growth (Mosisch *et al.*, 2001). Within the Pacific Northwest, both Gregory (1980) and Triska *et al.*, (1983) found that nitrogen was more limiting to algal periphyton production in streams than phosphorus, yet Stockner and Shortreed (1978) reported that algal periphyton responded most dramatically to phosphorus additions in a stream in British Columbia. Based on measurement of algal periphyton primary production by determining oxygen, several studies have reported increased primary production in association with the release of nutrients from decomposing organic matter from debri washed into the river (Chaloner *et al.*, 2002). In contrast Rand *et al.*, (1992) found that organic matter did not increase stream primary productivity or algal periphyton growth. The disparity in these findings may reflect the operation of other factors that override or co-limit algal periphyton production. Light is one such factor that frequently limits algal periphyton production, particularly in low-order forested streams (Vannote *et al.*, 1980). The importance of light in affecting algal periphyton production and taxonomic structure of periphyton assemblages has been confirmed in a large number of studies that have examined periphyton response to removal of riparian vegetation (Quinn *et al.*, 1997). Algal periphyton production were found to be higher in open stream sections of the Pacific Northwest as opposed to those shaded by riparian canopy (Hetrick *et al.*, 1998). Moreover considerable evidence supports a conclusion that light may override nutrients in limiting algal periphyton productivity in shaded streams (Hill *et al.*, 2001). Gregory (1980) and Triska *et al.*, (1983), for example, found that nitrogen enrichment of streams in northern California had little effect on increasing algal periphyton primary productivity unless the canopy was removed to increase light. In contrast, Stockner and Shortreed

(1983) found that algal periphyton production was similar before and after logging and that phosphorus, not light, was the major factor limiting primary productivity in a coastal rainforest stream in British Columbia. Apart from major nutrients and light, other factors that may also affect algal periphyton productivity include micronutrients, temperature, discharge, substrate and grazing (Triska *et al.*, 1983).

2.6 The Mara River climatic condition

The main source of surface water during periods of drought and dry season in the Mara River Basin is the Mara River and its tributaries such as Amala and Nyangores. However, in the recent years the flow of the water in the river and its tributaries have become erratic. This erratic flow is more conspicuous in the tributaries and the upper reaches of the river. Therefore, the uncertainties about the future impacts of climate change is perceived as compounding the challenges posed by unpredicted flow. According to Mango et al., (2011), the climate projections for the Mara River Basin can be described as modest with seasonally variable increase in precipitation (5-10%). According to WQBAR (2007) report, the very low flow levels in March due to reduced precipitation have been marked by sharp declines in dissolved oxygen levels specifically and subsequent fish deaths in the river. This seasonal variability in precipitation is generally accompanied by temperature increase ranging between 22.5–33.5 °C. Studies from simulated runoff responses to changes in climatic conditions within the basin have shown that the basin is highly vulnerable to dry season under low (−3 %) precipitation (Hilborn, 1995). Moreover, there is the occurrence of bimodal rainfall in the basin with mean values ranging from 1400mm per year in the upper catchment to 600 mm per year in the lowlands (Mango et al., 2011). Notably, the digital image analysis of the vegetation cover between 1973 to 2000 have shown that the shrub-land and forests in the basin have generally reduced by 34% and 32% respectively. In addition, the savannah, grassland and wetlands have reduced by 26%, 45% and 47% respectively. On the contrary, agricultural land and open forests have increased by over 95% (Lamprey and Reid 2004). The vegetation in the catchment of this river is being cleared by the riparian communities to pave way for growth of both cash crops such as tea and food crops such as maize among others.

There are limited studies that have been conducted in Mara River as a whole and Nyangores tributary in particular. These studies have focused majorly on ecological integrity and monitoring of physico-chemical variables. Amongst them is the study by Masese and McClain (2012) who found out that the growth in human population and apparent loss of forest cover are directly associated with the deteriorating water quality in the Nyangores tributary. In addition, the current nutrient levels as well as suspended solids in the Nyangores tributary are high particularly when the forest cover increasingly become cleared. Ultimately, these changes are expected to affect all other biota of the river apart from fish. Among the biota that are likely to be first to be affected by the changing water quality are the sessile algal community/ periphyton which are major primary producers in rivers (Hill *et al*., 2001). They rely on the physical and chemical parameters for growth and development.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study site

The study was carried out in Nyangores stream, a tributary of Mara River, located in the eastern arm of the Great Rift Valley in Kenya. The river lies at an altitude ranging between 2105 and 1855 m.a.s.l and a geographical location of 00°71.33'S, 035°51.23'E and 00°86.54'S, 035° 27.99'E (Figure. 1).

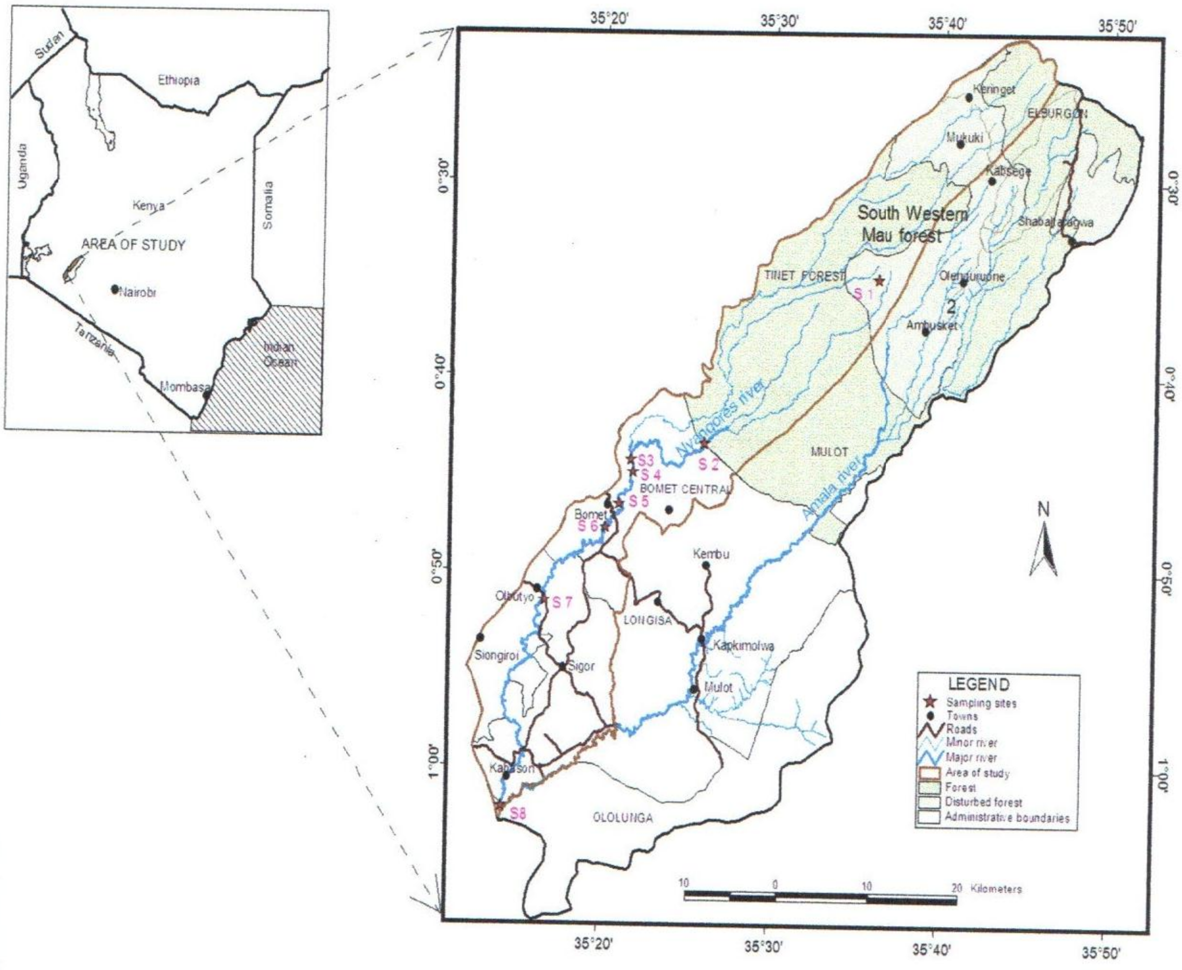

Figure 1: Mara River Basin showing Nyangores tributary (modified from Mati *et al.*, 2005)

Sampling sites were chosen based on the economic activities, especially land use practices within the area. (Table 1) as well as ecological zonation. The highest site in terms of altitude among the eight chosen stations was Kiptagich at 2105 metres above sea level with the lowest being at the confluence of Nyangores and Amala at 1855 metres above sea level. The sampling stations were clustered together and adopted as forested, farmland and rangeland.

Table 1: Location and dominant land use in the sampling sites along the Nyangores tributary

Stations	Local name	Location	Major land use/ human activities	Clustered sites
S1	Kiptagich	S 00°71.33', E 035°51.23'	Forested	Forested
S2	Ainapng'etunyek	S 00°72.47', E 035° 43.78'	Forested, Tea plantation	Forested
S3	Silibwet	S 00°73.78', E 035° 36.23'	Tea growing, Maize cultivation	Farmland
S4	Tenwek	S 00°74.64', E 035° 36.49'	Sewage disposal, Maize cultivation	Farmland
S5	Raiya	S 00°77.52', E 035° 35.14'	Washing, fishing, Maize cultivation	Farmland
S6	Bomet prison	S 00°79.58', E 035° 33.85'	Dumping of solid wastes, cattle grazing	Rangeland
S7	Olbutyo	S 00°85.66', E 035° 27.99'	Pastoralism, washing of vehicles	Rangeland
S8	Confluence of Nyangores and Amala	S 00°86.54', E 035° 27.99'	Pastoralism, charcoal burning	Rangeland

3.2 Sampling protocol

3.2.1 Collection of samples

Prior to the field sampling, a reconnaissance survey was carried out in order to select the sampling stations based on the dominant land use such as forest, crop farming and pastoralism. Eight sampling stations were selected on the Nyangores tributary (Table. 1). The sampling stations were selected about 900m to 10km from each other along the stretch of the river in order to avoid point sources of pollution that could adversely influence the results of the study (Aweng-Eh *et al.*, 2010). Sampling was done fortnightly for a period of four months.

3.2.2 River discharge

River discharge was measured through determination of the cross-sectional area and measuring the flow velocity using portable flow meter Model 2000 (Marsh Mc Birney Flo- mate^{TM}) placed at 0.6 of mean depth from the surface. For this, a dip stick was used to determine the water depth at different points along the area of discharge measurement. Cross-sectional area was determine by measuring the width of the channel. The depths were determined at 1m to 2m intervals. The area was computed by multiplying the width and the depths. Using the cross-sectional area (A), at the point where samples were collected, discharge was calculated by multiplying the Velocity (V in m/s) and the area (A in m^2) (APHA, 2005).

3.2.3 Physical and chemical variables

Selected physical and chemical properties including dissolved oxygen concentration and saturation, temperature, electrical conductivity and pH of the stream were measured *in situ* using the Multimeters probes and meters (HACH HQ 4d and HACH Eco 40 ®Canada). The probes were always calibrated before use.

3.2.4 Nutrient analyses in water samples

Water samples were collected using 500ml plastic bottles that were previously acid-washed in the laboratory. Before each sample collection, the sample bottles were rinsed with the river water at each sampling point. The water samples collected were kept in a cool box and preserved in ice after which they were transported to Egerton University laboratory for analysis. In the laboratory nutrient analyses were done according to the standard methods as given by the American Public Health Association (APHA, 2005). The soluble nutrients, including SRP, NO_3-N, NO_2-N and NH_4-N were analysed from filtered water samples, while unfiltered water sample was used for TP analysis after persulfate digestion. Total phosphorus (TP) and soluble reactive phosphorous (SRP) were analyzed using the ascorbic acid method with absorbance read at a wavelength of 885 nm. Nitrate - nitrogen (NO_3-N) was analysed using the salicylate method with the spectrophotometric absorbance read at a wavelength of 420 nm. Nitrite-nitrogen (NO_2-N) concentration was determined based on the reaction between sulfanilamide and N-naphthyl-(1)-ethylendiamin-dihydrochloride. The intensity of colour formed was read at 543 nm. Ammonium-nitrogen (NH_4-N) was analyzed through the reaction between sodium salicylate and hypochloride solutions with the spectrophotometric absorbance of the treated sample being read at a wavelength of 655 nm. The absorbance values read were used to work out the concentration using equations generated from the standard calibration curves made for each of the nutrient species.

3.2.5 Total suspended solids

The total suspended solids in the water was determined gravimetrically. Water sample of volume 250ml was filtered through an oven-dried, pre-weighed GF/C Whatman glass-fiber filters (0.45µm pore size with 47mm diameter) and oven-dried at 103 to 105^0C to constant dry weight. Weighing was done using SCALTEC®SPB31 analytical balance. Calculation of the concentration of total suspended solids in the sample was done using the following formula (APHA 2005):

$$\text{TSS}\ (\text{mgL}^{-1}) = \frac{(\text{A}-\text{B})}{\text{V}} \times 1000 \ldots\ldots\ldots\ldots\text{Equation i}$$

Where: A = Suspended solids retained on the filter paper/ residue (g), B = Weight of filter paper (g) and V = Sample volume, ml

3.2.6 Estimation of canopy cover

The percentage canopy cover along the sampling sections of the river was estimated by visual observation and presented as percentage.

3.3 Periphyton samples

3.3.1 Periphyton sampling

Algal periphyton community structure and biomass was determined from their growth on artificial wooden substrates introduced in the water on which the organisms were allowed to develop. Triplicates of wooden substrates measuring 12cm by 75cm were placed about 100m apart in different sampling stations and were left for colonization by the algal periphyton. The periphyton were harvested after two weeks and subsequent harvesting done bi-weekly for four months. Periphyton was removed from the substrate by scrapping of the surface of the substrates. Brushing was then done to collect periphyton into a 50ml plastic container with a funnel placed at the top of the container. The substrates were rinsed with distilled water to collect any remaining periphyton into the 50ml plastic container. The collected samples were preserved in a 4% formalin and then transported to Egerton University for further processing and analysis.

3.3.2 Algal periphyton identification

The collected periphyton samples were analysed for community composition by taking 1ml of well shaken sample and placing on the counting chamber of the inverted microscope (Motic®AE31 series). Periphyton species were identified through observation under the microscope at the magnifications of x 200 and x 400 and using identification keys by Sun & Liu (2003) as well as Wehr and Sheath (2003).

3.3.3 Algal periphyton biovolume

The identified species were enumerated by counting all individuals, including single cells, colonies and filaments on a cell-by-cell basis using a 3 ml Sedgwick–Rafter counting chamber. To estimate the taxa biovolumes, the individual cells were taken as the unit of measurement for each taxa. The cell shapes of each taxa were approximated to the standard geometric shapes such as spheres, cuboid or cylinders and their standard formulae used to calculate biovolume (Hildebrand *et al.*, 1999, Sun and Liu 2003). The measurements of the cell dimensions such as the lengths and widths were made using a calibrated stage micrometer and the ocular grids in the microscope. Mean cell volumes were obtained by averaging the volumes of 30 individual cells. The total biovolume for each species was calculated from the product of abundance or cell numbers and the mean biovolume of each species. The biovolumes determined were worked out per unit area of the substrate where the samples were collected.

3.3.4 Algal periphyton diversity

The diversity of algal periphyton was determined using the Shannon- Weinner diversity index equation (Shannon and Weinner, 1949) given as:

$$H' = -\sum_{i-1}^{n} Pi \ln Pi \quad \ldots\ldots \text{Equation i}$$

Where P_i is the proportion between the number of individuals of **n** species in the sample and *n* is the number of the species. Species diversity **(H')**, richness **(S)** and evenness **(E)** were calculated according to Shannon and Weinner (1949) and were used as measures of community structure.

3.3.5 Periphyton productivity

Algal periphyton productivity was estimated through changes in oxygen concentration per unit time in an enclosed primary production chamber where algal periphyton of known biomass was introduced. Oxygen content of the water in the chamber was determined at the beginning of the experiment and later at the end of the experiment to estimate the oxygen produced by the algal periphyton during the incubation period using the Winkler's method. In the experiment, three stones/pebbles covered by algal periphyton whose surface area were determined were placed in the improvised plastic chamber (Plate.1) for incubation for 60 minutes. This was done three times in each sampling station. A stirrer operated by an electric mortar was used to mix the water to mimic the turbulent condition of the river. After 60 minutes, 250ml of the water was transferred in a glass bottles carefully while avoiding mixing with atmospheric air. The samples were then fixed with Winkler reagents and transported to the laboratory for titration. The oxygen content in the incubated water samples was determined through titration of the samples with sodium thiosulphate in the laboratory.

Surface area covered by the periphyton was determined by covering the pebbles with a foil. It was then calculated by spreading the foil on the grid paper. Productivity was then estimated per unit area of the pebbles used. Periphyton productivity was calculated as a measure of dissolved oxygen in $mgO_2cm^{-2}day^{-1}$. This was then converted to $mgCm^{-2}day^{-1}$ by multiplying it by a conversion factor of 0.375 derived from the following formula (Bott, 1996):

$6CO_2 + 6H_2O + C_6H_{12}O_6 + 6O_2$; where $6CO_2$=72g and $6O_2$=192g.

Therefore:

$$\frac{72\text{gC fixed}}{192\text{gO}_2\text{produced}} = 0.375 \text{...Equation iii}$$

Where: 72gC is the mass in grams of carbon fixed during algal periphyton photosynthesis and $192gO_2$ is the mass of oxygen in grams produced during algal periphyton photosynthesis. C represents Carbon, H represents Hydrogen and O represent Oxygen atoms.

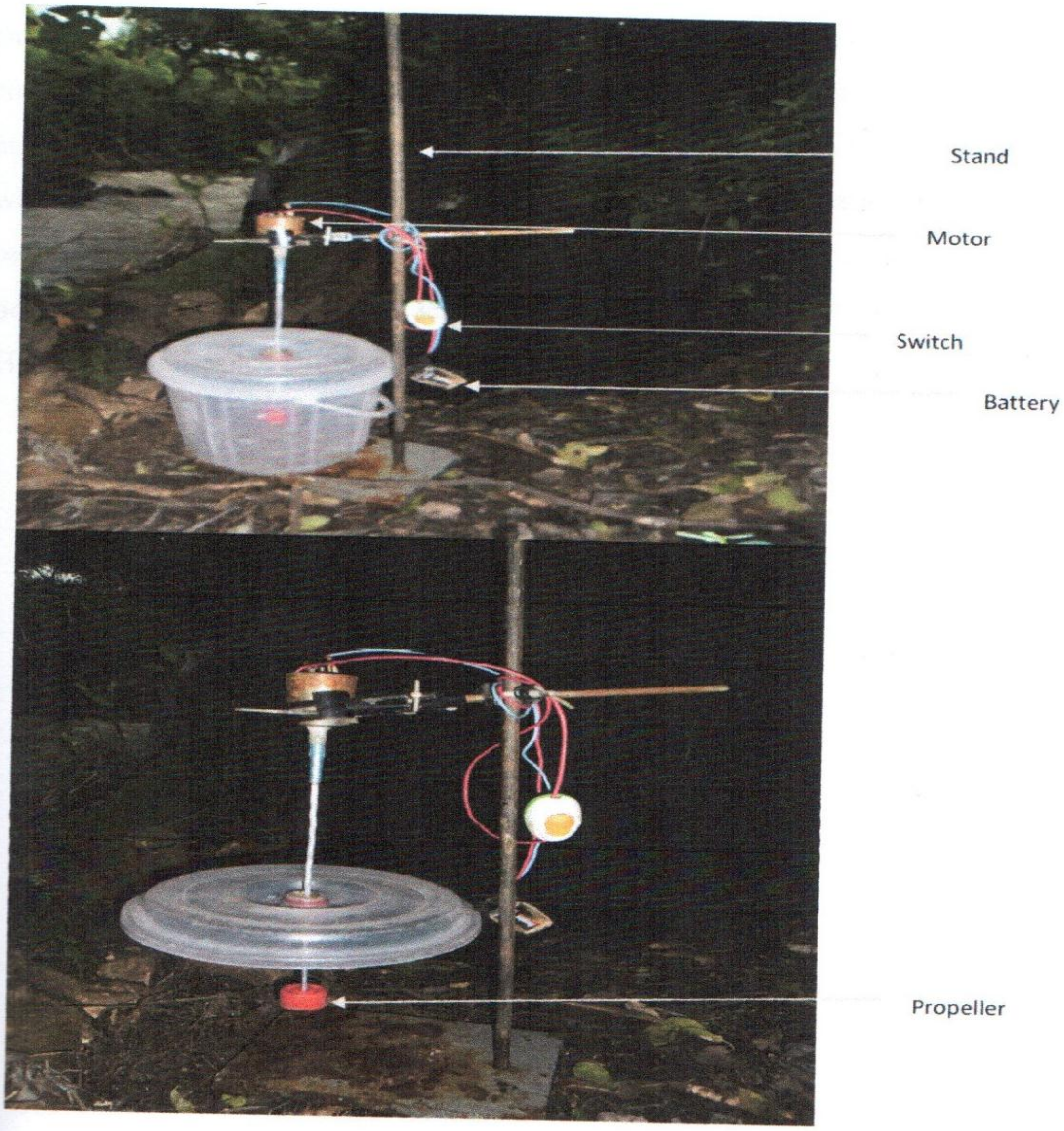

Plate 1: Improvised Periphyton productivity chamber

3.4 Data analysis

The data generated was entered into excel spreadsheets and later analyzed statistically using JMP version 10.0 statistical package. The main effects were months and and sites. For normally distributed data, parametric test such as two-way ANOVA was performed to determine the interactions of variables such as nutrients, physicochemical parameters, biomass and productivity between each month and each site. One-way ANOVA was performed to determine the significant difference of variables within sites in each month. Data that were not normally distributed were subjected to log transformations. Pearson correlation moment approach was used to determine relationships between periphyton biomass and nutrients concentrations after testing for normality. In this case also data that were not normally distributed were subjected to log transformations. Multiple linear regression was done to determine the physico-chemical parameter that best predicts algal periphyton productivity. Mean separation for the variables was done using Tukey's Honestly Significance Difference (HSD) test.

CHAPTER FOUR

RESULTS

4.1 Physical and chemical parameters

Generally the canopy cover was about 75% for forested site, 50% for farmland and 40% for rangeland site. Lower temperature values were recorded in forested sites upstream with a trend of increase in temperature downstream at the farmland site with the highest temperature being recorded at the rangeland (Table 2). However, spatial temperature variations ranged between 12 °C and 21 °C with a mean of 18.19 °C throughout the study period with no significant difference in between all the three sites (Tukey's HSD test, $p<0.05$). The mean temperature was 17.85, 19.38 and 19.15 °C in forested, farmland and rangeland sites respectively.

The mean conductivity for all the three sites was 83.80 μScm^{-1} throughout the study period. In addition the mean conductivity for each site was 32.81 , 85.78 and 115.82 µS/cm in forested, farmland and rangeland sites respectively. The conductivity values were lowest in the upper reaches in the forested zone (10.93 ± 0.42 μScm^{-1}) and highest in the rangeland zone (146.12 ± 2.99 μScm^{-1}) (Table 2). A temporal trend of increase in conductivity was noted from the month of February to May among all the sites. In March there was significant difference in electrical conductivity in forested site when compared to the farmland and rangeland sites (Tukey's HSD test, $p<0.05$).

Dissolved oxygen (DO) concentration generally decreased downstream with the lowest values recorded in the rangeland zones (6.13± 0.09 mgl^{-1}) and higher values being recorded in the forested upper zone (8.09±0.11 mgl^{-1}) (Table 2). The mean DO concentration for each site was 7.40, 7.34 and 7.28 mgl^{-1} for forested, farmland and rangeland sites respectively. During the months of February, March and April, there was a significant difference in DO concentrations only at the forested sites but the farmland and rangeland sites had similar concentrations (Tukey's HSD test, $p<0.05$). However in

May all sites had statistically different concentrations of dissolved oxygen (Tukey's HSD test, $p<0.05$).

A temporal trend of increase in the concentration of suspended solids was observed with the lowest value of 6.86±0.22 mgl^{-1}recorded in February in forested site and the highest values 351.77±1.4mg/l recorded in May in the rangeland site (Table 2). The mean TSS concentration for each site were 41.02, 99.26 and 148.51 $mgl^{-1}$for forested, farmland and rangeland respectively showing a spatial trend of increase downstream. During the months of February and May, TSS concentration in all the three sites were significantly different (Tukey's HSD test, $p<0.05$). However in March the TSS concentration at forested site was significantly lower than the other two sites (Tukey's HSD test, $p<0.05$).

pH values ranged between 6.3 and 8.3. (Table 2) with lower values being recorded in the forested zones and a trend of increase downstream. The highest value of 8.3 was recorded in the rangeland zones (Table 2). In the forested site pH ranged between 6.0 and 7.5 while in farmland and rangeland zones it was above 7.0.

4.2 Discharge variation over time across sites

Discharge measured during the study period ranged between 0.03 and 5.86±0.51 m^3s^{-1} and varied in all months across all sites. There was general increase of discharge with mpnths beginning from February to May. The maximum levels of discharge was observed in May but the lowest level of discharge occurred in February. Although peak discharges occurred in each month and at each site. For example in Farmland site temporal changes in discharge was observed to be 0.61±0.06, 1.25±0.07, 3.56±0.20 and 4.39±0.18 m^3s^{-1} during the months of February, March, April and May respectively. The highest discharge was in May (5.86±0.51 m^3s^{-1}) at the rangeland site (Table 2) while the lowest values were recorded in February (0.03 m^3s^{-1}) at the forested site. The Farmland site had average discharge as compared to the Forested and rangeland sites. However, discharge was significantly different among all sites (Two-way ANOVA, $F_{(2, 20)}=36.23$, $p<0.05$).

Table 2: Data on Physico-chemical variables measured between February 2012 and May 2012 in the Nyangores tributary study sites. (Mean ± SE), n=12.

Month	Site	Conductivity (μScm^{-1})	Temp(°C)	TSS (mgl^{-1})	DO (mgl^{-1})	pH	Discharge m^3s^{-1}
February	Forested	10.93 ± 0.42^{b}	17.65 ± 0.95^{a}	6.86 ± 0.22^{c}	7.76±0.3a	6.3^{b}	0.03
	Farmland	43.18 ± 2.39^{ab}	20.56 ± 0.07^{a}	34.56 ± 1.27^{b}	6.61±0.08b	7.3^{a}	0.61±0.06
	Rangeland	93.36 ± 1.6^{a}	18.84 ± 2.76^{a}	58.67 ± 1.26^{a}	7.14±0.06c	7.4^{a}	1.24±0.32
March	Forested	11.5 ± 0.14^{a}	14.34 ± 0.14^{a}	30.46 ± 2.35^{b}	8.08±0.07a	6.2^{b}	0.54±0.01
	Farmland	72.3 ± 5.52^{b}	18.86 ± 0.21^{a}	51.75 ± 0.25^{a}	7.26±0.05a	8.0^{a}	1.25±0.07
	Rangeland	113.96 ± 1.55^{b}	20.85 ± 1.01^{a}	81.39 ± 2.09^{a}	6.84±0.24b	7.9^{a}	2.44±0.32
April	Forested	13.47 ± 2.03^{ab}	14.01 ± 0.12^{a}	50.1 ± 1.28^{a}	8.09±0.11a	7.4^{b}	0.62±0.01
	Farmland	85.79 ± 1.29^{a}	17.27 ± 0.35^{a}	136.75 ± 1.51^{a}	7.03±0.04b	8.0^{a}	3.56±0.20
	Rangeland	110.79 ± 6.35^{b}	18.38 ± 0.56^{a}	249.25 ± 2.21^{a}	6.38±0.07b	8.1^{a}	4.57±0.07
May	Forested	19.2 ± 1.37^{a}	14.87 ± 2.9^{a}	73.39 ± 1.31^{c}	7.51±0.08a	7.5^{c}	0.70±0.11
	Farmland	92.87 ± 1.22^{a}	15.9 ± 0.24^{a}	162.04 ± 3.21^{b}	6.78±0.11b	8.0^{b}	4.39±0.18
	Rangeland	143.28 ± 2.99^{a}	19.26 ± 1.39^{a}	351.77 ± 1.4^{a}	6.13±0.09b	8.3^{a}	5.86±0.51

Values not bearing same superscript letter in the same month along the same column are significantly different.

4.3 Temporal and spatial changes in nutrients concentration

Low nutrient levels were recorded at upper reaches in forested zones than in farmland and rangeland sites. Different trends were observed for each nutrient. For example, the highest levels of ammonia (NH_4-N) were recorded in May at farmland site (184.23±5.72 $\mu g l^{-1}$). The concentration dropped from 92.67 $\mu g l^{-1}$in March to 80.33 $\mu g l^{-1}$in April in farmland site. There was significant differences in the amount of NH_4-N concentration in all the sites (Two-way ANOVA, $F_{(2, 20)}$ =236.44, $p<0.05$). NH_4-N concentrations showed a trend of gradual increase from the upper reaches in the forested area to the rangeland downstream (Figure 2).

Nitrite (NO_2-N) is usually unstable in water and occurs in low levels. In Nyangores tributary, the highest concentrations of NO_2-N (34.85±4.05 $\mu g l^{-1}$) was recorded in April at rangeland site. The lowest concentration was recorded in March (1.53±0.02 $\mu g l^{-1}$) at the forested sites (Figure. 2). NO_2-N levels fluctuated in all the sites but showed significant (Two-way ANOVA, $F_{(2, 20)}$ =278.73, $p<0.05$) differences between all the sites. This temporal fluctuation was especially significant at the rangeland site except between the months of March and May (Tukey's HSD test, $P<0.05$).

Nitrate (NO_3-N) is the most stable nitrogen species and occurs in high concentration than ammonium and nitrite. In Nyangores tributary, the highest NO_3-N concentrations was recorded in the rangeland site (653.86±35.34 $\mu g l^{-1}$) in May while the lowest concentration was recorded at the forest site (23.31±2.0 $\mu g l^{-1}$) in February (Figure. 2). There was significant differences in the NO_3-N concentrations between all the sites (Two-way ANOVA, $F_{(2, 20)}$ =1183.45, $p<0.05$). A trend of increase in NO_3-N concentrations was observed from forested site upstream to the rangeland site downstream. In the farmland site between months comparisons of NO_3-N concentrations were all significant. In the rangeland site there was no significant difference (Tukey's HSD test, $P<0.05$) of NO_3-N concentrations between the months of February and March.

Soluble reactive phosphate (SRP) depends on both uptake by plants and input from anthropogenic activities. In Nyangores tributary, the lowest concentration of SRP were recorded in February and March at the forested site (Figure 2). SRP concentrations increased remarkably in April and May with the highest concentration being recorded in May (119.91±3.39 μgl^{-1}) at rangeland site. There were significant spatial SRP concentration variations between all the sites (Two-way ANOVA, $F_{(2,\ 20)}$ =880.49, $p<0.05$). Temporal variations in SRP concentrations in the farmland site was not significantly different (Tukey's HSD test, $P>0.05$) between the months of February and March while the rangeland sites showed significant differences in all the months during the study (Tukey's HSD test, $p<0.05$).

Total Phosphorus (TP) has both SRP and particulate phosphorus. A trend of spatial increase in TP downstream was recorded in all the months with the highest concentrations recorded in Rangeland (246.11±24.31 μgl^{-1}) in the Month of May (Figure. 2). The concentration varied significantly (Two-way ANOVA, $F_{(2,\ 20)}$ =227.32, $p<0.05$) between all the sites. In farmland site there was no significant difference in TP concentrations between the months of February and March (Tukey's HSD test, $P<0.05$).

There was also variations of nutrients concentration with discharge. Nutrients concentrations showed an increase with discharge downstream. In March, NO_3-N, NO_2-N and TP showed weak positive correlation (Table 3) with discharge (Pearson product moment correlation coefficient, r=0.47, r=0.26, r=0.314, $p<0.05$, respectively).

In April, NO_3-N, NH_4-N, SRP and TP showed strong positive correlation (Table 3) with discharge (Pearson moment product correlation coefficient, r = 0.49, r = 0.74, r = 0.51, r = 0.52, $p<0.05$, respectively). In May, NO_3-N, NH_4-N, and TP showed strong positive correlation (Table 3) with discharge (Pearson moment product correlation coefficient, r = 0.72, r = 0.24, r = 0.53, $p<0.05$, respectively).

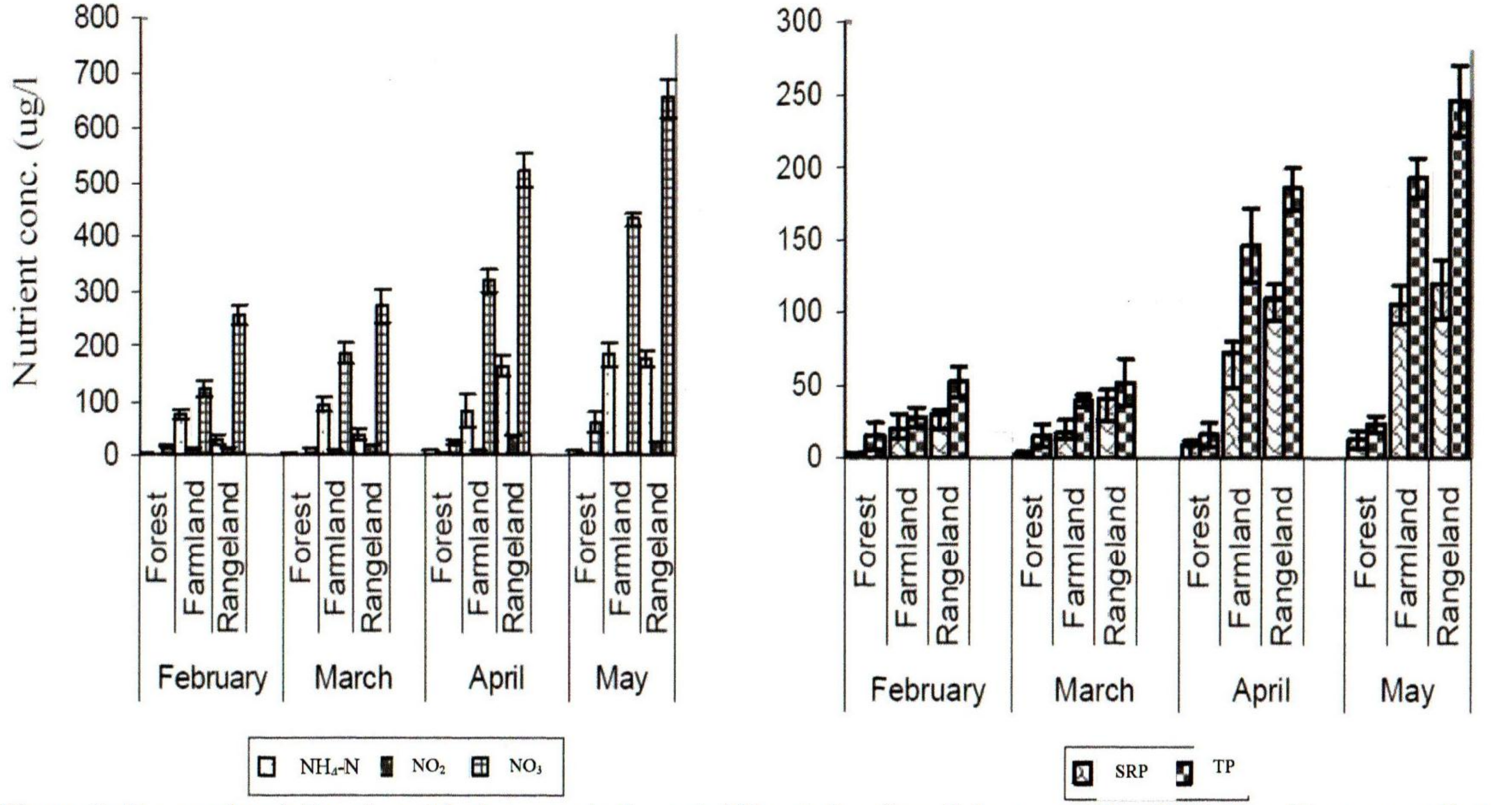

Figure 2: Temporal variations in nutrients concentrations at different sites from February to May 2012 along Nyangores tributary. (Mean ± SE), n=12.

Table 3: Discharge and nutrients concentrations in the Nyangores tributary study sites between February 2012 and May 2012

Month	**Site**	**Discharge (m^3s^{-1})**	**SRP (μgl^{-1})**	**TP (μgl^{-1})**	**NH_4-N (μgl^{-1})**	**NO_2-N (μgl^{-1})**	**NO_3-N (μgl^{-1})**
February	Forested	0.03	3.32	15.37	4.03	1.82	16.18
	Farmland	0.06±0.61	19.65	27.83	74.85	9.86	121.48
	Rangeland	0.32±1.24	29.48	52.36	28.70	11.87	255.50
March	Forested	0.01±0.54	3.04	15.35*	3.63	1.53*	14.01*
	Farmland	0.07±1.25	17.26	39.39*	93.11	7.28*	186.73*
	Rangeland	0.032±2.44	40.94	52.19*	37.22	19.61*	273.06*
April	Forested	0.01±0.62	8.80*	16.25*	9.47*	2.48	23.31*
	Farmland	0.20±3.56	72.88**	146.30*	80.91*	8.00	318.62**
	Rangeland	0.07±4.57	109.55**	185.55*	161.75*	34.85	520.67**
May	Forested	0.11±0.70	12.57	23.37*	8.81*	2.58	61.53*
	Farmland	0.18±4.39	106.37	193.25*	184.23*	5.86	431.01**
	Rangeland	0.51±5.86	119.91	246.11*	176.73*	20.96	653.86**

* shows significant correlation at $p<0.05$ (Pearson product moment correlation) and ± are means standard error, n=32.

** Correlation is significant at ($p<0.001$), n=32

The relationship between discharge and nutrient was analyzed using regression. The results showed that there was a significant relationship between discharge and SRP at Farmland site (Excel Stat, $y = 22.54x + 125.98$, $R^2=0.82$, $P<0.05$) and between discharge and TP at Forested site (Excel Stat, $y = 1.8854x + 12.87$, $R^2=0.93$, $P<0.05$) as indicated in Table 4. In addition, there was a significant relationship between discharge and NO_3-N (Excel Stat, $y = 86.598x + 8.58$, $R^2=0.91$, $P<0.05$) as indicated in Table 4.

Table 4: Regression values between discharge and nutrient in the Nyangores tributary study sites between February 2012 and May 2012

Nutrient	**Site**	**Equation**	**R^2**	**P**
SRP	Forested	$y = 22.54x + 125.98$	0.56	0.25
	Farmland	$y = 22.54x + 125.98$	0.82	0.01*
	Rangeland	$y = 22.54x + 125.98$	0.01	0.69
TP	Forested	$y = 1.8854x + 12.87$	0.93	0.04*
	Farmland	$y = 22.54x + 125.98$	0.88	0.06
	Rangeland	$y = 22.54x + 125.98$	0.24	0.51
NH_4-N	Forested	$y = 22.54x + 125.98$	0.17	0.58
	Farmland	$y = 22.54x + 125.98$	0.21	0.54
	Rangeland	$y = 22.54x + 125.98$	0.12	0.67
NO_2-N	Forested	$y = 0.1486x + 1.731$	0.33	0.42
	Farmland	$y = -0.6065x + 9.27$	0.29	0.46
	Rangeland	$y = 22.54x + 125.98$	0.17	0.57
NO_3-N	Forested	$y = 86.598x + 8.58$	0.91	0.11
	Farmland	$y = 420.4x + 327.82$	0.79	0.05*
	Rangeland	$y = 420.4x + 327.82$	0.24	0.51

*Shows significant regression at $p<0.05$ (Excel Stat 2013)

x is the discharge value

4.4 Algal Periphyton species composition in Nyangores tributary

Diatoms (Bacillariophytes), green algae (Chlorophytes) and blue-green algae (Cyanophytes) dominated the algal periphyton community structure throughout the study period ((Plate 2a and 2b). The major taxa identified for the diatoms included *Surirrella* sp, *Fragilaria* sp, *Navicula* sp, *Nitzschia* sp, *Gomphonema* sp, and *Cymbella* sp; blue-green algae (Cyanophytes) were *Limnothrix* sp and *Lyngbya* sp; and green algae was represented by *Closterium* sp (plate 2a). Most of these species were recorded in all the stations throughout the study period except *Limnothrix* sp which was absent in the forested site and *Lyngbya* sp which was absent in the rangeland site during the month of May (Table 5).

Table 5: Temporal variations in periphyton species in Nyangores tributary from February to May 2012 (+ or – denote presence or absence of species)

Month	Site	*Surirrella* sp	*Fragilaria* sp	*Navicula* sp	*Limnothrix* sp	*Nitzschia* sp	*Lyngbya* sp	*Gomphonema*	*Closterium* sp	*Cymbella* sp
February	Forested	+	+	+	-	+	-	+	+	+
	Farmland	+	+	+	+	+	+	+	+	+
	Rangeland	+	+	+	-	+	+	+	+	+
March	Forested	+	+	+	-	+	-	+	+	+
	Farmland	+	+	+	+	+	+	+	+	+
	Rangeland	+	+	+	+	+	+	+	+	+
April	Forested	+	+	+	-	+	-	+	+	+
	Farmland	+	+	+	+	+	+	+	+	+
	Rangeland	+	+	+	+	+	+	+	+	+
May	Forested	+	+	+	-	+	+	+	+	+
	Farmland	+	+	+	+	+	+	+	+	+
	Rangeland	+	+	+	-	+	+	+	+	+

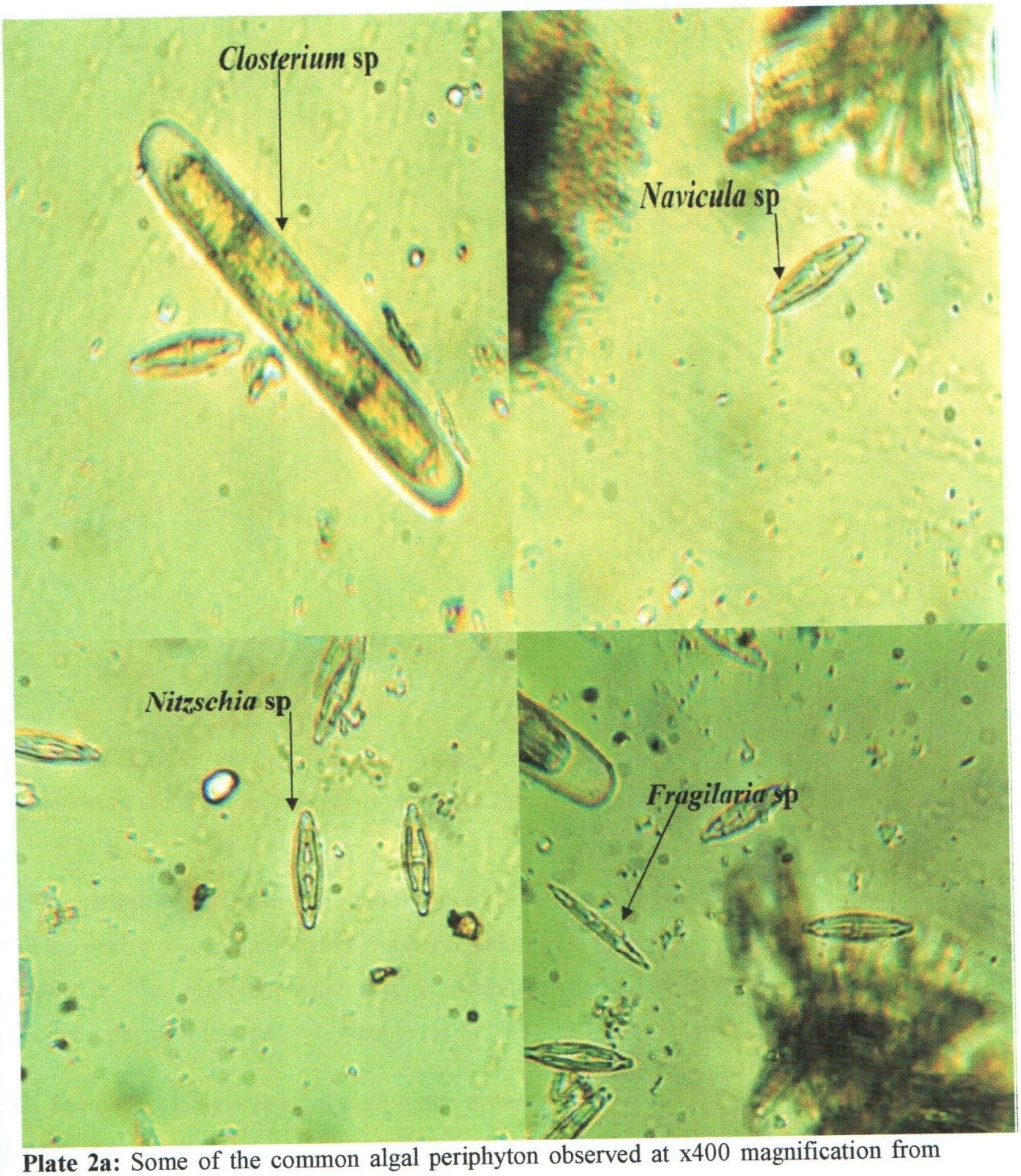

Plate 2a: Some of the common algal periphyton observed at x400 magnification from Nyangores tributary from February to May 2012 (*Closterium*, *Navicula*, *Nitzschia* and *Fragilaria* spp.)

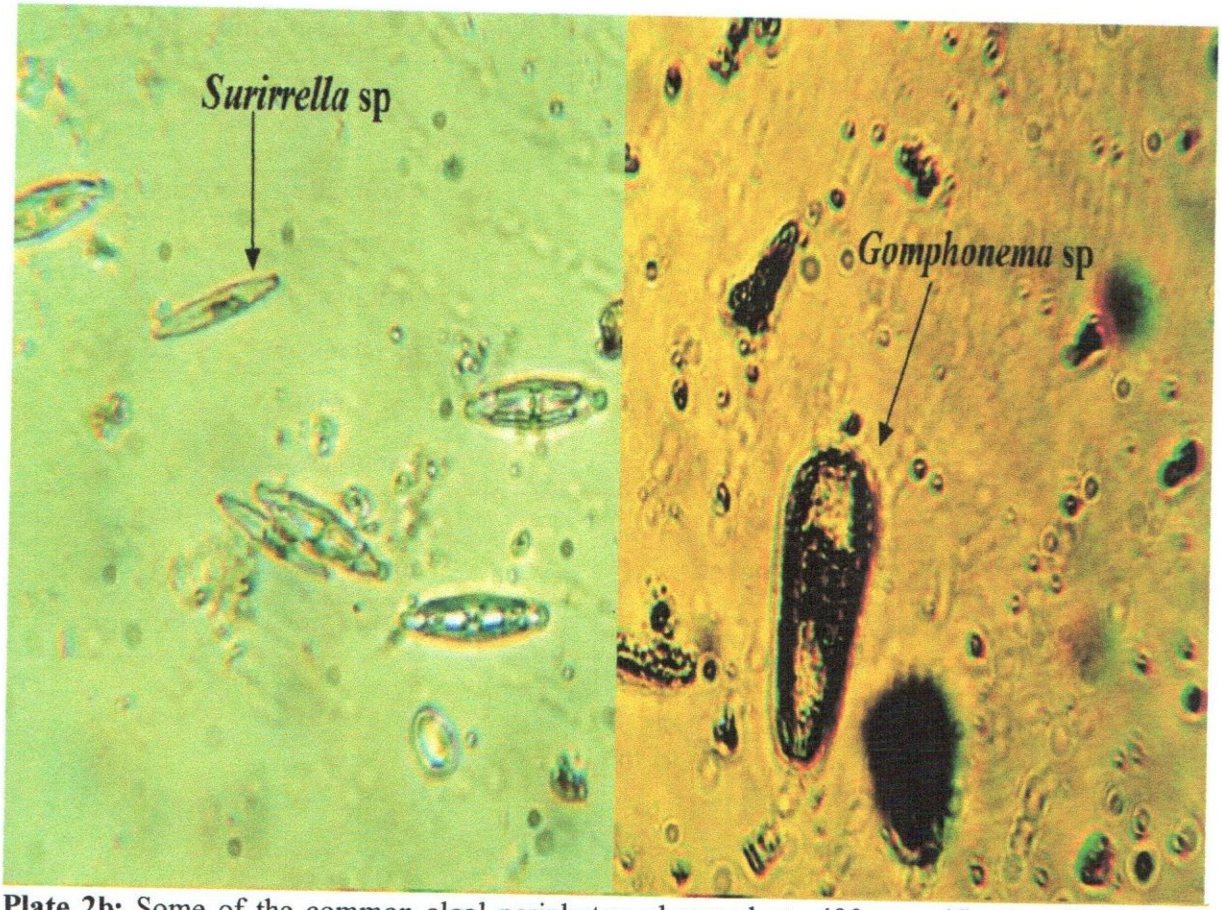

Plate 2b: Some of the common algal periphyton observed at x400 magnification from Nyangores tributary from February to May 2012 (*Surirrella*, and *Gomphonema* spp)

4.5 Contribution of the major algal divisions to total periphyton biovolume

All the genera of algal periphyton grouped together gave three major division as shown in (Table 7). The most dominant taxa of periphyton in terms of biovolume was the Bacillariophytes followed by Cyanophytes and then the Chlorophytes (Table 6).

4.6 Temporal changes in algal periphyton diversity

Generally low diversity was observed throughout the study period, with the month of February giving the lowest diversity values at the forested and rangeland site while

Table 6: Taxonomic mean algal periphyton biovolumes

Division	Species	Biovolume (mm^3cm^{-2})	Total biovolume (mm^3cm^{-2})
Bacillariophyta	*Surirrella* sp	0.0175	
	Fragilaria sp	0.0253	
	Navicula sp	0.0178	
	Cymbella sp	0.0634	
	Nitschia sp	0.0592	
	Gomphonema sp	0.0130	0.0925
Cyanophyta	*Limnothrix* sp	0.0154	
	Lyngbya sp	0.0145	0.0300
Chlorophyta	*Closterium* sp	0.0150	0.0130

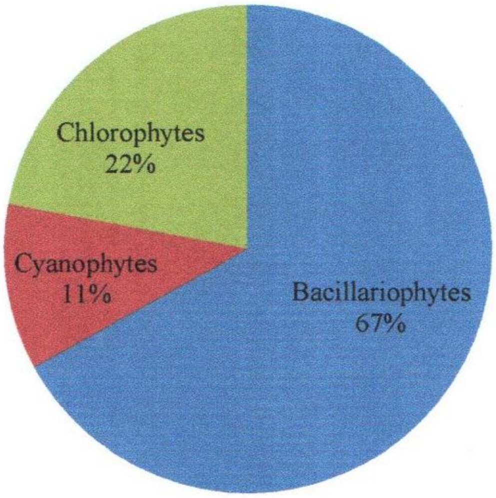

Figure 3: The percentage biovolume of major algal periphyton groups in Nyangores tributary from February to May 2012.

relatively higher diversity was obtained in May at all the sites. The site with the highest diversity during the study was farmland (H=2.14) in the month of April while the site with the least diversity was the forest site (H=1.77) during the month of February (Table 7) The same pattern was observed when species evenness was calculated with farmland site having species more evenly distributed (E=0.97) in the month of April. Forested site had the lowest species richness (S=7 to 8) while farmland and rangeland had the highest (S=8 to 9).

Table 7: Algal periphyton diversity from February to May 2012 in the Nyangores tributary study sites

Month	Site	Species diversity (H)	Evenness (E)	Species richness (S)
February	Forested	1.77	0.85	8
	Farmland	2.05	0.93	9
	Rangeland	1.95	0.89	9
March	Forested	1.80	0.92	7
	Farmland	2.11	0.96	9
	Rangeland	2.03	0.92	9
April	Forested	1.86	0.96	7
	Farmland	2.14	0.97	9
	Rangeland	2.10	0.95	9
May	Forested	2.02	0.97	8
	Farmland	2.10	0.96	9
	Rangeland	2.02	0.97	8

4.7 Spatio-temporal variations in algal periphyton biomass

The biomass (mm^3cm^{-2}) of individual taxa varied but were observed to generally increase from February to April with a decline occurring in May. The biomass of *Closterium* sp was recorded to be higher (1190 mm^3cm^{-2}) in April at the forested site of Nyangores tributary but lowest in rangeland site (218 mm^3/cm^2) (Figure 4). There were significant differences in *Closterium* sp biomass between all the sites (Two-way ANOVA, $F_{(2,\ 20)}$ =740.39, $p<0.05$) and between sampling periods (Two-way ANOVA, $F_{(3,\ 20)}$ =179.53, $p<0.05$). Statistical analysis showed that there was effect of spatio-temporal interaction of month and site on the biomass of *Closterium* sp (Two-way ANOVA, $F_{(6,\ 20)}$ =36.42, $p<0.05$) which increased from February to April but declined in May in all the sites. In February the *Closterium* sp biomass in the forested site was significantly different with that of farmland and rangeland sites which were similar (Tukey's HSD test, $p<0.05$). However all the three sites showed significant differences in *Closterium* sp biomass over time (Tukey's HSD test, $p<0.05$) in March and April. During May *Closterium* sp biomass in forested and farmland sites were similar while only those in rangeland site were significantly different (Tukey's HSD test, $p<0.05$).

During the months of March and April, there was an increase in the biomass of *Cymbella* sp (Figure 4). The lowest biomass of 105 mm^3cm^{-2} was recorded in the rangeland site in May while the highest ($1801 mm^3/cm^{2)}$ was recorded in forested site in April. The mean biomass differed significantly between sites (Two-way ANOVA, $F_{(2,\ 20)}$ =1815.74, $p<0.05$) and between sampling periods (Two-way ANOVA, $F_{(3,\ 20)}$ =194.05, $p<0.05$). Statistical analysis also revealed that there was effect of spatio-temporal interaction of month and site on the biomass of *Cymbella* sp (Two-way ANOVA, $F_{(6,\ 20)}$ =1815.74, $p<0.05$) which increased from February to April but declined in May in all the sites. In February and March the biomass of *Cymbella* sp was similar between forested and rangeland sites but significantly different in farmland site (Tukey's HSD test, $p<0.05$). In May the biomass was significantly different among all the three sites (Tukey's HSD test, $p<0.05$).

The biomass of *Gomphonema* sp was highest in April (370 mm^3cm^{-2}) in the farmland site but lowest in February (58 mm^3cm^{-2}) at forested site (Figure 4). Spatial comparison of its biomass showed that there were significant differences amongst all the sites (Two-way

ANOVA, $F_{(2, 20)} = 334.77$, $p<0.05$) and between sampling periods (Two-way ANOVA, $F_{(3, 20)} = 64.63$, $p<0.05$). In addition statistical analysis indicated that there was effect of spatio-temporal interaction of month and site on its biomass (Two-way ANOVA, $F_{(6, 20)} = 42.37$, $p<0.05$) which increased from February to April but declined in May in all the sites. Temporal comparison its biomass in February revealed significant differences in forested site, while farmland and rangeland sites were insignificant (Tukey's HSD test, $p<0.05$). However, the biomass *Gomphonema* sp during the subsequent months of March, April and May at the farmland site were significantly different but similar in forested and rangeland sites. (Tukey's HSD test, $p<0.05$).

Lyngbya sp biomass was highest in April at the farmland site (1500 mm^3cm^{-2}) (Figure 4). Its lowest biomass was recorded in the forested site across all the months. The biomass were significantly different (Two-way ANOVA, $F_{(2, 20)} = 217.81$, $p<0.05$) in all the sites and between the sampling periods (Two-way ANOVA, $F_{(3, 20)} = 37.47$, $p<0.05$). Spatio-temporal interaction of month and site on the biomass of *Lyngbya* sp was equally significantly different (Two-way ANOVA, $F_{(6, 20)} = 10.11$, $p<0.05$) with the biomass increasing from February to April but declinin in May in all the sites. In the months of February, March April and May, the biomass was significantly different between all the three sites (Tukey's HSD test, $p<0.05$).

Limnothrix sp biomass showed great fluctuations with the highest biomass being recorded in April (429 mm^3cm^{-2}) in the rangeland site (Figure 4). There was significant difference in its biomass between the sites (Two-way ANOVA, $F_{(2, 20)} = 3.77$, $p<0.05$). However statistical analysis on its biomass between the sampling periods was insignificant (Two-way ANOVA, $F_{(3, 20)} = 0.62$, $p>0.05$). In addition there was no significant difference of the effect of spatio-temporal interaction of month and site on the biomass of *Limnothrix* sp (Two-way ANOVA, $F_{(6, 20)} = 0.68$, $p<0.05$). During the months of February, March, April and May *Limnothrix* sp biomass were similar in forested and rangeland sites but significantly different in farmland site (Tukey's HSD test, $p<0.05$).

The highest biomass of *Navicula* sp was observed in the forest site (50,200 mm^3cm^{-2}) in March (Figure 5). Its biomass was significantly different (Two-way ANOVA, $F_{(2, 20)}$ =1682.71, $p<0.05$) between all the sites and between sampling periods (Two-way ANOVA, $F_{(3, 20)}$ =76.68, $p<0.05$). Statistical analysis also revealed that there was effect of spatio-temporal interaction on the biomass of *Navicula* sp (Two-way ANOVA, $F_{(6, 20)}$ =17.45,$p<0.05$) which increased from February to March and a decline noted from April to May in all the three sites. In the months of February, March, April and May the biomass were similar in forested and farmland sites but significantly different in the rangeland site (Tukey's HSD test, $p <0.05$).

Nitzschia sp biomass was highest in March and April (over 17,000 mm^3cm^{-2}) at the upper reaches in the forest sites (Figure 5) with lower values recorded at the downstream sites. Spatial biomass comparison showed that its biomass variations were significant (Two-way ANOVA, $F_{(2, 20)}$ =76.61, $p<0.05$) between all sites and between sampling periods (Two-way ANOVA, $F_{(3, 20)}$ =3.65, $p<0.05$). Statistical analysis revealed that there was effect of spatio-temporal interaction of month and site on this biomass (Two-way ANOVA, $F_{(6, 20)}$ =1.34, $p<0.05$) which increased from February to April but declined in May in all the sites. During the month of February *Nitzschia* sp biomass were similar in forested, farmland and rangeland sites (Tukey's HSD test, $p<0.05$). However in March, April and May the biomass was only similar between forested and farmland sites but significantly different in rangeland site (Tukey's HSD test, $p<0.05$).

The highest biomass of *Surirrella* sp was recorded in the month of May (9,500 mm^3cm^{-2}) at the forested site (Figure 5). Comparison of this biomass showed significant difference between the sites (Two-way ANOVA, $F_{(2, 20)}$ = 3016.70, $p<0.05$) and between sampling periods (Two-way ANOVA, $F_{(3, 20)}$ = 481.00, $p<0.05$). Statistical analysis revealed that there was effect of spatio-temporal interaction of month and site on this biomass (Two-way ANOVA, $F_{(6, 20)}$ = 10.78, $p<0.05$) which increased from February to April but declined in May in all the sites. In February the biomass was similar between farmland and rangeland sites but significantly different in forested site (Tukey's HSD test, p

<0.05). However during the subsequent months of March, April and May the biomass was significantly different in all the sites (Tukey's HSD test, $p<0.05$).

Fragilaria sp biomass reached its peak in April at the forested site while the lowest biomass was recorded in May at the rangeland site (Figure 6). This biomass showed significant difference between sites (Two-way ANOVA, $F_{(2, 20)} = 20360.38$, $p<0.05$) and between sampling periods (Two-way ANOVA, $F_{(3, 20)} = 249.56$ $p <0.05$). In addition statistical analysis showed that there was effect of spatio-temporal interaction of month and site on the biomass (Two-way ANOVA, $F_{(6, 20)} = 188.63$) which increased from February to April but declined in May in all the sites. In all the months the biomass was similar in the forested and farmland sites but significantly different in the rangeland site (Tukey's HSD test, $P<0.05$)

4.8 Influence of discharge and nutrient on the algal periphyton community in Nyangores tributary

Surirrella sp biomass correlated significantly positively with SRP (Pearson product moment correlation coefficient, $r=0.26$ $p<0.05$). *Fragilaria* sp biomass correlated positively with NH_4-N and SRP (Pearson product moment correlation coefficient $r=0.33$ and $r=0.32$, $p<0.05$, respectively). *Nitzschia* sp biomass correlated positively with NH_4-N (Pearson product moment correlation coefficient $r= 0.31$, $p<0.05$). *Lyngbya* sp biomass showed positive correlation with discharge, NH_4-N, NO_3-N, SRP and TP (Pearson product moment correlation coefficient $r=0.37$, $r=0.34$, $r=0.44$, $r=0.27$ and $r=0.42$, $p<0.05$, respectively).

Gomphonema sp biomass was observed to positively correlate with NH_4-N, NO_3-N, and TP (Pearson product moment correlation coefficient, $r=0.26$, $r=0.29$, $r=0.34$, $p<0.05$, respectively). *Closterium* sp biomass showed positive correlation with NH_4-N, SRP and TP (Pearson product moment correlation coefficient, $r=0.33$, $r=0.42$, $r=0.45$ $p<0.05$, respectively). *Cymbella* sp biomass also exhibited similar trend as *Closterium* sp biomass correlating positively with NH_4-N, SRP and TP (Pearson product moment correlation coefficient, $r=0.31$, $r=0.41$, $r=0.43$ $p<0.05$,respectively) as indicate in Table 8.

4.9 Algal periphyton productivity in Nyangores tributary

Generally very low algal periphyton productivity values were recorded. The highest productivity value was obtained in the month of March (Figure 3) at the forested site (2.85×10^{-6} $mgCm^{-2}day^{-1}$) and the lowest was in February at the rangeland site (1.77×10^{-6} $mgCm^{-2}day^{-1}$). There were significant differences in mean periphyton productivity between all the sites (Two-way ANOVA, $F_{(2, 52)} = 1.99 \times 10^{-11}$, $p<0.05$). However, there was no significant differences in productivity between sampling periods (Two-way ANOVA, $F_{(3, 52)} = 1.99 \times 10^{-11} = 0.14$, $p<0.05$). In addition, there was no effect of spatio-temporal interaction on the mean periphyton productivity ($F_{(6, 52)} = 2.69 \times 10^{-12}$, $p<0.05$) even though it increased from February to April but slightly declined in May in all the sites. In February the mean periphyton productivity in the forested and rangeland site were insignificant but different in the farmland site (Tukey's HSD test, <0.05).

There was a relatively strong positive correlation between productivity and all the nutrients except NO_2-N which showed relatively weak correlation (Pearson moment correlation coefficient, $r=0.68$, $p>0.05$) in February (Table 9). NO_2-N is very unstable and changes to other nitrogen species such as NH_4 and NO_3-N that are available for algal periphyton.

Temperature and discharge appeared to account for the ability to predict productivity ($P < 0.05$) in all the three sites than any other physicochemical parameters. Optimum temperature is essential for periphyton physiological processes while discharge washed in nutrients into the river to be taken by the periphyton (Table 10). The mean periphyton productivity was also predicted from a linear combination of the independent variables (nutrient) through multiple linear regression as shown in table 11.

It was noted that NH_4 and NO_3-N significantly influenced the growth of algal periphyton in the Nyangores tributary.

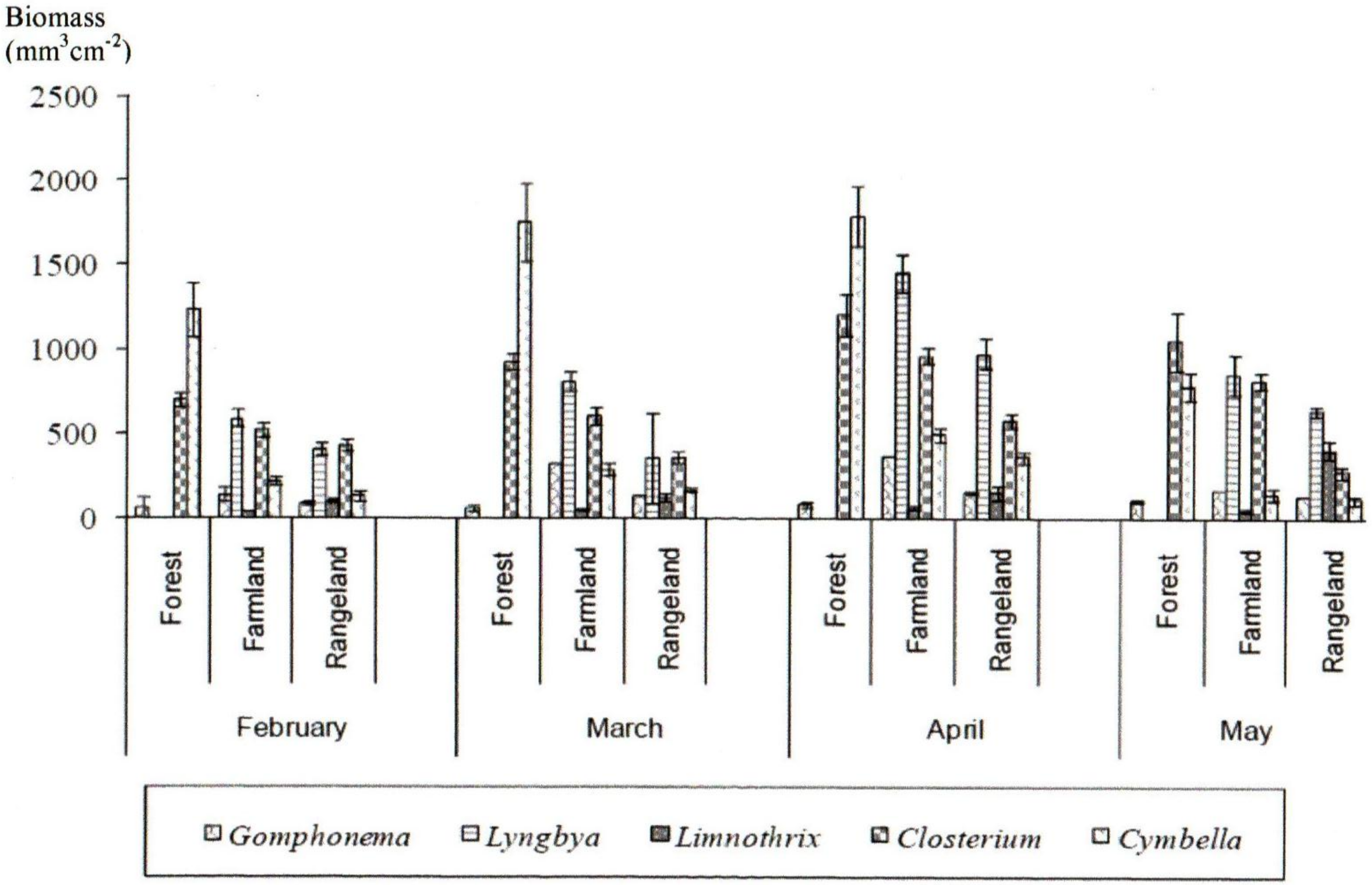

Figure 4: Temporal variations in biomass of *Gomphonema*, *Lyngbya*, *Limnothrix*, *Closterium* and *Cymbella* spp from February to May 2012 at different sites along Nyangores tributary. (Mean ± SE), n=12.

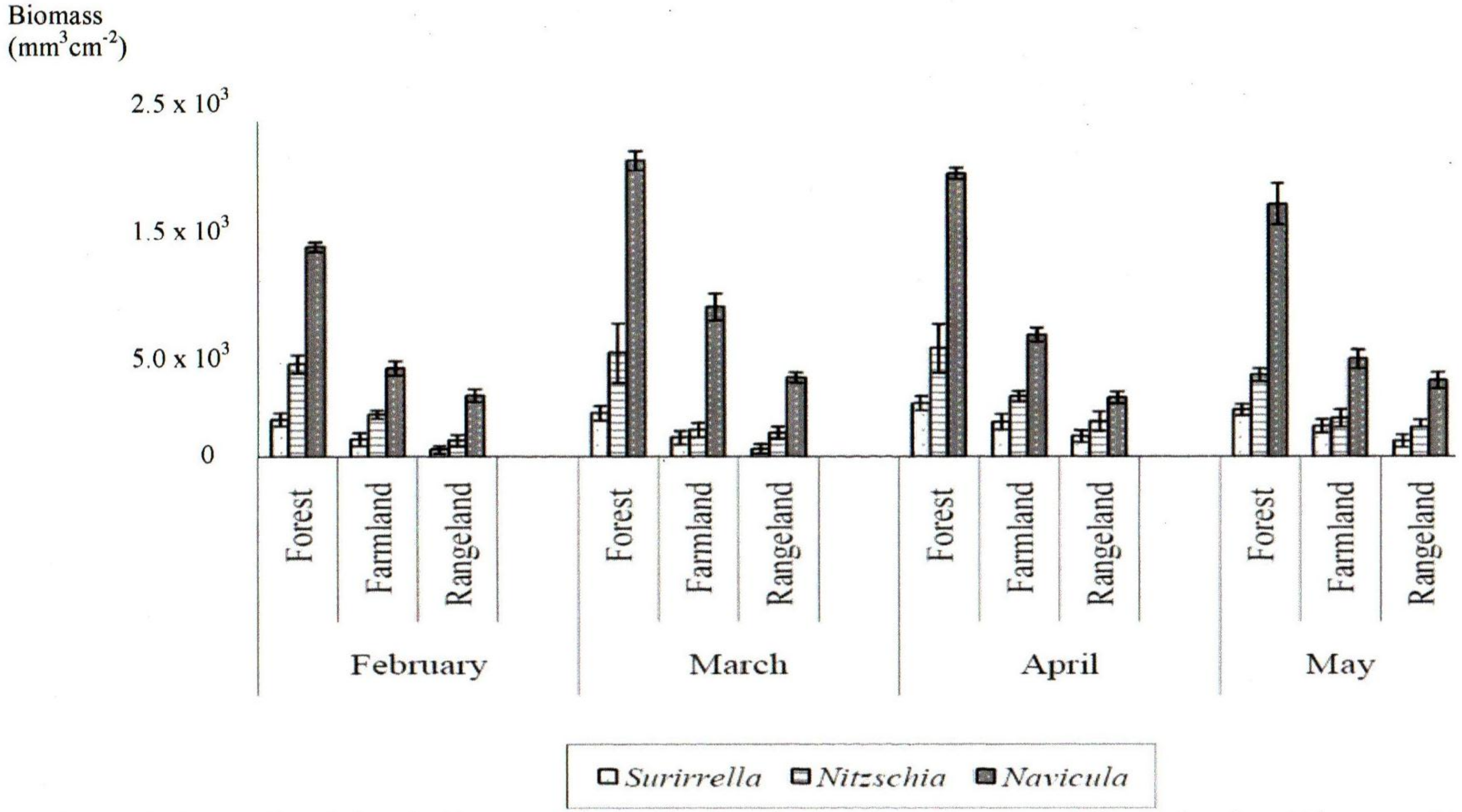

Figure 5: Temporal variations in biomass of *Surirrella*, *Nitzschia* and *Navicula* spp at different sites from February to May 2012 along Nyangores tributary. (Mean ± SE), n=12.

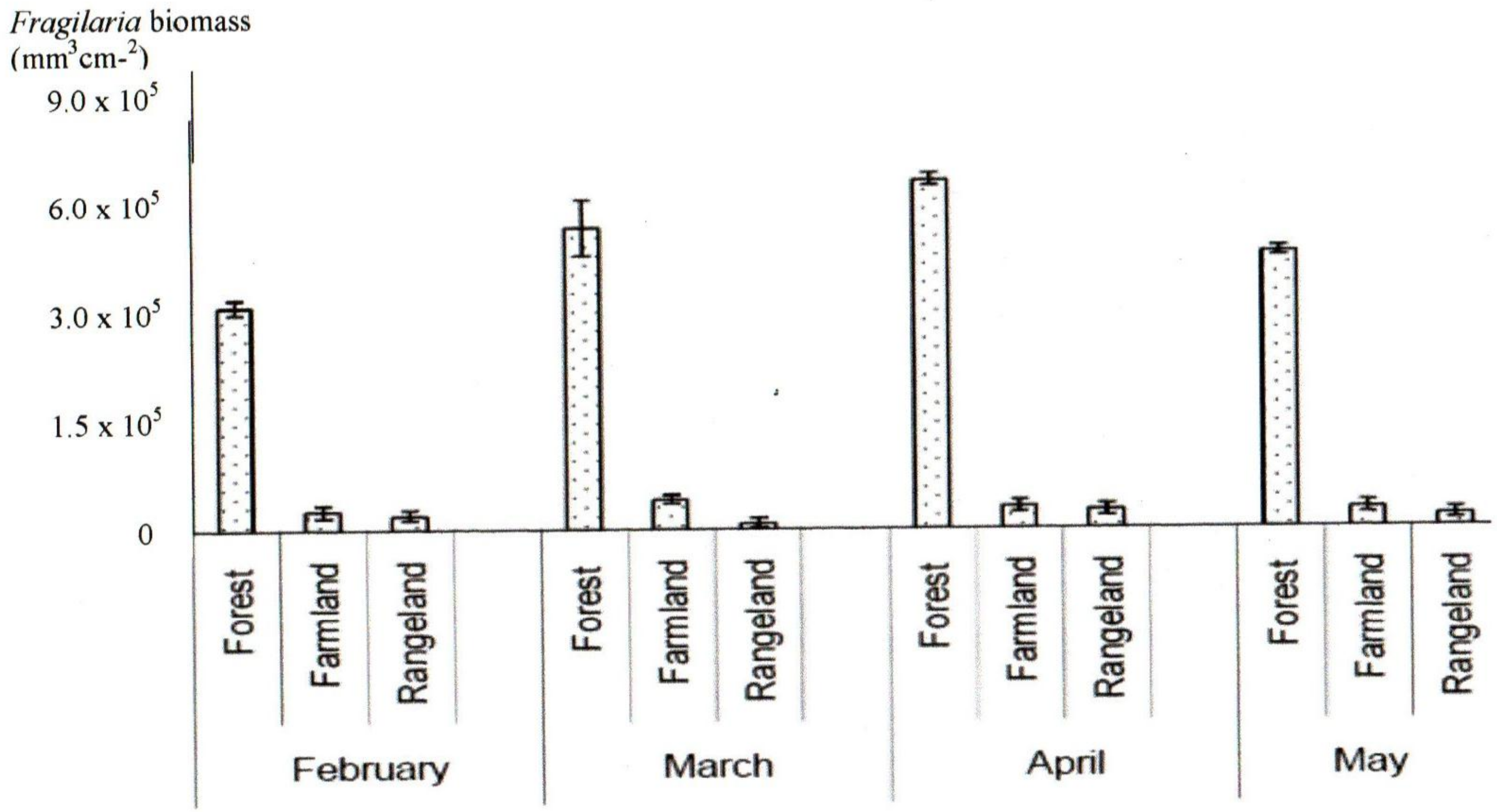

Figure 6: Temporal variations in Fragilaria sp biomass from February to May 2012 at different sites along Nyangores tributary. (Mean ± SE), n=12.

Table 8: Correlation matrix of algal periphyton taxa with discharge and nutrients in Nyangores tributary between February and May 2012

Species	Discharge	NH_4-N	NO_2-N	NO_3-N	SRP	TP
Surirrella sp	-0.08	0.19	-0.22	0.04	0.26*	0.23
Fragilaria sp	0.15	0.33*	-0.20	0.13	0.32*	0.24
Navicula sp	-0.06	0.23	-0.21	0.06	0.17	0.11
Limnothrix sp	0.16	0.15	-0.04	0.12	0.13	0.21
Nistchia sp	0.05	0.31*	-0.12	0.20	0.24	0.21
Lyngbya sp	0.37*	0.34*	0.17	0.44*	0.27*	0.42*
Gomphonema sp	0.19	0.26*	0.07	0.29*	0.24	0.34*
Closterium sp	0.13	0.33*	-0.13	0.20	0.42*	0.45*
Cymbella sp	0.14	0.31*	-0.12	0.20	0.41*	0.43*

*Correlation is significant at ($p<0.05$), n= 64

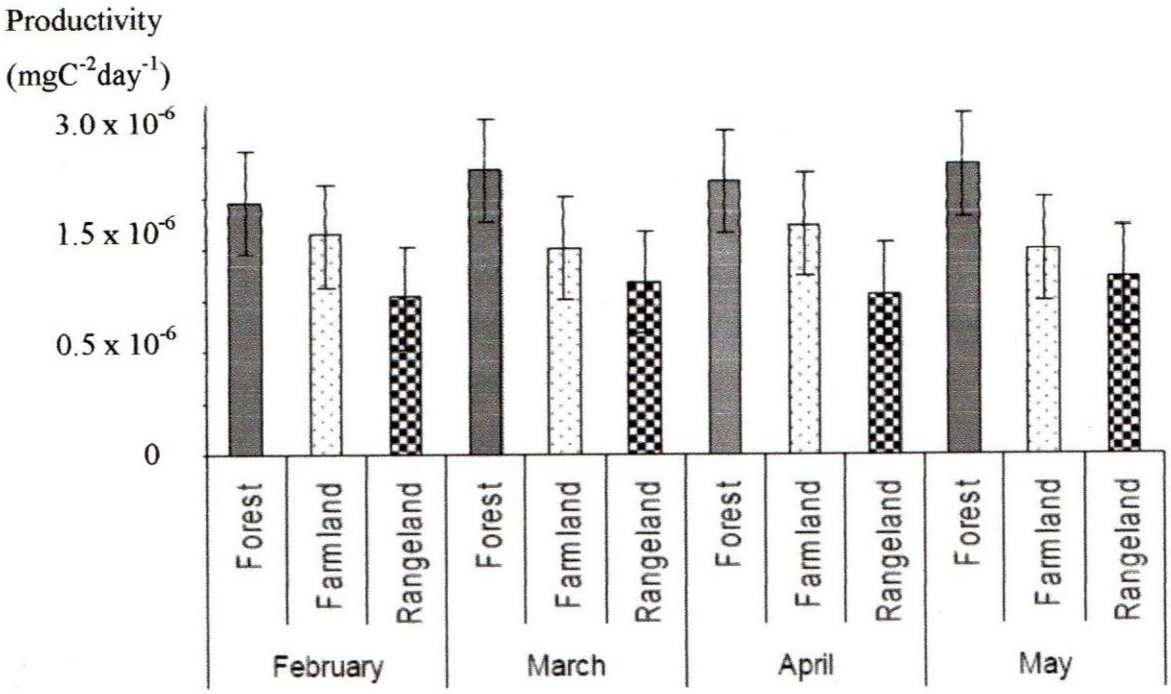

Figure 7: Temporal Periphyton primary productivity in Nyangores tributary from February to May 2012. (Mean ± SE), n=12.

Table 9: Correlation matrix of algal periphyton productivity with nutrient concentrations in the Nyangores tributary between February and May 2012.

	Nutrient				
Month	NH_4	NO_2-N	NO_3-N	SRP	TP
February	0.97	0.68*	0.97	0.87	0.98
March	0.92	0.99	0.92	0.99	0.94
April	0.97	0.95	0.97	0.94	0.87
May	0.97	0.95	0.97	0.89	0.89

$p<0.05$, n= 12; *Weak correlation.

Table 10: The mean algal periphyton productivity in Nyangores tributary in relation to physico-chemical parameters as predicted through multiple linear regression between February and May 2012

Physicochemical parameter	Temperature (°C)	TSS (mg/l)	Discharge (m^3/s)	pH	DO mg/l	Conductivity (µS/cm)
P value	<0.05*	0.08	0.04*	0.61	0.93	0.16

*Significant at $p<0.05$

Table 11: The mean algal periphyton productivity in Nyangores tributary in relation to nutrient as predicted through multiple linear regression between February and May 2012

Nutrient	NH4-N	NO_2-N	NO_3-N	SRP	TP
P value	<0.05*	0.08	0.04*	0.61	0.93

*Significant at $p<0.05$

NH_4-N, NO_3-N, SRP and TP appeared to account for the ability to predict productivity ($P<0.05$) as they are required for periphyton growth and metabolism.

CHAPTER FIVE

DISCUSSIONS

5.1 Physical and chemical properties in Nyangores tributary

Water temperature had slight variation among the three sites. The relatively slight increase in temperatures at rangeland site was as a result of direct heating of the river channel by the sun, and heat exchange with the atmospheric air due to the opening of canopy downstream. The relatively low temperatures in the forest sites could be attributed to the cooling effects rendered by the dense forest canopy and higher altitude. This observation agrees with the studies by Swift (1983) who found forest cover to influence the temperature regimes of rivers and their periphyton community structure. The small spatial temperature variations were due to the different sampling time which were always between 06:00 and 18:00 hour. However temporal variation in temperature could be attributed to difference in quantities of light and heat received at the water surface, hence amount transferred into the water column. The rainy months from mid-March to May tended to have relatively lower temperatures than the dry seasons between February and early March. This could have been attributed to the opening of the canopy at the farmland and rangeland sites. According to environmental monitoring studies in Southern Brazil (Lobo *et al.*, 1996; Oliveira *et al.*, 2004; Lobo *et al.*, 2004; Salomoni *et al.*, 2006) showed that algal periphyton community composition and biomass in lotic ecosystems are a result of changes in temperature. This observation agrees with this research findings that found that *Limnothrix* and *Lyngbya* spp absent in the periphyton communities within the forest but became dominant in the farmland and rangeland sites where temperatures had increased markedly. In addition, from the results it was noted that temperature was the most important factor other than discharge in predicting periphyton productivity response. This observation agrees with Lee (1999), who found that productivity of many algal periphyton species is at maximum when temperatures is optimum (20-22°C).

The increase in electrical conductivity observed from the month of February to May in farmland and Rangeland sites could be attributed to the increase in loading of sediments rich in ions from the catchment into the river as it flows downstream, as a consequence of the increased surface runoffs caused by increased rainfall. The rainfall results into washing of nutrients and other ions from the catchment into the rivers thus increasing the ionic concentration in the river. Electrical conductivity was noted to increase from forested to rangeland site, a characteristic attributed to the increased deposition of ions as a result of increased cumulative effects of catchment runoffs downstream. The results of this study indicated a positive correlation between electrical conductivity and discharge similar to an observation made by Aweng-Eh *et al.*, (2010). The implication is that surface runoff increases movement of ion from the catchment into the water column which consequently increases the discharge in the river channel. Increase in discharge results to cumulative effect of the ions from the catchment as well as increase of in-stream processes particularly re-suspension of the sediment and associated ions, hence increase in conductivity.

High dissolved oxygen (DO) was recorded at the forested reaches located upstream presumably due to high turbulence which enhances mixing of atmospheric air with the river water. This turbulence is due to more rapids and falls in the upper reaches. In addition, algal periphyton photosynthesis may have contributed to the high DO concentration upstream. Oxygen concentration in aquatic ecosystems is temporally and spatially more variable than on land due to water turbulence and mixing with atmospheric air (ANZECC, 1997). Generally upstream of rivers have high riffle sections and therefore experience eddying currents that enhance dissolution of oxygen in the water (ANZECC, 1997). Lack of both riffles and intermittent pools in lowland reaches reduces the rate of turbulence and thus lowers the dissolution of atmospheric oxygen in the water. The oxygen concentrations obtained ranged between 6-8 mgl^{-1}. The minimum oxygen level needed for survival of most aquatic organisms including algal periphyton is 5 mgl^{-1} (ANZECC, 1997). The relatively low oxygen concentrations recorded in farmland and rangeland sites could be attributed to reduced turbulence as the river becomes more gentle (Nilsson and Malm 2008).

Total Suspended Solids (TSS) are normally associated with soil erosion along the river channel and siltation from runoffs from the catchment. TSS content at the Nyangores tributary showed significant variations in most of the sites at different months which indicate changes in rates of sediment loading from upstream at different times, mainly associated with rainfall patterns with the observed high values in May coinciding with the rainy season. High TSS contents observed downstream can be attributed to the cumulative effects of surface runoffs coupled with the poor riparian vegetation cover due to clearing of vegetation along the river for farmland and charcoal burning downstream. Keeping of large number of domestic animals, mainly cattle and sheep around this area of the rangeland also causes overgrazing and opening up of soil thus enhancing soil erosion in this zone. This observation is supported by studies carried out by Johnson *et al.*,(2005) on various rivers of Southwest Ireland, whose results showed significant differences in suspended solids content due to changes in vegetation cover of the riparian zones along the rivers. Hondzo and Wang (2002) pointed that increased TSS mask the growth of periphyton due to light inhibition. However the result from this study showed that TSS was not as critical as temperature in determining algal periphyton productivity in the Nyangores tributary. This could be due to the fact that the algal periphyton were found on stable substrates such as rocks and the wooden substrates.

Generally pH range in this river is around neutral range (6.0 to 8.3) a condition always attributed to the nature of the soils and geology of the catchment (Bailey *et al.,* 1984). In addition pH values in rivers is dependent on anthropogenic inputs and bedrock properties (Yang *et al* 2010) and it influences growth and composition of aquatic biota (Lepori *et al.,* (2003). Therefore it can be deduced that the inorganic and organic materials discharged into Mara river did not lower or increased the pH to a greater magnitude. The slight increase in pH observed at the rangeland site in the month of May could have been attributed to use of fertilizers in the catchment and subsequent loading to aquatic environment through surface runoff into the river.

5.2 Relationship between nutrient and discharge

The relationship between discharge and nutrient is important in determining the algal community in a river. Discharge was shown to significantly influence SRP and TP at the farmland and forested sites in Nyangores tributary respectively. This can be attributed to the fact that increased discharge causes decomposing plant debri which are the main source of SRP in the forest to be flashed into the river (Dodds, 2003). In addition, the significant increase in TP and NO_3-N at the Farmland site was observed by WQBAR (2007), who conducted similar studies in the same river and attributed it to anthropogenic activities such as use of fertilizers in the farmlands as well from detergents used in washing clothes and vehicles of which the latter activities were pronounced in this site. Most detergents contains Phosphorus as ingredients. The increase in NO_2-N levels in the Farmland site could be attributed to high microbial decomposition activities as indicated by low oxygen in this site. Moreover, the urban waste from Bomet town which was discharged into the river at this site could have resulted to high biological demand for oxygen (BOD) which was found to be 20 mgL^{-1} (Rop's Thesis 2014). Due to this high BOD, the macroinvertebrate that was found to be tolerant at this site was *Chironomidae* spp (Chepkemboi's Thesis 2014). The low oxygen concentration due oxidative process can be attributed to increasing levels of Nitrite which is the unstable form of Nitrite. In addition there was high concentration of ammonia ($184 \mu gl^{-1}$).

Nutrients availability in aquatic systems is a major factor influencing growth of the aquatic flora, were high biomass of aquatic plants including algae are associated with high nutrient content and vice versa (Dodds, 2003). Both plants and algae require phosphorus and nitrogen as primary nutrients essential for their growth. However both nitrogen and phosphorus contents in the Nyangores tributary were moderate in concentration upstream and increased downstream together with increase in discharge. According to studies by Wetzel (1983), nutrients concentrations vary seasonally due to human activities and metabolism of terrestrial vegetation in watersheds ; diurnally with microbial metabolism and daily with weather related hydrologic factors and increase in biomass and nutrient uptake particularly during periphyton community development after storms.. The farmland and rangeland sites were highly disturbed with clearance of riparian vegetation, which facilitated runoff into the Nyangores tributary bringing in nutrients from the catchment into the river. Contribution of agricultural fertilizers and animal wastes from the catchment cannot be ignored as it is known to enhance nutrients concentrations in the adjacent river sites.

5.3 Relationship between algal periphyton community structure and nutrient concentrations

Periphyton require specific optimum environmental conditions such as optimum temperature, dissolved oxygen, electrical conductivity and pH for rapid growth and reproduction (Francoeur 2001). Changes in these conditions influence them either directly or indirectly through their growth and biomass. Dodds (2003) showed that variation in periphyton biomass among streams is related to nutrient concentrations. Biggs (2000) related periphyton biomass to soluble nutrients such as SRP and NH_4-N. The increased amounts of nutrients coupled with slight increase in discharge could explain the significant increase in biomass of *Surirrella* sp, *Fragilaria* sp, *Limnothrix* sp, *Lyngbya* sp and *Cymbella* sp at the rangeland site (Bomet, Olbutyo and Confluence stations). However it was observed that increase in nutrients as a result of high discharge, resulted to significant decline in the biomass of *Closterium* sp at the rangeland site. This could be attributed to the fact that *Closterium* tend to grow at the lower layers of periphyton mats from which they may not efficiently get adequate nutrients from the overlying water. Similar observation have been reported by Stevenson and Glover (1993) elsewhere. Other periphyton species such as *Surirrella* sp, *Fragilaria* sp, *Limnothrix* sp, *Lyngbya* sp and *Cymbella* sp tend to occur at the surface of the algal mat (Glover 1993), thus having a better chances to access the nutrients from the water, hence increase in their biomass. According to Pringe (1990) found that algal taxa in the upper layers of periphyton appeared to interfere with inorganic nutrient procurement by understorey sessile taxa such as *Closterium* sp. Thus nutrients may become limiting within periphyton mats even when nutrients supply in the water column is constant or abundant. A similar trend of periphyton growth and decrease in biomass was reported by Francoeur (2001) in Michigan and Kentucky streams where extensive growths of periphyton in high nutrient streams was due to less frequent flood disturbances.

The occurrence of high biomass of some algal periphyton species such as *Fragilaria* sp in low nutrients conditions in some of the sites in Nyangores tributary could be attributed to their fast growth rates and abilities to exploit resources more effectively than others which leads to their dominance in periphyton community (Stevenson and Glover 1993). The biomasses of *Navicula* sp and *Limnothrix* sp did not show significant correlation with nutrient concentration. Such species could be classified as tolerant to changes in environmental conditions and particularly nutrients. *Limnothrix* sp was observed to occur in farmland sites and rangeland sites rather than the forested site. These sites were highly disturbed with a lot of nutrients influx. Therefore, it can be deduced that Limnothrix prefers a nutrient rich environment with high light intensity hence not a good indicator of good water quality in the Nyangores tributary.

Development of algal periphyton biomass may also be affected by other factors such as the grazing pressure and the changes in river discharge. Wootton *et al.,(*1996) observed that frequent disturbances brought by storm events reduce the ability of algal periphyton to recolonize by scouring them off from the substrata. In areas with very low disturbance regimes such as groundwater-fed streams having hydrologically stable streams one would expect thick mats of algal periphyton. However such areas may also have high densities of grazers which may again constrain algal periphyton biomass accumulation. Thus, the greatest response of periphyton biomass to discharge is most likely when discharge is moderate thus allow periphyton growth and do not dislodge them.

Excess nutrients results in decline of some species and emergence of others. In Nyangores there was decrease in *Closterium* sp but with the emergence of *Limnothrix* sp at the farmland site with increased nutrients concentrations. For this reason it can be deduced that the filamentous *Limnothrix* sp accumulated in nutrient rich sections of Nyangores tributary rather than the forested areas with minimal or low nutrient concentrations. Other studies have also shown that diatoms with more complex morphologies such as *Fragilaria ulna* thrive in nutrients rich waters and also in r-selected habitats which are usually unpredictable and disturbed (Biggs *et al*., 1998). In addition *Gomphonema* sp and *Navicula* sp were frequent in the assemblages in Nyangores tributary, concurring with the observations of Juttner *et al*., (2003) who reported that diatom communities might respond differently to changes in nutrient concentrations. These studies also found that *Navicula cryptocephala* significantly increased in abundance in nutrient enriched sites (Biggs *et al*., 1998). *Gomphonema* sp were reported by Fukushima *et al*., (1994) in rivers Toriyama and Izumi in Japan which had high nutrients concentrations from sewage treatment plants and domestic waste effluents. In this study *Gomphonema* sp were relatively high in farmland site which also received nutrients rich discharge from Tenwek sewage treatment plant. Furthermore, in River Ter (Catalonia, NE Spain), Sabater and Sabater (1988) reported that *Gomphonema parvulum*, (Kutz.) developed in sites that received high agricultural wastes.

Generally, members of the bacillariophyta with the highest percentage in biomass are the most important primary producers in Nyangores followed by cyanophyta. The extreme pollution resistant genera of bacillariophyta such as *Gomphonema* sp and *Navicula* sp documented by Juttner *et al*.,(2003) dominanted the genera identified for Nyangores tributary especially the farmland site which had high nutrient concentration. Stevenson and Glover (1993) pointed that *Gomphonema* and *Navicula* spp have fast growth rates and abilities to monopolize space as well as high nutrient conditions similar to conditions found in the farmland areas of the Nyangores tributary.

5.3 Algal periphyton diversity and biomass changes in Nyangores tributary

There was generally low diversity of algal periphyton as given by the low Shannon Wiener diversity index (H). The rangeland site was more disturbed and therefore a less stable environment hence lower H values obtained agreeing with Potapova and Charles (2003) and Duong *et al*., (2006) who argue that increased disturbance results into disappearance of some algal species and the dominance of tolerant species. The site bearing the most diverse (H) community was the farmland site hence can be considered as less disturbed with more stable environmental conditions. This result agrees with Murdock *et al*., 2004.

The forested site had low nutrient while the farmland site had relatively high nutrient that may have affected distribution in terms of evenness (Chételat *et al*.,1999). In terms of species richness, there was appearance of *Lyngbya* and *Limnothrix* species at farmland site which contributed to increased species richness in this site. This result agrees with Potapova and Charles (2003) findings working on benthic diatoms in numerous USA rivers who established that moderate disturbance due to moderate discharge results to high species richness.

The common periphytic diatoms genera that included *Surirrella*, *Gomphonema* sp, *Nitzschia* sp and *Fragilaria* sp accounted for large proportion of the community in all the sites in terms of biomass. *Surirrella* sp and *Fragilaria* sp have been observed to prefer neutral to low pH, and low conductivity of about 10µS/cm similar to the results obtained during this study in the forest station. In contrast *Gomphonema* sp, *Nitzschi*a sp and *Navicula* sp thrived in wide pH and conductivity ranges. According to the study done by Kinyua and Pacini (1991), the level of pH was identified as one of the factors that can have direct effect on the algal periphyton community structure. When the pH changes, it adversely impact on non-tolerant periphyton species, which may decline. This would result to periphyton community dominated by a certain tolerant taxa (Sutcliffe and Hildrew, 1989). The normal pH range for freshwater aquatic systems ranges between 6 to 9 (Boney, 1989). Most periphyton are sensitive to rapid pH changes and survive within the optimum ranges.

Lobo *et al.* (2004) considered *Gomphonema* sp, the most abundant genus at downstream eutrophic sites with high nutrients concentrations and documented them as pollution tolerant species for his study . *Gomphonema* sp was abundant at farmland and rangeland sites located at Nyangores downstream, hence comparable to the findings by Lobo *et al.* (2004). In streams located in the Municipal District of Mato Leitão (Brazil), Lobo *et al.* (2004) classified this genera as belonging to polysaprobic environments. In the same streams, Potapova and Charles (2003) registered the occurrence of this genera in moderately polluted waters. Other studies carried out in rivers in Japan confirmed the observation that this genera is tolerant to inorganic pollutants (Kobayasi and Mayama, 1989; Lobo *et al,* 1996). Similarly, Whitton and Kelly (1995), working in UK rivers described this species as highly tolerant to nutrient enrichment. *Nitzschia sp* and *Gomphonema sp* are commonly reported to be tolerant to high nutrients concentration and inorganic pollution and have been frequently recorded in waters that are nutrient rich and poorly oxygenated (Duong *et al*., 2006).

5.4 Periphyton productivity changes in Nyangores tributary

Periphyton productivity in Nyangores had a maximum value of 2.85 x 10^{-6} mgCm^{-2}day^{-1} at the forested site. This was extremely low as compared to the average periphyton productivity in some other rivers such as Shark River Slough (SRS) which ranged between 55.89 to 223.56 mgCm^{-2}day^{-1} according to Sharon *et al.*, (2006). The low periphyton productivity in Nyangores could be as a result of relatively low nutrient levels and low light climate because of the forest cover. This experiment was done in a first order stream where nutrients concentrations are generally low while the SRS is a third order stream. In addition, the experiments at SRS were conducted at the river mouth where nutrients concentrations were very high. The algal periphyton productivity values in SRS were among the highest values in the world. According to Conclaves (2007), tropical rivers have low algal periphyton productivity because of low nutrient content compared to temperate rivers, which have high algal periphyton productivity due to increased nutrients input washed from commercial farms using high amounts of fertilizer to grow crops. According to studies conducted by Conclaves (2007), NO_3-N which is one of the key nutrient influencing algal periphyton productivity was as low as 0.05 mgl^{-1} in Cerrado River which is a tropical river as compared to an average of 1.06 mgl^{-1} in most temperate stream.

Algal periphyton productivity estimated for Nyangores tributary was high at the forested site. This observation was similar to studies by Minshall (1967) working in Columbia River where some small streams at the catchment of this river had very high productivity especially those with sufficient NH_4-N and SRP concentrations and flowing through less dense forests with open canopy cover. In Nyangores tributary, it was observed that NH_4-N, NO_3-N, TP and SRP appeared to account for the ability to predict productivity in Nyangores tributary. According to Mosisch *et al.*, (1999), nutrient concentrations can affect periphyton productivity but nutrient limitation occurs only if light conditions are favorable. This is in contrast with the results of this study which showed that periphyton productivity was lowest at the rangeland where nutrient concentrations were highest in the month of May. The high primary production measurements made in rangeland site, partially support the fact that there was greater cumulative periphyton abundance on the substrates in this site (Mosisch *et al.*, 2001). In addition, Rosemond (1994) observed that periphyton productivity in some streams can be primarily limited by light and secondarily limited by nutrient. It can be argued that the periphyton productivity in this study was neither light limited nor nutrient limited since light and nutrient were available in adequate quantities (Reynolds and Descy, 1996). However with the increase in water level, there was a reduced light reaching the substrate resulting to low productivity in the rangeland site. In addition, multiple factors could be attributed to reduced periphyton productivity downstream of this river; for example TSS and discharge which scoured and dislodged the periphyton biomass from the susbstrata hence reducing the standing crop resulting to low productivity (Mallin *et al.*, 2004) at the rangeland site. According to Borduqui *et al.*, (2008) algal periphyton productivity was coupled to its biomass increase. This findings agrees partly with this study since high biomass in some downstream sites did not translate to increased productivity. However, this could be attributed to other factors influencing biomass accumulation such as discharge.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusion

1. Nutrients concentrations increased significantly both temporally and spatially along Nyangores stream with increased discharge downstream. This was influenced greatly by the effect of land use on catchment hydrology, as noted during the months of April and May when discharge was at peak.

2. Algal periphyton community structure and biomass varied significantly with the changing nutrients concentrations. Therefore the composition of periphyton assemblages is a useful metric to assess potential effects of land use at the catchment of riverine ecosystem. However, other physico-chemical variables are also potentially important in controlling periphyton distribution.

3. Generally very low periphyton productivity was found (2.85×10^{-6} $mgCm^{-2}day^{-1}$) as compared to other river systems such as Shark River Slough (223.56 $mgCm^{-2}day^{-1}$).

6.2 Recommendation

On the basis of the findings from this study, it is recommended that;

1. The catchment and riparian areas of this river be well managed through re-forestation programmes to stabilize the catchment areas and lower excess nutrient influx into the river caused by increased surface runoffs.

2. There is need for continuous monitoring of the rivers physical, chemical and biological variables in order to understand the effects of climate variation on its ecology and develop the right mitigation and management measures. This can be done by developing periphyton indices that reflects the local environmental changes and therefore can be applied in local scenario to monitor water quality in rivers.

3. Studies of periphyton productivity may be used to cement the indices developed for holistic river biomonitoring approach. Therefore more studies should be done on periphyton productivity in the Mara River.

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APPENDICES

Appendix Table 1. Physicochemical parameters

Month	Site		Conduct. (µS/cm)	Temp(°C)	TSS (mg/l)	DO (mg/l)
February	Forested	Mean ±S.D	10.93±0.42	17.65±0.95	6.86±0.22	7.76±0.3
		min-max	10.63-11.23	16.98-18.33	6.71-7.01	7.55-7.97
	Farmland	Mean ±S.D	43.18±2.39	20.56±0.07	34.56±1.27	6.61±0.08
		min-max	40.63-45.37	20.5-20.63	33.13-35.57	6.55-6.7
	Rangeland	Mean ±S.D	93.36±1.6	18.84±2.76	58.67±1.26	7.14±0.06
		min-max	92.28-95.20.14	15.77-21.12	57.75-60.1	7.1-7.21
March	Forested	Mean ±S.D	11.5±0.14	14.34±0.14	30.46±2.35	8.08±0.07
		min-max	11.4-11.6	14.24-14.43	28.8-32.13	8.03-8.13
	Farmland	Mean ±S.D	72.3±5.52	18.86±0.21	51.75±0.25	7.26±0.05
		min-max	62.3-78.22	18.62-18.99	51.46-51.93	7.21-7.31
	Rangeland	Mean ±S.D	113.96±1.55	20.85±1.01	81.39±2.09	6.84±0.24
		min-max	112.23-115.21	20.01-21.97	79.37-83.53	6.56-7
April	Forested	Mean ±S.D	13.47±2.03	14.01±0.12	50.1±1.28	8.09±0.11
		min-max	12.03-14.9	13.93-14.1	49.2-51	8.01-8.17
	Farmland	Mean ±S.D	85.79±1.29	17.27±0.35	136.75±1.51	7.03±0.04
		min-max	84.37-86.87	16.94-17.63	135.13-138.11	7-7.07
	Rangeland	Mean ±S.D	110.79±6.35	18.38±0.56	249.25±2.21	6.38±0.07
		min-max	106.17-118.03	17.73-18.77	247.01-251.41	6.31-6.45
May	Forested	Mean ±S.D	19.2±1.37	14.87±2.9	73.39±1.31	7.51±0.08
		min-max	18.23-20.17	12.82-16.92	72.47-74.31	7.46-7.57
	Farmland	Mean ±S.D	92.87±1.22	15.9±0.24	162.04±3.21	6.78±0.11
		min-max	91.87-94.24	15.66-16.15	158.97-165.37	6.67-6.89
	Rangeland	Mean ±S.D	143.28±2.99	19.26±1.39	351.77±1.4	6.13±0.09
		min-max	140.15-146.12	17.85-20.62	350.6-353.32	6.03-6.2

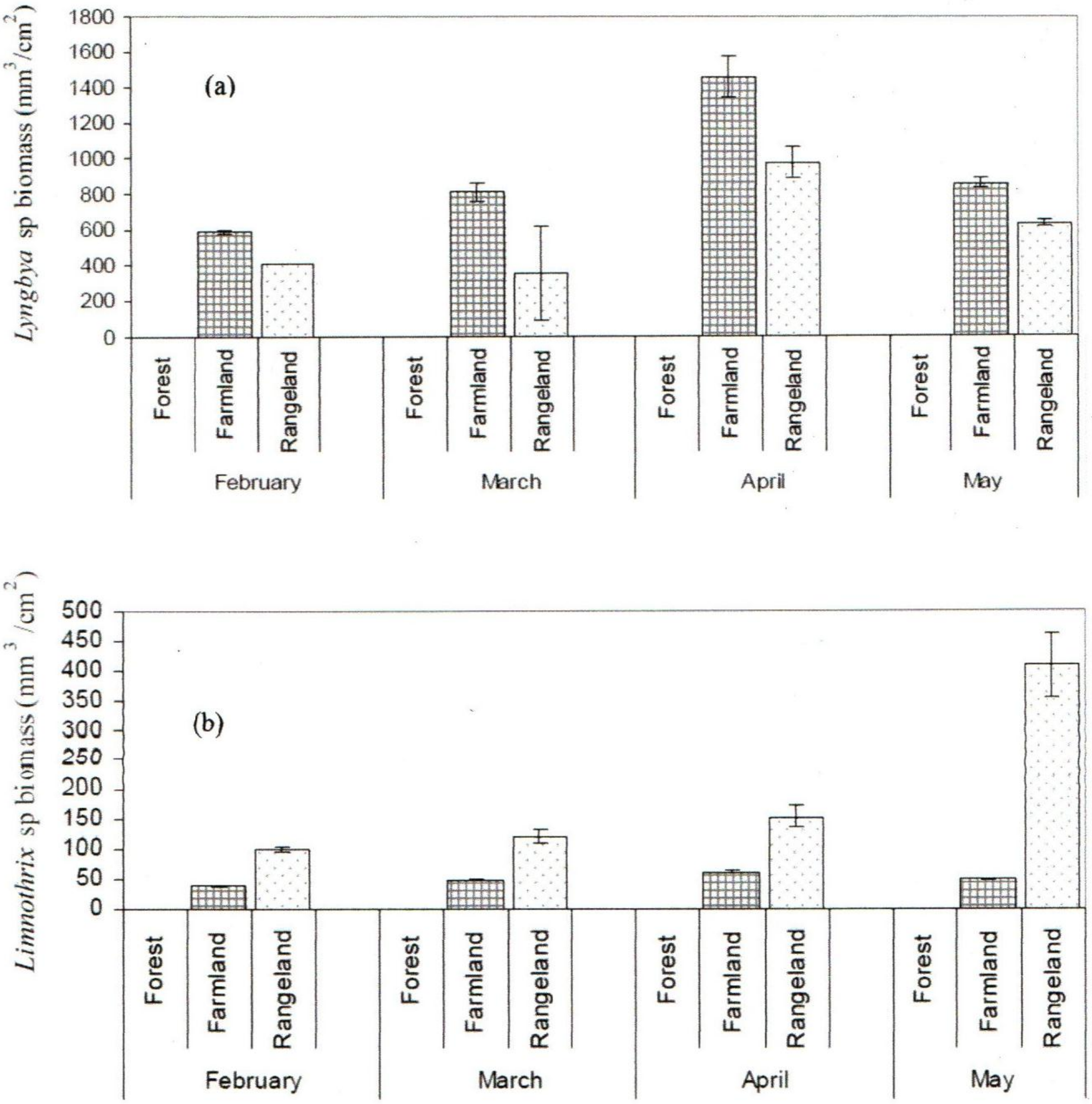
Appendix Table 2: pH data at various sampling points

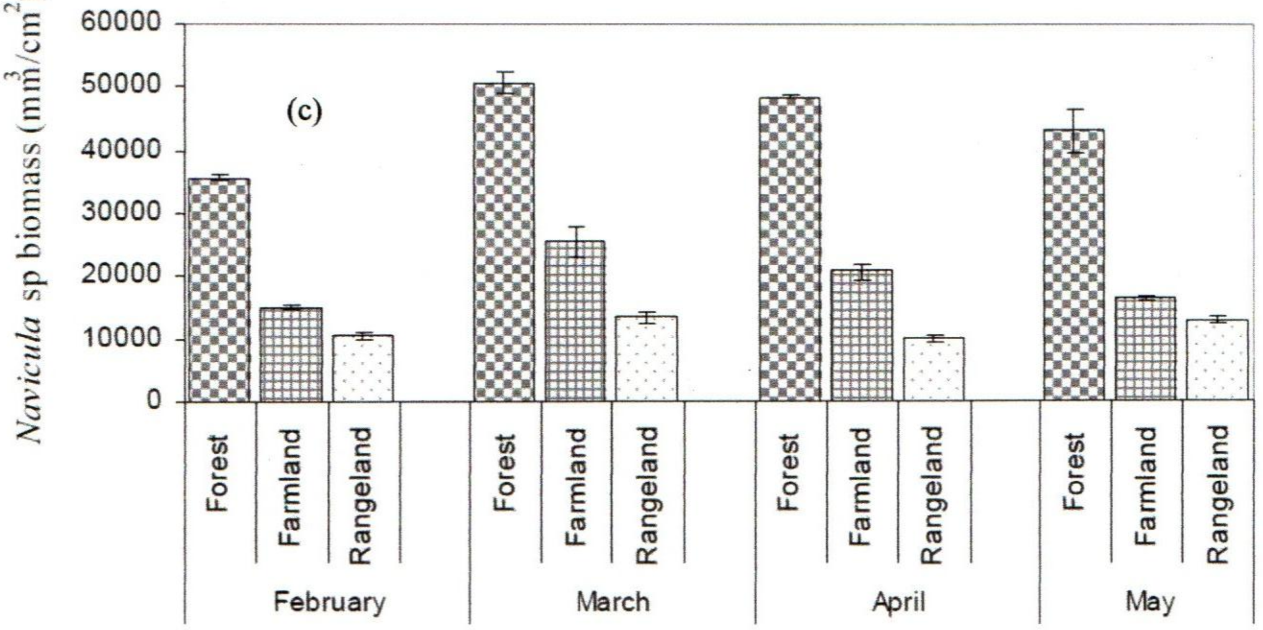
Month	Site	Minimum	Maximum	Range
February	Forested	6.1	6.3	0.2
	Farmland	6.8	7.3	0.6
	Rangeland	7.2	7.4	0.3
March	Forested	6.2	6.2	0.0
	Farmland	7.3	8.0	0.8
	Rangeland	7.2	7.9	0.7
April	Forested	6.8	7.4	0.4
	Farmland	7.7	8.0	0.3
	Rangeland	7.9	8.1	0.2
May	Forested	7.3	7.5	0.2
	Farmland	7.9	8.0	0.1
	Rangeland	8.2	8.3	0.1

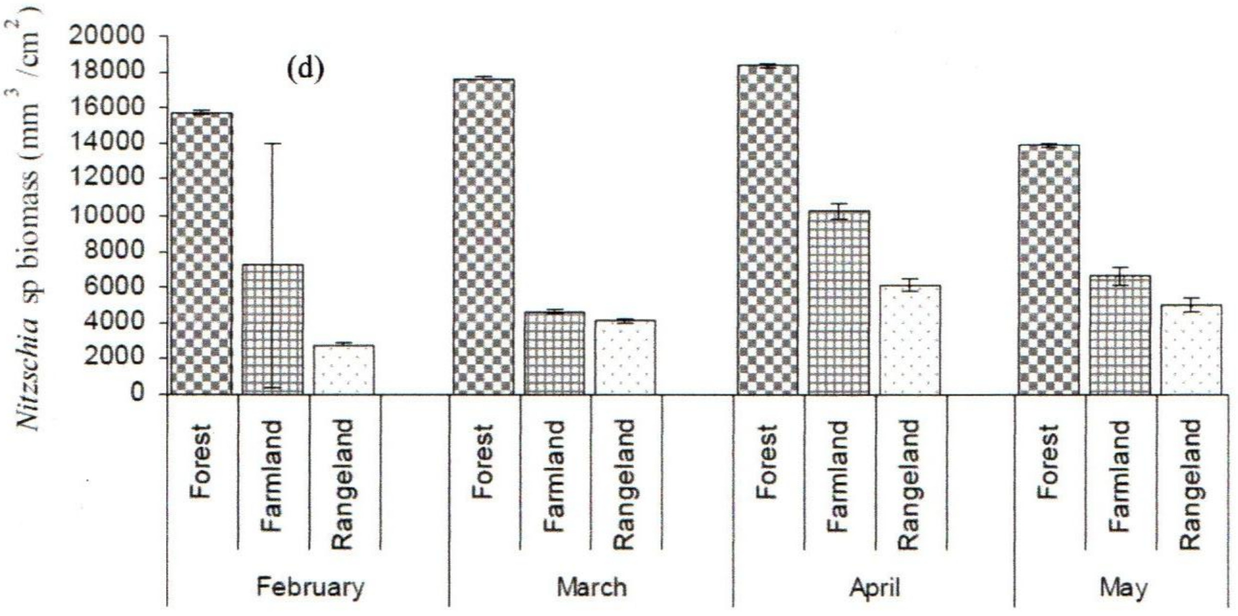
Appendix Table 3: Summary results for discharge (m^3s^{-1})

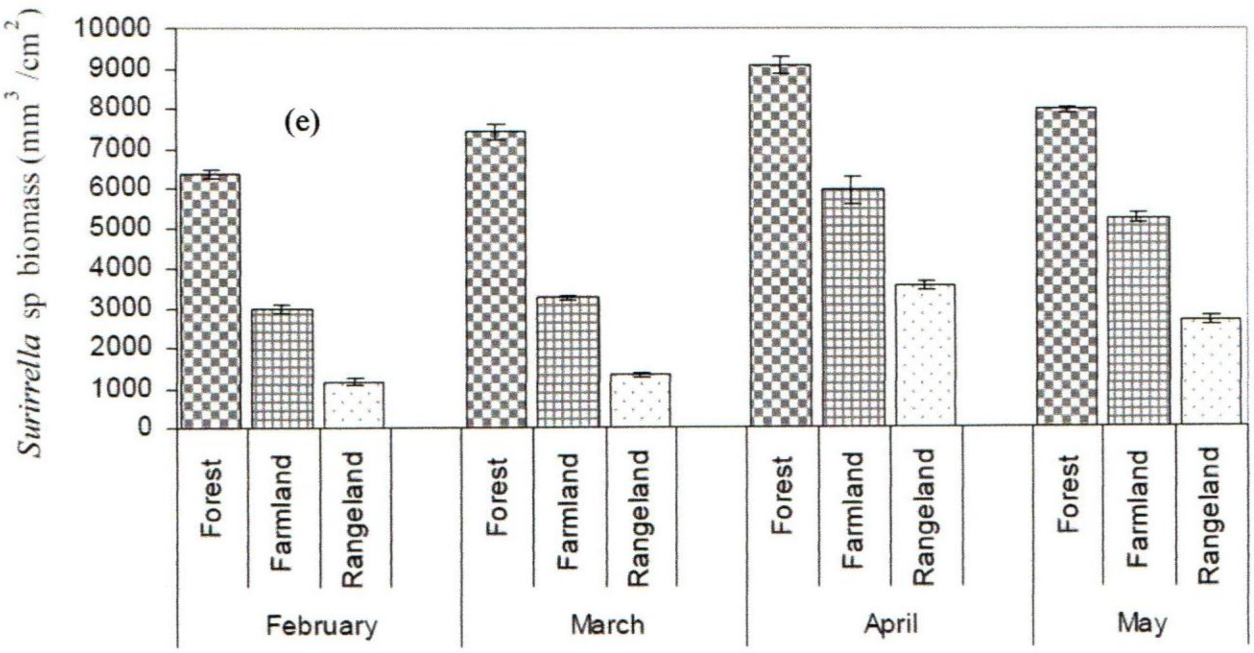
Month	Site	Mean±S.D	Minimum	Maximum	Range
February	Forested	0.03	0.03	0.03	0.00
	Farmland	0.61±0.06	0.55	0.68	0.13
	Rangeland	1.24±0.32	1.00	1.60	0.60
March	Forested	0.54±0.01	0.53	0.54	0.01
	Farmland	1.25±0.07	1.17	1.30	0.14
	Rangeland	2.44±0.32	2.12	2.77	0.65
April	Forested	0.62±0.01	0.61	0.62	0.01
	Farmland	3.56±0.20	3.36	3.76	0.40
	Rangeland	4.57±0.07	4.53	4.65	0.12
May	Forested	0.70±0.11	0.62	0.78	0.16
	Farmland	4.39±0.18	4.22	4.58	0.36
	Rangeland	5.86±0.51	5.34	6.36	1.02

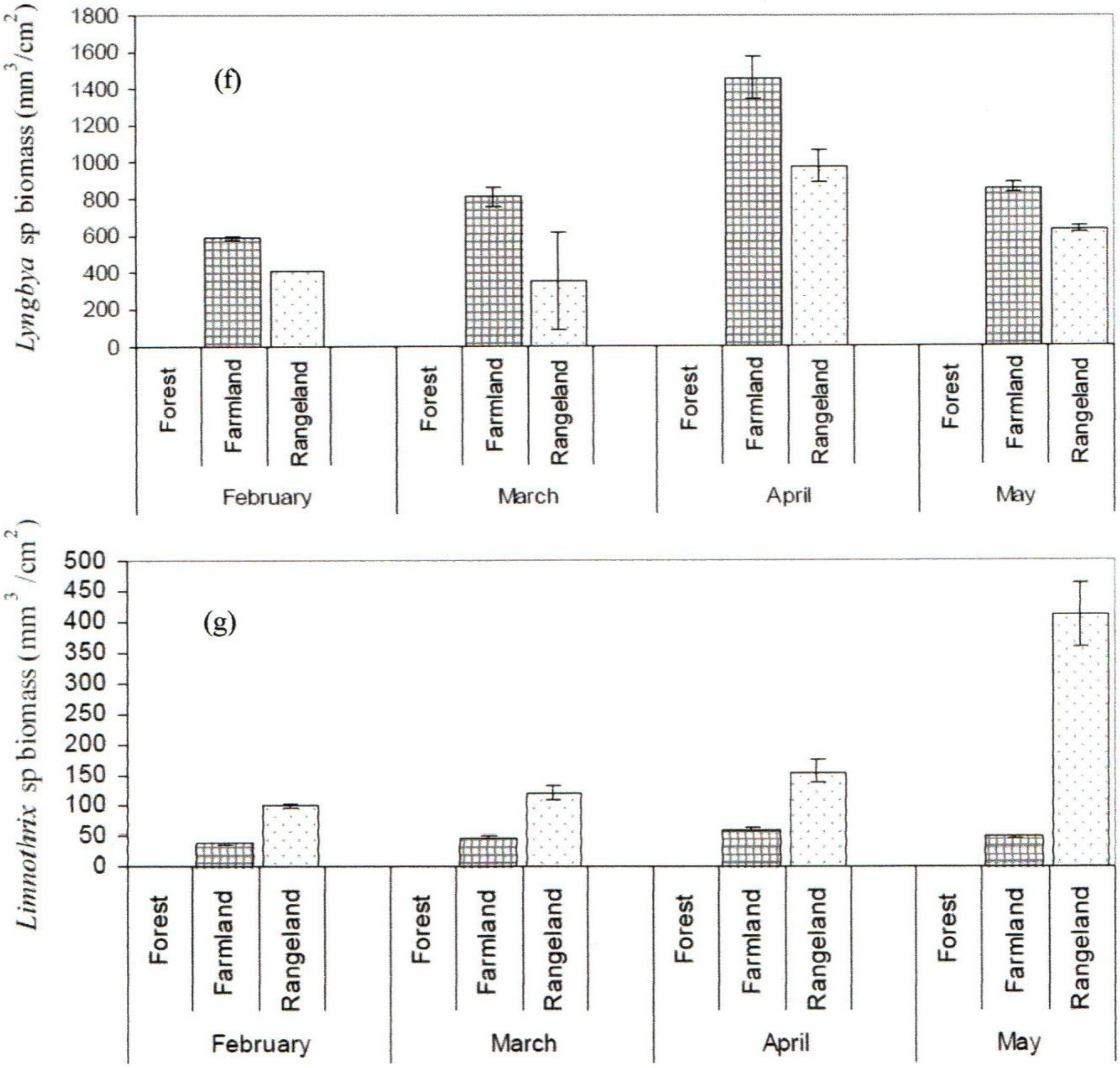
Appendix Figure 1. Graphs of temporal changes in periphyton biomasses

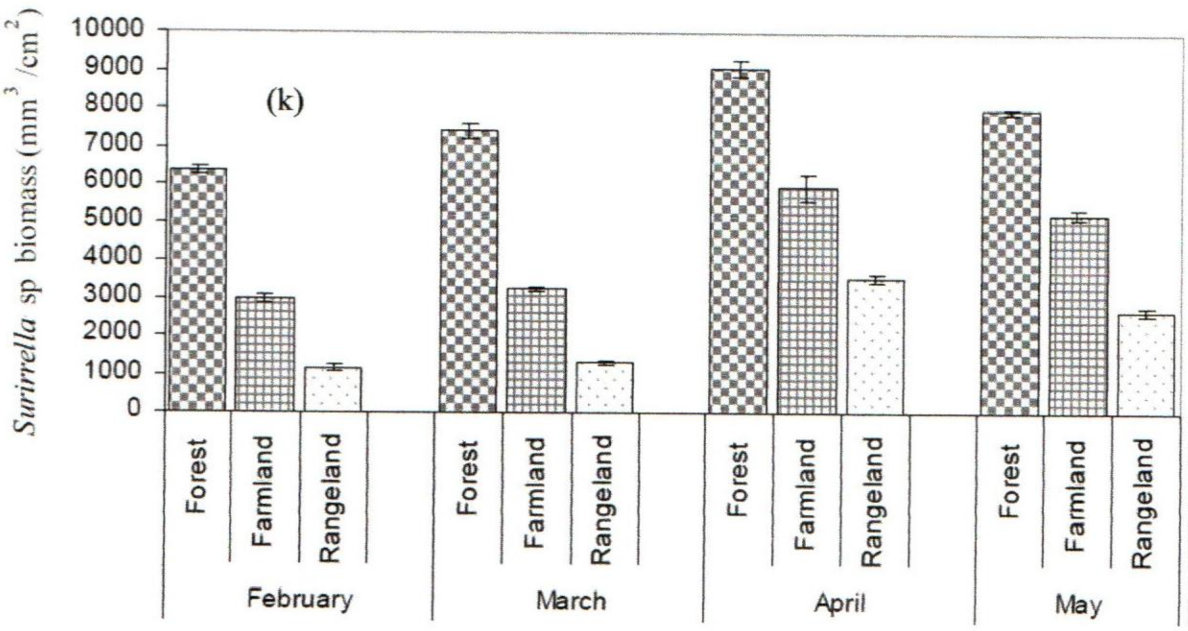



(c)
Navicula sp biomass (mm3/cm2)
60000
50000
40000
30000
20000
10000
0
Forest
Farmland
Rangeland
February
March
April
May


(d)
Nitzschia sp biomass (mm 3 /cm 2)
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Forest
Farmland
Rangeland
February
March
April
May


Surirrella sp biomass (mm³ /cm²)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
(e)
Forest
Farmland
Rangeland
Forest
Farmland
Rangeland
Forest
Farmland
Rangeland
Forest
Farmland
Rangeland
February
March
April
May


(f)
Lyngbya sp biomass (mm^3/cm^2)
0
200
400
600
800
1000
1200
1400
1600
1800
Forest
Farmland
Rangeland
February
March
April
May
(g)
Limnothrix sp biomass (mm^3/cm^2)
0
50
100
150
200
250
300
350
400
450
500


Surirrella sp biomass (mm^3/cm^2)
(k)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Forest
Farmland
Rangeland
February
March
April
May

Appendix Table 4: Periphyton species biovolumes raw data

Site	Date	*Surirrella* sp	*Fragilaria* sp	*Navicula* sp	*Limnothrix* sp	*Nitschia* sp	*Lyngbya* sp	*Gomphonema* sp	*Cymbella* sp	*Closterium* sp
Forest	2-Feb-12	0.002255	0.003247	0.012422	0	0.000851	0	1.32E-05	0.000618	0.000947
Forest	2-Feb-12	0.005218	0.041563	0.027375	0	0.009932	0	7.94E-05	0.000546	0.000837
Farmland	2-Feb-12	0.002319	0.027276	0.035426	0	0.011493	0.073015	0.000113	0.000166	0.000255
Farmland	2-Feb-12	0.000773	0.009092	0.00276	13.50778	0.00298	0.328568	0.000243	0.000214	0.000328
Farmland	2-Feb-12	0.000386	0.01169	0.008742	2.161244	0.002128	0.29206	0.000106	7.13E-05	0.000109
Rangeland	2-Feb-12	0.000515	0.000649	0.003911	0	0.002554	0.036508	9.05E-05	0.000356	0.000546
Rangeland	2-Feb-12	0.000451	0.013638	0.007821	0	0.001703	0.255553	7.5E-05	0.000523	0.000801
Rangeland	2-Feb-12	0	0.007144	0.003681	0.270156	0.002554	0.036508	3.97E-05	2.38E-05	3.64E-05
Forest	28-Feb-12	0.002319	0.002598	0.014032	0	0.001419	0	1.99E-05	0.000546	0.000837
Forest	28-Feb-12	0.004767	0.044161	0.036116	0	0.011067	0.048677	0.000104	0.000428	0.000655
Farmland	28-Feb-12	0.002577	0.052603	0.029445	0	0.011351	0.097353	0.000108	0.000546	0.000837
Farmland	28-Feb-12	0.001546	0.009741	0.002991	15.39886	0.003121	0.401583	0.000243	0.00019	0.000291
Farmland	28-Feb-12	0.00058	0.01169	0.009892	2.161244	0.002696	0.279891	0.000113	0.000214	0.000328
Rangeland	28-Feb-12	0.001353	0.001299	0.005061	0	0.003263	0.085184	0.00011	0.000356	0.000546
Rangeland	28-Feb-12	0.001288	0.009092	0.009662	0	0.003263	0.29206	7.94E-05	0.000546	0.000837
Rangeland	28-Feb-12	0.000451	0.014937	0.003911	1.620933	0.002554	0.036508	4.41E-05	7.13E-05	0.000109
Forest	10-Mar-12	0.002899	0.005845	0.015643	0	0.00298	0	4.63E-05	0.000784	0.001201
Forest	10-Mar-12	0.005862	0.059097	0.042327	0	0.013479	0	9.49E-05	0.000546	0.000837
Farmland	10-Mar-12	0.004251	0.052603	0.041637	0	0.014472	0.133861	0.000117	0.000808	0.001238

		Surirrella	*Fragilaria*	*Navicula*	*Limnothrix*	*Nitschia*	*Lyngbya*	*Gomphonema*	*Cymbella*	*Closterium*
Site	Date	sp	sp	sp	sp	sp	sp	sp	sp	sp
Farmland	10-Mar-12	0.002126	0.014287	0.004601	17.56011	0.003405	0.474598	0.00028	0.000428	0.000655
Farmland	10-Mar-12	0.001031	0.014937	0.010582	4.862799	0.003547	0.365075	0.000113	0.000285	0.000437
Rangeland	10-Mar-12	0.001482	0	0.008281	0	0.003689	0.194707	0.000108	0.000428	0.000655
Rangeland	10-Mar-12	0.001417	0.01169	0.010352	0	0.00298	0.29206	0.000104	0.000594	0.00091
Rangeland	10-Mar-12	0.000644	0.015586	0.004831	2.4314	0.001845	0.060846	5.3E-05	0.000143	0.000218
Forest	25-Mar-12	0.004123	0.010391	0.017713	0	0.00454	0	7.28E-05	0.001022	0.001565
Forest	25-Mar-12	0.006184	0.059747	0.044398	0	0.014756	0	0.000115	0.00076	0.001165
Farmland	25-Mar-12	0.003672	0.040914	0.043018	0	0.01504	0.255553	0.00013	0.00095	0.001456
Farmland	25-Mar-12	0.002705	0.020782	0.006901	21.8826	0.004682	0.58412	0.0003	0.000642	0.000983
Farmland	25-Mar-12	0.00161	0.020782	0.013112	7.564354	0.004682	0.365075	0.000117	0.000499	0.000765
Rangeland	25-Mar-12	0.002319	0	0.010812	0	0.004824	0.29206	0.000135	0.00057	0.000874
Rangeland	25-Mar-12	0.002255	0.017534	0.012652	0	0.004682	0.304229	0.000126	0.000713	0.001092
Rangeland	25-Mar-12	0.001353	0.021431	0.006901	6.213577	0.003405	0.182538	7.94E-05	0.000356	0.000546
Forest	7-Apr-12	0.004316	0.012339	0.017713	0	0.004824	0	7.94E-05	0.001093	0.001675
Forest	7-Apr-12	0.00657	0.064293	0.038647	0	0.014047	0	0.000124	0.000832	0.001274
Farmland	7-Apr-12	0.004316	0.058448	0.035426	0	0.015182	0.29206	0.00015	0.000998	0.001529
Farmland	7-Apr-12	0.002899	0.03377	0.008281	22.15275	0.005108	0.693643	0.000305	0.00076	0.001165
Farmland	7-Apr-12	0.001546	0.02273	0.014032	8.104665	0.005108	0.462428	0.000132	0.000499	0.000765

Site	Date	*Surirrella* sp	*Fragilaria* sp	*Navicula* sp	*Limnothrix* sp	*Nitschia* sp	*Lyngbya* sp	*Gomphonema* sp	*Cymbella* sp	*Closterium* sp
Rangeland	7-Apr-12	0.002319	0	0.011042	0	0.005675	0.401583	0.000141	0.000665	0.001019
Rangeland	7-Apr-12	0.002126	0.020132	0.011042	0	0.004257	0.401583	0.000119	0.000523	0.000801
Rangeland	7-Apr-12	0.001353	0.021431	0.007591	5.943421	0.003263	0.219045	7.28E-05	0.00038	0.000582
Forest	28-Apr-12	0.004187	0.02273	0.020244	0	0.005959	0	0.00011	0.001307	0.002002
Forest	28-Apr-12	0.005862	0.069488	0.042097	0	0.015324	0	0.00013	0.000832	0.001274
Farmland	28-Apr-12	0.004702	0.058448	0.045548	0	0.016317	0.401583	0.00017	0.00114	0.001747
Farmland	28-Apr-12	0.003285	0.037667	0.009662	23.77369	0.004824	0.766658	0.000331	0.000808	0.001238
Farmland	28-Apr-12	0.001932	0.023379	0.014723	9.725599	0.005959	0.462428	0.000128	0.000689	0.001056
Rangeland	28-Apr-12	0.00277	0	0.011732	0	0.005675	0.474598	0.000159	0.000784	0.001201
Rangeland	28-Apr-12	0.001997	0.017534	0.012422	0	0.005108	0.462428	0.000121	0.00057	0.000874
Rangeland	28-Apr-12	0.001546	0.021431	0.007591	6.483732	0.00298	0.255553	8.83E-05	0.000475	0.000728
Forest	12-May12	0.001546	0.02273	0.014032	8.104665	0.005108	0.462428	0.000132	0.000499	0.000765
Forest	12-May12	0.002319	0	0.011042	0	0.005675	0.401583	0.000141	0.000665	0.001019
Farmland	12-May-2	0.002126	0.020132	0.011042	0	0.004257	0.401583	0.000119	0.000523	0.000801
Farmland	12-May12	0.001353	0.021431	0.007591	5.943421	0.003263	0.219045	7.28E-05	0.00038	0.000582
Farmland	12-May12	0.004187	0.02273	0.020244	0	0.005959	0	0.00011	0.001307	0.002002
Rangeland	12-May12	0.005862	0.069488	0.042097	0	0.015324	0	0.00013	0.000832	0.001274
Rangeland	12-May12	0.004702	0.058448	0.045548	0	0.016317	0.401583	0.00017	0.00114	0.001747

Site	Date	*Surirrella* sp	*Fragilaria* sp	*Navicula* sp	*Limnothrix* sp	*Nitschia* sp	*Lyngbya* sp	*Gomphonema* sp	*Cymbella* sp	*Closterium* sp
Rangeland	12-May12	0.003285	0.037667	0.009662	23.77369	0.004824	0.766658	0.000331	0.000808	0.001238
Forest	26-May12	0.001932	0.023379	0.014723	9.725599	0.005959	0.462428	0.000128	0.000689	0.001056
Forest	26-May12	0.00277	0	0.011732	0	0.005675	0.474598	0.000159	0.000784	0.001201
Farmland	26-May12	0.001997	0.017534	0.012422	0	0.005108	0.462428	0.000121	0.00057	0.000874
Farmland	26-May12	0.001546	0.021431	0.007591	6.483732	0.00298	0.255553	8.83E-05	0.000475	0.000728
Farmland	26-May12	0.004702	0.028575	0.020704	0	0.006385	0	0.000126	0.001473	0.002257
Rangeland	26-May12	0.005218	0.073385	0.043938	0	0.016743	0	0.000124	0.000974	0.001493
Rangeland	26-May12	0.006119	0.054552	0.044628	0	0.017878	0.559782	0.000161	0.001117	0.001711
Rangeland	26-May12	0.004123	0.040914	0.010352	24.85431	0.005959	0.693643	0.000305	0.001069	0.001638