The Dynamics of Selected Limnological Data Along a Land Use Gradient in River Molo, Kenya

Kipkorir K. G. Kiptoo [1*], Nyakeya Kobingi [2] and Kerich Emmy [1]

[1]Department of Biology and Health, School of Environmental Science, University of Eldoret, P.O. Box 1125 – 30100, Eldoret

[2] Kenya Marine and Fisheries Research Institute, P. O. Box 81651, Mombasa

Corresponding author's email address: kipkorirk@gmail.com

Abstract

Rivers provide a suite of ecosystem goods and services to fisheries, as well as water that benefit the domestic and industrial use of the riparian communities. The increasing intensification of human activities along River Molo in the Rift Valley, Kenya continues to affect the diversity of aquatic life including fish. Whereas, information on the status and changes in fish population and ecological attributes along the river is fundamental, knowledge is currently lacking. The study evaluated the status of R. Molo fisheries and the environmental conditions longitudinally along the river. All the physicochemical water quality parameters demonstrated significant (P < 0.05) spatial variations in the sampled stations of R. Molo. There were 54 different species of algae identified in this study and the average algal density fluctuated between 2 to 16 cells ml-1. There were also, significant differences in the occurrence of macroinvertebrate among sites (Chi-square; ・2 = 20.1121, df = 3, P = 0.0031). There was a significant difference in the fish catch data based on the sampling location and fish species (P < 0.05). The minimum sizes at which the species mature differed with species. Of all the species sampled, only Labeo cylindricus exhibited a positive allometric growth (b < 3). Variations in limnology attributes of R. Molo were associated with longitudinal anthropogenic activities. Consequently, the need for R. Molo watershed management plan with a single economic vision of the resource use based on an ecosystem approach cannot be overstated. The plan should capture among other components, the hydrological regime, and species life history traits, fishing impacts and stakeholders' socioeconomic requirements as key elements for sustainability.

Keywords: Limnology, anthropogenic, River Molo, River Molo, sustainability

INTRODUCTION

Rivers provide a suite of ecosystem goods and services to fisheries as well as water that benefit the domestic and industrial use of the riparian communities. Dominance of small-scale fisheries in the rivers plays a critical role in local livelihoods, mainly as food sources and poverty relief (Béné et al., 2016). However, unsustainable land use due to several human activities including agriculture, deforestation, input of nutrients from domestic and municipal sewage, overfishing and illegal fishing methods etc pose threats to the biological integrity of riverine environments (Arthington et al., 2006; Acreman et al., 2014; Oeding et al. 2018). Each of these human activities may invariably affect the riverine ecosystems based on the intensity of the human activities, size of the catchment as well as volume of water discharged (Tonkin et al., 2018). Changes in the riverine ecosystem further fuel changes in ecosystem structure, affects aquatic assemblages, and aquatic community structures (Hering et al., 2016). Therefore, information on the changes of riverine biological indicators is urgently needed.

Flowing down from the Mau Complex, the Molo River has served citizens of the Rift Valley for several years. Over the approximately 100 km length that the river covers from the Mau Forest to Lake Baringo, this waterway is a primary source of livelihood amongst the communities it flows through. The constituencies that the Molo River serves along its coverage include: Kuresoi, Molo, Rongai, Mogotio, and Baringo Central.

Up to 1985, the water in Molo River remained clean, safe, and sufficient for communities in the region and for fisheries. However, in the recent past the water has decreased substantially in volume and became polluted resulting to the fishery decline being observed. These problems have been exacerbated, as community settlement and extreme drought conditions worsen, threatening the continued existence of the R. Molo itself. Anthropogenic activities in the upper catchment have had severe impacts on the flow of the Molo River.

Starting in the region of Kuresoi, massive deforestation of the Mau Complex has led to a decrease in the forest cover causing many other issues such as soil erosion, reduced rainfall, and a general decrease in water. These issues cause problems that affect the R. Molo throughout its course, as muddy water with a decreased flow have become common in many areas. Another key component of the degradation has been the community re-settlement that has occurred in the past few years. Due to poor land allocation systems, and the lack of implementation when dealing with land policies and laws, individuals have encroached into forestland, clearing the trees and destroying the local environment. Additionally, poor farming methods, and a lack of conservation among community individuals in the region, have had dramatic effects on the river. These methods include farming on sloped lands, farming into riverbanks, planting of inappropriate species such as Eucalyptus, and lack of soil conservation measures. However, knowledge on the status of physico-chemical water quality parameters, fisheries, phytoplankton and macroinvertebrates in this important riverine environment continues to languish behind other riverine environments and thus posing great challenge to prescribing the management strategies for restoration of the river. On the basis of the foregoing, this study assessed the dynamics of selected limnological data along a land use gradient in River Molo, Kenya.

MATERIALS AND METHODS

Study Area

This study was conducted longitudinally along R. Molo (Figure 1). The upper catchment in the Molo and Kuresoi areas, functions as the primary source of the Molo River. Several streams that begin in the Mau Complex flow into the Molo River and are depended upon all the way down to Lake Baringo. An important aspect of the upper catchment is the Mau Complex, which is among the major water towers in the country with numerous rivers, other than Molo, emanating from it such as, Njoro River and Mara River. It is important to focus on the upper catchment when viewing the R. Molo as a whole, because of the effects and problems upstream have to the rest on downstream communities. The catchment of R. Molo is a highland plateau with altitude ranging between 2400 to 3100 m asl. Rainfall in Molo is reliable and evenly distributed with two peaks in April to May and November to December and a drier spell from November to February. The region has a mean annual rainfall of 1100 mm although some areas receive up to 1500 mm. The average temperature is 23°C during the wet season with a maximum of 27 o^C during the dry season and a minimum of 12 o^C in the coolest season. February is the hottest month, and June is the coolest. Soils in the area are typically reddish to brown volcanic soils. They are thin, drain freely and have a friable texture with layers of cellular ironstone. Brown loam soils occur in high altitude areas and they are derived from both volcanic and basement complex rocks.

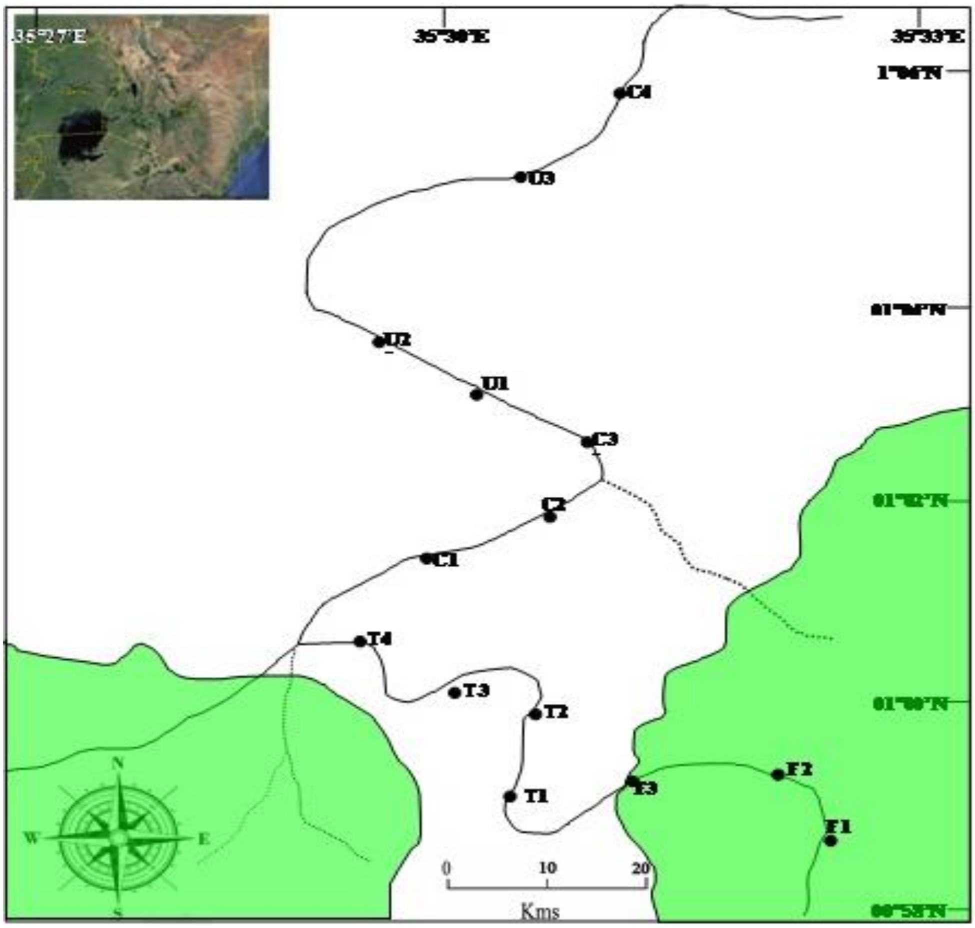

Figure 1: Map showing the location of the sampled locations along River Molo. Ten sampled stations were: F1, Sirindet; T1, Kibunja Molo Bridge; T3, Sangwani; C1, Molo Quarry Mkinyai; C2, Salgaa Bridge; C3, Ravine Nakuru Bridge; U1, Mogotio Bangra; U2, Mogotio Bridge/Upper; U3, Sirwe; and C4. Lororo Bridge (the rest of the stations were not sampled due to inaccessibility).

Selection of Study Sites

Sampling sites were selected randomly based on a number of factors: accessibility, proximity, habitat diversity and riparian land uses. The Geographical Position System (GPS) was used to mark the sampled points during sampling. Sites with differing riparian land uses activities were selected in current study, and their characteristics described as depicted in Table 1. Watershed delineation and classification were conducted in ArcGIS version 3.2. Based on topographic maps at a scale of 1:250,000, the watersheds were delineated and overlain on aerial photos then divided into polygons of different land use type. The areas of the polygons were calculated to determine the dominant land use type. Only the watershed areas upstream of the sampling locations were considered.

Table 1: Description sampling sites

Sampling sites	Latitude	Longitude	Mean depth (m)	Mean width (m)
Lororo Bridge	036º00'04.3" E	00º26'24.7" N	1.5 ± 1.0	11.0 ± 2.3
Sirwe	035º57'23.4" E	00º08'12.4" N	2.3 ± 0.7	10.1 ± 1.1
Mogotio upper	035º57'50.6" E	00º01'18.4" S	1.2 ± 0.4	10.4 ± 2.3
Mogotio Bangara	035º57'38.5" E	00º01'24.6" S	3.6 ± 0.4	8.2 ± 2.5
Ravine Nakuru Bridge	035º54'48.3" E	00º04'49.8" S	0.8 ± 0.2	0.13 ± 0.04
Salgaa Bridge	035º49'46.9" E	00º11'59.5" S	0.2 ± 0.1	0.5 ± 0.1
Molo Quarry Mkinyai	035º48'37.7" E	00º12'57.2" S	0.8 ± 0.3	11.4 ± 1.3
Sachagwani	035º46'12.9" E	00º13'31.5" S	0.6 ± 0.1	6.9 ± 1.3
Kibunja Molo Bridge	035º44'02.7" E	00º13'26.6" S	0.3 ± 0.1	9.9 ± 2.5
Sirendet	035º41'18.2" E	00º10'54.6" S	0.3 ± 0.1	2.8 ± 1.7

Measurement of the Physical and Chemical Parameters

Water was sampled and analyzed using standard methods described in APHA (2005). Triplicate samples of all parameters were collected at the surface (0 m) along River Molo during the sampling expedition. Temperature, conductivity, Dissolved oxygen (DO), total dissolved solutes (TDS), pH, salinity and sechi depth were measured in situ at each sampling sites, using a surveyor II model hydrolab, with independent probes for each variable.

Water samples for nutrient fractions were collected directly from the river using pre-treated 1 litre polyethelene sample bottles. The bottles were labeled, filled, preserved using sulphuric acid and stored in cooler boxes at temperatures of about 40C, for further laboratory analysis for dissolved nutrient and TSS using methods adopted from APHA (2005). The analyzed Water samples for nutrient fractions were collected directly from the river using pre-treated 1 litre polyethelene sample bottles. The analysed nutrient compounds were Nitrates-N, Ammmonia-N, Nitrites-N, Soluble Reactive Phosphorous (SRP) and Silicates. Water samples for Total Nitrogen (TN) and Total Phosphorus (TP) were contained without controlled preservation and were analyzed following the same standard methods described by APHA (1985).

Sampling for Phytoplankton

Water samples for phytoplankton analysis were collected from the surface. A portion of the water sample (25 mls) was preserved in acidic Lugol's solution. A 2 ml phytoplankton sub-sample was placed in an Utermöhl sedimentation chamber and left to settle for at least three hours. Phytoplankton species identification and enumeration were done using a Zeiss Axioinvert 35 inverted microscope at 400x magnification. At least, ten fields of view were counted for the very abundant coccoid cyanobacteria and a 12.42 mm2 transect was counted for the abundant and large algae. The whole bottom area of the chamber was examined for the big and rare taxa under low (100x) magnification. Phytoplankton taxa were identified using the methods of Huber –Pestalozzi (1968) as well as some publications on East African lakes (Cocquyt et al., 1993). Phytoplankton were estimated by counting all the individuals whether these organisms were single cells, colonies or filaments.

Fish Sampling and Processing

Fish were sampled at each sampling site using electro-fisher along the river. At each of the sampling site, electro-fishing time was about 10 minutes covering an area of approximately 100 m for each sampling site. Sampling gears were deployed proportionally according to habitats suitability within each bend. After capture, the fork length (FL) and standard length (SL) were measured to the nearest 0.1 mm and the eviscerated body weight (W) to the nearest 0.01 g. The specimens were dissected to expose the viscera where the dominant food items were recorded. The total catch from each gear was weighed in g, using a digital weighing scale (5kg Vibra Model from Shinko Devshi Co. Ltd, Japan).

Upon data collection, fish specimens were immediately tagged and gut content extracted and preserved in 5% formalin for laboratory examination. The frequency of occurrence was used to compute the individual food items sorted and identified. The number of stomachs where the food item occurred was recorded and expressed as a percentage of all the stomachs being analyzed. The index of occurrence (Io): Io = Na/Nt × 100 (%), (Windell, 1968; Hyslop, 1980) (Na = the number of stomachs where a food category is recorded, NT = a total number of stomach).

Macro-Invertebrate Sampling and Laboratory Processing
A total of 10 benthic samples in triplicate were collected at random locations in each of the selected sites with a Surber sampler (0.09 m2, 250'' mesh size). The Surber was placed on the stream bottom in a shallow flowing habitat. For each site, invertebrates were sampled at sites according to guidelines of the "Indice Biologique Global Normalise" (hereafter IBGN), a normalized tool commonly used for monitoring biotic integrity in several rivers. Substratum inside the frame was agitated by hand to collect invertebrates into the net; larger pebbles were removed and scrubbed to detach the invertebrates residing on them. This was done three times at each site. Samples were preserved using ethanol (70% v/v) until analyzed in the laboratory. The containers were carefully labeled to maintain identity-giving details such as site, date, code and location.

In the laboratory, each sample was handled individually. The samples were washed through a 250'' mesh size sieve to remove mud, sand and other debris. The benthic macro-invertebrates were transferred to labeled bottles and preserved in 70% ethanol until identified whereas the inorganic debris components were discarded. The macro-invertebrates were removed from the bottle one after the other and identified to the lowest-possible taxonomic level with the aid of several keys and illustration and counted using a stereomicroscope and dissecting microscope at ×50 magnifications.

Data Analysis
All statistical analyses were performed with a STATISTICA 6.0. Normality and homoscedasticity of data distribution was checked by means of the skewness and kurtosis. In case where data was found not to follow normal distribution (heteroscedastic), log transformation was used to normalize all the biological data. For each tested data set, between-site differences in concentrations of abundances of benthic invertebrates, fish species and taxonomic richness were tested using Chi-square. The assumption of normality prior to Chi-square test was verified using the Shapiro–Wilk test. Fish species distribution was analyzed using two-way interaction (ANOVA) where sampling location and fish species were factors. Abundance data were not normally distributed even after log-transformation, and between-sites differences were tested using the non-parametric Kruskall–Wallis test. All results were declared significant at $P < 0.05$.

RESULTS AND DISCUSSION

Water Quality Parameters

Physico-chemical Parameters
An overview of the physical and chemical water quality parameters along R. Molo are provided in Figure 2. All the physicochemical water quality parameters demonstrated significant ($P < 0.05$) spatial variations. The physicochemical environment along R. Molo displayed significant spatial variation, which is thought, be exacerbated by the diverse human activities along the river. Lororo Bridge exhibited significantly ($P < 0.05$) higher temperature values than other sites. This was associated with discharge of warm water from a factory within the area. The variation in temperature along the river could as well be attributed to differences in water depth such that the deep and shallow water in the sites

translates to relatively larger water mass, which takes longer to warm up or cool down. Conductivity values were highest in the upstream station of Lororo and Sirwe. This is probably associated with factory effluents discharged into the within the area resulting into high amount of total dissolved solids

Meanwhile the pH was found to be relatively high which is common for R. Molo that is of volcanic origin (Rad et al., 2007), the high pH was recorded in Molo Quarry Mkinyai followed by Ravine Nakuru Bridge and lowest at Kibunja Molo Bridge. Higher pH levels were suspected to be due to mining activities within the area. The pH in the lower parts of the River Molo was somewhat lower compared to the other sites, a statement attributed to the high influx of fresh water from the incoming tributaries of river Molo. Sirwe had the highest TDS and salinity among all the sites. Sachang'wan and the upper reaches of Mogotio had the highest DO and a part from upper Mogotio, DO levels were high at the lower reaches of the river. Lororo Bridge, Ravine Nakuru Bridge and Salgaa Bridge all recorded DO levels <6.0 mg/l. However, DO levels at Salgaa Bridge/upper had levels below 4.9 mg L-1 that could be attributed to decomposing of organic matter and detritus hence proliferation of blue green algae and diatoms.

The preferred optimal temperature range for good fish health especially Oreochromis niloticus baringoensis, growth and reproductive performance range between 23 and 320C. The river is within the tropical region; thus, provide good ambient water temperature for fish. The observed water temperatures were good for tilapia's overall performance, but when considered alongside water pH may change the ambient environmental conditions from acceptable to unacceptable.

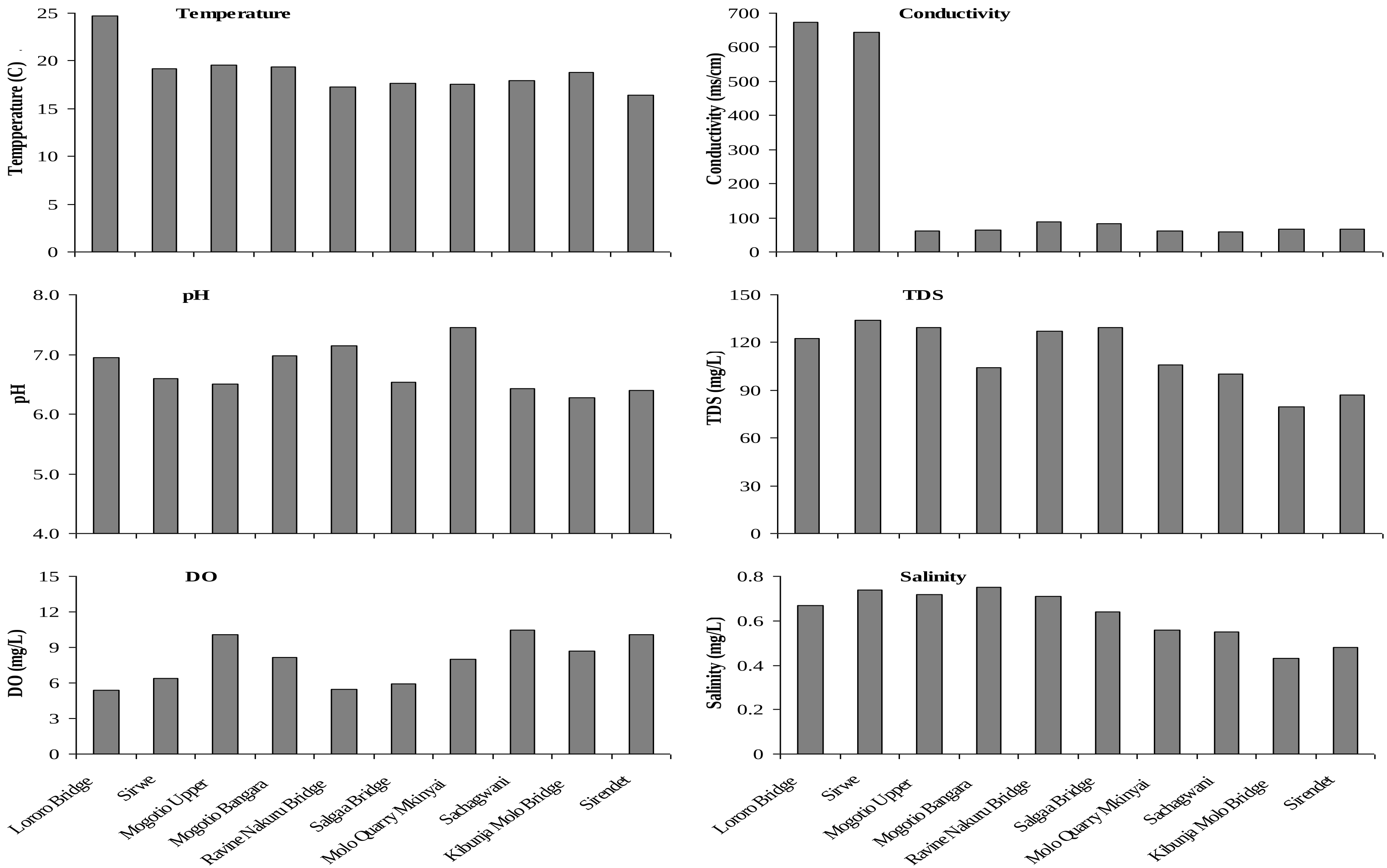

Figure 2: Water quality parameters along the sampling locations of R. Molo

Mogotio Bridge had the highest mean of ammonia concentrations of 458.5 µgL-1 followed by Mogotio Bangara with a mean of 102.8 µgL-1 (Fig. 3). TN concentrations ranged between 17.5 and 105.4 µgL-1. Sampling Stations showed a decline in trend from the source, to river mouth. Salgaa Bridge had the highest concentrations with a mean of 105.4 µgL-1 followed by Sirwe with a mean of 92.3 µgL-1.

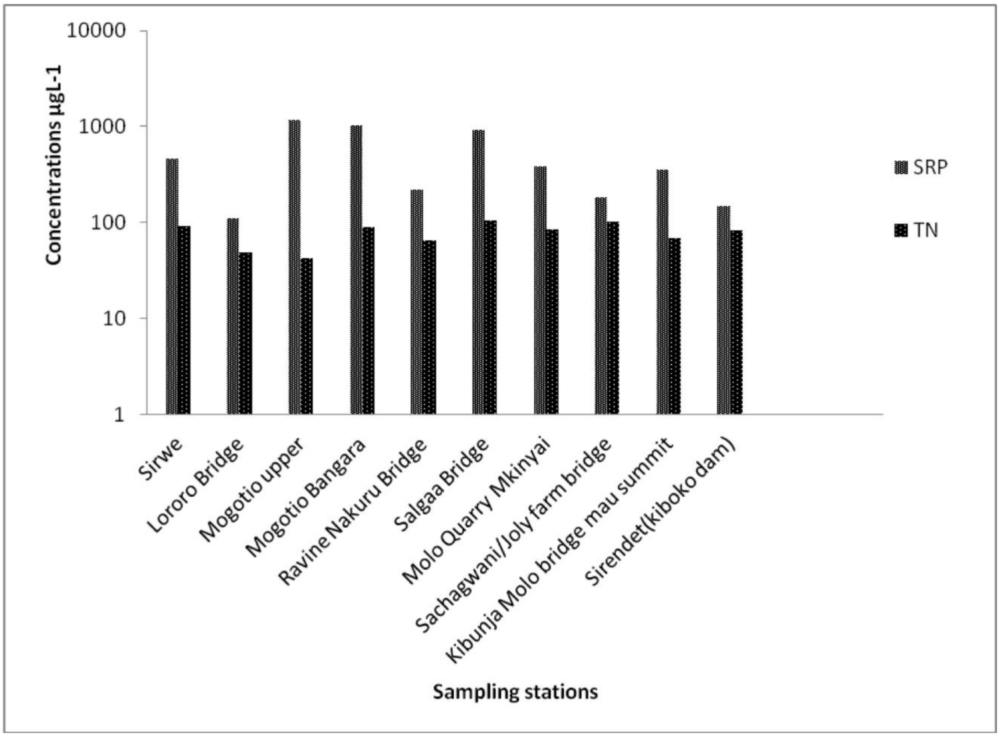

Figure 3. Variations in Total Ammonia and Total Nitrogen at R. Molo

Fluctuations in temperature and pH highly influence the dissociation of ionized ammonia (NH4—N) into unionized ammonia (NH3). Ammonium (NH4+) and nitrate (NO3-) assimilation are the two principle processes by which nitrogen obtains primary production. Nitrite provides an additional, but subsidiary, dissolved N source. At highly elevated concentrations, NH4+ becomes toxic depending on water quality factors. The unionized ammonia (NH3) at concentration levels > 20 µgL-1 is toxic to fish. Therefore, the toxicity levels of total ammonia are expressed as a function of temperature and pH. The NH4+ concentration levels, observed temperature and pH, gave acceptable range. However, in order to make any meaningful conclusions, further investigation should be done during dry and wet seasons.

Nutrients

Soluble Reactive Phosphorus (SRP) ranged between 23.0 and 1110.56 µgL-1 (Fig. 4). The levels were lower especially at Molo Quarry Mkinyai. TP concentrations varied from 42.5 to132.2 µgL-1. Generally, Stations on the source of the river had the lowest concentrations.

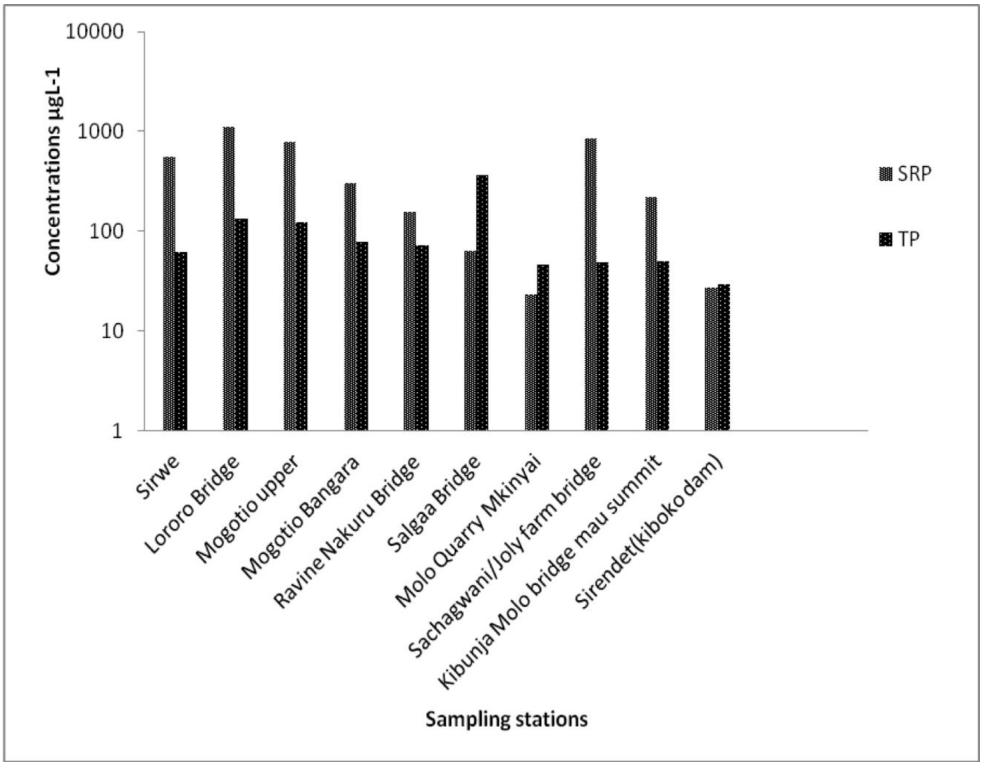

Figure 4: Variations in Soluble Reactive Phosphorus (SRP) and Total Phosphorus (TP) at R. Molo

TN: TP ratios of stations within the river habitats varied between 3.5 and 17.3 (Fig. 5). Lororo Bridge, Sirwe and Mogotio Bangara exemplified the highest mean ratio of 12.7. The enriched nitrogen and phosphorus nutrients have made the river highly productive. The waters are eutrophic thus providing conducive environment for algal proliferation especially diatoms and cyanobacteria. Turbidity of the waters is mainly influenced by algal productivity and mineral composition. Algal communities are highly enriched in nitrogen (N), due to their high protein (which accounts for much of the N) and lipid content. The high nitrogen in the TN is therefore mainly organic nitrogen derived from algae. SRP concentrations are influenced by nutrient remobilization from sediments. Higher TP concentrations within stations are an indication that the agricultural farm practices are impacting negatively on the environment. TN/TP ratios observed within the study sites indicated nitrogen limitation.

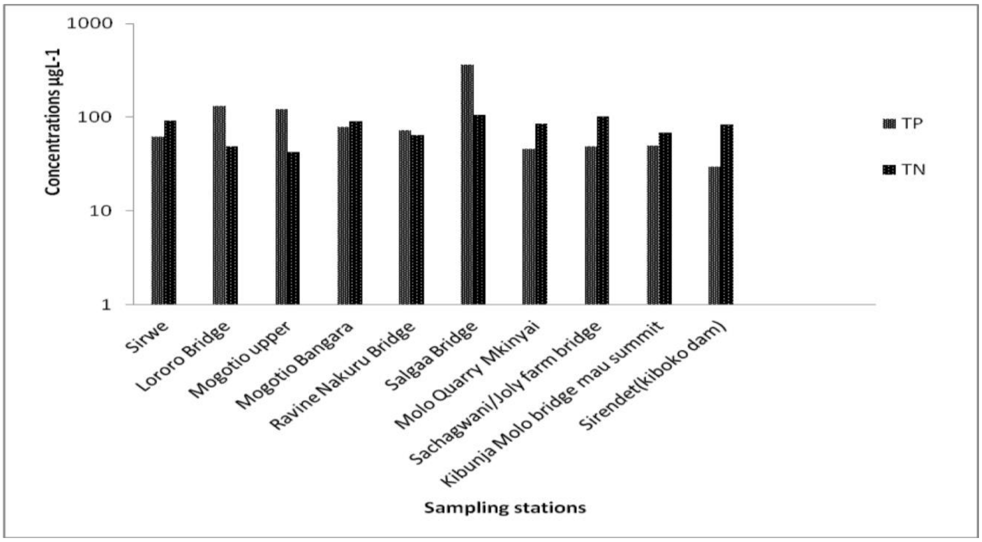

Figure 5: Variation in TN/TP ratios of R. Molo sites

Phytoplankton results

There were 54 different species of algae identified from R. Molo during this survey. Of the 9 different species of cyanophytes encountered, Chroococcus, Anabaena and Aphanocapsa were the most common genera especially in Mogotio upper/bridge. Similarly, there were 15 species of chlorophytes encountered of which Scenedesmus, Ankistrodemus and Tetraedron were the most frequently encountered genera. Only one species of dinoflagellates (glenoridinium spp.) was encountered in Kasamoyo station. Seventeen different species of diatoms, mainly represented by Nitzschia, Surillella, Navicula and Cyclotella genera were also observed. The 5th major algal groups encountered were the euglenophytes, which were represented by 8 genera with 10 different species.

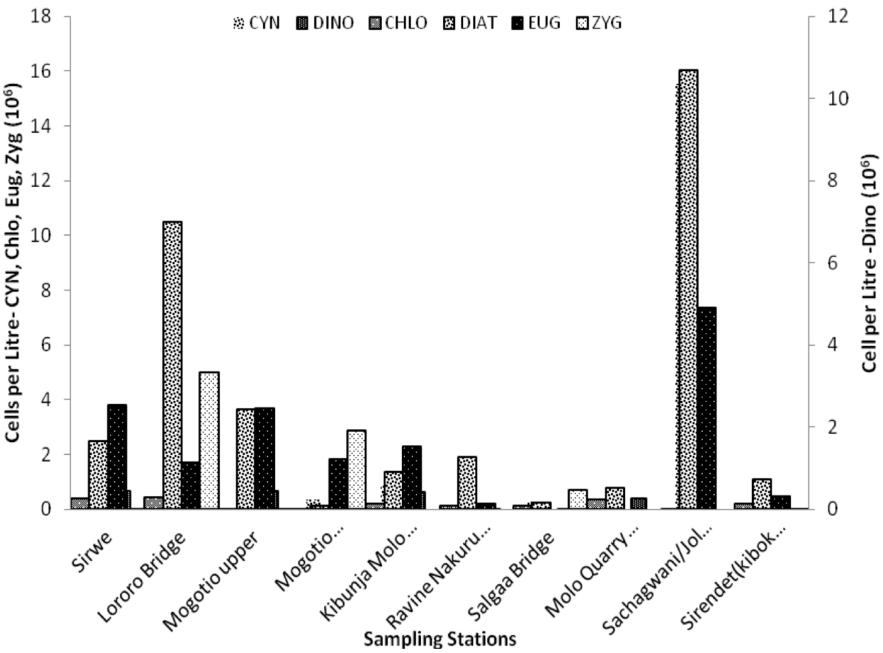

Figure 6: Phytoplankton cell density (cells x 106) as recorded at different stations of the river.

Most sampling stations had very high algal densities, for example, in Salgaa upper/bridge had 3 cells ml-1, which were recorded. The average algal cell density for Molo River during this survey fluctuated between 2 to 16 cells ml-1 with the highest observed at Sachangwan Jolly firm, 16 (Fig. 6).

Phytoplankton Composition was largely co-dominated by diatoms contributing between 45 %. Ravine Nakuru Bridge had the highest with 77 % unlike Mogotio Bangara, which had the lowest with 1.9%. Cyanophytes forming an equally important flora, contributed between 0.8% and 20 % (Fig. 7).

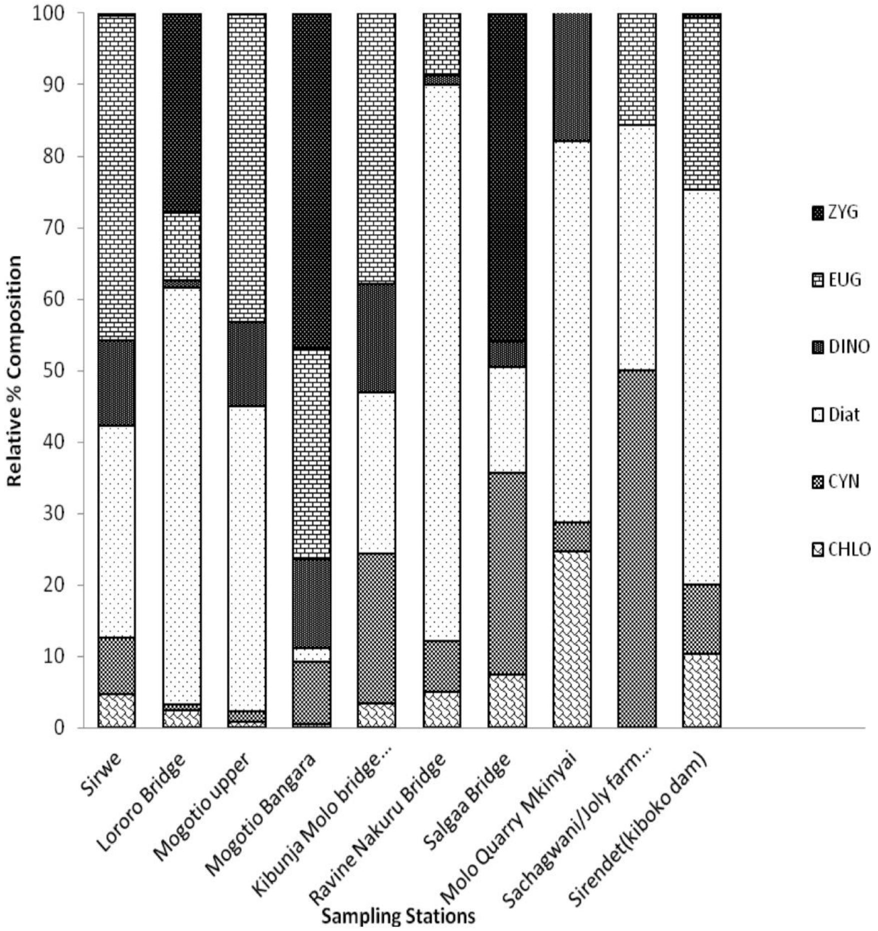

Figure 8: Percentage phytoplankton composition (mm3 l-1) assigned to phytoplankton classes or families as recorded at different sites of River Molo

Euglenophytes contributed between 0% in Salgaa Bridge, Ravine Nakuru Bridge and 45 % at Sirwe station. Occurrence of other algal families such as Zygnematophyceae had 0 % in most of the sampling stations, but Mogotio Bangara had 46% being the highest. Dinoflagellate never appeared in two stations and was highest at Molo Quarry Mkinyai with 41 %. Chrolophytes was highest in Molo quarry Mkinyai with 24 % and lowest at Sachangwani/Jolly farm bridge with 0.1% respectively.

Results from the present study showed temporal changes of phytoplankton community structure, which is influenced by anthropogenic inputs of nutrients from agricultural flower firms from Mau catchment areas. Diatoms were dominant by over 45 %, because of a direct result of supply of nutrients from agricultural lands that surround the river. It was noted that Mogotio bridge/upper and Mogotio Bangara had the highest mean concentration of ammonia (92.3 μgL-1). This may be as a result of dinoflagellates and blue green algae which causes depletion of oxygen thus reducing habitats for living organisms especially fish and other aquatic organisms.

Flower farms deposits high amounts of waste for the rapid proliferation of the phytoplankton. The study observed high concentrations of algal families especially, Diatoms, Cynophyceae, Euglenophytes and Chlorophytes, which were mainly dominant in the survey. Although diatoms dominate, it appears to be some pockets of other algal groups such as Chlorophytes and Cynobacteria which also contribute significantly to phytoplankton community although this varies with time and space. The most significant driving forces that cause predictable variations in phytoplankton composition is due to algal species occupying different ecological niches within the river. The high abundance of diatom families is an indication of cultural eutrophication that is a clear indication of trophic status of the river.

This is correlated with the high physio-chemical parameters recorded in the stations sampled. Turbidity favours the dominance of cynobacteria, which are able to fix nitrogen from the atmosphere. The high nutrients enrichment seems to enhance growth and is responsible for the increased algal density and more especially diatoms that are proportionately high in most of the stations. The greens and diatoms species are known to prevail in nutrient rich (Wetzel, 1991) and high light intensity areas and can attain high photosynthetic efficiencies. Thus, physiochemical parameters such as temperature, dissolved oxygen (DO), river depth and size affect the abundance, species composition, stability, productivity, and physiological condition of indigenous populations of aquatic organisms. Thus, the nature and health of aquatic communities is an expression of the limnological status of water body. Changes in these water quality variables bring about changes in phytoplankton communities and consequently affect the quantity and quality of food items available for invertebrates as well as fish, thus, affecting fish production. Phytoplankton studies, therefore, help to explain the distribution and abundance of fishes in a particular environment.

Fish abundance and distribution

A total of 7 fish species were collected during the longitudinal River Molo sampling expedition (Table 2). There was a significant difference in the fish catch data based on the sampling location and fish species ($P < 0.05$). Meanwhile the interaction between sampling location and fish species resulted in difference in the catch data. Mogotio upper had the highest number of sampled species at 6 followed Lororo Bridge where 5 species were sampled while Sirwe, Ravine Nakuru Bridge, Salgaa Bridge contained only two species of fish, Molo Quarry Mkinyai Bridge had one species of fish with no observation of any fish species in Sachagwani, Kibunja Molo Bridge and Sirendet. It’s therefore worth highlighting that the river had very low species diversity at the upper reaches, and the fish were small in size making commercial fisheries exploitation not feasible. However, the upper river section can be very useful in recruitment into the fisheries downstream and eventually into the Lake Baringo. Therefore, the results shows that species diversity of the river increased as one moved from upstream to downstream. In terms of species distribution, Barbus spp. especially Barbus altianalis was the most widely distributed species in river. There were also differences in the sex ratios of the species with Barbus altenialis and Barbus neumayeri being the only species where males dominated over the female, while most of the species had higher proportion of females than males.

Table 2: Fish composition and catch data

Sampling sites	Fish species	Condition factors	Counts	% frequency
Lororo Bridge	*Barbus altenialis*	1.03	10	9.4
	Oreochromis niloticus baringoensis	1.11	12	11.3
	Labeo cylindricus	1.01	35	33.0
	Barbus cercops	1.35	45	42.5
	Clarias theodorae	1.67	4	3.8
Sirwe	*Barbus altianalis*	1.06	11	84.6
	Clarias theodorae	1.72	2	15.4
Mogotio upper	*Labeo cylindricus*	1.22	1	2.4
	Clarias theodorae	1.36	2	4.9
	Barbus altianalis	1.43	12	29.3
	Barbus neumayeri	0.99	20	48.8
	Barbus paludinosus	1.02	3	7.3
	Aplocheilichthys sp.	0.96	3	7.3
Mogotio Bangara	*Clarias theodorae*	1.22	1	6.3
	Barbus altianalis	1.32	7	43.8
	Barbus neumayeri	0.97	7	43.8
	Aplocheilichthys sp.	0.92	1	6.3
Ravine Nakuru Bridge	*Barbus neumayeri*	0.88	11	91.7
	Barbus neumayeri	0.92	1	8.3
Salgaa Bridge	*Clarias theodorae*	1.34	1	2.3
	Barbus neumayeri	1.18	43	97.7
Molo Quarry Mkinyai	*Clarias theodorae*	1.05	6	100
Sachagwani	No fish			
Kibunja Molo Bridge	No fish			
Sirendet	No fish			

Food and feeding habits

The dietary status of fish sampled longitudinally along River Molo is shown in Table 3. The variations in the levels of food consumption by the various fish species correspond closely well based on the sampled sites. The predatory nature of riverine species was reported by Groenewald (1998), who described the feeding habits as opportunist. Considerable variability in the diet was observed. The ability to thrive on whatever food available has probably been one of the factors that have allowed these species wide distribution and success. Barbus spp. showed the highest diversity in diets.

Table 3: Dietary status of fish sampled along different locations of River Molo

Sampling sites		Stomach fullness	Dominant food type
Lororo Bridge	*Barbus altenialis*	0.5	Plant materials, Coleoptera remains, insect remains, plant seeds
	Oreochromis niloticus baringoensis	0.7	Plant materials, detritus, Coleoptera remains, insect remains
	Labeo cylindricus	0.58	Plant materials, detritus insect remains, plant seeds
	Barbus cercops	0.65	Insect remains, Coleoptera remains, plant seeds
	Clarias theodorae	0.75	Coleoptera remains
Sirwe	*Barbus altianalis*	0.65	Plant materials
	Clarias theodorae	1.00	Coleoptera remains, Ephemeroptera remains, Chironomids
Mogotio upper	*Barbus altenialis*	0.75	Plant materials
	Labeo cylindricus	0.5	Chironomids, detritus
	Clarias theodorae	0.85	Plant materials, insect remains
	Barbus neumayeri	0.75	Coleoptera remains, plant seeds, Odonata, insect remains
	Barbus paludinosus	0.55	Plant seeds
	Aplocheilichthys sp.	0.45	Plant remains
Mogotio Bangara	*Clarias theodorae*	0.52	Plant remains
	Barbus altianalis	0.75	Plant materials, detritus
	Barbus neumayeri	0.42	Plant materials
	Aplocheilichthys sp.	0.55	Plant materials
Ravine Nakuru Bridge	*Barbus neumayeri*	0.35	Detritus
	Barbus neumayeri	0.45	Detritus
Salgaa Bridge	*Clarias theodorae*	0.85	Plant materials, insect remains, simulium, Chironomids
	Barbus neumayeri	0.82	Plant remains
Molo Quarry	*Clarias theodorae*	0.72	Plant materials
Sachagwani	No fish		
Molo Bridge	No fish		
Sirendet	No fish		

Length/Weight relationships

The length/weight relationships of the fish species sampled during the study is provided in Figure 3. The b exponent value of the relationship shows the type growth exhibited by the fish species in River Molo. For instance, only Labeo cylindricus had $b < 3$, an indication that the species exhibited a positive allometric growth. L. cylindricus were plumb a pointer to the river being ideal for the species growth. The rest of the groups' exhibited negative allometry which represents skinny fish.

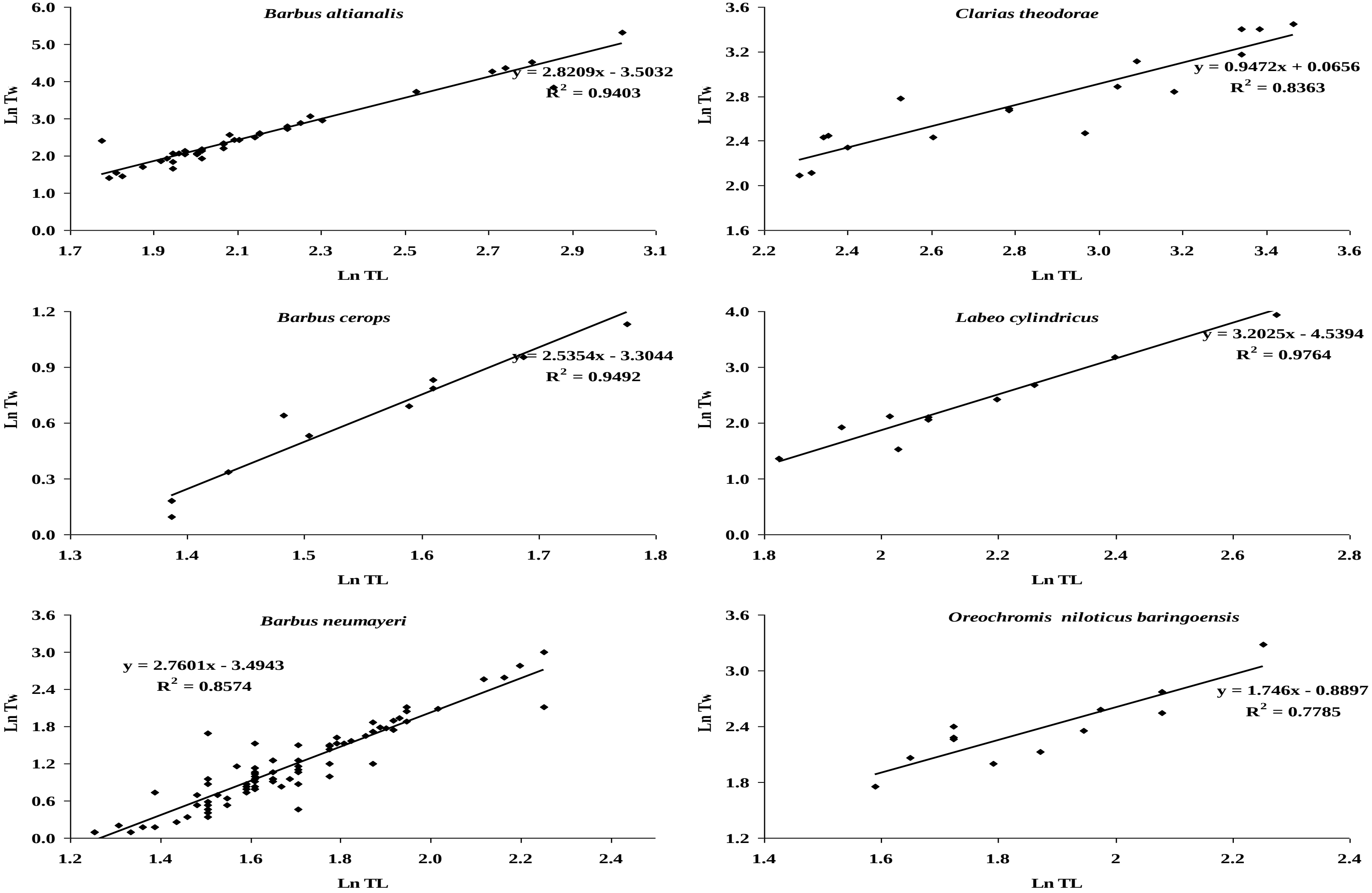

Figure 9: Length Weight relationships of the fish species sampled from River Molo

Breeding

Sex ratio

Sex ratios of fish sampled along different locations of River Molo is provided in Table 4.

Table 4: Sex ratios of fish sampled along different locations of River Molo

Sampling sites	Fish species	Sex ratio (male: female)
Lororo Bridge	*Barbus altenialis*	6:4
	Oreochromis niloticus baringoensis	4:8
	Labeo cylindricus	6:28
	Barbus cercops	13:32
	Clarias theodorae	1:3
Sirwe	*Barbus altianalis*	7:4
	Clarias theodorae	1:1
Mogotio upper	*Labeo cylindricus*	0:1
	Clarias theodorae	0:2
	Barbus altianalis	7:5
	Barbus neumayeri	12:8
	Barbus paludinosus	2:1
	Aplocheilichthys sp.	2:1
Mogotio Bangara	*Clarias theodorae*	ND
	Barbus altianalis	4:3
	Barbus neumayeri	4:3
	Aplocheilichthys sp.	ND
Ravine Nakuru Bridge	*Barbus neumayeri*	11:0
	Barbus neumayeri	1:0
Salgaa Bridge	*Clarias theodorae*	1:0
	Barbus neumayeri	36:6
Molo Quarry Mkinyai	*Clarias theodorae*	3:3
Sachagwani	No fish	-
Kibunja Molo Bridge	No fish	-
Sirendet	No fish	-

Sizes and ages at maturity

The minimum sizes at which the species mature 24 cm for Clarias theodorae, 25 cm for Oreochromis niloticus baringoensis, 17 cm for Barbus altenialis, 23 cm for Labeo cylindricus, and 13.5 cm for Barbus cercops. If larger samples were available, it is probable that smaller maturing individuals would be found. The average sizes at first maturity for specimens of each species are probably 3–4 cm larger than those given above. The majority of all specimens of all species studied matured for the first time at the end of their second year. A decrease in mean length is often accounted for by an observed increase in catch and particularly as the result of uncontrolled fishing activities. Alternatively, however, this diminution could also be explained by an increase in recruitment success through the sporadic flooding events. A common observation was that fish of 30 cm length were being harvested, implying that the corresponding changes in the gill net selectivity had resulted in the removal of a significant number of immature fish that were accordingly smaller than size at first maturation. We therefore support the notion that a minimum legal size of 42 cm is an appropriate catch limit. Such a minimum size would guarantee that recently recruited individuals in the fishery have the opportunity to reproduce completely at least once.

Macroinvertebrate distribution data of River Molo

During the study, 39 species belonging to 12 families of benthic macroinvertebrates were observed at the 10 sampling sites having variant land use activities. There were significant differences in the occurrence of macroinvertebrate among sites (Chi-square; $\chi^2 = 20.1121$, df = 3, P = 0.0031). Baetidae were the most abundant in the samples and appeared in all the sampling sites. Tricorythidae, Naucoridae, Limnephilidae larvae, Dytiscidae, Ceratopogonidae, Lymnaeidae, Crab and Grasshopper were found in only one sampling site perhaps due to the limited number of sampling and suggest that these species display seasonality in occurrence. There were significant differences in abundance of all species among the sampling sites (One-Way ANOVA; $P < 0.05$), which seems to vary based on differing land use activities. Upper reaches stations had the highest abundance of Hemiptera of genus Veliidae, Gerridar and coleopteran of genus Gyrinidae Agrion, Planorbis, Lumbricus, Heptogenia, Collicorixa and Gyrinus. Meanwhile the mid reaches of the river was dominated by macroinveterbrate of genera: Baetidae, Limnaea, Gerris, Agrion, Platambus and Ilybius. The lower reaches were dominated by Heptogenia, Chironomus and Haliplus. The areas with most human activities were dominated by: Baetis, Tipula, Caenis, Epeorus and Ephemeralla.

Table 5: Data on the macro invertebrate species composition during the study along River Molo

	Loororo Bridge	Sirwe	Mogotio Upper	Mogotio Bangara	Ravine Nakuru Bridge	Salgaa Bridge	Molo Quarry	Sachangwan	Molo Bridge	Sirendet
Ephemeroptera										
Baetidae	1	1	21	22	0	13	29	25	32	11
Caenidae	1	0	4	7	0	2	33	85	16	170
Heptageniidae	0	0	2	0	0	0	5	0	23	0
Tricorythidae	0	0	9	0	0	0	0	0	0	0
Odonata										
Corduliidae	0	0	0	0	0	0	0	1	1	1
Aeshnidae	0	0	0	0	0	0	0	2	0	6
Gomphidae	0	0	1	0	0	0	0	0	0	0
Coenagrionidae	0	0	37	55	0	6	17	7	8	27
Hemiptera										
Veliidae	4	0	16	13	0	1	0	0	1	0
Hebridae	0	0	0	0	0	0	1	0	0	1
Corixidae	0	1	0	0	0	2	0	0	3	0
Notonectidae	3	1	0	0	0	1	0	8	13	2
Naucoridae	0	0	0	0	0	1	0	0	0	0
Gerridae	8	1	0	1	0	0	0	0	0	0
Trichoptera										
Hydropsychidae	0	0	9	14	0	1	0	0	0	1
Limnephilidae larvae	1	0	0	0	0	0	0	0	0	0
Brachycentridae	0	0	0	0	0	0	0	0	0	1
Leptoceridae	0	0	0	2	0	0	0	0	0	0
Coleoptera										
Hydrophilidae	1	0	1	0	0	1	1	1	3	2
Hydrophilidae larvae	0	0	0	0	0	0	0	2	0	3
Hydraenidae	0	0	0	1	0	1	0	0	0	0
Haliplidae	0	0	1	0	1	0	0	0	1	0
Gyrinidae larvae	0	0	0	0	0	0	0	1	0	0

Gyrinidae	8	1	0	0	0	0	0	3	1	32
Dytiscidae	0	0	0	0	0	0	0	0	0	3
Landkevers	0	0	1	0	0	0	0	0	0	1
Helodidae	0	0	0	0	0	0	0	2	0	11
Plecoptera										
Perlidae	0	1	0	0	4	0	2	0	0	1
Diptera										
Chironomidae	0	1	0	0	133	19	10	12	3	26
Simuliidae	1	0	0	9	0	0	1	23	0	7
Ceratopogonidae	0	0	0	0	0	0	0	0	0	8
Gastropoda										
Physidae	0	0	0	0	0	0	0	5	0	21
Lymnaeidae	0	0	0	0	0	0	0	0	0	6
Pelecypoda										
Sphaeriidae	0	0	0	0	0	0	0	0	0	2
Planorbidae	0	0	0	0	0	0	0	20	0	41
Annelida										
Oligochaeta	0	0	0	0	0	0	7	0	1	0
Tubifex	0	0	2	3	0	17	0	0	0	0
Decapoda										
Crab	0	0	0	0	0	0	0	0	1	0
Orthoptera										
Grasshopper	0	2	0	0	0	0	0	0	0	0
Total abundance	28	9	104	127	138	65	106	197	107	384

Species diversity of macroinvetebrates are shown in Figure 4. Highest diversity of macroinvetebrates occurred in Sirwe and Lororo Brige probably due to the undisturbed nature of these stations and the lowest was in Ravine Nakuru Bridge where there was discharge of several pollutants from the flower farms, agricultural runoffs from the nearby commercial farms and defecation by livestock.

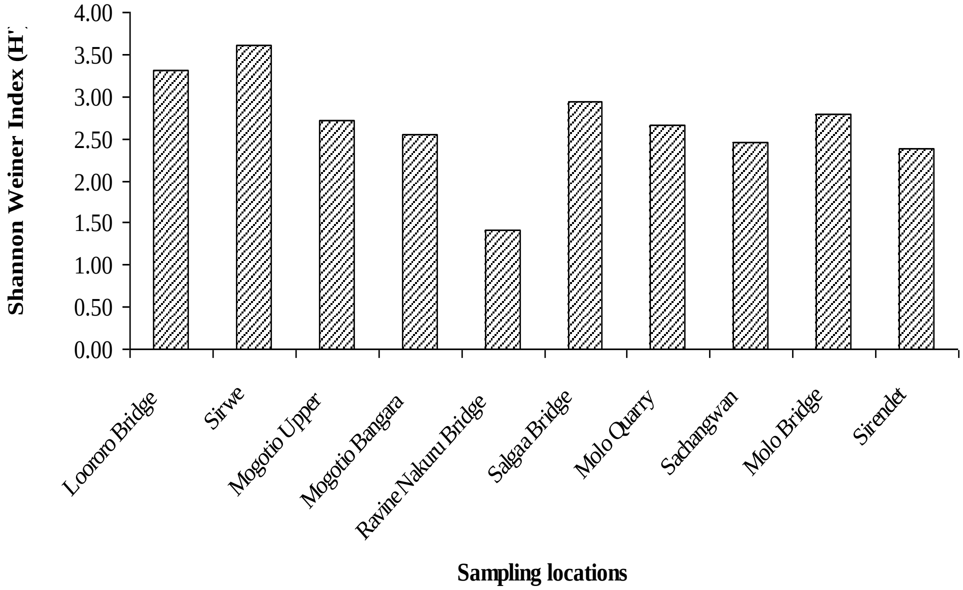

Figure 10: Shannon-Weiner diversity index for macroinvertebrates in River Molo

CONCLUSION

The River Molo fisheries study constitutes the first documented example within the Mau Catchment Basin where the fish status has been assessed under changing land use patterns. Therefore, the results presented can be termed as preliminary taking into consideration the few specimens recorded for some species and study duration. More so, the factors affecting River Molo fisheries are not clear at the moment, even though anthropogenic activities in the catchment could be among the factors. A comprehensive study conducted throughout the year capturing seasonality patterns need to be done since the present study was accomplished during the wet season. The fisheries of River Molo were observed be low and unsustainable with fish showing poor living conditions and restricted feeding habits.

MANAGEMENT RECOMMENDATIONS

1. There is need to allocate more funds for regular monitoring exercises in the river's aquatic ecosystem to enhance the protection of its biota and propose appropriate mitigation measures.
2. The River Molo and its catchment areas are considered Environmentally Significant Areas, and established governmental policies should strictly be enforced to ensure all effluent from individual farms adhere to EMCA standards.
3. WRMA should take lead in developing policy framework governing resource use across the river basin based on integrated management of water and resources.
4. Communities' awareness creation is emphasized for re-evaluation of ways to sustainably utilize the river Molo with minimal adverse effects on its biota.

REFERENCES

Acreman, M., Arthington, A.H., Colloff, M.J., Couch, C., Crossman, N.D., Dyer, F., Overton, I., Pollino, C.A., Stewardson, M.J. and Young, W. (2014). Environmental flows for natural, hybrid, and novel riverine ecosystems in a changing world. Frontiers in Ecology and the Environment. 12: 466–473.

APHA (2005). Standard Methods for the Examination of Water and Wastewater. American Public Health Association, Washington, DC.

Arthington, A.H., Bunn, S.E., Poff, N.L. and Naiman, R.J. (2006). The challenge of providing environmental flow rules to sustain river ecosystems. Ecological Applications. 16: 1311–1318.

Béné, C., Arthur, R., Norbury, H., Allison, E.H., Beveridge, M., Bush, S., Campling, L., Leschen, W., Little, D., Squires, D. and Thilsted, S.H. (2016). Contribution of fisheries and aquaculture to food security and poverty reduction: assessing the current evidence. World Development. 79: 177–196.

Boerema, L.K. and Gulland, J.A. (1973). Stock assessment of the Peruvian anchovy (Engraulis ringens) and management of the fishery. Journal of the Fisheries Board of Canada. 30: 2226–2235.

Cadwalladr, D.A. (1965). The decline in the Labeo victorianus Blgr.(Pisces: Cyprinidae) fishery of Lake Victoria and an associated deterioration in some indigenous fishing methods in the Nzoia River, Kenya. East African Agricultural and Forestry Journal. 30: 249–256.

Hering, D., Carvalho, L., Argillier, C., Beklioglu, M., Borja, A., Cardoso, A.C., Duel, H., Ferreira, T., Globevnik, L., Hanganu, J. and Hellsten, S. (2016). Managing aquatic ecosystems and water resources under multiple stress—An introduction to the MARS project. Science of the total environment. 503: 10–21.

Ochumba, P.B.O. and Ala, J. (1992). Distribution of fishes along the Sondu-Miriu River of Lake Victoria, Kenya with special reference to upstream migration, biology and yield. Aquaculture Research. 23: 701–719.

Oeding, S., Taffs, K.H., Cox, B., Reichelt-Brushett, A. and Sullivan, C. (2018). The influence of land use in a highly modified catchment: Investigating the importance of scale in riverine health assessment. Journal of Environmental Management. 206: 1007–1019.

Rad, S.D., Allègre, C.J. and Louvat, P. (2007). Hidden erosion on volcanic islands. Earth and Planetary Science Letters. 262: 109–124.

Tonkin, J.D., Merritt, D.M., Olden, J.D., Reynolds, L.V. and Lytle, D.A. (2018). Flow regime alteration degrades ecological networks in riparian ecosystems. Nature Ecology & Evolution. 2: 86.

Welcomme, R.L. (1985). River fisheries [Pesca fluvial]. FAO fisheries technical paper, 262, p. 330.

Whitehead, P.J.P. (1959). The River Fisheries of Kenya I—Nyanza Province. The East African Agricultural Journal. 24: 274–278.