SPATIAL DISTRIBUTION AND HABITAT CHARACTERISATION OF MOSQUITOES AND VECTOR SNAILS, AND COMMUNITY PERCEPTIONS ON MALARIA AND SCHISTOSOMIASIS IN RELATION TO AQUATIC HABITATS, IN LAKE VICTORIA BASIN OF WESTERN KENYA

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ABSTRACT

Infections with vector-borne parasites are common in human populations inhabiting tropical regions of the world. Malaria and schistosomiasis are endemic along Kenyan Lake Victoria basin (LVB), and their vectors are fresh water breeders. However, much less is known about the current spatial distribution and habitat characterisation of mosquitoes including vectors of malaria and human schistosomiasis intermediate hosts snails in the Lake Victoria waters and adjacent terrestrial aquatic habitats. The current study was designed to determine differential mosquitoes and schistosomiasis snails' abundance in lake and land aquatic habitats; measure the aquatic habitats' (water) physico-chemical parameters and establish their effects on the abundance of *Anopheles* mosquitoes and schistosomiasis snails in lake and land habitats; enumerate the numbers of phytoplankton, zooplankton, and fish species, and determine the effects of their abundance on the abundance of *Anopheles* mosquitoes and schistosomiasis snails ; carry out gut contents analysis of the different fish species to determine which ones are more insectivorous and can be used as biological agents against mosquito larvae in lake and land aquatic habitats; and lastly find out the community knowledge and perceptions regarding malaria and schistosomiasis transmission and control, and relationship with aquatic habitats in the Lake Victoria basin (LVB) of western Kenya. Mosquitoes and schistosomiasis intermediate-host snails were sampled to determine their abundance and distribution in the lake and land aquatic habitats using entomological and malacological techniques, respectively. Also, 243 individuals randomly recruited from fish landing beaches in the Kenyan Lake Victoria basin were interviewed about their knowledge and perceptions regarding malaria and schistosomiasis. Data obtained was entered in Microsoft Excel, then cross-checked and transferred to SPSS for analysis. MSTAT-C software was used to determine whether there were significant variations between the locations, habitats or vegetation types. Descriptive statistics were carried out to determine relative frequencies, percentages and averages of variables. Chi-square test (X^2) was used to determine relationships between level of education, age, gender and occupation, and correctness of responses of the study participants. $P<0.05$ was considered statistically significant. Results showed that *Anopheles* and *Culex* species of mosquitoes were absent in different locations in the lake but abundant in different aquatic habitats in different locations on land. There was heterogeneity in the relative abundance of *Anopheles* and *Culex* species in the aquatic habitats in different locations on land, $p<0.001$, Bartlett's test. There were significantly more *Biomphalaria sudanica* than *Bulinus africanus* sampled in different locations in the lake and in land aquatic habitats, one way ANOVA, $p<0.001$. There were no significant correlations between abundance of *Anopheles* mosquitoes, *Biomphalaria sudanica* and *Bulinus africanus* snails, different physico-chemical parameters, and phytoplankton abundance, $p > 0.05$, Pearsons' correlation, but there was significant correlation between abundance of *Biomphalaria sudanica* and *Bulinus africanus,* and some phytoplankton in the lake and on land, $p<0.03$, Pearsons' correlation. There were significant correlations between abundance of *Anopheles* mosquitoes and Calanoid on land, $p = 0.014$, but no significant correlation with most zooplankton on land, $p>0.05$, Pearsons' correlation. There were no significant correlations between *Biomphalaria sudanica* and *Bulinus africanus* abundance with zooplankton in lake and on land though significant correlation between *Bulinus africanus* and Calanoid, copepoid in the lake were found, $p<0.05$, Pearsons' correlation. *Clarias gariepinus* were more insectivorous compared to other fish species. Most of the respondents (66.53%) were aware of symptoms of malaria and how it is transmitted (77.8%) but had poor knowledge on the breeding habitats of mosquitoes and aquatic plants harbouring schistosomiasis snails. The study results calls for removal of water hyacinth from the aquatic habitats both on land and in the lake as they harbour more schistosomiasis transmitting snails and recommends that concerted effort is needed to scale-up health education and improve the knowledge of the community about mosquitoes and snails and their breeding habitats, particularly malaria vectors which do not breed in deep lake waters. Introduction of *Clarias gariepinus* as a bio-control agent is suggested by the findings of this study.

CHAPTER ONE

1.0. INTRODUCTION

1.1. Background Information

Malaria presents a substantial public health and financial burden (WHO, 2011). In 2010 alone, there were an estimated 216 million cases worldwide and at least 660 000 deaths, with most morbidity and mortality (90%), occurring in sub-Saharan Africa (WHO, 2011). An estimated US$ 2 billion was spent on malaria control in 2011 (WHO, 2011). The disease is mainly confined to poorer sub-Saharan African countries, Asia and Latin America (WHO, 2011). In Kenya, it is the leading cause of morbidity and mortality, accounting for over 30% of all out-patient attendance in the country's health facilities and 20% of all in-patient admissions (KMIS, 2010).

Appendix I shows the life cycle of malaria parasites. While malaria transmission has been reduced considerably in some regions in Kenyan, it still remains high among the residents in the Lake Victoria basin in western Kenya (Noor *et al.*, 2009). Intense malaria transmission is often observed in villages near lakes and large water reservoirs in Africa (Keiser *et al.*, 2005). Studies have shown that malaria cases increase with decreasing distance to the shores of large water bodies (Yawhalaw *et al.*, 2009). For example, construction of dams has been observed to shift seasonal transmission to perennial transmission (Jobin, 1999). Thus, it is reasonable to hypothesize that the environment associated with the shoreline of Lake Victoria supports a high density of malaria vectors given the year-round availability of water.

The major African malaria vectors, *Anopheles arabiensis* and *Anopheles gambiae* s.s., often inhabit small and sunlit temporary water pools (Gimnig *et al.*, 2001; Minakawa *et al.*, 2005). Although earlier studies suggested that breeding occurs in permanent and semi-permanent water pools (Fillinger *et al.*, 2004; Imbahale *et al.*, 2011), the characteristics of their habitats suggest that they do not breed within the lake water itself (Ndenga *et al.*, 2011).

Another important malaria vector, *Anopheles funestus* s.s., usually inhabits large, stable water pools covered with aquatic vegetation that can be found in wetlands adjacent to lake Victoria (Gimnig *et al.*, 2001). These habitats may exist throughout the year because of a constant supply of seepage water from the lake. Malaria vectors also inhabit large back-water pools (lagoons) along the shore of lake Victoria (Minakawa *et al.*, 2008). Lagoons appear on strips of land that emerge following reductions in the lake water levels. Waves transport sands, which build up along the shore. The body of water that becomes enclosed behind the mounds of sand creates a lagoon. If a lagoon is large and stable, emergent and floating plants colonize the area. Previously, three major malaria vector species have been recorded in such sites, although the micro-habitats of these vectors within lagoons have not been documented in detail (Minakawa *et al.*, 2008).

Given that *An. funestus s.s.* is closely associated with aquatic vegetation (Gimnig *et al.*, 2001), it has been proposed that the infestation of water hyacinth (*Eichhornia crassipes*) in African lakes has increased breeding site availability for this vector species (Minakawa *et al.*, 2002). A potential secondary vector, *Anopheles rivulorum*, may also occur in water hyacinths, because the larvae of this species are often associated with floating plants such as Nile cabbage (*Pistia stratiotes*) (Gillies & Coetzee, 1987; Gimnig *et al.*, 2001). The water hyacinths originated from South America, and were first reported in Lake Victoria in 1989. Since then, they have quickly spread throughout the lake, covering 80% of the Ugandan coastline by 1995 (Twongo *et al.*, 1995). One study found no malaria vectors amongst water hyacinth supported sites in Lake Victoria (Ofulla *et al.*, 2010), whilst another reported larvae of the *An. funestus* complex within a water hyacinth mat at the margin of the lake (Minakawa *et al.,* 2002) suggesting that more studies are required to validate the role of water hyacinth in supporting malaria vectors.

An account of previous studies, primarily in sub-Saharan Africa, indicates that several environmental factors determine larval density and may influence the development/survival rate of the malaria vector larvae (Mwangangi *et al.*, 2007; Paaijmans *et al.*, 2008; Service, 1977). These factors include climate, physical and chemical conditions of the aquatic habitats, land cover and vegetation type, and other biotic factors including predators such as fish. No similar study has been purposely set up to shed light on the environmental factors that are associated with the malaria vector breeding sites in Kenyan Lake Victoria waters and its basin.

Lake Victoria is the second largest lake in the world, and the effects of the lake habitats on local malaria transmission could be substantial if they support vector breeding. This threat would not be limited to Lake Victoria, as water hyacinths have already invaded several lakes and reservoirs in malaria endemic areas of Africa (Navarro & Phiri, 2000). Although the occurrence of malaria vectors in western Kenya is well documented (Imbahale *et al.,* 2011; Minakawa *et al.*, 1999; Minakawa *et al.*, 2002), however, knowledge of larval habitats in Kenyan Lake Victoria waters is limited as implied by previous anecdotal reports that water hyacinth in the Lake increases malaria transmission in adjacent regions (Ofulla *et al.*, 2010). Given that most inhabitants of the Lake Victoria basin depend on the Lake for their lively hoods (Okeyo-Owuor, 1999), it is important to develop understanding of mosquito breeding habitats in these sites in order to design better malaria control measures.

Appendix II shows the life cycle of *Schistosoma* parasites. Schistosomiasis is a parasitic disease infecting 243 million people worldwide and is endemic in 78 countries with over 85% of cases occurring in sub-Saharan Africa (WHO, 2012). Urinary schistosomiasis is caused by a trematode flatworm *Schistosoma haematobium* while intestinal schistosomiasis is caused by *Schistosoma mansoni* and *Schistosoma japonicum* (Appendix II). In coastal Kenya, *S. haematobium* is the sole endemic schistosome species within 100 km of the coast with *S. mansoni* occurring further inland (Kariuki *et al.*, 2004). The *Bulinus africanus* group of snails is responsible for local transmission with *Bulinus nasutus* being the sole snail host in the Kenyan coastal region. It has been hypothesized that the lack of *S. mansoni* transmission in the area is due to the intolerance of *S. mansoni* transmitting snails, *Biomphalaria* species to the high coastal temperatures (Sturrock, 1965).

Schistosomiasis (bilharzia) continues to be a major public health and socio-economic problem for several millions of people living in rural areas in the tropics (Chitsulo *et al.*, 2000). In Kenya, Uganda and Tanzania, studies have shown that most transmission of the intestinal form of bilharzia (*S. mansoni*) tends to be closely confined to narrow zones along the shores of large bodies of water such as lake Victoria where it is endemic and the intermediate host is found (Handzel *et al.*, 2003; Kabatereine *et al.*, 2001; Lwambo *et al.*, 2004; Mwanga *et al.*, 2004).

In the Lake Victoria region, there are two types of schistosomiasis, which include intestinal schistosomiasis caused by *Schistosoma mansoni* and urinary schistosomiasis caused by

Schistosoma haematobium, though the former is more prevalent (Handzel *et al*., 2003; Opisa *et al*., 2011). Earlier studies showed that the prevalence and intensity of schistosomiasis is inversely related to distance from the Lake (Handzel *et al*., 2003). The mean school prevalence of *S. mansoni* infection was 16.3% and proximity to the Lake and contact with lake water were associated with infection, as were specific water-related activities including swimming, fishing and collecting water (Karanja *et al*., 1997). Karanja *et al*. (1997) also reported that persons employed as vehicle washers along the beaches of Kisumu town, Kenya, were exposed for several hours each day to water in lake Victoria that contains *Schistosoma mansoni*-infected *Biomphalaria pfeifferi* snails. This could result in a focus of high endemicity for schistosomiasis in the Lake Victoria region. Both species of the disease parasites are focal in their distribution around the Lake, and their intermediate hosts are *Biomphalaria pfeifferi, Biomphalaria sudanica,* (both for *Schistosoma mansoni*) and *Bulinus africanus* (for *Schistosoma haematobium*) (Handzel *et al*., 2003; Opisa *et al*., 2011).

Biotic as well as abiotic environmental factors are important in the dynamics of schistosomiasis transmission. Biotic factors influencing vector populations include vegetation, food supplies, predators, competitors, and pathogens (Kariuki *et al*., 2004; Sturrock *et al*., 2001). A study in the Msambweni area in Kenya found that the presence of *Nymphaea* species water lilies was highly predictive of a water body being infested with *Bulinus nasutus* snails, whereas *Cyperus exaltatus* sedges were negatively associated with presence of these snails (Kariuki *et al*., 2004). Abundance of phytoplankton and zooplankton also influences species composition and population dynamics of other aquatic organisms including schistosomiasis snails in aquatic ecosystems (Allison *et al*., 1996; Green, 2009; Wakwabi *et al.,* 2006; Waya & Mwambungu, 2004). Important abiotic factors determining microhabitats of snail populations include physical factors such as water current, temperature, turbidity, transparency and distribution of suspended solids, chemical factors such as ion concentration and dissolved gases in water (Ofoezie, 1999), as well as toxicological factors (Williamson *et al.*, 2004).

The development of an effective strategy of integrated control requires study of population dynamics of the intermediate hosts and their relation to environmental factors (Hussein *et al.*, 2011). Several factors can affect the ecology of snails and other intermediate disease hosts and therefore their focal and seasonal distributions. The importance of different ecological factors, however, can vary significantly from one ecological zone to the other and even from one water body to another, suggesting local investigations to identify important factors in each zone or water bodies (Hussein *et al.*, 2011). Thus, the purpose of the present study was to determine the spatial distribution and habitat characterization of schistosomiasis host snails in the lake and land habitats of western Kenya, as well as the possible influences of vegetation types, physicochemical parameters, phytoplankton, zooplankton and fish on relative abundance of the snails.

Various researchers have documented numerous findings on perceptions, knowledge, attitudes and practices among communities in many parts of the world including Africa. Most of the reports concur that wrong perceptions concerning malaria transmission and control is still common among communities living in endemic areas (Miguei *et al.*, 1999; Vundule & Mharakurwa, 1996). Therefore, community awareness, perceptions, beliefs and practices need to be established so as to be able to come up with effective malaria surveillance and control activities within the affected communities (Ruebush *et al.*, 1994).

Differing ethno-medical concepts on human health prevention and treatment strategies, based on traditions, culture and beliefs must be considered if the malaria control program is to succeed (Sharma *et al.*, 1994). However, even with perfectly planned program, the target population will not participate in it if there are misconceptions concerning the relationship between vectors and disease, and concerning conventional pharmaceutical therapies. In many areas, the primary health care practitioners in local populations do not subscribe to the conventional methods of malaria diagnosis and treatment, but instead rely on observation and patient provided information (Agyepong, 1992; Sharma *et al.*, 1994). Folk healers commonly known as traditional medicine men may disregard the conventional means of malaria treatment, and choose to treat their patients in a traditional way (Service, 1993b).

Many studies have demonstrated the existence of different beliefs on causes of water-borne diseases among the affected communities, with other researchers reporting that, even if the local communities have an accurate knowledge on transmission, treatment and prevention of malaria, they could still fail to participate effectively, in National Malaria Control Program if their perceptions about various aspects of malaria remains poor (Agyepong, 1992; Sharma *et al.*, 1994). There can be no significant participation of local communities in malaria control program if the locals and conventional medics' view of the disease remain divergent. Such differences in views and perceptions among the stakeholders will only lead to refusal to participate or partial community's perception of the disease, to make the control of schistosomiasis more effective and sustainable in endemic areas (Handzel *et al.*, 2003; Kloos, 1995; WHO, 1995). In its report, the World Health Organisation (WHO, 1995) noted that prevention of transmission of the trematode can be greatly improved if local communities are aware of processes by which schistosome eggs are transmitted. Previous studies support that both individual and community perceptions and attitudes of parasitic worm infections and their preventions and treatment are important (Mwanga *et al.*, 2004). Health education and promotion campaigns are therefore essential for any change in behaviour to be realized in areas where schistosomiasis is prevalent.

Since community members living along the Lake Victoria basin of Kenya may have different perceptions on the scientific aspects of transmission of water-related and vector-borne diseases, it was important to assess the level of their knowledge on association between the aquatic habitats and transmission of malaria and schistosomiasis. Data from this study will help in determining community's understanding on malaria transmission and control in relation to aquatic habitats in the Lake Victoria basin and assist in designing effective control program for the disease in the Lake Victoria basin and beyond.

1.2. Statement of the Problem

Despite malaria transmission being reduced substantially in some parts of Kenya, it still remains high among the residents in the Lake Victoria basin (Noor *et al.*, 2009). In Kenya, an estimated 27 million people (about 70 % of the population) are at risk of infection, and roughly 34,000 young children die of malaria related causes annually (KMIS,2007). According to malaria indicator survey of 2010 statistics, malaria constituted approximately 32% of the total outpatient cases in Nyanza and Western provinces in Kenya (KMIS, 2010).

Anopheles funestus s.s, an all important malaria vector, is closely associated with aquatic vegetation (Gimnig *et al.*, 2001), it has been proposed and even reported that the infestation of water hyacinths (*Eichhornia crassipes*) in African lakes' sheltered lagoons and lakeshore pools have increased breeding site availability for malaria mosquitoes (Minakawa *et al.*, 2012), though some of these reports have been anecdotal as previously reported (Ofulla *et al.*, 2010). Numerous findings on perceptions, knowledge, attitudes and practices among communities in many parts of the world including Africa, concur that wrong perceptions concerning malaria transmission and control is still common among communities living in endemic areas (Miguei *et al.,* 1999; Vundule & Mharakurwa, 1996). Therefore, community awareness, perceptions, beliefs and practices need to be established so as to be able to come up with effective malaria surveillance and control activities within the affected communities (Ruebush *et al.*, 1994).

Regarding community's knowledge, attitude and practice on vectors and their habitats, a study on baseline evaluation of locally-recruited community-based personnel in terms of their ability to detect potential *Anopheles* breeding sites in Dar es Salaam, Tanzania, concluded that, the level of coverage achieved by modestly trained community resource persons were insufficient to enable effective suppression of malaria transmission through larval control (Vanek *et al.*, 2006). Hence these attributes need to be evaluated in regions with high malaria transmission if malaria is to be effectively controlled.

Schistosomiasis infections cause a huge burden of disease in the developing world (Chitsulo *et al.*, 2000), and have been associated with significant educational and nutritional effects (King *et al.*, 2005; Stephenson, 1993). In children and adults, *Schistosoma mansoni* can have nonspecific clinical manifestations such as bloody diarrhoea and abdominal discomfort, and if untreated can lead to serious liver complications. While this burden is difficult to measure, global deaths due to schistosomiasis have been estimated as high as 200,000 per year (King *et al.*, 2005).

In Kenya, over 6 million people are estimated to be infected (Chitsulo *et al.*, 2000) and many more are at risk. The highest infection rates are found in adolescents aged 10–19□years, but adult workers in rural areas who are employed in activities associated with water contact are also affected (Karanja *et al.*, 1997). Overall, the prevalence of schistosomiasis ranges from 5% to over 65% in communities in Kenya and contributes to significant morbidity (Karanja *et al.*, 1997). In the Nyanza region, schistosomiasis is largely associated with Lake Victoria (Handzel *et al.*, 2003). There are still many areas where the true burden with schistosomiasis is not well known as disease mapping has not been adequate (King *et al.*, 2005).

A previous study by Ofulla *et al.* (2010) indicated a considerable presence of the schistosomiasis host snails, which were associated with aquatic weeds in the Nyanza Gulf of lake Victoria. Studies by Chlyeh *et al.* (2006) also showed that *Bulinus truncatus* was positively associated with macrophytes. The link between snails and aquatic plant species occurs because the plants serve as sources of shelter, protection and surfaces for oviposition, as well as sources of snail food after decomposing for weeks and months in water (Alves & Blair, 1953). Studies by Arora & Mehra (2003) indicated that *Eichhornia* supported more diverse rotifer fauna, some of which can be foods for snails. This association was so intense that some species of sessile rotifers were recorded exclusively in association with *Eichhornia* roots. It is possible the thick bushy rhizoids of *Eichhornia* provide abundant food, as well as protection from predators (Arora & Mehra, 2003).

Ecological factors, however, can vary significantly from one ecological zone to the other and even from one water body to another, suggesting local investigations to identify important factors in each zone or water bodies (Hussein *et al.*, 2011). Thus, the purpose of the present study was to determine the spatial distribution and habitat characterization of mosquitoes and schistosomiasis snails in the lake and land habitats of western Kenya, as well as the possible relationships with vegetation types, physico-chemical parameters, phytoplankton, zooplankton, and fish on relative abundance of mosquitoes and schistosomiasis snails. Since malaria and schistosomiasis are endemic along the study area, monitoring the vectors' occurrence, distribution, habitat characteristics, and assessment of the level of community knowledge regarding the two diseases' vectors habitats are crucial for the management and control of the diseases.

1.3. General Objective

To determine the spatial distribution and habitat characterisation including vegetation types, physico-chemical parameters, and abundance of phytoplankton, zooplankton and fish species on abundance of mosquitoes and snails that transmit schistosomiasis, and also find out community perceptions on transmission dynamics and control of the two diseases, in Lake Victoria basin of western Kenya.

1.4. Specific Objectives

(a) To determine differential mosquitoes abundance in lake and land aquatic habitats in the Lake Victoria basin of western Kenya;

(b) To determine differential schistosomiasis snails abundance in lake and land aquatic habitats in the Lake Victoria basin of western Kenya;

(c) To establish the effects of physico-chemical parameters on abundance of *Anopheles* mosquitoes and schistosomiasis snails in lake and land aquatic habitats in the Lake Victoria basin of western Kenya;

(d) To determine the effects of phytoplankton, zooplankton and fish species abundance on the abundance of *Anopheles* mosquitoes and schistosomiasis snails in lake and land aquatic habitats in the Lake Victoria basin of western Kenya;

(e) To carry out gut contents analysis of the different fish species to determine which ones are more insectivorous and can be used as biological agents against mosquito larvae in lake and land aquatic habitats in the Lake Victoria basin of western Kenya;

(f) To find out the community knowledge and perceptions on malaria and schistosomiasis transmission and control, and relationship with aquatic habitats in the Lake Victoria basin of western Kenya.

1.5. Null Hypotheses

(a) The abundance of different species of mosquitoes is similar in different locations and habitat types in the lake and on adjacent terrestrial aquatic sites in the Lake Victoria basin of western Kenya;

(b) The abundance of different species of schistosomiasis snails is similar in different locations and habitat types in the lake and on adjacent terrestrial aquatic sites in the Lake Victoria basin of western Kenya;

(c) There is no effect of physico-chemical parameters on abundance of *Anopheles* mosquitoes and schistosomiasis snails in lake and land aquatic habitats in the Lake Victoria basin of western Kenya;

(d) There are no relationships between phytoplankton, zooplankton and fish species abundance on the abundance of *Anopheles* mosquitoes and schistosomiasis snails in lake and land aquatic habitats in the Lake Victoria basin of western Kenya;

(e) Gut contents analysis of the different fish species will not determine which ones are more insectivorous and can be used as biological agents against mosquito larvae in lake and land aquatic habitats in the Lake Victoria basin of western Kenya;

(f) The level of community's knowledge and perceptions on association between aquatic habitats and abundance of *Anopheles m*osquitoes and schistosomiasis snail hosts is not related to prevalence of malaria and schistosomiasis in the Lake Victoria basin of western Kenya.

1.6. Study Justification

Malaria and schistosomiasis transmission only occurs given successful vector-human and parasite-human contact respectively. Characteristics of the habitat can modify the extent to which individuals interact with infected *Anopheles* mosquitoes and schistosomiasis vector snails and thus their risk of contracting malaria and / or schistosomiasis. Mosquito larval habitat ecology is important in determining larval densities and species assemblage which in turn can influence malaria transmission in an area (Mwangangi *et al.*, 2007). It is also important to carry out studies to identify which fish species are more insectivorous and can be used as biological agents against mosquito larvae in lake and land aquatic habitats in the Lake Victoria basin of western Kenya.

Larval ecological studies have been investigated in western Kenya in the past (Minakawa *et al.*, 1999; Minakawa *et al.,* 2002; Minakawa *et al.*, 2008; Munga *et al.,* 2005). These studies conducted primarily on land habitats demonstrate significant and clear associations between risk of malaria and environmental factors. However few, studies have recently been conducted in the Kenyan Lake Victoria and its basin examining the association between the relative abundance of malaria vectors / schistosomiasis snail intermediate hosts and water hyacinth and or other aquatic vegetations in both lake waters and terrestrial adjacent habitats.

Knowledge of the impact of aquatic macrophytes such as water hyacinth, hippo grass on the abundance of the vectors will aid in the design of interventions that are acceptable to the community living along the Kenyan Lake Victoria basin. Because community members living along the Lake Victoria basin may have different perceptions on the scientific aspects of transmission of water-related and vector-borne diseases, it was important to assess the level of their knowledge on malaria and schistosomiasis vectors in relation to aquatic habitat characteristics.

The reduction of malaria morbidity and mortality to a manageable level cannot be achieved by a single strategy, but rather by a combination of many strategies. Selective applications of insecticides and sustainable environmental management have been recognized by World Health Organisation as some of the suitable strategies for malaria control (WHO, 1985). These strategies aim at reducing the number of mosquitoes by targeting the larval stages at their breeding sites. To optimize these strategies, detailed information and knowledge on types of larval breeding habitats, factors that may influence larval productivity in a particular habitat, and their variation is necessary. Previous studies showed that *Biomphalaria* and *Bulinus* species of snails, the two most common hosts of schistosomiasis in the Nyanza Gulf, were found associated with the aquatic macrophytes in the lake waters, and the schistosomiasis snail hosts were more associated with water hyacinth than with hippo grass (Ofulla *et al.,* 2010), which called for studies comparing these associations in the lake habitats and adjacent terrestrial habitats.

The emerging microhabitats created by invasive weeds such as water hyacinth and other aquatic vegetation may increase the threats of water borne and water related diseases, especially malaria and schistosomiasis, hence the data from this study will help in understanding malaria and schistosomiasis vector and hosts habitat ecology in relation to aquatic vegetation and other habitats characteristics in the Lake Victoria and also local community members' perceptions regarding malaria and schistosomiasis prevalence, transmission and control. These findings will assist in designing effective control programs for the two diseases along the Kenyan Lake Victoria basin and beyond.

CHAPTE TWO

2.0. LITERATURE REVIEW

2.1 Ecology of Mosquitoes Including *Anopheles* Mosquito Larvae

The occurrence and abundance of mosquito immature in different breeding habitats reflects the oviposition preferences of females as well as the ability of the immature to survive in the conditions under which they find themselves. Changes in the physico-chemical and biotic characteristics of surface water habitats may condition either favourable or unfavourable to the breeding success of mosquitoes, depending on the range of different species. This can have implications for vector-borne diseases, because habitats changes that favour potential vector species can ultimately lead to increased rate of parasite or pathogen transmission (Munga *et al.*, 2005).

Mosquitoes (Diptera: Culicidae) are widely distributed throughout the world and they utilise different water bodies for their breeding (WHO, 1982). The distribution of mosquitoes is influenced both directly and indirectly by climatic and environmental factors (Mafiana *et al.*, 1998). Mosquitoes prefer an environment with certain resources (food, shelter, breeding sites, favourable temperature and suitable humidity) in sufficient amount and at appropriate time for survival and development (Romoser & Stoffolano, 1998).

Mosquitoes have become widespread in the Lake Victoria basin and some mosquito-transmitted pathogens, such as Rift Valley fever virus in the highland and malaria in the low land areas; have become serious problems (Githeko & Ndegwa, 2001). In the past three decades, agricultural expansion and urbanisation have tremendously affected insect fauna in the Lake Victoria region

(Mutie *et al.*, 2006; Odada *et al.*, 2004), with mosquito and other disease transmitting pathogens being abundant (Minakawa *et al.*, 2012). The genus *Culex* Linnaeus includes 25 subgenera and at least 751 species in the world fauna (Service, 1993c). Certain species of the genus *Culex* are involved in the transmission of the various arboviral and filarial diseases to humans and domesticated animals and / or are important for their biting nuisance in different parts of the world (Service, 1993c). *Wuchereria bancrofti,* the causative agent of lymphatic filariasis (LF) is transmitted by mosquito species belonging to *Anopheles, Aedes, Culex* and *Mansonia* depending on the geographic area (Dunyo *et al.*, 1996).

Breeding of *Anopheles* mosquitoes in particular, *Anopheles gambiae* s.l. and *Anopheles funestus,* the main malaria vectors in Africa, occurs in a variety of habitats such as permanent or stable water bodies like dams, rivers, rice paddies and temporal pools of water such as hoof prints, ditches and gutters (Coetzee *et al.*, 2000; Gillies & Coetzee, 1987; White & Rosen, 1973). Earlier studies had shown that *Anopheles gambiae* s.s. and *Anopheles arabiensis*, the two main members of *Anopheles gambiae* complex found in western Kenya may exploit similar breeding habitats (Minakawa *et al.*, 1999; Gimnig *et al.*, 2001). On the other hand, *Anopheles arabiensis* has been reported to extensively breed in rice paddies in Ahero irrigation scheme (Githeko *et al.*, 1996). Similarly, *Anopheles funestus* is associated with more stable water bodies with aquatic vegetations (Gillies & Coetzee, 1987; Gimnig *et al.*, 2001).

Abundance of mosquitoes' larvae in their breeding habitats may be influenced by both abiotic and biotic factors (Onori *et al.*, 1993). The main abiotic factors include, water temperature, its chemical composition, water pH and turbidity. The main biotic factors are competitors, predators, bacteria, fungi and aquatic plants. In Dakar, Senegal, earlier studies showed that breeding habitats with temperatures greater than 27°C, water depth of less than 40 cm, high carbonate concentration, high water pH and presence of water lettuce favoured *Anopheles arabiensis* larvae (Robert *et al.*, 1998). In Asembo, western Kenya, differences in habitat characteristics were observed between habitats with both *Anopheles gambiae* s.s. and *Anopheles arabiensis* compared with habitats with only one species (Gimnig *et al.*, 2001). For example, habitats with both species were reported to be warmer and less likely to have surface film or aquatic vegetation than habitats with only *Anopheles gambiae* s.s. or only *Anopheles arabiensis* (Gimnig *et al.*, 2001).

Chemical composition of water may influence larva species and their population (Service,1993a). *Anopheles merus* and *Anopheles melas*, both members of *Anopheles gambiae* complex, breed in salt water, with a pH greater than 7.0 (Gillies & Coetzee, 1987). In Mbita point, western Kenya, water pH was shown not to determine the occurrence of anopheline mosquitoes (Minakawa *et al.*, 1999).

Turbidity of water has been reported to have an effect on larval population by influencing adult oviposition behaviour. Adult females of *Anopheles gambiae* were shown to prefer oviposition on turbid water rather than on clean water (McCrae, 1983). Laboratory studies have also shown that chemo-attractants from decaying organic matter may play a role in the oviposition behaviour of gravid *Anopheles gambiae* mosquitoes (Blackwell & Johnson, 2000).

Earlier studies have shown that aquatic vegetations are associated with increase in abundance of mosquitoes. For instance, in Lake Volta in Ghana, West Africa, *Pistia* was found to harbour many mosquito larvae, among which *Aedomyia africana* dominated the fauna, followed by *Ficalbia splendens* and *Mansonia africana*. *Anopheles funestus,* a malaria vector, and *Aedomyia africana*, a vector of yellow fever, encephalitis and filariasis, were found commonly associated with *Pistia* in Volta Lake (Obeng, 1969).

However, studies on macrophyte-vector associations, have elicited contradictory findings. For example, according to Pope *et al.* (2005), *Typha domingensis* marsh and flooded forest are habitats of immature *Anopheles vestitipennis*, and *Eleocharis* species marsh, is the habitat for immature *Anopheles albimanus*. Whereas, in Cameroon, Kengne *et al.* (2003) found out that although macrophyte based waste water treatment systems dominated by *Pistia stratiotes* permitted the fixation of a great number of larvae to the macrophyte roots, only 0.02% of captured larvae were *Anopheles gambiae*, suggesting that this waste water macrophytes treatment system does not significantly contribute to the development of the malaria vectors.

Species assemblages and abundance in specific locations can also be influenced by historical factors and population dynamics mainly, previous colonization or non colonization of the location or area by the particular species, and how population increase or decrease depend on local environmental pressures, which can be true for differential abundance of mosquito species in different locations (Minakawa *et al.*, 1999; Onori *et al.*, 1993; Robert *et al.*, 1998). Therefore, mosquito larval habitat location and ecology is important in determining larval densities and species assemblage which in turn will influence malaria transmission in an area (Mwangangi *et al.*, 2007).

2.2. Ecology of Fresh Water Snails Including Snails that Transmit Schistosomiasis

Both abiotic and biotic factors influence the distribution of African fresh water snails (Appleton, 1978; Brown, 1994). Among the abiotic factors, temperature emerges as a factor of greatest importance in determining the distribution of host snails in lentic environment (Appleton, 1978). Intermediate host snails seem to have broad ranges to field water temperatures. However, *Bulinus globosus* is sensitive to temperature gradients and will seek out parts of the habitats where temperatures are nearest its optimum (Brown, 1994). *Bulinus africanus* is more capable of colonizing habitats under cooler climatic conditions than *Bulinus globosus* (Brown, 1994). Temperature also determines whether or not snails can reproduce. Below 10°C, reproduction is severely inhibited. Both adults and eggs succumb at temperatures that exceed 30°C (Brown, 1994).

Temperature affects the amount of time needed to complete shedding cercariae. Cooler temperatures decrease the rate of development while warmer temperatures up to the optimum of 22°C are known to increase the rate of development (Pflüger, 1981). Pflüger describes this portion of the schistosome life cycle as being the most restrictive with respect to temperature. The free swimming cercariae released from snail hosts infect the human host by penetrating the skin. The thermal development requirements of *S. haematobium* and *S. mansoni* have been reported in detailed studies (Pflüger, 1981). A minimum temperature and maximum temperature for development of the parasite was established as well as the number of growing degree day (GDD) required for them to complete one life cycle in the snail host for both *S. mansoni* and *S.*

haematobium. The rate of development, as influenced by temperature, was shown to have a linear relationship starting with the minimum temperature (15.3°C for *S. haematobium*) to an optimum temperature (22°C for *S. haematobium*) above which there is an inverse relationship of development and temperature.

Parasitic development within the snail has the most restricted range of temperatures throughout the life cycle (Handzel *et al*., 2003). The optimum temperature for population growth is 25°C. Rainfall and water temperature are the most important variables for controlling the population of *B. globosus* (Pflüger, 1981). Low temperatures tend to reduce activity and breeding. Optimum temperatures are generally between 20 and 30°C. Of the planorbid snails, *Biomphalaria pfeifferi* are less tolerant of higher temperatures, and are absent where temperatures of more than 27°C last for more than 120 hours per week. On the other hand, bulinid snails appear better adapted to the higher temperatures (Sturrock, 1965).

Salinity (proportion of dissolved minerals) also conditions fresh water snail habitats. Studies done by Pretorious *et al*. (1982) found out that a natural population of *Bulinus africanus* declined in relation to increasing salinity. It was also proved experimentally that the mineral content of water can be limiting either when too low or too high (Donnelly *et al*., 1983). Salinity influence the biology of *Bulinus africanus* in that there is progressive and significant reduction in both the rate of hatching and mean percentage egg hatch with increasing salinity (Donnelly *et al*., 1983).

Oxygen is introduced into water (particularly moving water) from the air; swift streams and surface water with waves are normally saturated with oxygen. It is also produced in water by submerged vegetation; this is of special importance in small bodies of water with little movement. Richness of submerged vegetation means a rich production not only of oxygen but also of material eventually to be decomposed by bacterial action - a process which consumes oxygen, and which therefore makes an oxygen deficit fairly common in highly eutrophic waters, particularly at the bottom. When there is not enough oxygen for aerobic bacterial decomposition, anaerobic decomposition replaces it, and gives rise to the production of hydrogen sulphide, which appears to be toxic to snails. In water collections of small size they may die when hydrogen sulphide is produced, even if they live in the oxygenated surface water. In habitats rich in aquatic weeds and algae, photosynthetic activity can produce over-saturation of oxygen and a diurnal oxygen fluctuation (Brown, 1994).

Four environmental factors that affect the density and viability of snail populations include water levels (depth), flooding, elevation, and water velocity (Brown, 1994). Flooding can prove problematic, as annual floods in certain environments have been found to drown adult snails. Large-scale floods have a measurable negative impact on snail populations (Sturrock *et al.*, 2001).

The water current speed in riparian environments often determine the density of snail populations; and during times of high water it may re-locate large populations down river. Flood-driven currents can also devoid areas of snails. This feature of lentic ecosystems has proven to be problematic in controlling snail populations, since snails upstream from areas of flooding can easily re-populate barren zones (Brown, 1994).

Elevation also plays an important role in determining the density of snail populations, particularly for marshlands that lie above the mean low water level of lakes and rivers. Seasonal standing ponds or inlets with sparse vegetation are characteristic of these elevated areas. Optimal snail habitats are typified by expanses of flat, mid-level land with numerous dry-season ponds and streams, and thick grass covering the ground (McCullough *et al.*, 1972). Marsh grass and silt along the banks maintain the shaded and humid microclimate optimal for a thriving snail population (Sturrock *et al.*, 2001). In general, snails tolerate wide limits of chemical and physical environmental conditions; Salinity, electrical conductivity, concentration of calcium and magnesium ions, and oxygen tension appear to be of significance (Pretorious *et al.*, 1982).

There is an association between snails and aquatic plant species - the plants providing shelter, protection, and surfaces for oviposition, and supplying snail food when decomposing in water for weeks and months (Handzel *et al.*, 2003; Kabatereine *et al.*, 2001; Ofulla *et al.*, 2010). Planorbid (*Biomphalaria species*) snails prefer shallow water in streams with a moderate organic content, little turbidity, a muddy substratum with submerged or emergent vegetation, and moderate light penetration (Brown, 1994).

In tropical countries, it has particularly been hypothesised that water hyacinth contributes to an increase in populations of the snails that transmit schistosomiasis (Badejo *et al.*, 1988; Ntiba *et al.*, 2001; WHO, 1985) since many schistosome host snail species thrive in the presence of aquatic vegetations (Ndifon & Ukoli, 1989). However, the schistosome host snail species can vary widely in their ecologic requirements within the microenvironment (Kariuki *et al.*, 2004).

Earlier studies have monitored the distribution of snails elsewhere and within the Lake Victoria basin (Boelee & Hammou, 2004; Brown, 1994; Kariuki *et al.*, 2004; Ofulla *et al.*, 2010; Opisa *et al.*, 2011; Sturrock *et al.*, 2001). However, these studies focused on vector snails and they generally did not take into account the fact that these snails belong to communities of benthic organisms. As such the current study sought to determine habitat characteristics of the snails, effects of physico-chemical parameters, flora, fauna and their influence on the abundance of snails.

2.3. Phytoplankton, Zooplankton and Fish Abundance and their Effects on Mosquitoes and Snail Abundance

Excessive algal proliferation (algal blooms) might cause death to a number of aquatic animals, either from lack of oxygen (at night) or algal toxins (Boney, 1975). Previous studies indicate there were 344 species of phytoplankton in 140 genera and 8 phyla in Lake Victoria and surrounding water bodies (Wakwabi *et al.,* 2006). The eight identified phyla include Cyanophyta, Chlorophyta, Bacillariophyta, Dinophyta, Euglenophyta, Pyrrophyta, Chrysophyta and Cryptophyta. Bacillariophyta (diatoms) is the most diverse group, with 111 species existing on the Kenyan side of the lake. Cyanophyta (cyanobacteria or blue-green algae) is well represented, often constituting between 60 and 97% of individuals (cells or filaments) in Lake Victoria and surrounding water bodies (Wakwabi *et al.,* 2006). Cyanobacteria, especially Microcystis, occur in high abundance in Lake Victoria and some of the small water bodies (SWBs) in its basin. In Lake Kyoga, Uganda, however, the phytoplankton varied along a gradient from east to west, being dominated by Cyanobacteria in the east (Green, 2009).

Zooplankton are microscopic organisms suspended in water, including various kinds of protozoans, micro crustaceans and other micro invertebrates that are planktonic in water bodies (Waya & Mwambungu, 2004). Benthic micro invertebrates are higher-level invertebrates associated with life at the bottom of streams, ponds, lakes, either crawling, burrowing or attached to different kinds of solid objects such as plants, stones and woods. Zooplankton occupies a strategic trophic level in aquatic ecosystems (Allison *et al.,* 1996). More often than not, zooplankton associations play a vital role in the food web of any aquatic ecosystem and can be adversely affected by a number of environmental factors, including low dissolved oxygen concentrations, which have been found to be limiting in maintaining aquatic life in some cases (Allison *et al.,* 1996). Thus, cyanobacterial contamination also can influence the species composition and population dynamics of other aquatic organisms, including schistosomiasis snails in aquatic ecosystems.

The development of an effective strategy of integrated control requires study of population dynamics of the intermediate hosts and their relation to environmental factors (El-Khayat *et al.,* 2011; Hussein *et al.,* 2011). Several factors can affect the ecology of snails and other intermediate disease hosts and therefore also their focal and seasonal distributions. These include physical factors such as water current, temperature, turbidity, transparency and distribution of suspended solids, chemical factors such as ion concentration and dissolved gases in water, and biological factors such as the availability of food, competition and predator–prey interactions (Ofoezie, 1999), as well as toxicological factors (Williamson *et al.,* 2004). The importance of different ecological factors, however, can vary significantly from one ecological zone to the other and even from one water body to another, suggesting local investigations to identify important factors in each zone or water bodies (Hussein *et al.,* 2011).

Mosquito breeding in aquatic habitats is largely influenced by the presence of predators (Service, 1977; Sunahara *et al*., 2002). These predators include larvivorous fish. Predation of larvae by larvivorous fish (Gerberich and Laird, 1985) and cannibalism among larvae (Koenraadt & Takken, 2003; Reisen *et al*., 1982) also influence the population dynamics of mosquito larvae hence playing a major role in population size (Service, 1977). For example, in Ahero rice irrigation scheme, Kenya, Service (1977) estimated larval mortality of *An. arabiensis* due to larvivorous fish to be about 93% whereas in the Philippines and Thailand rice fields, it was estimated to be about 98% (Mogi *et al.,* 1984; Mogi *et al*., 1996). Some of the larvivorous fish have shown potential as bio-control agents in rice fields (Hoy *et al*., 1971).

Recent studies by Ofulla *et al.* (2010) showed that *Oreochromis niloticus* and Haplochromines fish were more abundant in the water hyacinth mats compared to hippo grass and open water habitats. Also, there were more fingerlings of *Oreochromis niloticus* and Haplochromines within the water hyacinth mats compared to the same species within the hippo grass habitats and in the open waters showing that actually the aquatic mats in the lake waters were harboring abundant fish which can predate on the mosquito larvae.

The larvivorous nature of *Oreochromis niloticus* had been reported by Njiru *et al.* (2004) where zooplankton and insects formed the main food component in all the seasons (dry and short rainy). *Clarias gariepinus* fingerlings have also been reported to feed on insects including mosquito larvae/pupae (Britz & Hecht, 1988) and act as biological control agents (Ghosh *et al.*, 2005). Green, (2009) also reported that Haplochromines (astatotilapia) feeds primarily on larval and adult insects, further reinforcing the role these fish species can play in controlling mosquito populations in aquatic habitats. It was therefore important in this thesis research to carry out gut contents analysis of the different fish species to determine which ones are more insectivorous and can be used as biological agents against mosquito larvae in lake and land aquatic habitats in the Lake Victoria basin of western Kenya.

It is with this background, that the current study was undertaken to determine the differential distribution of mosquito species in the lake and land locations in relation to abiotic and biotic environmental factors in aquatic habitats of western Kenya.

2.4. Community Knowledge and Perceptions on Vector Borne Diseases

Malaria risk and disease burden is inequitably distributed, not only at global and regional levels but also at household level because poor housing, lack of education and access to healthcare services create a vicious cycle of enhanced vulnerability to malaria due to increased exposure, high household medical costs, reduced ability to pay for treatment, and so on (Bates *et al.*, 2004). Decisions for prevention or treatment are made depending on economic ability of the household, perceived susceptibility and assessment of consequences. Furthermore, malaria transmission is often facilitated because environmental degradation, poor drainage and clearing of vegetation readily promote the proliferation of mosquito species such as *Anopheles gambiae* which propagates itself in sunlit, transient water bodies, notably artificial habitats associated with human activities (Munga *et al.*, 2005; Mutuku *et al.*, 2006). Malaria, poverty and environmental change are inextricably linked and remain closely associated across most of Africa (Lindsay & Birley, 2004).

Rural areas have always been a major challenge for disease control worldwide, but the involvement and active participation of communities has been identified as a key factor for success in these environments (Townson *et al.*, 2005). Knowledge, attitudes and practices (KAP) of malaria risk factors, transmission, symptoms, and prevention are potentially important factors of disease avoidance behaviours and consequently of disease prevalence. However, knowledge does not always translate into behaviour change and the processes by which individuals' knowledge regarding malaria affects behaviours are influenced by other factors such as gender, age and socio-economic position (SEP) (Vundule & Mharakurwa, 1996; Worrall *et al.*, 2005).

A previous study in Kenya compared the behavioural and socioeconomic factors associated with malaria prevention in two urban environments. Results showed a significant association between wealth, education and use of mosquito nets in both locations, but associations between use of multiple prevention activities and wealth and education differed between cities (Macintyre *et al.*, 2002). The effect of knowledge on health seeking behaviours is also likely to vary depending on infrastructural and community realities such as distance to health centres, availability and cost of treatment and quality of available health care (Bates *et al.*, 2004; Baume *et al.*, 2005).

Similar to socioeconomic factors, KAP regarding individual water contact behaviours and risk of schistosomiasis disease are likely to be influenced by the cultural, geographical, and ecological realities of a given local context. In areas where schistosomiasis morbidity is considered secondary to concerns of hunger, poverty and lack of services, KAP is not likely to predict risk of disease. This phenomenon was observed in Egypt where contact with infected water persisted despite high levels of knowledge regarding schistosomiasis risk and morbidities (Kloos, 1982). Similarly, in a Malawian study, knowledge of disease outcomes and infection control was positively associated with adherence to prevention and control procedures (Ager, 1992). Alternatively, those with the least knowledge of schistosomiasis may exhibit severe infection avoidance behaviours out of fear of disease, as was reported by one study in the Philippines (Kloos, 1995). Within different cultural and geographic contexts, knowledge of schistosomiasis may have variable effects on risk of disease.

Global burden of schistosomiasis is currently estimated to be 240 million people infected and about 600 million people are at risk of infection with schistosome parasites in more than 76 endemic countries (WHO, 2012). Through a full consideration of the amount of end-organ pathologies to the liver (in the case of *Schistosoma mansoni* and *Schistosoma japonicum* infections), and to the bladder and kidneys (in the case of *Schistosoma haematobium* infection (van der Werf *et al.*, 2003) together with the chronic morbidities associated with impaired child growth and development, chronic inflammation, anaemia, and other nutritional deficiencies, some new disease burden assessments estimate that schistosomiasis accounts for up to 70 million disability-adjusted life years (DALYs) lost annually (King & Dangerfield-Cha, 2008). This global burden estimate exceeds that of malaria or tuberculosis, and is almost equivalent to the DALYs lost from HIV/AIDS (King & Dangerfield-Cha, 2008). Further, almost 300,000 people die annually from schistosomiasis in Africa (van der Werf *et al.*, 2003) and there is evidence that female genital schistosomiasis caused by *S. haematobium* may significantly increase the likelihood of contracting HIV/AIDS (Kjetland *et al.*, 2006).

Several studies done in various parts of the world revealed that there exist a wide range of beliefs as to the causes of various vector-borne diseases and that the misperceptions have important implications to effective implementation of any vector-borne diseases (Agyepong, 1992; Service, 1993b; Sharma *et al.*, 1994). Since community members may lack information on scientific aspects of transmission of water-related and vector-borne diseases, this study was conducted to assess the level of community members' knowledge and perceptions on association between the aquatic habitats and transmission of malaria and schistosomiasis in different regions of lake Victoria basin of Kenya.

CHAPTER THREE

3.0. METHODOLOGY

3.1. Study Area

The research area for this study was the Lake Victoria basin of Kenya particularly in the Nyanza Gulf of Kenyan Lake Victoria waters and adjacent terrestrial areas. Administratively, the study area covered several districts / counties and ranged from Lwanda Gembe beach in Mbita District of Homa-Bay County to Dunga beach of Kisumu East District, Kisumu County in western part of Kenya.

During the study period (2009-2011), the weather was erratic with no well defined wet and dry season in the study area. In 2011, there was more rain in the normally short rainy season between September and November. From available previous records, the wettest period in western Kenya is usually from the end of February to mid June with an annual rainfall of 150-260 mm, followed by a short rainy season between September and November with monthly rainfall of at least 125 mm (Lake Basin Development Authority weather data, 2011). The dry period occurs between December to February with a mean temperature varying between 17^{0}C minimum to 32^{0}C maximum. The study area is relatively humid due to its proximity to Lake Victoria (Githeko *et al.*, 1996).

The study area lies about 1100m above sea level, with savannah type of vegetation of low shrubs without tree growth (Service, 1977). The area is characterised by undulating topography with steep and gentle sloping hills with cultivated swamps occurring mainly at valley bottom (Githeko & Ndegwa, 2001). Some slopes are as steep as 85% while the valley bottoms are mainly gentle sloping and in some places nearly flat (Service, 1977).

The study area is inhabited predominantly by the Luo ethnic group, comprising about 95% of the population (Okeyo-Owuor, 1999). The remainder is from the other ethnic groups in Kenya, working here as government workers and in the fishing industry. A few immigrants from Uganda, which neighbours the study area, are also residents in the study area. The inhabitants in the area live in scattered family compounds that consist of one or more houses surrounded by agricultural fields and grazing lands (Githeko *et al.*, 1996). Most of the houses are constructed using wood and mud, with roofs that are predominantly of corrugated iron sheets. Most household owners keep one or more domestic animals such as cattle, sheep, goats, dogs, cats, and chicken. Animals sleep either in structures outside of the main house called kraals or inside of human dwellings (Githeko *et al.*, 1996).

The majority of the people in this area are mainly occupied in subsistence farming consisting of maize, beans, millet and livestock farming of indigenous cattle, goats and sheep. This type of farming, relying as it does on rain, is sometimes hampered by a scarcity of rain, resulting in poor harvests and low quality animals. However, a few people have started horticultural farming (tomatoes, cabbages and vegetables) along the shores of Lake Victoria. Fishing is the second most important occupation in the area. Inhabitants here practice fishing for both domestic and commercial purposes (Githeko *et al.*, 1996; Okeyo-Owuor, 1999).

3.2. Research Design, Sampling Locations and Procedures

This study was done in specific locations within Lake Victoria waters in the Nyanza gulf and the adjacent terrestrial areas within the Lake Victoria basin (LVB). Efforts were made to sample from different or replicate sites from each study area location. The location of the sampling sites were marked using a GPS Garmin GPS II Plus (Garmin Corporation, Kansas, USA). In the waters, the locations sampled were: Asembo bay (9 sites), Homa bay (8 sites) Kendu bay (7 sites), Kisumu bay (6 sites), Lwanda Gembe (8 sites), Nyando Nyakach (9 sites), off Sondu Miriu (6 sites), and Usoma point (6 sites). On land, the sites sampled were: Ahero (3 sites), Asembo (5 sites), Auji (3 sites), Dunga (5 sites), Homa bay (4 sites), Kendu bay (1 site), Kisumu (3 sites – Ongalo quarry, Nyawita quarry, and Nawa stream), Lwanda Gembe (3 sites), Olambwe river (1 site), Osienala pond (1 site), and Sondu Miriu (4 sites). The sampled sites are shown in Figure 1 and in Table 1 (locations in the lake), and Table 2 (locations on land). Tables 1 and 2 also show the number of replicate sites, the GPS readings, elevation, and the habitat types and vegetation.

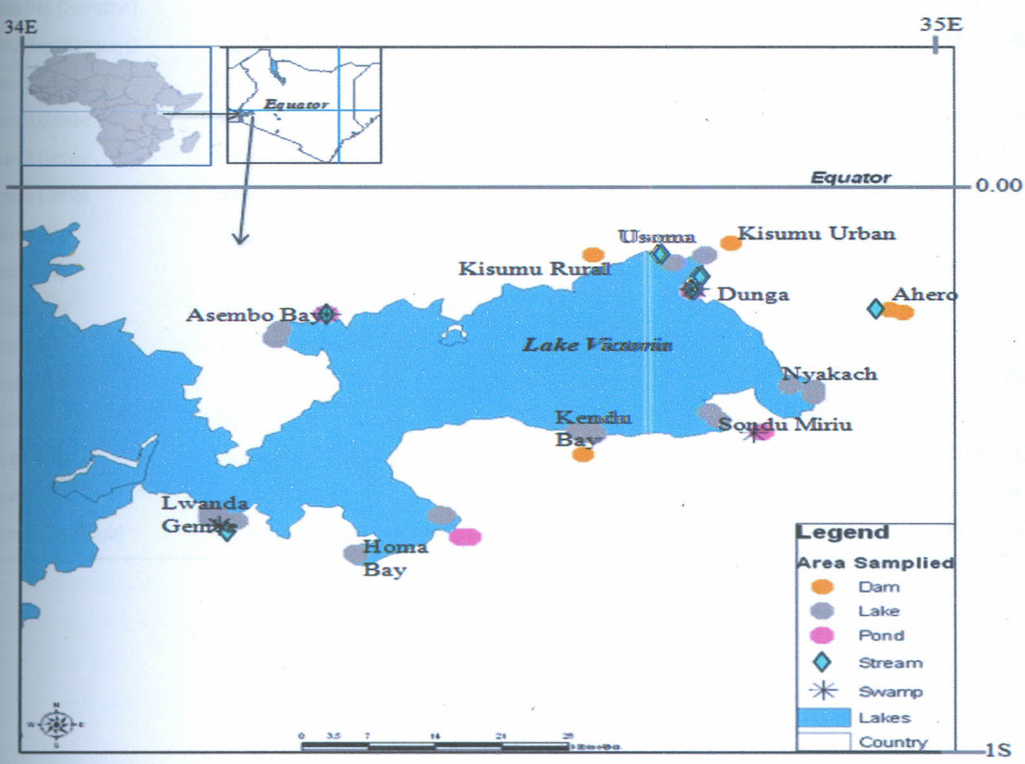

Figure 1. Map of the Nyanza gulf showing sites sampled (in dots)

Table 1. Sampling locations, replicate sites, GPS reading, elevation and habitat or vegetation type of the study areas in the lake within Nyanza Gulf of Lake Victoria, Kenya.

Sampling Locations	Habitat/Vegetation	Replicate Site	Elevation	GPS Reading
Nyando (Nyakach Bay)	Open Water	5	3738	S:00' 16.742' E: 034' 49.688'
Nyando (Nyakach Bay)	Hippo Grass & Hyacinth	2	3727	S:00' 16.935' E: 034' 51.027'
Nyando (Nyakach Bay)	Water Hyacinth Zone	2	3729	S:00' 17.525' E:034' 51.039'
Sondu Miriu	Open Water	3	3741	S:00' 18.947' E: 034 45.191'
Sondu Miriu	Hippo Grass Zone	3	3736	S:00' 19.619' E: 034' 45.642'
Kendu Bay (Awach)	Open Water	3	3725	S:00' 20.604' E: 034' 38.743'
Kendu Bay (Awach)	Hippo Grass/Hyacinth Zone	2	3721	S:00' 20.919' E: 034' 38.786'
Kendu Bay (Awach)	Water Hyacinth Patch	1	3733	S:00' 20.848' E: 034' 38.089'
Kendu Bay (Awach)	Ambatch Tree Zone	1	3736	S:00' 20.512' E: 034' 37.783'
Homa Bay (Oluch)	Hippo Grass Zone	1	3799	S:00' 27.706' E: 034' 29.957'
Homa Bay (Oluch)	Water Hyacinth Zone	1	3793	S:00' 27.730' E: 034' 30.068'
Homa Bay (Oluch)	Hippo Grass/Hyacinth Zone	1	3746	S:00' 27.715' E: 034' 30.210'
Homa Bay (Oluch)	Pure Hyacinth Mat	1	3713	S:00' 27.719' E: 034' 30.226'
Homa Bay (Oluch)	Open Water	2	3724	S:00' 27.793' E: 034' 30.191'
Homa Bay (Samunyi)	Open Water	1	3726	S:00' 31.042' E: 034' 25.254'
Homa Bay (Samunyi)	Hippo Grass/Hyacinth Zone	1	3727	S:00' 30.910' E: 034' 25.182'
Lwanda Gembe	Open Water	3	3723	S:00' 27.707' E: 034' 17.321'
Lwanda Gembe	Water Hyacinth	2	3732	S:00' 27.462' E: 034' 16.924'
Lwanda Gembe	Hippo Grass/Hyacinth Zone	1	3730	S:00' 27.925' E: 034' 16.880'
Lwanda Gembe	Hyacinth Zone	2	3730	S:00' 28.141' E: 034' 18.380'
Asembo Bay	Hippo Grass zone	2	3742	S:00' 12.688' E: 034' 20.617'
Asembo Bay	Open water	3	3761	S:00' 12.208' E: 034' 20.859'
Asembo Bay	Hippo Grass/Hyacinth Zone	1	ND	S:00' 12.798' E: 034' 20.640'
Asembo Bay	Water Hyacinth Zone	1	3738	S:00' 12.818' E: 034' 20.651'
Asembo Bay	Ambatch Tree Zone	2	3735	S:00' 12.059' E: 034' 20.920'
Usoma Point	Open Water	3	3739	S:00' 06.420' E: 034' 43.110'
Usoma Point	Hippo grass/Hyacinth Zone	3	3728	S:00' 06.412' E: 034' 43.185'
Kisumu	Open Water	3	3720	S:00' 05.706' E: 034' 44.890'
Kisumu (Car Wash)	Hippo grass/Hyacinth zone	3	3731	S:00' 05.793' E: 034' 44.883'

Table 2. Sampling locations, replicate sites, GPS reading, elevation, habitat type and vegetation type of the study area on land within the Lake Victoria basin, Kenya.

Sampling location	Vegetation	Replicate site	Elevation	Habitat	GPS Reading
Auji (Drainage)	Hippograss/Hyacinth	1	3749	Stream	S:00' 07.524' E: 034' 44.700'
Auji (Drainage)	Hyacinth/Hippo grass	2	3749	Stream	S:00' 07.524' E: 034' 44.700'
Auji (Drainage)	Hippo grass/Hycinth zone	3	3749	Stream	S:00' 07.525' E: 034' 44.701'
Dunga Beach (DU)	Other vegetation	1	3720	Swamp	S:00' 08.688' E: 034' 44.277'
Dunga Beach (DU)	Other vegetation	2	3720	Swamp	S:00' 08.688' E: 034' 44.277'
Dunga Beach (DU)	Other vegetation	3	3727	Stream	S:00' 08.664' E: 034' 44.279'
Dunga Beach (DB)	Hippograss/Other vegetation	4	3730	Stream	S:00'08.657' E: 034' 44.282
Dunga Beach (DB)	Hippograss/Other vegetation	5	3734	Stream	S:00' 08.649' E: 034' 44.289'
Osienala Pond (OS1)	Hippograss/Hyacinth	1	3735	Pond	S:00' 08.775' E: 034' 44.136'
Asembo (Pond Banda)	Hippograss/Other vegetation	1	3758	Pond	S:00'10.756' E:034' 23.564'
Asembo (Pond Banda)	Hippograss/Other vegetation	2	ND	Stream	S:00' 10.759' E: 034' 23.564'
Asembo (Pond Banda)	Other vegetation	3	ND	Stream	S:00' 10.761' E: 034' 23.564'
Asembo (Pond Banda)	Other vegetation	4	ND	Temporary Pond	S:00' 10.766' E: 034' 23.512'
Asembo (Banda)	Other vegetation	5	ND	Natural Swamp	S:00' 10.773' E: 034' 23.512'
Kisumu Rural (Ongalo Quarry)	Hyacinth/Other vegetation	1	3790	Quarry	S:00' 05.957' E: 034' 09.092'
Kisumu Urban (Nyawita Quarry)	Other vegetation	1	3849	Nyawita quarry	S:00' 04.728' E: 034' 46.373'
Kisumu Rural (Nawa Stream-Bdg)	Other vegetation	1	3716	Stream	S:00' 05.637' E: 034' 42.447'
Luanda Gembe	Other vegetation	1	3824	Natural Swamp	S:00' 28.634' E: 034' 17.366'
Luanda Gembe	Other vegetation	2	3745	Natural Swamp	S:00' 28.633' E: 034' 17.363'
Luanda Gembe	Other vegetation	3	3761	Natural Swamp	S:00' 28.638' E: 034' 17.366'
Olambwe River	Hyacinth/Other vegetation	1	3741	River	S:00' 29.069' E: 034' 17.854'
Homa Bay (Kanam Kochia)	Hippograss/Other vegetation	1	3757	Temporary Pond	S:00' 29.504' E: 034' 31.218'
Homa Bay (Kanam Kochia)	Hippograss/Other vegetation	2	3768	Temporary Pond	S:00' 29.514' E: 034' 31.201'
Homa Bay (Ondiche Kochia)	Other vegetation	1	3786	Temporary Pond	S:00' 29.541' E: 034' 31.651'
Homa Bay (Ondiche Kochia)	Other vegetation	2	3724	Temporary Pond	S:00' 29.534' E: 034' 31.661'
Kendu Bay-Kanyanjom Dam	Hippograss/Other vegetation	1	3960	Dam	S:00' 25.550' E: 034' 35.765'
Sondu Miriu (Yawo Kojwang dam)	Other vegetation	1	3999	Dam	S:00' 20.703' E: 034' 48.047'
Sondu Miriu	Other vegetation	2	3759	Dam	S:00' 20.682' E: 034' 48.149'
Sondu Miriu (Roadside)	Other vegetation	1	3764	Roadside pond	S:00' 20.682' E: 034' 48.109'
Ahero (District Hospital)	Other vegetation	1	3760	Dam	S:00' 10.368' E: 034' 55.404'
Ahero (Apida Dam)	Hyacinth	2	3827	Dam	S:00' 10.590' E: 034' 56.115'
Ahero (Rice Irrigation Scheme)	Hyacinth	1	3776	Stream	S:00' 10.306' E: 034' 54.634'
Sondu Miriu	Other vegetation	1	3748	Flood Plain	S:00' 20.810' E: 034' 47.615'

3.2.1. Sampling procedures

In the lake within the gulf, sampling was done using boats. Habitat types were either in-shore or off-shore and were characterized into the following categories: hippo grass, open lake waters, hippo grass / water hyacinth (HG/WH), water hyacinth, or Ambatch tree habitats. In-shore habitats were at the shoreline, and off-shore habitats were located about 500 metres away from the aquatic vegetation (macrophytes) or the shoreline. On land, sampling was done using 4-wheel drive vehicles and on foot. Habitat types were broadly classified into ten categories: dam, stream, natural swamp, permanent pond, shoreline swamp, temporary pond, quarry, river, flood plain, and roadside pond. On land, vegetation types in the sampled location (sites) were: hippo grass, hippo grass and other vegetation (N.B. non aquatic plants on land habitats were simply categorized as other vegetation since they were numerous and classifying them to species would have been a challenging task), water hyacinth and other vegetation, and other vegetation habitats. Identification was carried out by use of keys by Agnew & Agnew (1994), Cook *et al.* (1974), and Sainty & Jacobs (1994).

Locations and habitat analysis included vegetation type, presence of mosquitoes, presence of schistosomiasis host snails (*Biomphalaria sudanica, Biomphalaria pfeifferi* and *Bulinus africanus*), physico-chemical parameters analysis of water (dissolved oxygen, pH, alkalinity, hardness, turbidity, conductivity, temperature, turbulence, depth and salinity), presence and abundance of phytoplankton, presence and abundance of zooplankton, and abundance of fish. Photographs were taken using a HSC50 Sony model digital camera (Sony Corporation, Tokyo, Japan). Plates 1-7 show photos of some of the various sampled habitat types.

Plate 1. Sampling process in the lake shoreline fringed with water hyacinth

Plate 2. Water hyacinth fringed with papyrus in the Lake Victoria shoreline

Plate 3. Water hyacinth infested pond on land in Ahero

Plate 4. Swamp puddles on land in Asembo, a suitable *Anopheles* breeding habitat

Plate 5. Permanent swamp on land in Ahero, a non suitable *Anopheles* breeding habitat

Plate 6. Water hyacinth infested semi permanent quarry pond on land at Hayer site in Kisumu rural, a suitable *Anopheles* breeding habitat

Plate 7. Previously water hyacinth infested semi permanent quarry pond on land at Nyawita site in Kisumu city suburb, a very suitable *Anopheles* breeding habitat

3.3. Sampling of Mosquitoes

Larval sampling was done using the standard dipping method with a 350 ml mosquito scoop (Bioquip, Gardena, CA, USA) as described by Service (1993a) and Silver (2007). Sampling effort consisted of 10 dips taken at each collection point. After dipping once, a minute was allowed to elapse before the next dip in order to allow time for the larvae to resurface again. Mosquito larvae collected were differentiated in the dipper into anophelines or culicines, depending on whether they float parallel with the water surface (anopheline) or hang down from the surface (culicines) (Rozendaal, 1997). Counting and recording was performed on site before proceeding to the next sampling site.

Adult mosquitoes (both anophelines and culicines) were sampled using a battery operated aspirator (CDC backpack aspirator model 1412), Plate 8. They were then separated into anophelines and culicines based on their morphological characteristics (Gillies & Coetzee, 1987). These were then taken to Kenya Medical Research Institute (KEMRI), Centre for Global Health Research (CGHR), Kisumu laboratory, for further identification using the identification keys by Gillies and Coetzee (1987) and Highton (1983).

Plate 8. Sampling of adult insects using a battery operated aspirator in Lake Victoria

3.4. Snail Sampling and Identification

Snail sampling was conducted by one trained field collector (author) searching each site using a standard flat-wire mesh scoop with a mesh size of 2mm (Ouma *et al.*, 1989). Sampling was fixed at approximately 30 minutes per site. Snails associated with the root masses of the vegetation (see Plate 9) were sampled by manually uprooting ten plants from each site. Snails were then separated from the collected root mass by vigorously shaking each root sample in a bucket containing water, causing them to detach from the roots and sorted in a white plastic tray with 2-3cm of clear water. They were then put in plastic containers with water and then taken to the lab for taxonomic identification. At each collection point, snails from each site were labelled and transported in separate perforated containers to the laboratory at Kenya Medical Research Institute (KEMRI), Centre for Geographical Health Research (CGHR), Kisumu, Kenya. Snails were identified to species level based on shell morphological characteristics using standard keys (Brown, 1994; DBL-WHO, 1998).

The shells of freshwater pulmonates offer a great number of characters useful in taxonomy and for identification: the general shape, the number, coiling and shape of whorls; the shape and development of opening also called the aperture; the sculpture. The direction of coiling is also an important character. A coiled shell may be either dextral or sinistral. In the dextral (or right-handed) shell, the coiling runs clockwise when seen from top of the shell, while in the sinistral (or left-handed) shell, the coiling runs the opposite way (Brown, 1994; DBL-WHO, 1998).

Plate 9. ***Biomphalaria* species snails attached to hippo grass in the lake aquatic plants**

3.5. Physico-Chemical Parameters Determination

Physico-chemical parameters recorded for each location on land and in the lake were; water depth, pH, conductivity, temperature, turbidity, and dissolved oxygen. The physicochemical parameters of water were measured using a YSI 556 MPS handheld multi parameter instrument (YSI Incorporation, Yellow Spring, USA).

3.6. Sampling and Determination of Phytoplankton Presence and Abundance

Samples for determination of phytoplankton were collected at the subsurface. The water samples (25 mls) were preserved in acidic Lugol's solution. One ml water with phytoplankton sub-sample was placed in a rafter-cell chamber and left to settle. Representative numbers of strips were counted for algal abundance quantification. Phytoplankton species identification and enumeration was done using an inverted microscope at 400x magnification. Phytoplankton taxa were identified using the methods of Huber-Pestalozzi (1968). Phytoplankton densities were estimated by counting all the individuals whether the organisms were single celled, colonies or filaments. Plate 10 shows algal bloom at Awach in Kendu Bay, Lake Victoria, Kenya.

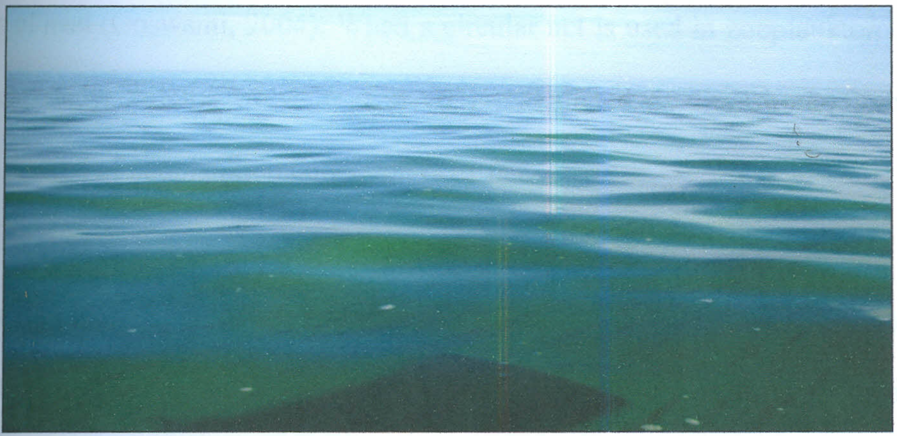

Plate 10. Algal bloom at Awach in Kendu Bay, Lake Victoria, Kenya

3.7. Determination of Zooplankton Presence and Abundance

Samples for determination of zooplankton were collected at the subsurface using a cone shaped Nansen net in open water areas. The integrated sample was then stirred before a sub-sample was filtered through 60µm plankton net. The contents were then washed into a 300ml vial, fixed in a 4% formaldehyde solution and taken to the laboratory for analysis. The samples were then made to appropriate volume, depending on the density of the organisms. Samples were stirred for uniform distribution and sub-samples poured into a counting tray and analysed under an Olympus dissection microscope (Olympus Corporation, Tokyo, Japan) at a x50 magnification. The number of individuals per litre was computed as follows:

$D = N/V$

Where:

N = number of organisms in sample = (number in sub sample x volume of sample) / sub-sample volume

V= volume of lake water filtered = $\pi r^2 d$, where:

r =radius of mouth of net (25cm)

d= depth of haul (Goswami, 2004). When a circular net is used in zooplankton collection, as in the current study, volume of water filtered is calculated by the above formula. The most common method of zooplankton collection is by net.

Copepoda were grouped into immature copepod (nauplii and early copepodid stages), Cyclopoida and Calanoida. Cladoceran and some Rotifera were identified to species level using identification keys of Smirnov (1996), Korovchinsky (1992), and Koste & Shiel (1986) for the latter.

3.8. Fish Sampling and Determination of Gut Contents

Fish sampling from the lake and land habitats was performed by use of an electro-fisher (Septa operations, Philadelphia, USA). Electro-fishing activity was carried out using a Septa model unit which discharges voltages of up to 600 volts with accompanying Amperes of between 5 to 30 Amps (Septa operations, Philadelphia, USA). A pulsed mode of discharge was adapted for electrocution lasting ten minutes at each attempt, and was repeated 10 times at each appropriate habitat site (Plate 11). Species identification and determination of abundance for fish followed descriptions given by Hyslop (1980) using morphometric and meristic characteristics. The gut contents of fish was also analyzed following the methods used by Hyslop (1980). The procedure entailed cutting open the fish and removal of the stomach. The stomach was then preserved in 5% neutralized formalin for analysis. During analysis, a longitudinal cut was made across the stomach and the contents transferred into a Petri dish. The contents were then kept for five minutes to remove excess formalin after which they were examined under Olympus binocular microscope (Olympus Corporation, Tokyo, Japan). Identification of the gut contents was made and the number of food items in each stomach counted and expressed as a percentage of the gut content of each specimen examined, from which the total percentage composition was estimated.

This was done to show which fish species was more insectivorous and could be suitable for biological control of mosquito larvae in aquatic habitats.

Plate 11. Electro-fishing in Ahero pond on land habitat

3.9. Community Perceptions on Malaria and Schistosomiasis Prevalence, Transmission, Treatment and Control in Relationship to Aquatic Habitats in Kenyan Lake Victoria Basin

In addition to mosquito and snails studies, community-based survey was also conducted to assess the level of community members' knowledge on association between the aquatic habitats and prevalence of malaria and schistosomiasis in the Lake Victoria basin of Kenya. A representative sample of the local community along the beaches was randomly selected. The minimum sample size required was calculated using the formula of Kothari (2008): $n= p.q. (z/d)^2$, where: n is the required minimum sample size, p is the proportion of the community who participated in the study, q is the proportion of those who did not, z is the standard normal deviate (taken to correspond to the 95% level of confidence) and d is the margin of error (taken as 5%). It was taken from a pilot study (pre test done by the researchers before carrying out the current study) that only 20% of the community participates in such activity and thus p and q were 0.2 and 0.8, respectively.

A finite population factor was applied because the population was less than 10000. Taking a 95% level of confidence, a 5% margin of error and applying the sample size formula of Kothari, (2008), a minimum sample of 230 was required for the study. A total of 243 respondents were therefore randomly drawn from 14 beaches along the Kenyan Lake Victoria basin. The beaches were selected because of proximity to the lake and earlier anecdotal reports by the local community along the beaches that occurrence of water hyacinth in the lake creates suitable breeding habitats of mosquitoes, leading to high prevalence of malaria along the Kenyan Lake Victoria basin, and it was also important to find out community perceptions on schistosomiasis and aquatic snails that transmit the disease and their habitats.

Structured questionnaire schedule (Appendix III) was first pre-tested in separate beaches within Lake Victoria and later administered to the respondents after detailed explanation in a language they understand. The first part of the questionnaire included demographic profiles of the participants, and the second part assessed their knowledge on malaria and schistosomiasis transmission, recognition, symptoms, treatment, control and association with aquatic habitats in the lake and on adjacent land in the Lake Victoria basin of western Kenya.

3.10. Ethical Considerations

Studies on mosquitoes and snails abundance and distribution in the Lake Victoria waters and adjacent terrestrial aquatic habitats did not require ethical approval. However, for community based studies, approval was given by Director of Public Health and Sanitation, Nyanza Province

(Appendix IV). The study was done as part of East Africa Community, Lake Victoria Basin Commission (LVBC) Project on Spatial Distribution and Habitat Characterization of Malaria Vectors and Schistosomiasis Host Snails Associated with Water Hyacinth in Nyanza Province (currently Nyanza Region). Full verbal explanation of the study was given to participants and full verbal consent obtained before commencement of the interviews. Privacy of the respondents' answers was guarded by not recording any name of the respondents.

3.11. Statistical Analysis

All vector-based data generated was entered and stored in Microsoft Excel, normalized by log transformation using $\log_{10}(n+2)$ (Reisen &Lothrop, 1999) but only non-transformed means were reported. Data was analyzed using MSTAT-C and Excel data analysis softwares to determine whether there were significant variations between the sampling locations, habitats, organisms, or vegetation types. One-way analysis of variance (ANOVA) and /or Bartlett's test of heterogeneity of means were used to compare the differences in physico-chemical parameters, phytoplankton, zooplankton and mosquitoes and schistosomiasis snails abundance between different locations, habitats and vegetation type on land and in the lake. Student t-test was used to compare the differences in means between *Bulinus* species and *Biomphalaria* species in different locations or habitats on land and in the lake. Regression analysis was used to determine associations between the abundance of mosquitoes and schistosomiasis snails versus physico-chemical parameters, phytoplankton, zooplankton and fish species abundance. Descriptive statistics were carried out to measure percentages and determine which fish species were more insectivorous. The community-based study data obtained was entered in Microsoft Excel spread sheets, cross-checked and transferred, and statistically analyzed using SPSS for Windows version 12.0 (SPSS, Atlanta. GA, USA). Descriptive statistics were carried out to measure percentages, averages and relative frequencies of variables. Chi-square test (X^2) was used to determine association between level of education, age, occupation, and gender, and correctness of responses of the study participants. Levels of significance were accepted at 95% confidence limits ($p<0.05$).

CHAPTER FOUR

4.0. RESULTS

4.1. Introduction

In this chapter, the study findings are presented as per the study objectives, in tables, figures, plate and textual forms.

4.2. Differential Mosquito Abundance in Different Sites and Locations in the Lake and on Land Aquatic Habitats

Habitat locations and types and how they influence abundance of mosquitoes were determined, and results are indicated in Tables 3 to 7. *Anopheles* and *Culex* species of mosquitoes were absent in different locations in the lake though *Aedes* and *Mansonia* species were abundant. There was heterogeneity in the relative abundance of *Aedes* and *Mansonia* species in the different locations in the lake waters, $p<0.001$, Bartlett's test, Table 3.

Table 3: Mosquito species abundance in different sites and locations in the lake

Locations	Mean (±SD) No. of Mosquitoes				
(No. of sites)	*Anopheles*	*Culex*	*Aedes*	*Mansonia*	p value
Asembo Bay (9)	0	0	0	10±8.2	-
Homa Bay (8)	0	0	0	2.6±4.1	-
Kendu Bay (7)	0	0	1.0±1.9	0.3±1.5	0.9438
Kisumu (6)	0	0	0	6.7±10.6	-
Lwanda Gembe (8)	0	0	0	7.5±17.5	-
Nyando Nyakach (9)	0	0	0.76±2.3	1±1.8	-
Sondu Miriu (6)	0	0	1.0±2.8	0.3±1.8	0.7121
Usoma point (6)	0	0	1.33±1.8	5.7±5.5	0.1015
ANOVA	-	-	0.19	0.075	
Bartlett's test	-	-	p<0.001	p< 0.001	

In contrast to the situation in the lake waters, *Anopheles* and *Culex* species were abundant in different aquatic habitats in different locations on land, while *Aedes* and *Mansonia* species were absent. There was heterogeneity in the relative abundance of *Anopheles* species and *Culex* species of mosquitoes in the aquatic habitats in different locations on land, $p<0.001$, Bartlett's test, Table 4.

Table 4: Mosquito species' abundance in different sites and locations on land

	Mean (±SD) No. of Mosquitoes		
Location (No. of sites)	*Anopheles* ±SD	*Culex* ±SD	p- value
Ahero (3)	12.3±11.2	11.7±12.6	0.8313
Asembo (5)	11±14.4	8.8±17.5	0.4942
Auji (3)	0	0	-
Dunga (6)	25.7±19.3	1.2±1.8	0.0010
Kendu/Homabay (5)	0	1.2±1.8	-
Kisumu (3)	33±36.4	0.3±0.58	-
Luanda Gembe (4)	0	6±7.1	-
Sondu Miriu (4)	8.5±7.0	1±2.0	0.0419
ANOVA	0.013	0.361	
Bartlett's test	p<0.001	p<0.001	

There were more *Anopheles* mosquitoes in quarry and shoreline swamp, floodplain and stream puddles compared to natural swamps, rivers and more permanent pond habitats. These differences were significant by Bartlett's test, $p<0.001$, Table 5.

Table 5. Mosquito species abundance in different physical habitats and sites on land

Habitats	Mean (±SD) No. of Mosquitoes		
(No. of sites)	*Anopheles* spp	*Culex* spp.	p – value
Dam (7)	19.6±25.7	4.1 ± 9.3	0.002
Stream (11)	13.0±18.3	5.9 ± 12.0	0.0084
Natural Swamp (7)	12.9±14.4	2.4 ± 5.2	0.0084
Pond (8)	0.8 ±1.4	1.3 ±1.8	0.5840
ANOVA	P= 0.18	P= 0.80	
Bartlett's test	p<0.001	p<0.001	

Aedes and *Mansonia* species were abundant in the different habitats in the lake. There was no difference in the relative abundance of *Mansonia* species in the different habitats in the lake, p=0.202, Bartlett's test. There was a significant difference in relative abundance of *Aedes* species, p<0.001, Bartlett's test, Table 6.

Table 6. Mosquito species abundance in different vegetation and open water habitats in the lake

Habitats (No. of sites)	Mean (±SD) No. of Insects		
	Aedes spp	*Mansonia* spp.	p-value
Hippo grass (6)	1.02 ± 2.4	6.2±8.0	0.1253
Open water (26)	0.2±0.9	2.0±4.3	0.3580
Hippo grass/Hyacinth (14)	0.6±1.6	8.1±14.9	0.1589
Water hyacinth (10)	0.7±2.2	2.3±4.2	0.3450
Ambatch zone (3)	0.0	11.3±9.9	-
ANOVA	p=0.806	0.144	
Bartlett's test	p=0.001	P=0.202	

Anopheles and *Culex* species mosquitoes were uniformly abundant in different vegetation types on land, p >0.05, Bartlett's test. *Aedes* and *Mansonia* species were absent from different vegetation habitats on land, Table 7.

Table 7. Mosquito species abundance in different vegetation habitats on land

Vegetation (no. of sites)	**Mean (±SD) No. of Insects**		
	Anopheles spp.	*Culex* spp.	p- value
Hippo grass (4)	14.3 ± 9.9	8.8 ±11.8	0.4953
Hippo grass / Other veg. (7)	5.0 ± 12.0	6.0 ± 14.9	0.0936
Water Hyacinth (2)	24.0 ± 17.0	2.0 ± 2.8	0.0068
Water hyacinth/Other veg. (2)	33 .5 ± 24.7	0	-
Other vegetation (18)	9.6 ± 19.2	2.1 ± 3.9	0.5963
ANOVA	0.2	0.097	
Bartlett's test	p=0.90	p=0.18	

4.3. Schistosomiasis Snails Abundance in Lake and Land Habitats

There were more *Biomphalaria sudanica* than *Bulinus africanus* snails in the lake and land locations / habitats (Tables 8, 9, 10, 11 and 12). There were significantly more *Biomphalaria* and

Bulinus species in Asembo Bay, Kisumu, Usoma Point and Lwanda Gembe, p< 0.001, one way ANOVA and Bartlett's test. There were no host snails in Kendu Bay, Nyando Nyakach and Sondu Miriu, Table 8.

Table 8. Snails' abundance in different locations in the lake

Locations (No. of sites)	Mean (±SD) No. of Snails	
	Biomphalaria sudanica	*Bulinus africanus*
AsemboBay (9)	39.4±40.6	9.6±9.3
HomaBay (8)	0	1.3±3.5
KenduBay (7)	0	0
Kisumu (6)	39.5±41.5	5.33±5.5
Lwanda Gembe (8)	3.88±6.3	1.5±2.8
Nyando Nyakach (9)	0	0
Sondu Miriu (6)	0	0
Usoma point (6)	21.67±24.31	4±4.6
ANOVA	p< 0.001	p=0.003
Bartlett's test	p<0.001	p<0.001

There were significantly more *Biomphalaria sudanica* than *Bulinus africanus* sampled in different locations in the lake (one way ANOVA, p<0.001). In land aquatic habitats, more *Biomphalaria sudanica* snails were found in Osienala pond, Dunga, Kisumu, Homabay and Auji but not in Ahero, Table 9, p< 0.001, Bartlett's test.

Table 9. Snails' abundance in different locations on land

Location (No. of sites)	Mean (±SD) No. of Snails	
	Biomphalaria sudanica.	*Bulinus africanus.*
Ahero (3)	0	0
Asembo (5)	2±4.5	0
Auji (3)	9.3±2.3	0.7±1.2
Dunga (5)	10±12.3	2±3.1
Homabay (4)	10±17.5	2±6.0
Kendubay (1)	8.75	3
Kisumu (3)	12±1.7	0
Luanda Gembe (3)	1	0
Olambwe river (1)	0	0
Osienala pond (1)	25	0
Sondu Miriu (4)	0	0
ANOVA	0.088	-
Bartlett's test	p< 0.001	p< 0.001

Biomphalaria sudanica and *Bulinus africanus* host snails were more abundant in the shoreline swamps, temporary ponds, ponds, streams, natural swamp, and dam in that order, compared to quarry, river, flood plain and roadside ponds, $p < 0.005$, Bartlett's test, Table 10.

Table 10. Snails' abundance in different physical habitats on land

	Mean (±SD) No. of Snails	
Habitats (No. of sites)	*Biomphalaria sudanica*	*Bulinus africanus*
Dam (7)	1.7±4.5	0.0±0.0
Natural Swamp (7)	4.1±9.2	0.4±1.1
Pond (8)	8.8±13.8	1.5±4.2
Stream (11)	4.7±6.9	1.1±2.1
Shoreline swamp (2)	11.5±13.4	3.5 ±4.9
Temporary pond (5)	9.0 ±15.2	2 .4±5.4
Quarry (2)	0	0
River (2)	0	0
Flood plain (1)	0	0
Road side pond (1)	0	0
ANOVA	-	-
Bartlett's test	p<0.005	p<0.001

In the lake habitats, more *Biomphalaria sudanica* and *Bulinus africanus* snails were found in the hippo grass/water hyacinth zone, hippo grass zone, ambatch tree zone, and water hyacinth zone compared to open water, $p < 0.001$, one way ANOVA and Bartlett's test, Table 11.

Table 11. Snails' abundance in different vegetation habitats in the lake

Habitats (No. of sites)	Mean (±SD) No. of Snails	
	Biomphalaria sudanica	*Bulinus africanus*
Hippo grass (6)	17.7±29.4	5.7±9.0
Open water (26)	1±2.8	0.2±0.8
H.G/WH (14)	33.1±38.5	6.9±7.3
Water Hyacinth (10)	10.6±20.5	1.7±4.1
Ambatch zone (3)	17.0±15.1	4.7±4.0
ANOVA	0.002	0.0002
Bartlett's test	< 0.001	< 0.001

The results revealed that on land aquatic habitats, more schistosomiasis snails were associated with water hyacinth and other vegetation ($p< 0.001$, Bartlett's test, $p=0.001$), Table 12.

Table 12. Snails' abundance in different vegetation types on land

Vegetation (No. of sites)	Mean (±SD) No. of Snails	
	Biomphalaria sudanica	*Bulinus africanus*
Hippo grass (4)	0	0
Hippo grass/Other veg. (7)	5±5.3	0
Water Hyacinth (2)	0	0
Water Hyacinth/Other veg. (2)	11.5±13.4	3.5±4.9
Other vegetation (18)	5.7±10.9	1.0±2.9
ANOVA	0.3	0.17
Bartlett's test	< 0.001	< 0.001

4.4. Effects of Physico-chemical Parameters on Abundance of *Anopheles* Mosquitoes and Schistosomiasis Snails in Lake and Land Locations / Habitats

The effects of physico-chemical parameters on the abundance of *Anopheles* mosquitoes and schistosomiasis snail were determined. All the physico-chemical parameters analysed (dissolved oxygen (DO), pH, alkalinity, hardness, turbidity, conductivity, temperature, turbulence, depth and salinity) varied between the habitat locations on land and in the lake (one-way ANOVA, $p<0.001$; $p<0.0001$), Tables 13 and 14, respectively.

Table 13. Variations of physico-chemical parameters in different locations on land

Location (No. of sites)	Mean (±SD) Values of the Physico-chemical Parameters							
	Dissolved Oxygen (mg/l)	pH	Alkalinity (mg/l)	Hardness (mg/l)	Turbidity (NTU)	Conductivity (μS/cm)	Temperature (°C)	Salinity (mg/l)
Ahero (3)	5.1±1	8.2±0.3	106.7±40	79.3±23.2	118.9±115.9	248.3±83.5	26.9±2.8	0.07±0.06
Asembo (5)	5.7±0.8	6.7±0.1	218±23.5	436.6±175.1	37.5±29.7	139.4±30.1	24.9±0.6	0.7±0.1
Auji (3)	2.7	8.5±0.2	162±11.1	147.3±4.2	15.2±7.8	503.3±188.2	25.1±0.6	0.2±0.1
Dunga (6)	6.3±1.1	7.8±0.5	48±6.1	40.3±5.6	101.7±121	164.5±85.5	27.5±2.5	0
Homa/Kendu bay (5)	5.5±1.4	8.2±0.2	114.8±60.8	81.2±33.4	316.6±174.2	333.4±160.3	24.5±1.8	0.1±0.8
Kisumu (3)	2.6±3.4	6.8±1.5	255.3±62.2	130.7±42.4	247.7±266.2	279±168.9	31.6±5	0.2±0.3
Luanda Gembe (4)	2.7±2	7±0.6	477.5±245	90.5±9.3	370±158.4	190±60.7	23.5±0.4	0.6±0.3
Sondu Miriu (4)	6.4±0.6	8±0.4	57.8±2.9	42±12.2	208±133.4	104±17	27.8±2.2	0
ANOVA	< 0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Table 14. Variations of physico-chemical parameters in different locations on lake

Locations (no. of sites)	Mean (±SD) Values of the Physico-chemical Parameters								
	DO (mg/l)	pH	Alkalinity (mg/l)	Hardness (mg/l)	Turbidity (NTU)	Conductivity (µS/cm)	Temperature (°C)	Turbulence (m/s)	Depth (m)
Asembo Bay (9)	4.7±1.8	8.2±0.4	70.2±7.0	48.7±5.5	99.5±27.6	164.9±3.3	27±0.5	0.04±0.03	1±0.5
Homa Bay (8)	8.0±1.5	7.6±0.5	56.0±10.8	45.8±5.4	103.9±68.3	154.6±0.9	27.8±0.5	0.1±0.05	1.4±0.6
KenduBay (7)	6.1±1.6	7.6±0.2	58.6±5.4	48.3±8	108.5±40.4	165.6±2.9	26.2±0.5	0.07±0.2	0.8±0.1
Kisumu (6)	1.6±1.2	8.4±0.2	92±18.4	56±9.2	197.1±47.2	220.2±23.5	27.5±0.1	0.02±0.01	1.28±0.4
Lwanda Gembe (8)	6.7±0.5	7.6±0	53.3±7.6	42.3±3.8	29.4±13.1	133.9±0.6	26.4±0.4	0.09±0.03	1.9±1.1
Nyando Nyakach (9)	5.7±0.9	7.8±0.2	76.4±12.3	64.4±10.3	181.8±46.9	213.2±8.8	27.3±0.5	0.17±0.1	0.7±0.1
Sondu Miriu (6)	6.9±0.8	7.7±0	45±10.2	37.3±7.2	54.8±10.6	184.2±7.3	28±0.3	0.23±0.1	0.7±0.1
Usoma point (6)	5.6±1.5	7.7±0.4	74±10.4	54.3±6.1	153±43	174.1±6.2	27.8±0.2	0.05±0.02	1.45±0.7
ANOVA	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	<0.0001

As regards the abundance of mosquitoes and physico-chemical parameters, there were no significant correlation between abundance of *Anopheles* mosquitoes and hardness, alkalinity, temperature, conductivity, depth, salinity, dissolved oxygen and pH, p> 0.05, Figures 2, 3, 4, 5 and 6.

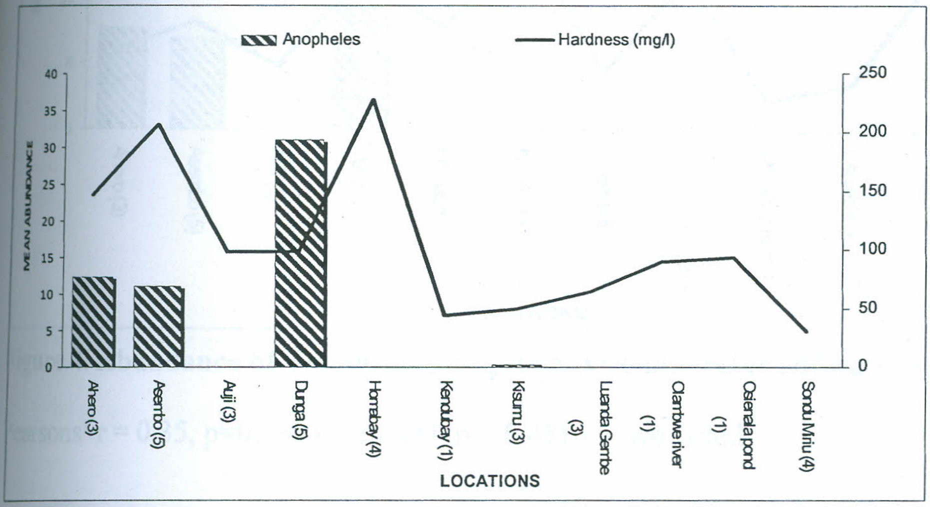

Figure 2. Abundance of *Anopheles* mosquitoes vs. water hardness on land

Pearsons' r= 0.226, p=0.23 one tailed.

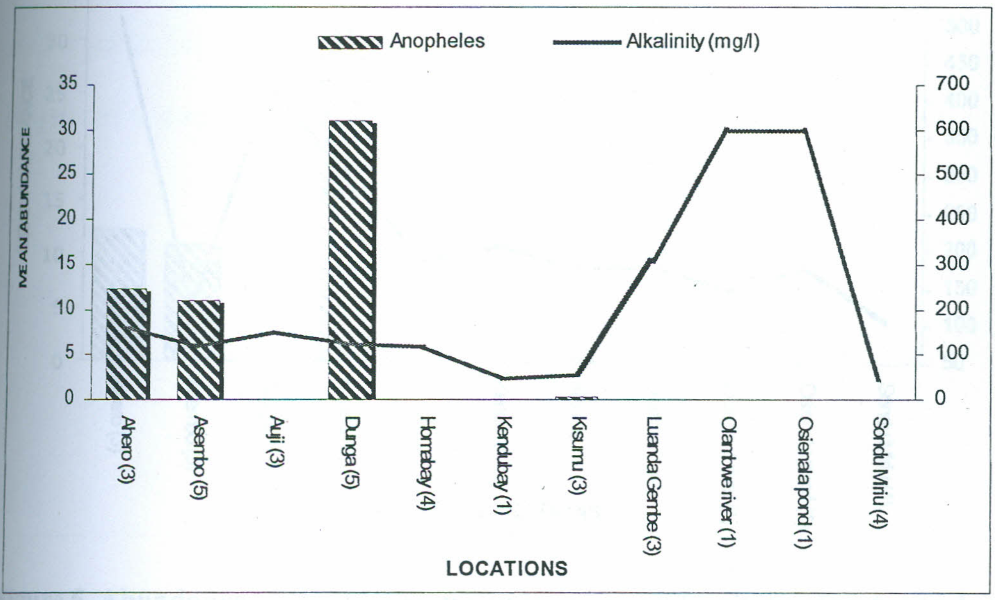

Figure 3. Abundance of *Anopheles* mosquitoes vs alkalinity of water on land

Pearsons' r = -0.22, p=0.27 one tailed.

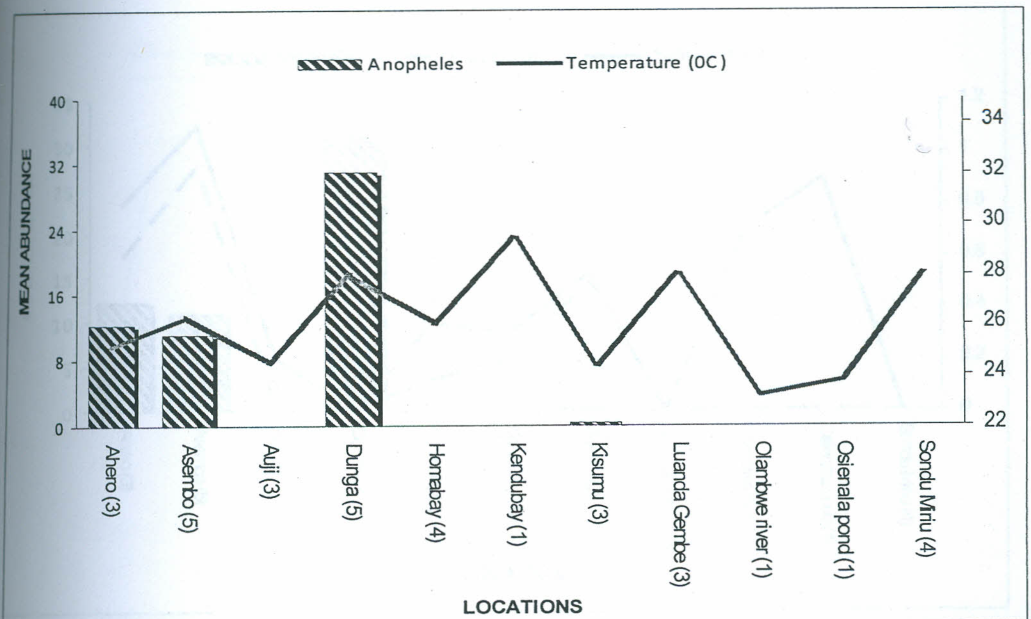

Figure 4. Abundance of *Anopheles* mosquitoes vs temperature of water on land

Pearsons' r = 0.35, p=0.282 one tailed, p = 0.4516 – two tailed.

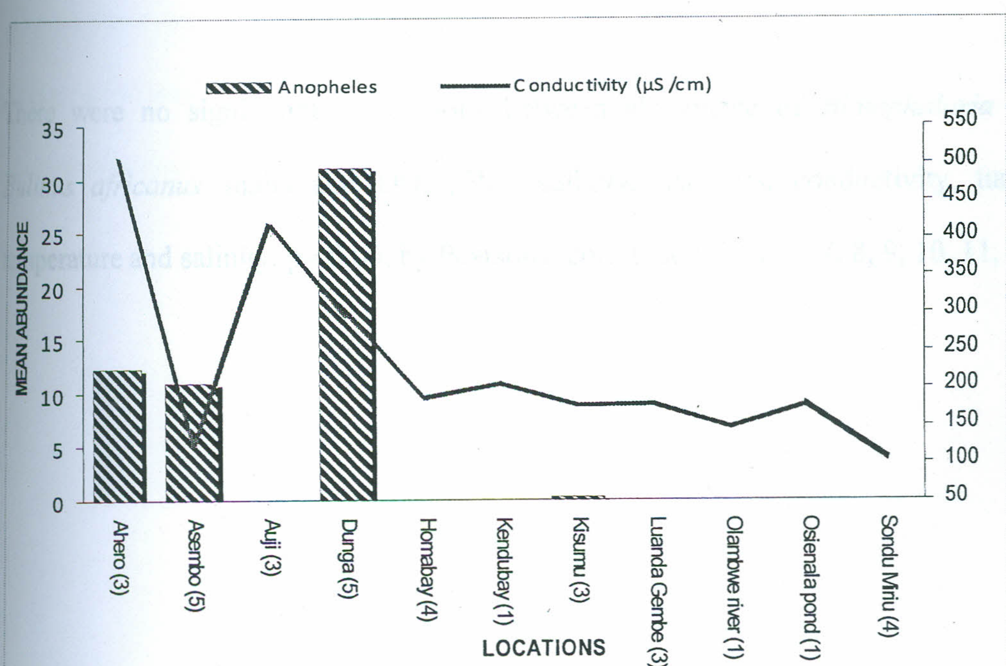

Figure 5. Abundance of *Anopheles* mosquitoes vs conductivity of water on land

Pearsons' r = 0.35, p=0.16 one tailed, p = 0.3215 – two tailed.

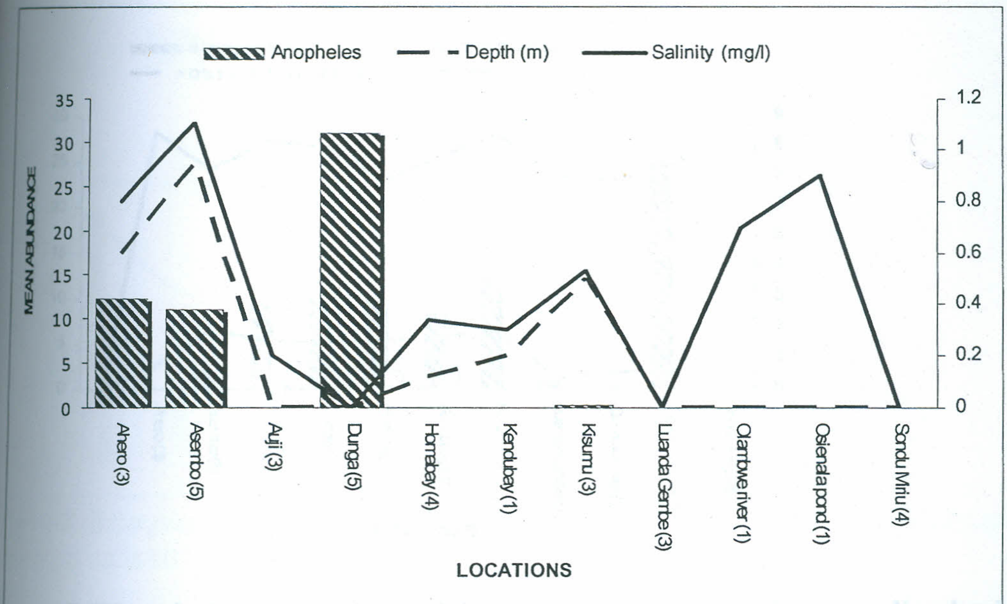

Figure 6. Abundance of *Anopheles* mosquitoes vs salinity and depth of water on land

Anopheles spp. vs. depth: Pearsons r=0.194, p=0.2158 one tailed.

Anopheles spp. s. salinity: Pearsons r = -0.281, p= 0.4316 – two tailed.

There were no significant correlations between abundance of *Biomphalaria sudanica* and *Bulinus africanus* snails and DO, pH, alkalinity, hardness, conductivity, turbidity, depth, temperature and salinity, p> 0.05, by Pearsons' correlation, Figures 7, 8, 9, 10, 11, 12 and 13.

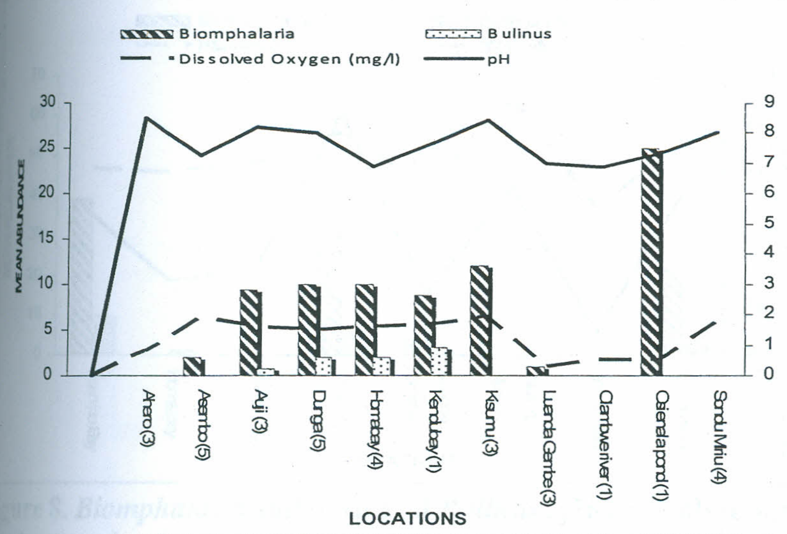

Figure 7. ***Biomphalaria sudanica*** **and** ***Bulinus africanus*** **abundance vs dissolved oxygen and pH on land**

Biomphalaria sudanica vs. DO: Pearsons' r= -0.00022, p>0.05 one tailed.

Biomphalaria sudanica vs. pH: Pearsons' r= 0.02403, p>0.05 one tailed.

Bulinus africanus vs. DO: Pearsons' r =0.36, p>0.05 one tailed.

Bulinus africanus vs. pH: Pearsons' r=-0.0334, p>0.05 one tailed.

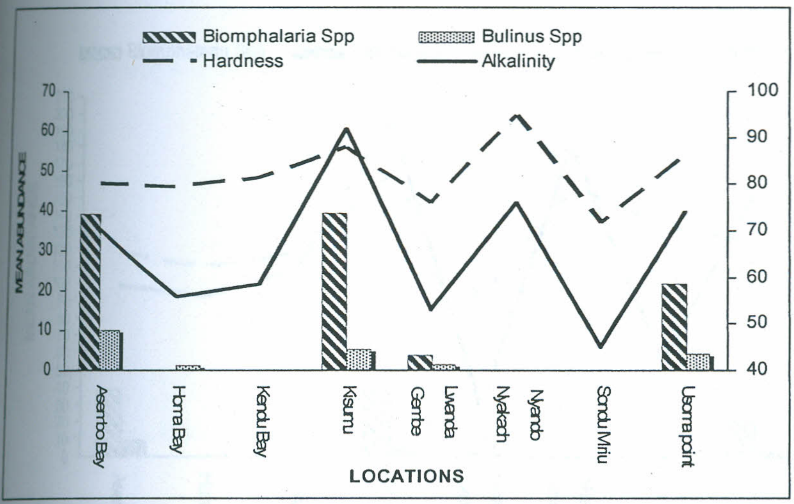

Figure 8. ***Biomphalaria sudanica*** **and** ***Bulinus africanus*** **abundance vs alkalinity and hardness on land**

Biomphalaria vs. Alkalinity: Pearsons r= 0.25, p>0.05 one tailed.

Biomphalaria vs. Hardness: Pearsons r = -0.036, p>0.05 one tailed.

Bulinus vs. Alkalinity: Pearsons r= -0.398, p>0.05 one tailed.

Bulinus vs. Hardness: Pearsons r= 0.067, p>0.05 one tailed.

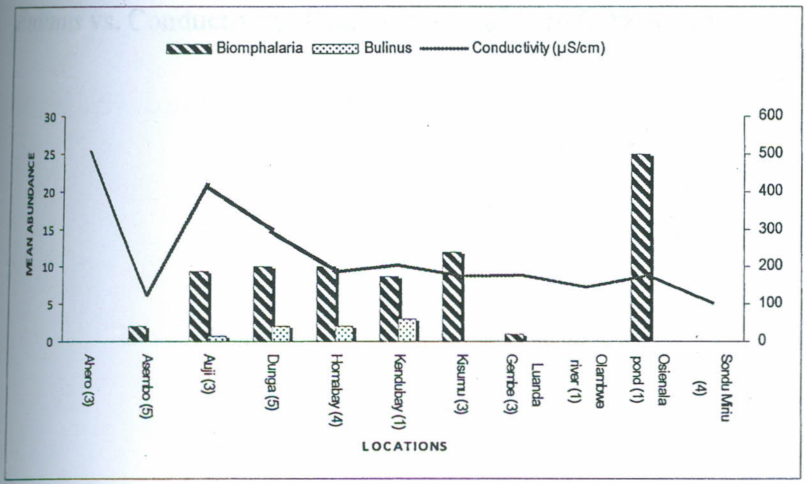

Figure 9. ***Biomphalaria Sudanica*** **and** ***Bulinus africanus*** **abundance vs conductivity of water on land**

Biomphalaria sudanica vs. Conductivity: Pearsons' r= -0.038, p>0.05 one tailed.

Bulinus africanus vs. Conductivity: Pearsons' r = 0.084, p>0.05 one tailed.

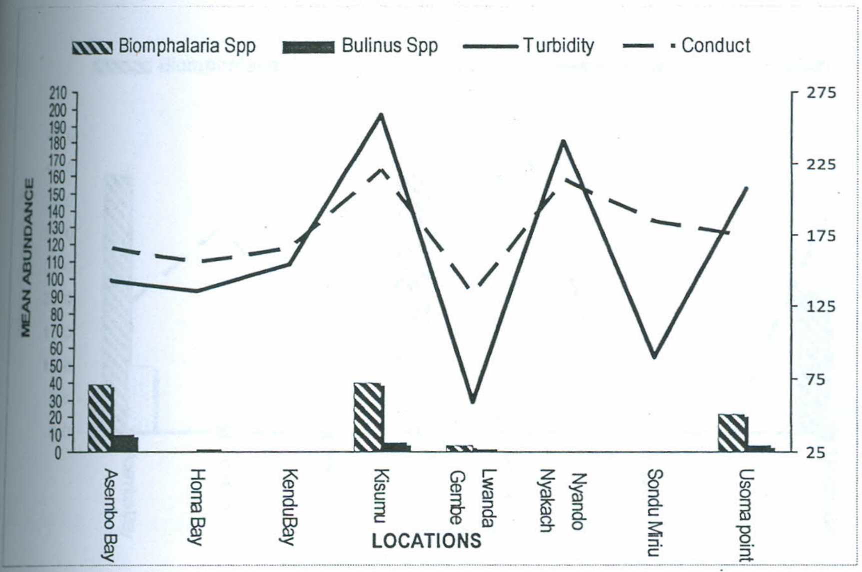

Figure 10. ***Biomphalaria sudanica* and *Bulinus africanus* abundance vs water turbidity and conductivity in the lake**

Biomphalaria vs. Turbidity: Pearsons r= 0.433, $p>0.05$ one tailed.

Biomphalaria vs. Conductivity: Pearsons r= 0.2982, $p>0.05$ one tailed.

Bulinus vs. Turbidity: Pearsons r= 0.198, $p>0.05$ one tailed.

Bulinus vs. Conductivity: Pearsons r= 0.027, $p>0.05$ one tailed.

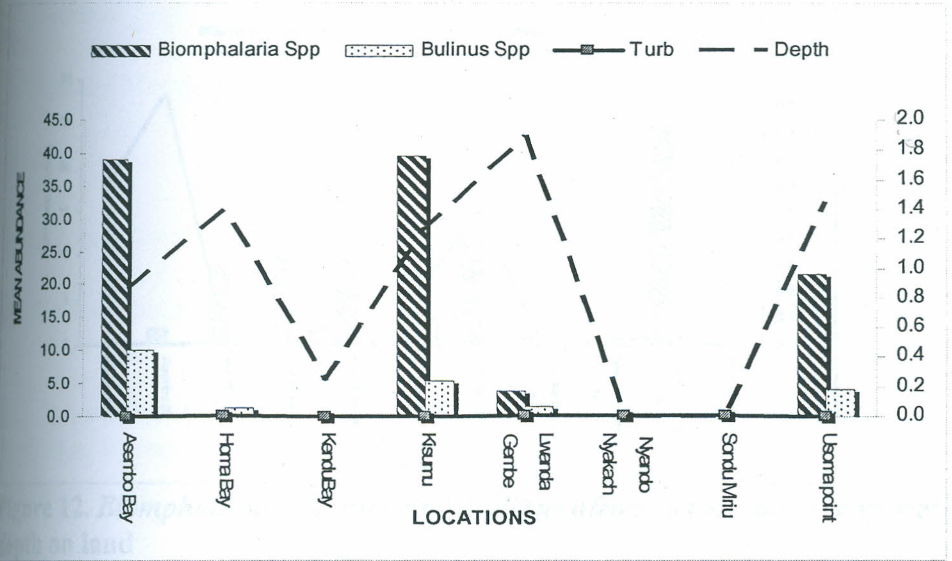

Figure 11. ***Bulinus africanus*** **and** ***Biomphalaria sudanica*** **abundance vs water turbidity & depth in the lake**

Biomphalaria. sudanica vs. Turbidity: Pearsons' r= 0.717, p=0.023 one tailed, p=0.045 – two tailed.

Biomphalaria. sudanica vs. Depth: Pearsons' r = 0.341, p>0.05 one tailed.

Bulinus. africanus vs. Turbidity: Pearsons' r= -0.669, p=0.035 one tailed, p=0.071 – two tailed.

Bulinus. africanus vs. Depth: Pearsons' r= 0.34, p>0.05 one tailed.

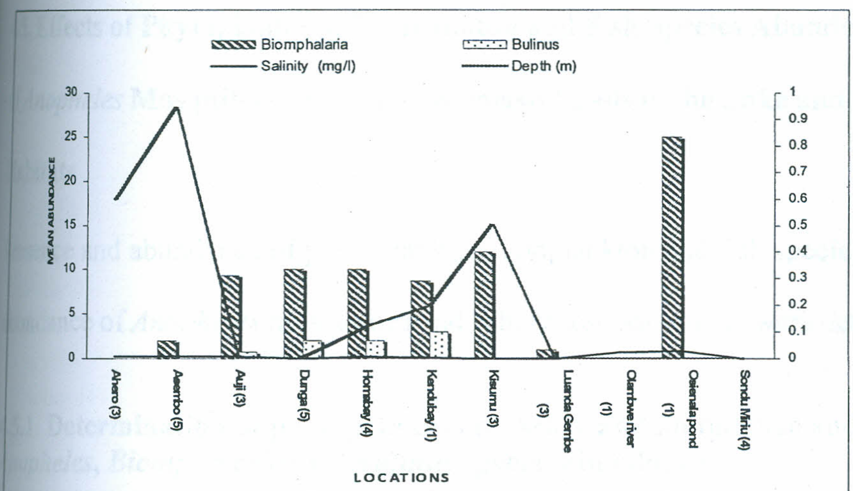

Figure 12. ***Biomphalaria sudanica*** **and** ***Bulinus africanus*** **abundance vs water salinity and depth on land**

Biomphalaria vs. Salinity: Pearsons r= 0.452, p>0.05 one tailed.

Biomphalaria vs. Depth: Pearsons r= -0.23998, p>0.05 one tailed.

Bulinus vs. Salinity: Pearsons r= -0.267, p>0.05 one tailed.

Bulinus vs. Depth: Pearsons r= -0.229, p>0.05 one tailed.

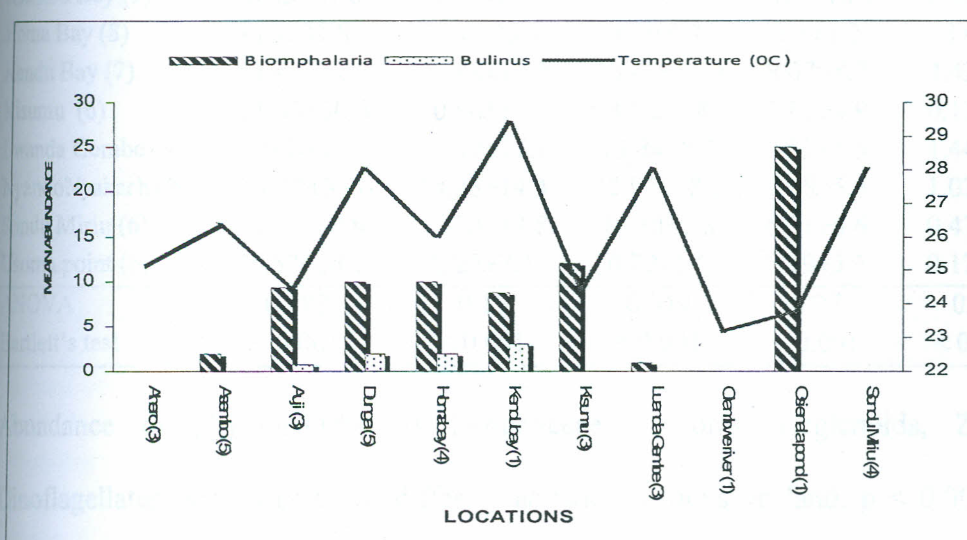

Figure 13. ***Biomphalaria sudanica*** **and** ***Bulinus africanus*** **abundance vs water temperature on land**

Biomphalaria vs. temperature: Pearsons r= 0.33, p>0.05 one tailed.

Bulinus vs. temperature: Pearsons r= - 0.33, p>0.05 one tailed.

4.5. Effects of Phytoplankton, Zooplankton and Fish Species Abundance on the Abundance of *Anopheles* Mosquitoes and Schistosomiasis Snails in the Lake and Land Locations / Habitats

Presence and abundance of phytoplankton, zooplankton and fish species, and how they influence abundance of *Anopheles* mosquitoes and schistosomiasis snails were determined.

4.5.1. Determination of phytoplankton presence and abundance and correlation with *Anopheles*, *Biomphalaria* and *Bulinus* species abundance

Abundance of phytoplankton (Cyanobacteria, Chlorophyceae, Diatoms, Euglenoids, Zygnematids and Dinoflagellates) varied between locations in the lake, $p < 0.001$, Bartlett's test, Table 15.

Table 15. Variations (Mean ±SD) of phytoplankton abundance in different locations in the lake

Locations (no. of sites)	Mean (±SD) Phytoplankton Abunndance					
	Cyanobacteria	Chlorophyceae	Diatoms	Euglenoids	Zygnematids	Dinoflagelletes
Asembo Bay (9)	88.65±21.0	7.11±8.5	3.08±3.9	5.67±10.5	0.27±0.5	0.23±0.4
Homa Bay (8)	68.3±31.8	19.6±25.3	6.9±6.7	2.5±4.2	1±1.8	1.6±1.7
Kendu Bay (7)	50.9±37.8	23.88±17.2	10.48±11.9	8.07±8.7	3.42±3.9	3.2±6.0
Kisumu (6)	81.33±30.6	10.96±19.4	4.52±7.8	2.85±4.9	0.13±3.3	0.07±2.3
Lwanda Gembe (8)	63±26.2	17.49±17.7	13.84±9.3	3.52±4.5	1.44±3.0	1.24±1.6
NyandoNyakach (9)	67.17±35.6	14.28±14.4	12.92±18.6	2.68±5.5	1.02±2.0	1.94±2.7
Sondu Miriu (6)	58.78±30.9	19.30±13.8	10.38±7.8	6.51±6.6	0.47±0.8	7.57±6.7
Usoma point (6)	96.57±28.1	2.27±7.3	0.79±5.6	0.19±3.6	0.17±0.6	0.01±5.7
ANOVA	0.189	0.17	0.049	0.27	0.13	0.003
Bartlett's test	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

Abundance of phytoplankton (Chlorophyceae, Diatoms, Euglenoids, Zygnematids and Dinoflagellates) varied between different aquatic locations on land, $p < 0.001$, Bartlett's test, Table 16.

Table 16. Variations (Mean ±SD) of phytoplankton abundance in different locations on land

Locations (No. of sites)	Mean (±SD) Phytoplankton Abundance					
	Cyanobacteria	Chlorophyceae	Diatoms	Euglemiods	Zynematids	Dinoflagellates
Ahero (3)	0.6±1.0	32.6±25.1	43.2±42.0	1.4±1.3	11.7±11.0	10.5±14.0
Asembo (5)	20.4±40.1	20.39±35.3	15.29±28.7	0.02±0.04	2.11±4.3	1.8±3.3
Auji (3)	41.6±47.0	29.4±31.4	10.2±12.1	12.4±18.4	4.4±7.2	2.1±2.8
Dunga (5)	38±20.6	28±12.7	25±12.0	3±4.1	1±0.7	6±10.0
Homabay (4)	5.4±10.6	28.87±40.2	13.19±20.9	1.72±2.2	0.82±1.6	0
Kendubay (1)	0	0	0	0	0	0
Kisumu (3)	6.28±10.8	17.15±17.4	33.21±38.2	3.38±5.9	5.25±2.4	1.39±0.04
Luanda Gembe (3)	4±6.4	7±12.1	15±26.4	2±4.3	5±8.6	0
Olambwe river (1)	0	0	0	0	0	0
Osienala pond (1)	37.5	12.5	12.5	37.5	0	0
Sondu Miriu (4)	39±37.7	14±11.4	10±12.6	10±12.6	1±2.6	0
ANOVA	0.13	0.18	0.15	0.048	-	-
Bartlett's test	0.58	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001

Abundance of phytoplankton in different habitats on land only varied for Cyanobacteria, Euglenoids and Dinoflagellates, $p < 0.03$, Bartlett's test, but not for Chlorophyceae, Diatoms and Zygnemattids, $p > 0.05$, Bartlett's test, Table 17.

Table 17. Variations (Mean ±SD) of phytoplankton abundance in different habitats on land

Habitat (no. of sites)	Mean (±SD) Phytoplankton Abundance					
	Cyanobacteria	Chlorophyceae	Diatoms	Euglenoids	Zynematids	Dinoflagellates
Dam (5)	14.7±21.0	26.8±21.5	15.6±12.4	8.4±10.2	8.1±9.5	6.4±11.3
Stream (10)	35.4±35.7	31.6±26.5	20.8±26.2	6.3±10.4	2.9±4.9	3.1±7.2
Natural swamp (4)	2.8±5.6	5.2±10.5	11.4±22.8	1.9±3.7	3.7±7.4	0
Pond (2)	18.8±26.6	14.3±2.6	39.5±38.2	18.8±26.5	4.9±6.8	3.8±5.3
Shoreline swamp (2)	40.8±6.3	20.2±2.9	35.3±7.9	1.0±1.4	0.3±0.5	2.3±3.2
Temporary pond (5)	4.3±9.5	23.1±37.1	10.6±19.0	1.4±2.0	0.7±1.5	0
Quarry (2)	0	8.3±11.8	37.5±53.0	0	2.1±2.9	2.1±2.9
River (1)	0	0	0	0	0	0
Flood plain (1)	0	0	0	0	0	0
Roadside pond (1)	84.04	12.01	2.11	1.56	0.28	0
ANOVA	0.1	0.3	0.21	-	-	-
Bartlett's test	0.02	0.29	0.55	0.02	0.46	< 0.001

Abundance of phytoplankton in different habitats in the lake only varied for Cyanobacteria, and Dinoflagellates, $p < 0.03$, Bartlett's test, but not for Chlorophyceae, Diatoms, Euglenoids and Zygnematids, $p > 0.005$, Bartlett's test, Table 18.

Table 18: Variations (Mean ±SD) of phytoplankton abundance in different habitats in the lake

	Mean (±SD) Phytoplankton Abundance					
	Cyanobacteria	Chlorophyceae	Diatoms	Euglenoids	Zygnematids	Dinoflagelletes
Hippo grass (6)	45±29.5	30.5±23.5	10.5±5.6	9.1±10.5	0.5±0.6	3.9±6.0
Open water (26)	79.1±21.4	11.6±15.2	5.0±6.6	1.7±3.0	0.8±1.6	1.9±3.9
H.G/WH (14)	60.3±37.4	16.6±15.9	13.0±16.2	7.3±9.7	1.0±2.4	1.9±4.8
Hyacinth (10)	73.2±31.5	10.9±17.3	9.4±11.0	3.3±4.5	2.1±3.9	1.2±1.6
Ambatch zone (3)	87.3±20.5	8.4±13.7	2.2±1.7	1.0±1.7	1.0±0.1	0
ANOVA	0.075	0.098	0.13	0.065	-	-
Bartlett's test	< 0.001	0.771	0.204	0.061	0.073	0.023

There were no significant correlations between abundance of *Anopheles* mosquitoes and Cyanobacteria, Chlorophyceae, Diatoms, Euglenoids and Zygnematids, $p>0.05$, Figure 14, 15 and 16, but significant correlations with Dinoflagellates, $p=0.014$, by Pearsons' correlation, Figure 16.

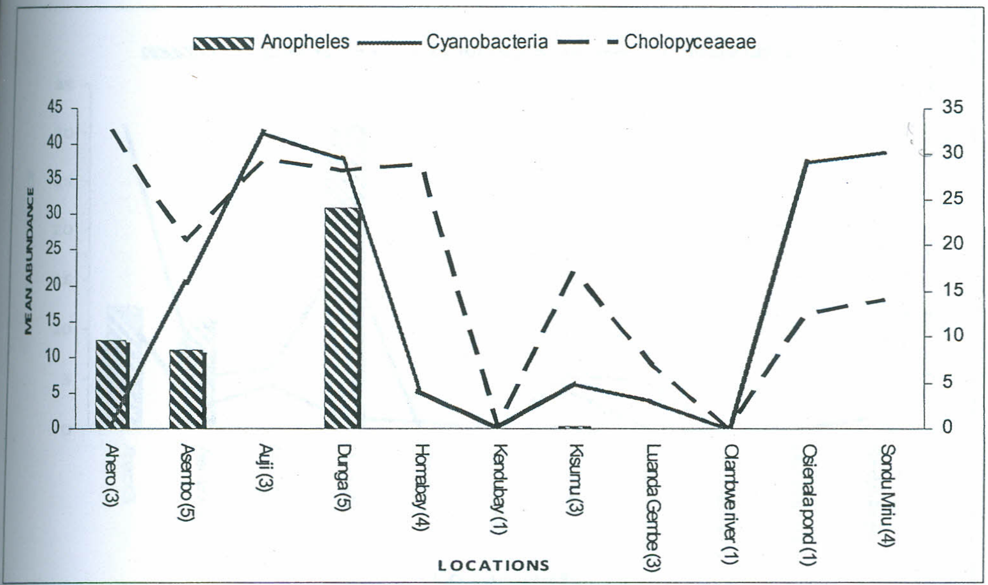

Figure 14. Abundance of *Anopheles* mosquitoes vs. Cyanobacteria & Chlorophyceae on land

Anopheles vs. Cyanobacteria: Pearsons r=0.258, p>0.05 one tailed.

Anopheles vs. Chlorophyceae: Pearsons r=0.483, p=0.079 one tailed.

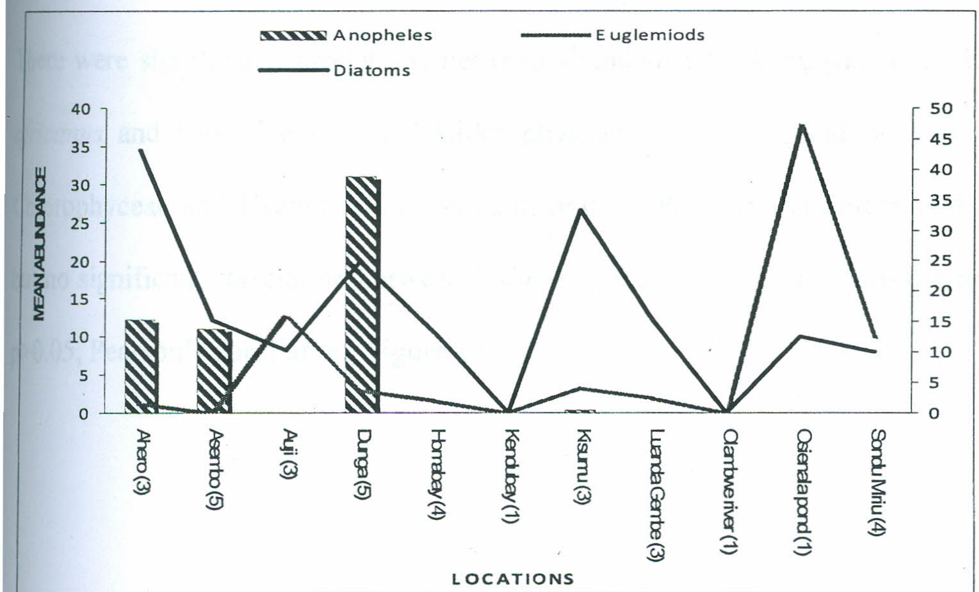

Figure 15. Abundance of *Anopheles* mosquitoes vs. Euglenoids & Diatoms on land

Anopheles vs. diatoms: Pearsons' r= 0.47, p=0.085 one tailed.

Anopheles vs. euglenoids: Pearsons' r=- 0.224, p>0.05 one tailed.

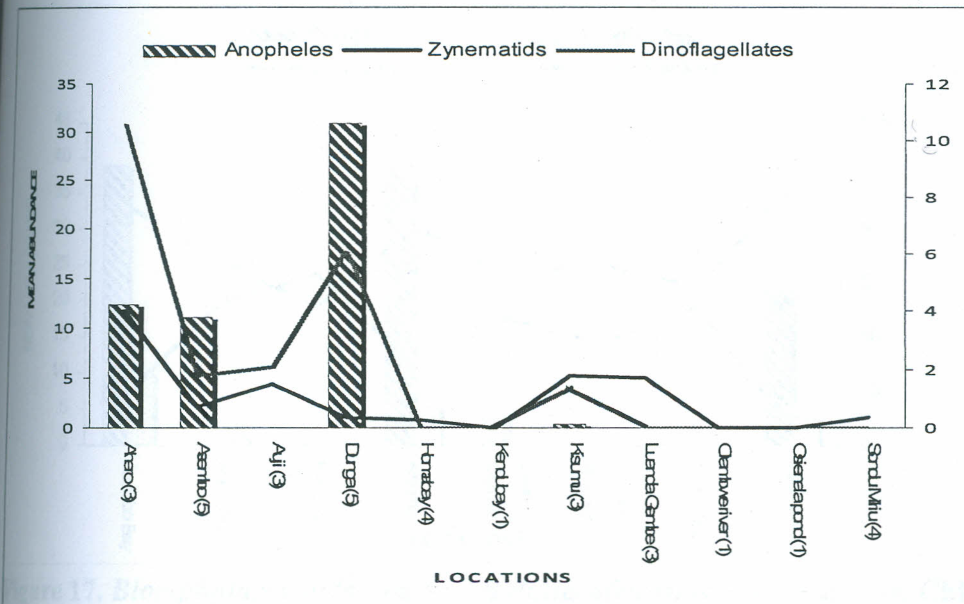

Figure 16. Abundance of *Anopheles* mosquitoes vs. Zygnematids & Dinoflagellates on land

Anopheles vs. Zynematids: Pearsons' r=0.127, p>0.05 one tailed.

Anopheles vs. Dinoflagellates: Pearsons' r= 0.69, p=0.014 one tailed.

There were significant correlations between abundance of *Biomphalaria sudanica* and *Bulinus africanus* and Cyanobacteria and Chlorophyceae in the lake and between *B. sudanica* and Chlorophyceae and Cyanobacteria on land, p<0.03, Pearson's correlations, Figures 17 and 18, but no significant correlation between *Bulinus africanus* and Chlorophyceae and Cyanobacteria, p>0.05, Pearson's correlation, Figure 18.

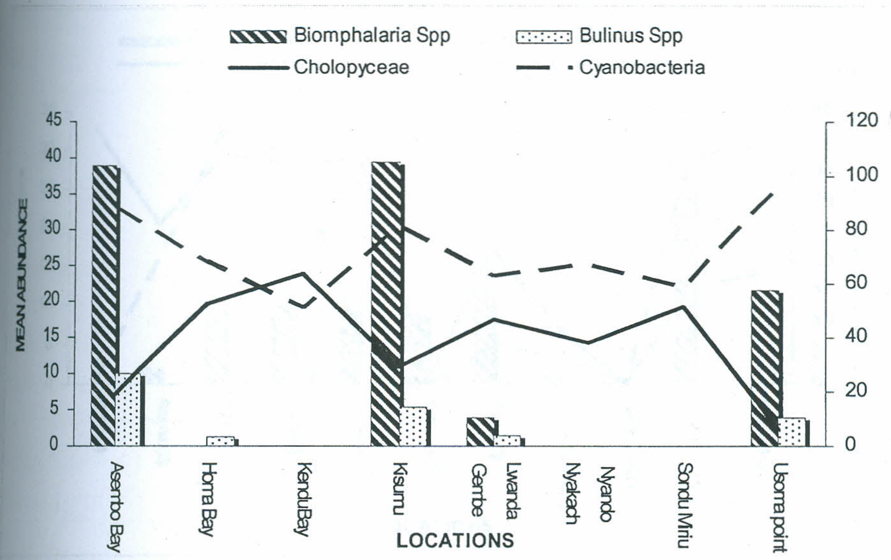

Figure 17. ***Biomphalaria sudanica* and *Bulinus africanus* abundance vs. Chlorophyceae & Cyanobacteria in the lake.**

Biomphalaria. sudanica vs. Chlorophyceae: Pearsons' r= 0.745, p=0.01 one tailed, p=0.02 - two tailed.

Biomphalaria. sudanica vs. Cyanobacteria: Pearsons' r = 0.789, p=0.02 one tailed, p=0.03 - two tailed.

Bulinus africanus vs. Cyanobacteria: Pearsons' r= 0.778, p=0.012 one tailed, p=0.023 – two tailed.

Bulinus. africanus vs. Chlorophyceae: Pearsons' r=- 0.717, p=0.023 one tailed, p=0.045 – two tailed.

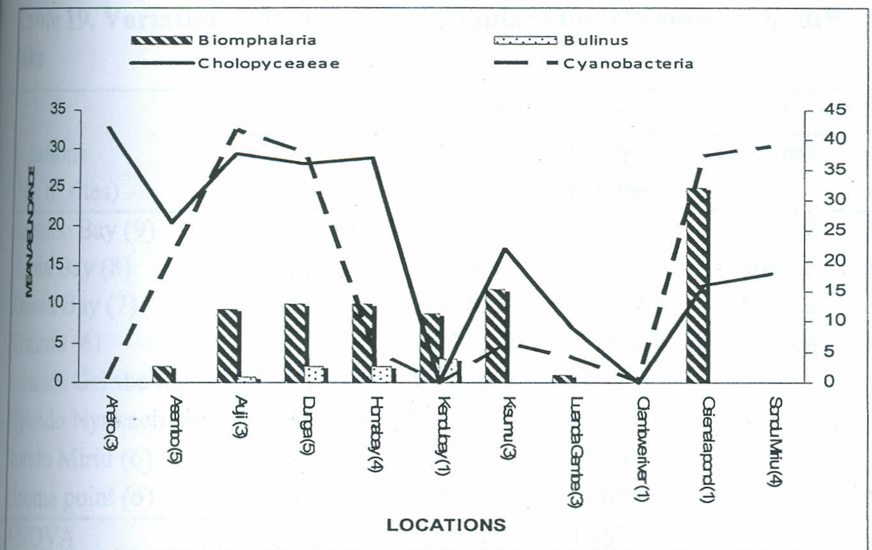

Figure 18. *Biomphalaria sudanica* and *Bulinus africanus* vs. Chlorophyceae & Cyanobacteria on land.

Biomphalaria sudanica vs. Chlorophyceae: Pearsons' r= 0.68, p=0.015 one tailed, p=0.031 two tailed.

Biomphalaria sudanica vs. Cyanobacteria: Pearsons' r= 0.3723, p>0.05 one tailed.

Bulinus africanus vs. Chlorophyceae: Pearsons r= 0.107, p>0.05 one tailed.

Bulinus africanus vs. Cyanobacteria: Pearsons r= -0.096, p>0.05 one tailed.

4.5.2. Determination of zooplankton presence and abundance and correlation with *Anopheles, Biomphalaria and Bulinus* species abundance

Abundance of zooplankton (Cyclopoid, Calanoid, *Daphnia sididae, Bosmina,* Calanoid Copepoid and *Keratella*) varied between locations, habitats and vegetation in the lake and on land, p<0.001, Bartlett's test, Tables 19, 20, 21 and 22.

Table 19. **Variation (Mean ±SD) of zooplankton abundance in different locations in the lake**

Locations (No. of sites)	Mean (±SD) Zooplankton Abundance					
	Cyclopoid	Calanoid	*Daphnia sididae*	*Bosmina*	Calanoid, copepoid	*Keratella* spp.
Asembo Bay (9)	11.48±13.7	6.02±4.2	0	0.27±0.8	2.14±3.7	0
Homa Bay (8)	9.0±7.6	6.6±8.4	2.2±2.7	0.60±0.6	0.9±1.6	2.7±5.9
Kendu Bay (7)	5.66±5.1	7.7±6.8	0.07±2.6	0.57±1.2	0.14±0.9	0.28±5.9
Kisumu (6)	0	0.07±2.9	0.04±0.8	0.01±0.4	0	0.01±2.0
Lwanda Gembe (8)	1.2±0.9	0.78±0.9	0.2±0.4	0.05±0.2	0	0.27±0.7
Nyando Nyakach (9)	8.13±11.0	4.52±4.4	0.96±2.5	0.47±0.8	0	0.18±0.1
Sondu Miriu (6)	2.88±10.6	4.42±6.6	2.24±3.8	0.77±1.1	0.44±0.5	0.24±0.9
Usoma point (6)	1.34±3.3	1.55±2.1	1.06±1.8	0.1±0.5	0	0.59±0.3
ANOVA	0.0001	0.0012	0.067	-	0.23	0.18
Bartlett's test	<0.001	<0.001	<0.001	< 0.001	<0.001	<0.001

Table 20. Variation (Mean ±SD) of zooplankton abundance in different locations on land

Location (No. of sites)	Mean (±SD) Zooplankton Abundance						
	Cyclopoid	Calanoid	*Daphnia*	*Bosmina*	*Keratella*	Calanoid, copepoid	Cyclopoid copepoid
Ahero (3)	1.1±2.0	0.8±1.4	0.6±1.0	0.3±0.6	0	0.2±0.4	0
Asembo (5)	0	0	0	0	0	0	0
Auji (3)	0.10±0.3	0.1±0.3	0	0	0	0	0
Dunga (5)	0	0	0	0	0	0	0
Homabay (4)	0	0	0	0	0	0	0
Kendubay (1)	0	0	0	0	0	0	0
Kisumu (3)	0.02±0.04	0.07±0.12	0	0	0	0	0
Luanda Gembe (3)	0	0	0	0	0	0	0
Olambwe river (1)	0	0	0	0	0	0	0
Osienala pond (1)	0	0	0	0	0	0	0
Sondu Miriu (4)	0	0	0	0	0	0	0
ANOVA	-	-	-	-	-	-	-
Bartlett's test	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	-

Table 21. Variation (Mean ±SD) of zooplankton abundance in different habitats on land

Habitats (No. of sites)	Mean (±SD) Zooplankton Abundance						
	Cyclopoid	Calanoid	*Daphnia*	*Bosmina*	*Keratella* spp	Calanoid, copepoid	Cyclopoid, copepoid
Dam	0.3±0.6	0.3±0.7	0.1±0.3	0.4±0.8	0	0	0
Stream	0.5±1.1	0.3±0.8	0.2±0.6	0.2±0.34	0	0.1±0.23	0
Natural swamp	0	0	0	0	0	0	0
Pond	0	0	0	0	0	0	0
Shoreline swamp	0	0	0	0	0	0	0
Temporary pond	0	0	0	0	0	0	0
Quarry	0	0	0	0	0	0	0
River	0	0	0	0	0	0	0
Flood plain	0	0	0	0	0	0	0
Roadside pond	0	0	0	0	0	0	0
ANOVA	-	-	-	-	-	-	-
Bartlett's test	<0.001	<0.001	<0.001	<0.001	-	-	-

Table 22. Variation (Mean ±SD) of zooplankton abundance in different habitats in the lake

Habitat (No. of sites)	Mean (±SD) Zooplankton Abundance					
	Cyclopoid	Calanoid	*Daphnia sididae*	*Bosmina*	Calanoid, copepoid	Keratella
Hippo grass (6)	8.3±17.6	7.8±5.1	0	0.7±1.1	2±3.4	0
Open water (26)	4.9±6.0	4.6±6.1	1.3±2.6	0.3±0.8	0.9±1.8	0.8±3.4
H.G/WH (14)	4.4±7.3	4.2±6.1	0.4±1.0	0.5±0.1	0.1±0.2	0
Water Hyacinth (10)	7.1±9.6	3.3±3.7	0.9±2.3	0.2±0.4	0.3±0.4	0.4±1.2
Ambatch zone (3)	4.4±2.0	4.3±3.1	0	0	0	0.3±0.6
ANOVA	-	-	0.377	-		-
Bartlett's test	0.48	0.019	<0.001	<0.001	<0.001	<0.001

There were significant correlations between abundance of *Anopheles* mosquitoes and Calanoid on land, p<0.001, but no significant correlation with cyclopoid on land, *Daphnia, Bosmina,* calanoid and copepoid, p>0.05, Figures 19, 20 and 21.

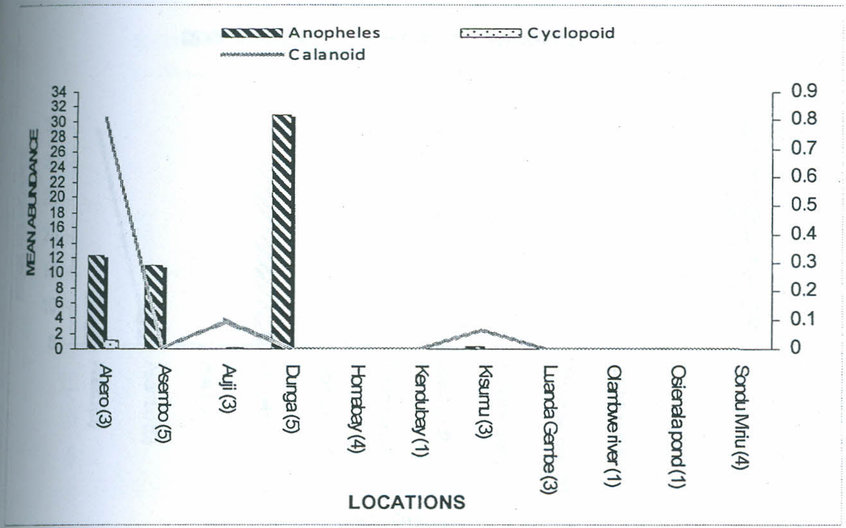

Figure 19. Abundance of *Anopheles* mosquitoes vs. Cyclopoid and Calanoid on land

Anopheles vs. Calanoid: Pearsons' $r=0.997$, $p<0.0001$ one and two tailed.

Anopheles vs. Cyclopoid: Pearsons' $r=0.23$, $p>0.05$ one tailed.

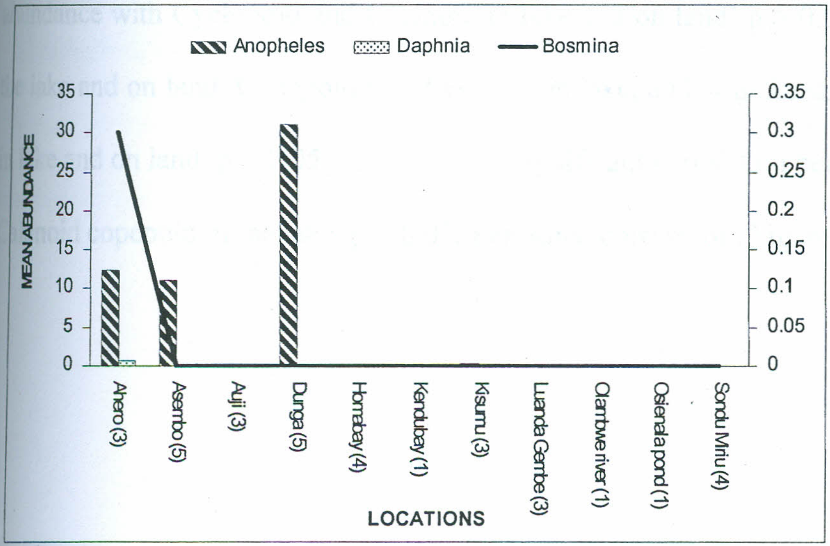

Figure 20. Abundance of *Anopheles* spp. Vs. *Daphnia* and *Bosmina* on land

Anopheles vs. Daphnia: Pearsons' $r=0.25$, $p>0.05$.

Anopheles vs. Bosmina: (small sample size).

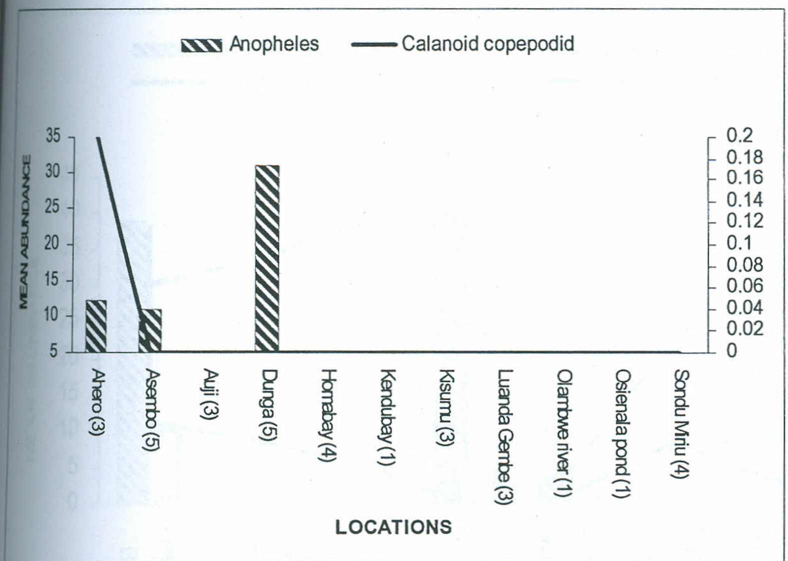

Figure 21. Abundance of *Anopheles* mosquitoes vs Calanoid and copepoid on land

Anopheles vs Calanoid copepoid: Pearsons' r=0.25, p>0.05 one tailed.

There were no significant correlations between: *Biomphalaria sudanica* and *Bulinus africanus* abundance with Cyclopoid and Calanoid in lake and on land' $p > 0.05$; Daphnia and *Bosmina* in the lake and on land, Copepoid and *Keratella* in lake, and with *Keratella* and Calanoid copepoid in lake and on land, $p > 0.05$; but there was significant correlation between *Bulinus africanus* and Calanoid copepoid in the lake, $p < 0.05$, Pearsons' correlation, Figures 22, 23, 24, 25, 26 and 27.

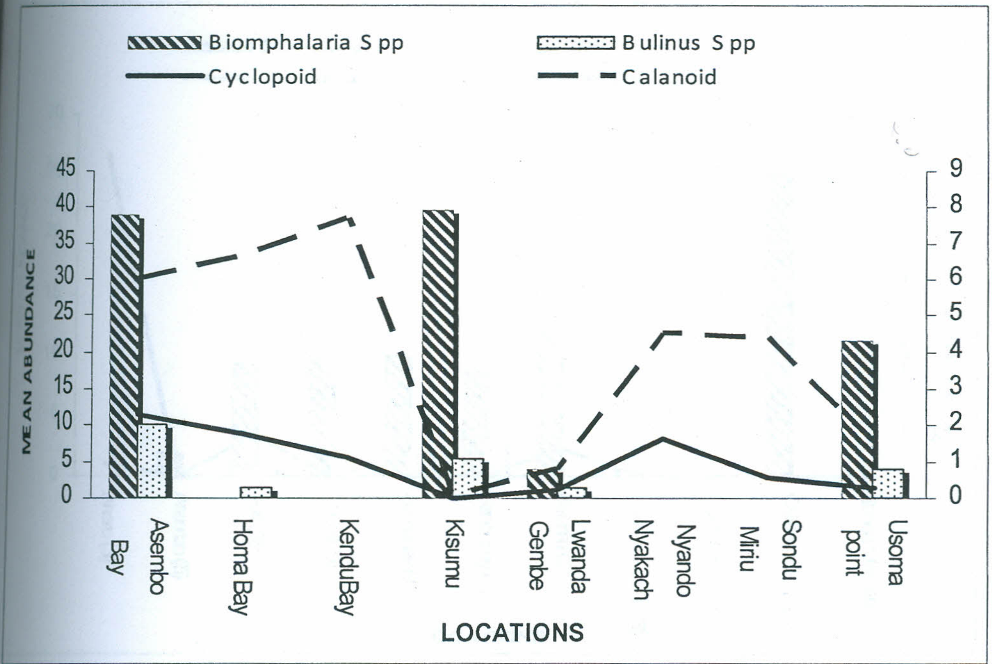

Figure 22. ***Biomphalaria sudanica* and *Bulinus africanus* abundance vs. Cyclopoid and Calanoid in the lake**

Biomphalaria sudanica vs. Cyclopoid: Pearsons' r= -0.066, p>0.05 one tailed.

Biomphalaria sudanica vs. Calanoid: Pearsons' r= -0.3883, p>0.05 one tailed.

Bulinus africanus vs. Cyclopoid: Pearsons' r= 0.228, p>0.05 one tailed.

Bulinus africanus vs. Calanoid: Pearsons' r=-0.157, p>0.05 one tailed.

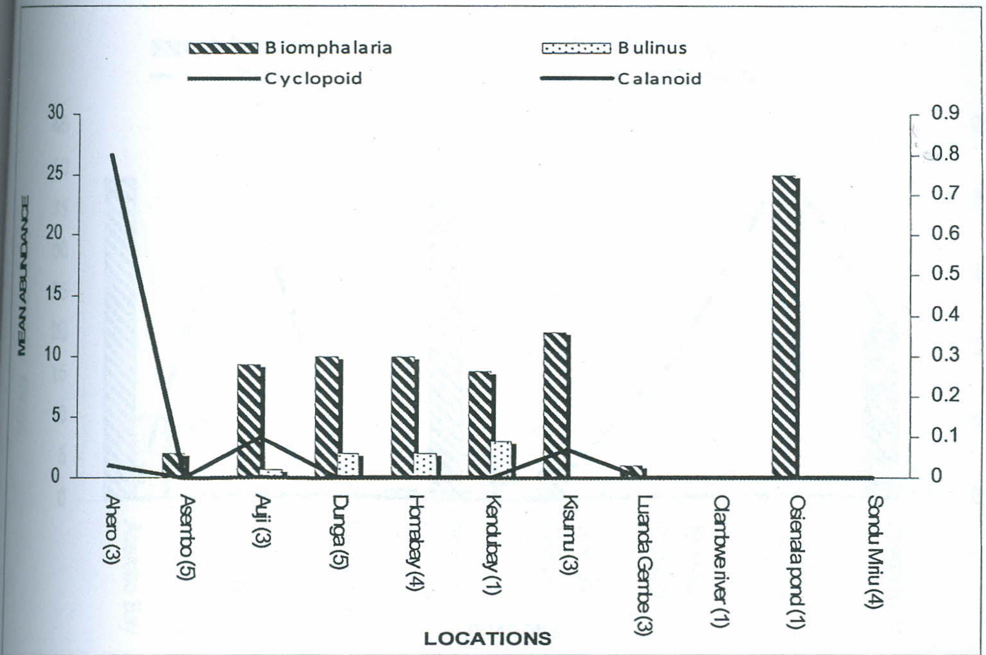

Figure 23. *Biomphalaria sudanica* and *Bulinus africanus* abundance vs. Cyclopoid and Calanoid on land

Biomphalaria sudanica vs. Cyclopoid: Pearsons' r=-0.298, p>0.05 one tailed.

Biomphalaria sudanica vs. Calanoid: Pearsons' r=-0.28, p>0.05 one tailed.

Bulinus africanus vs. Cyclopoid: Pearsons' r=-0.216, p>0.05 one tailed.

Bulinus africanus vs. Calanoid: Pearsons' r = -0.232, p>0.05 one tailed.

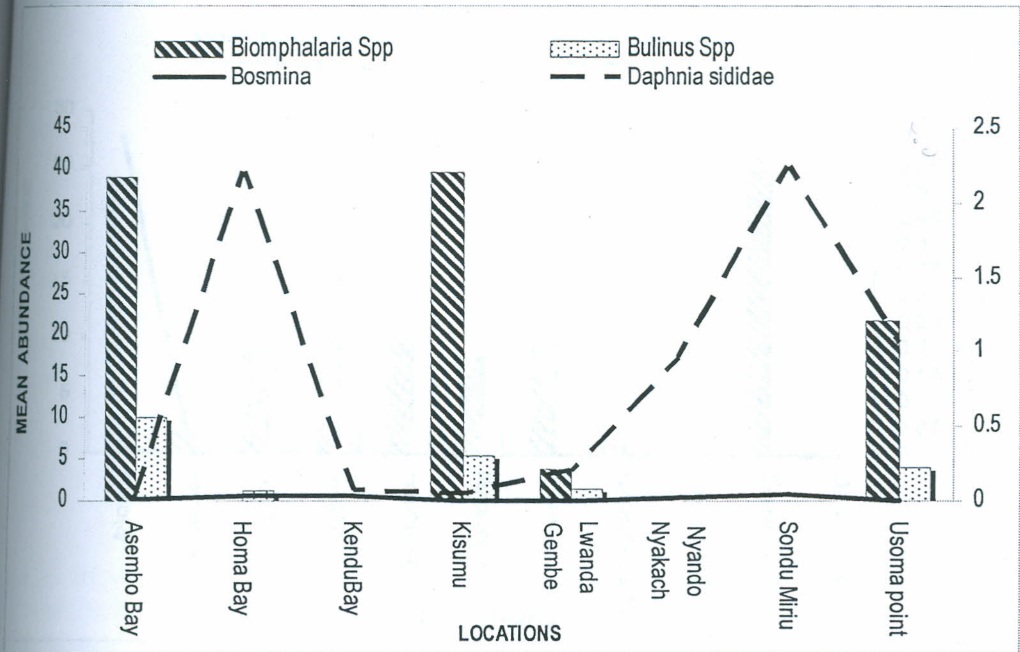

Figure 24. ***Biomphalaria sudanica*** **and** ***Bulinus africanus*** **abundance vs.** ***Bosmina*** **and** ***Daphnia sididae*** **in the lake**

Biomphalaria sudanica vs *Daphnia*: Pearsons r=-0.535, $p>0.05$ one tailed.

Biomphalaria sudanica vs *Bosmina*: Pearsons r= -0.6625, p=0.037 one tailed, p=0.07 – two tailed.

Bulinus africanus vs *Daphnia:* Pearsons r= -0.477, $p>0.05$ one tailed.

Bulinusafricanus vs *Bosmina*: Pearsons r= -0.543, $p>0.05$ one tailed.

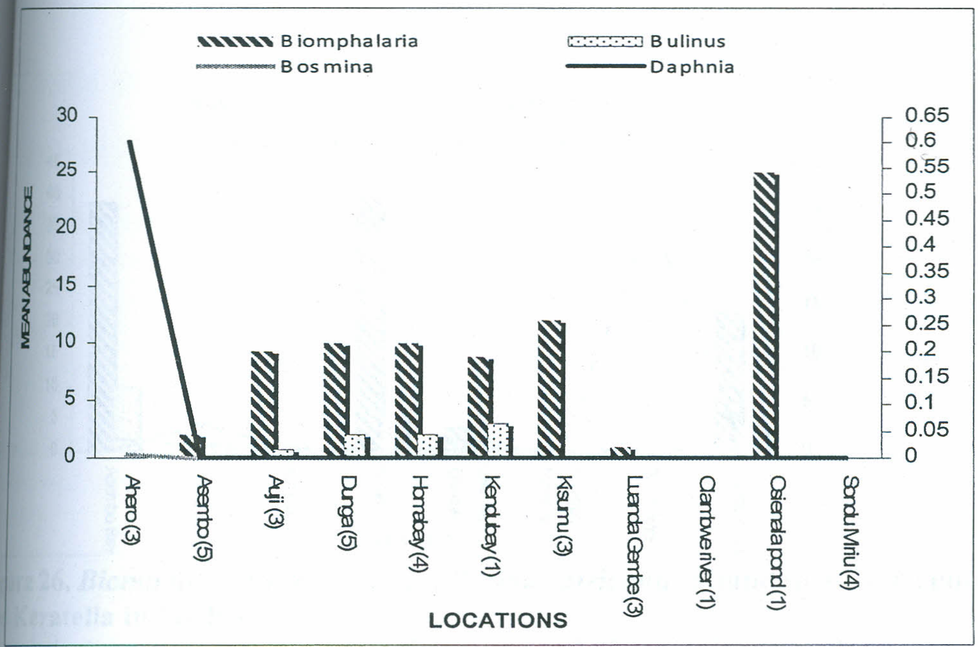

Figure 25. ***Biomphalaria sudanica*** **and** ***Bulinus africanus*** **abundance vs.** ***Bosmina*** **and** ***Daphnia sididae*** **on land**

Biomphalaria sudanica vs. *Bosmina*: Pearsons' r= -0.308, p>0.05 one tailed.

Biomphalaria sudanica vs. *Daphnia:* Pearsons' r =-0.308, p>0.05 one tailed.

Bulinus africanus vs. *Bosmina*: Pearsons' r=0.211, p>0.05 one tailed.

Bulinus africanus vs. *Daphnia*: Pearsons' r=-0.211, p>0.05 one tailed.

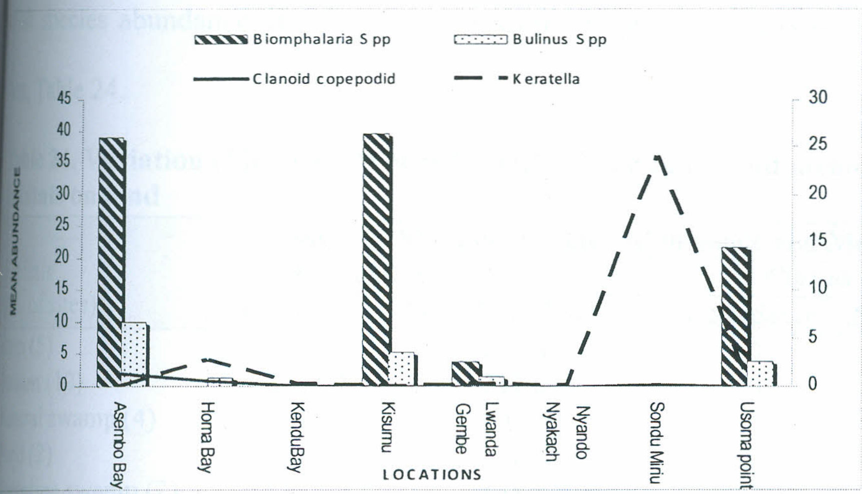

Figure 26. *Biomphalaria sudanica* and *Bulinus africanus* abundance vs. Calanoid, copepoid and Keratella in the lake

Biomphalaria sudanica vs. Calanoid: Pearsons' r=0.388, p>0.05 one tailed.

Biomphalaria sudanica vs. *Keratella*: Pearsons' r=-0.338, p>0.05 one tailed.

Bulinus africanus vs. Calanoid: Pearsons' r=0.676, p=0.033 one tailed.

4.5.3. Fish abundance and mean length, gut contents analysis, and correlation of fish abundance with *Anopheles*, *Biomphalaria sudanica* and *Bulinus africanus* abundance

Oreochromis niloticus and *Clarias gariepinus* fish species abundance and mean length varied between different locations in the lake and aquatic habitats in different locations on land, p< 0.001, Bartlett's test, Tables 23 and 24.

Table 23. Variation (Mean ±SD) of fish species abundance and mean length in different locations in the lake

	Mean (±SD) Fish Spp. Abundance and Mean Length			
Locations (No. of sites)	Abundance *O. niloticus*	Mean length (cm) *O. niloticus*	Abundance *C. gariepinus*	Mean length (cm) *C. gariepinus*
Asembo Bay (9)	8.67±24.2	3.03±5.1	0.44±0.9	4.01±8.8
Homa Bay (8)	26.1±32.5	1.7±1.8	0.1±0.4	1.0±3.7
Kendu Bay (7)	1.86±11.2	1.73±4.0	0.43±1.0	4.16±9.6
Kisumu (6)	0.17±3.7	7.82±15.5	0.33±0.7	2.0±4.8
Lwanda Gembe (8)	2.88±5.3	1.73±5.8	0	0
Nyando Nyakach (9)	0.59±1.0	1.24±2.1	1.04±1.4	13.67±1.7
Sondu Miriu (6)	1.17±2.3	2.25±4.5	1±2.0	6.08±12.7
Usoma point (6)	0.50±1.2	3.27±6.5	0.33±0.9	3.73±8.1
ANOVA	0.077	-	-	-
Bartlett's test	< 0.001	< 0.001	< 0.001	< 0.001

Fish species abundance and mean length varied between habitats on land, p<0.001, Bartlett's test, Table 24.

Table 24. Variation (Mean ±SD) of fish species abundance and mean length in different habitats on land

Habitats (No. of sites)	Mean (±SD) Fish Species Abundance and Mean Length			
	Oreochromis niloticus		*Clarius gariepinus*	
	Abundance	Mean Length (cm)	Abundance	Mean length (cm)
Dam (5)	3±4.9	2±2.8	0	0
Stream (10)	16±44.9	2±2.8	0	3±6.1
Natural swamp (4)	0	0	4±7.0	2±4.6
Pond (2)	0	0	1±1.41	5±7.2
Shoreline swamp (2)	3±3.5	4±5.2	3±4.2	10±13.4
Temporary pond (5)	0	0	0	0
Quarry (2)	0	0	2±2.8	10±13.6
River (1)	0	0	0	0
Flood plain (1)	0	0	1	13
Roadside pond (1)	0	0	0	0
ANOVA	-	-	-	-
Bartlett's test	< 0.001	< 0.001	< 0.001	< 0.001

Gut contents analysis of the different fish species showed that *Clarias gariepinus* were more insectivorous compared to other fish species. 74.8% of *Clarius gariapinus* gut contents were insect tissues, while only 3.8% of *Oreachromis leucostictus*, 16% of *Oreochromis niloticus*, 1% of *Protopterus aethiopicus*, and 0% of *Tilapia zillii* of the gut contents were insects' tissues, Table 25.

Table 25. Gut contents of different fish species caught from lake and land waters in different locations

Fish Species	Length (cm)	No.	Percentage Gut Contents									
			Empty	Plant remains	Insects	Molluscs	Worms	Zooplankton	Phytoplankton	Fish remains	Food remains	Mud /debris
Barbas altianalis	10.7	1	0	0	0	0	0	70	0	0	30	0
Clarias gariepinus	10-20	3	1	0	90	10	0	0	0	0	0	0
	21-30	13	0	3.9	73.1	1.5	9.2	0	0	11.5	0	0.8
	31-40	4	1	0	100	0	0	0	0	0	0	0
	41-50	8	3	10	36	0	0	0	0	50	0	4
		28	5	3.5	74.8	2.9	2.3	0	0	15.4	0	1.2
Clarias nurei	9	1	0	0	5	0	5	0	0	0	90	0
Oreochromis leucostictus	0-10	2	0	0	0	0	0	0	0	0	100	0
	10-20	14	0	0	7.1	0	0	5	6.8	0	81.1	0
		16	5	0	3.8	0	0	2.5	3.4	0	90.1	0
Oreochromis niloticus	5.6	1	0	0	0	0	0	0	0	0	100	0
	10-20	17	2	3.3	28.7	0	0	36.7	20	0	11.3	0
	21-30	6	0	0	3.3	0	0	25	20	0	41.7	0
		24	5	1.1	16	0	0	17.9	13.3	0	51	0
Protopterus aethiopicus	25	1	0	30	0	50	20	0	0	0	0	0
	46.9	1	0	70	30	0	0	0	0	0	0	0
		2	5	50	15	25	10	0	0	0	0	0
Tilapia zillii	15.2	1	0	0	0	0	0	0	10	0	0	90

There were non-significant correlations between *Anopheles* mosquitoes' abundance versus abundance of *Clarias gariepinus* and *Oreochromis niloticus*, p>0.05, Pearsons' Correlation, Figure 27.

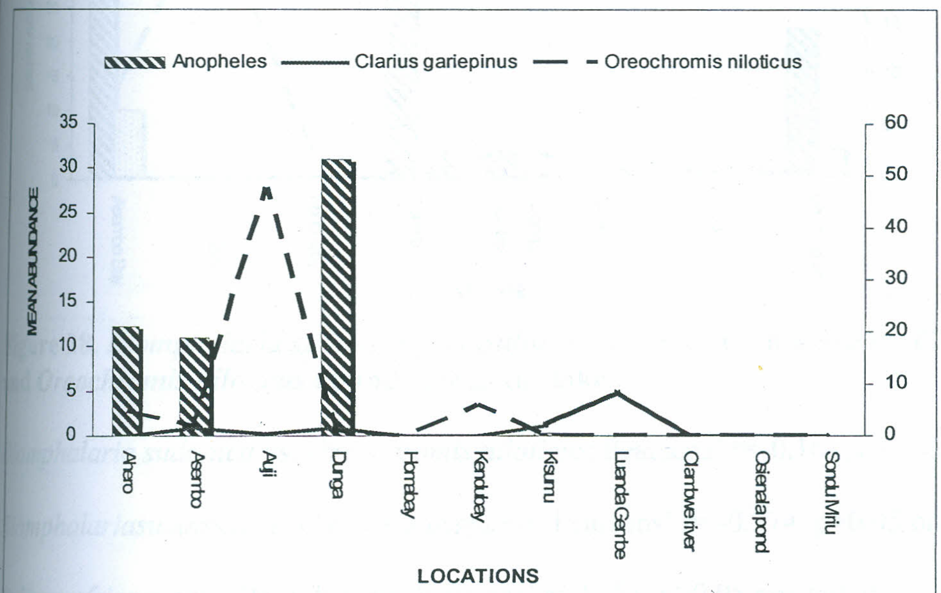

Figure 27. Abundance of *Anopheles* mosquitoes vs. *Clarias gariepinus* and *Oreochromis niloticus* abundance on land [n = 10, r = -0.002 (*Clarias gariepinus*); r = -0.141 (*Oreochromis niloticus*)]

There were non-significant correlations between *Biomphalaria sudanica* and *Bulinus africanus* abundance and the abundance of *Clarias gariepinus* and *Oreochromis niloticus* in the lake, Figure 28, and between *Biomphalaria sudanica* abundance and the abundance of the two fish species on land, Figure 29, and between *Bulinus africanus* and *Clarias gariepinus* abundance on land, p> 0.05, Pearsons' correlation. However, there was significant correlation between *Bulinus africanus* and *Oreochromis niloticus* abundance on land, p=0.015, Pearsons' Correlations, Figures 28 and 29.

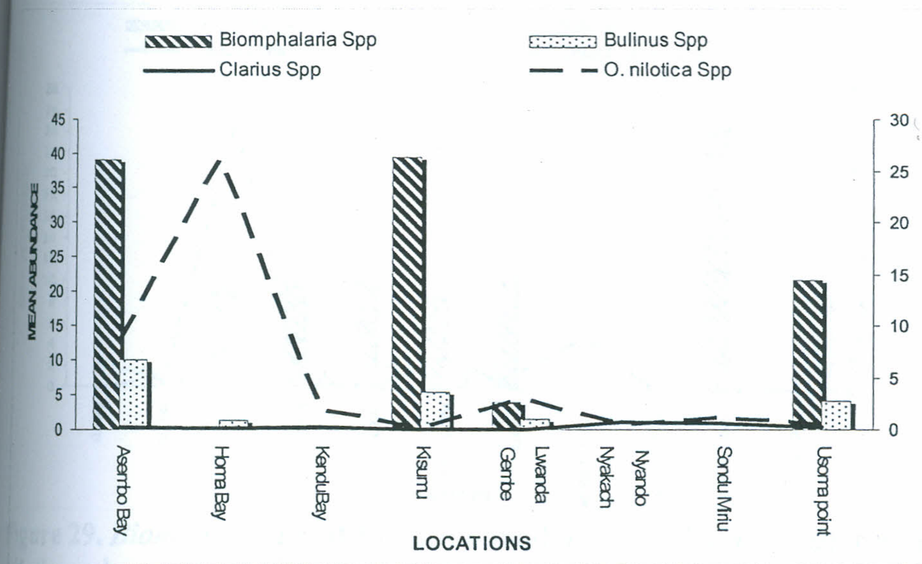

Figure 28. ***Biomphalaria sudanica*** **and** ***Bulinus africanus*** **abundance vs.** ***Clarias gariepinus*** **and** ***Oreochromis niloticus*** **abundance in the lake**

Biomphalaria sudanica vs. *Oreochromis niloticus*: Pearsons' r=-0.161, p>0.05 one tailed.

Biomphalariasudanica vs. *Clarias gariepinus:* Pearsons' r= -0.374, p>0.05 one tailed.

Bulinus africanus vs. *Oreochromis*: Pearsons' r=0.055, p>0.05 one tailed.

Bulinus afrianus vs. *Clarias gariepinus*: Pearsons' r=-0.334, p>0.05 one tailed.

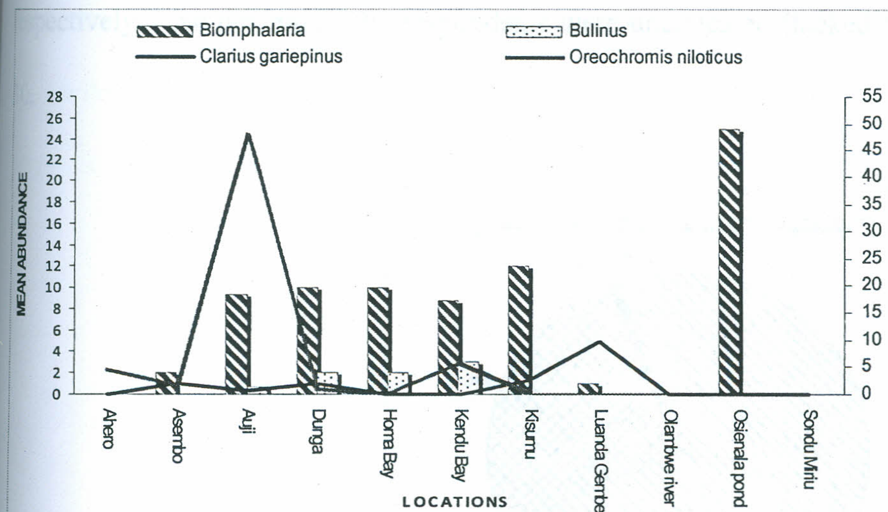

Figure 29. *Biomphalaria* and *Bulinus* abundance vs. *Clarias gariepinus* and *Oreochromis niloticus* abundance on land

Biomphalaria sudanica vs. *Oreochromis niloticus*: Pearsons' r=0.0699, p>0.05 one tailed.

Biomphalariasudanica vs. *Clarias gariepinus*: Pearsons' r= -0.226, p>0.05 one tailed.

Bulinus vs. *Oreochromis*: Pearsons' r=0.68, p=0.015 one tailed, p=0.031- two tailed test.

Bulinus vs. *Clarias gariepinus*: Pearsons' r=-0.233, p>0.05 one tailed.

4.6. Community Perceptions on Malaria and Schistosomiasis Transmission and Control, and Relationship with Aquatic Habitats and Vegetation Types

The level of community members' knowledge and perceptions on the association between aquatic vegetation and the abundance of malaria vectors, schistosomiasis intermediate host snail and the prevalence of malaria and schistosomiasis was assessed and results are given in the sections that follow.

Out of 243 respondents, 57% (139/243) were females and 43% (104/243) were males. Their mean age was 32 years. A larger percentage (68%) of the respondents were educated up to primary school level while those educated up to secondary and tertiary levels were 26% and 1%, respectively. Five percent of the respondents were uneducated (lacked formal education), Figure 30.

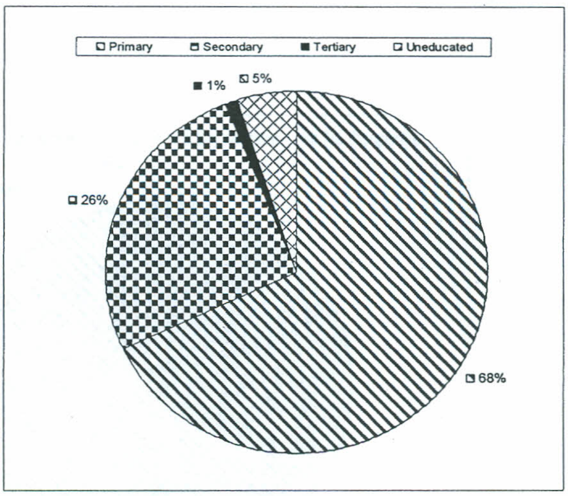

Figure 30. Education level of respondents

Most of the respondents were either fish vendors 80 (32.9%) or fishermen 58 (23.9 %). Farmers accounted for 11.9% of the respondents. Less than 5% of the respondents were engaged in other activities/occupations, Figure 31.

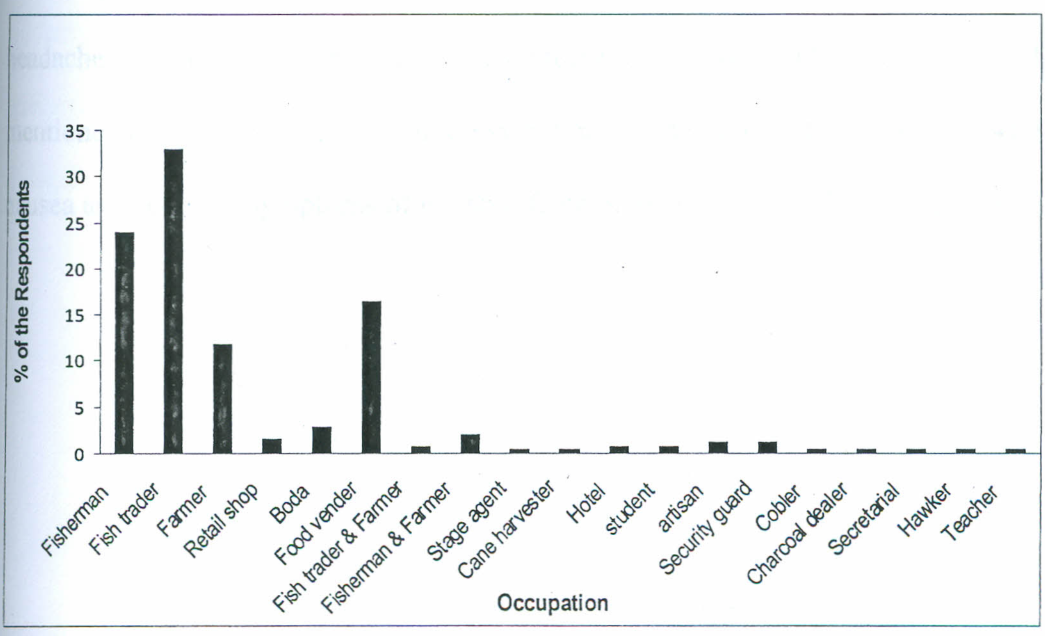

Figure 31. Occupation/activities of the respondents

Most respondents (89%) reported that malaria cases were highest during the rainy season while 6% attributed it to the dry season. A small percentage (1%) declined to respond while 4% of the respondents attributed cases of malaria to both wet and dry seasons, Figure 32.

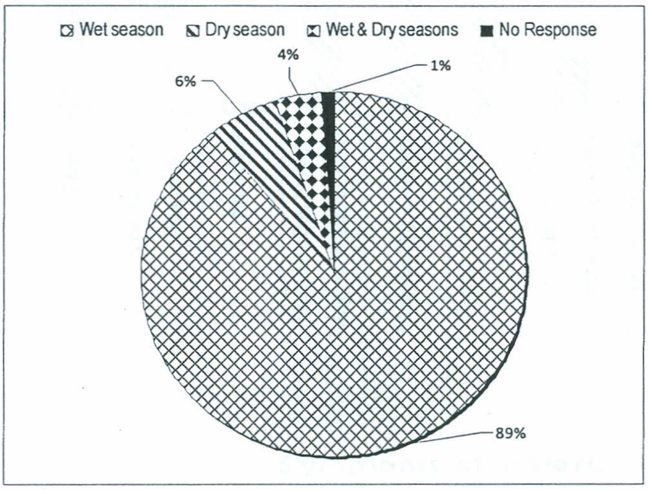

Figure 32. Season when malaria cases are common

Most respondents, 161 out of 242 (66.53%) were aware of symptoms of malaria and mentioned headache and fever as one of the symptoms of malaria, while 143 respondents (59.1%) mentioned only headache as one of the symptoms of malaria. 100 respondents (41.32%) reported nausea as one of the symptoms of malaria. Other symptoms were also mentioned, Figure 33.

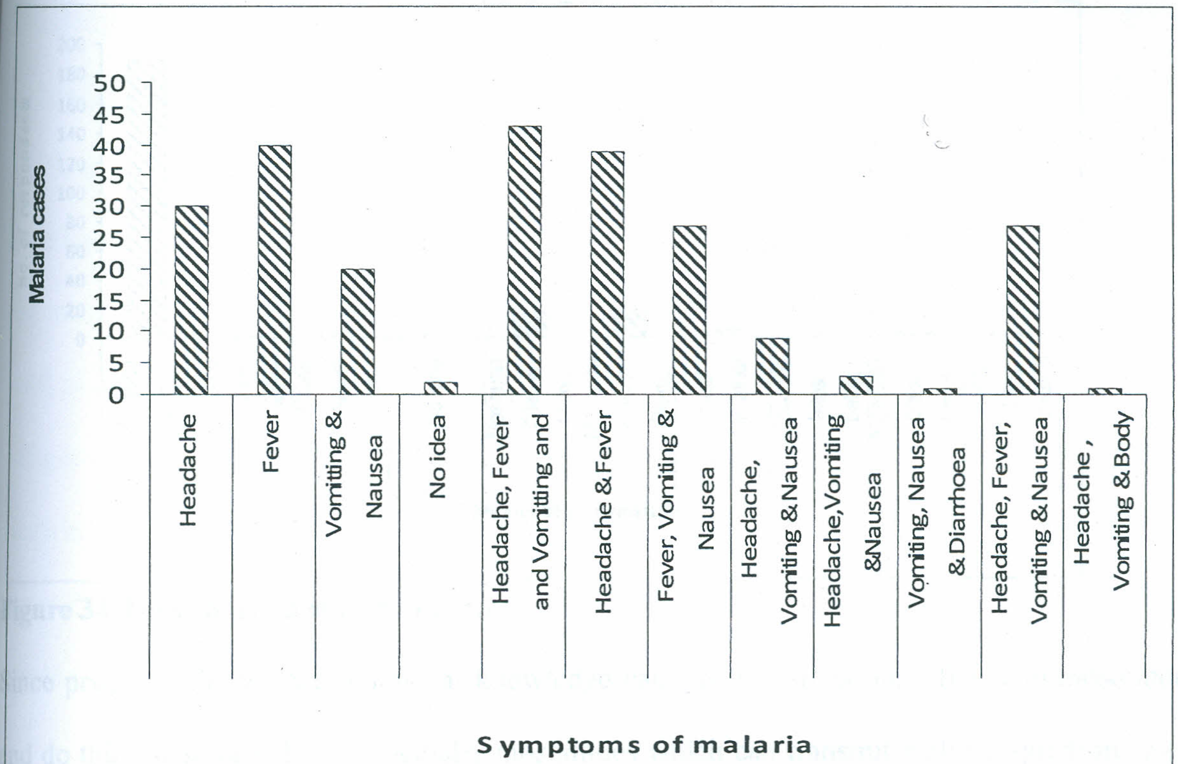

Figure 33. Symptoms of malaria

A large number (189 out of 243), 77.8 % of the respondents mentioned that malaria was transmitted by mosquito bites, while (7.8%) 19 of the respondents mentioned that it was transmitted by mosquito bites and being rained on. A total of 7% of the respondents cited mosquito bites and dirty water as the most common way of malaria transmission, Figure 34.

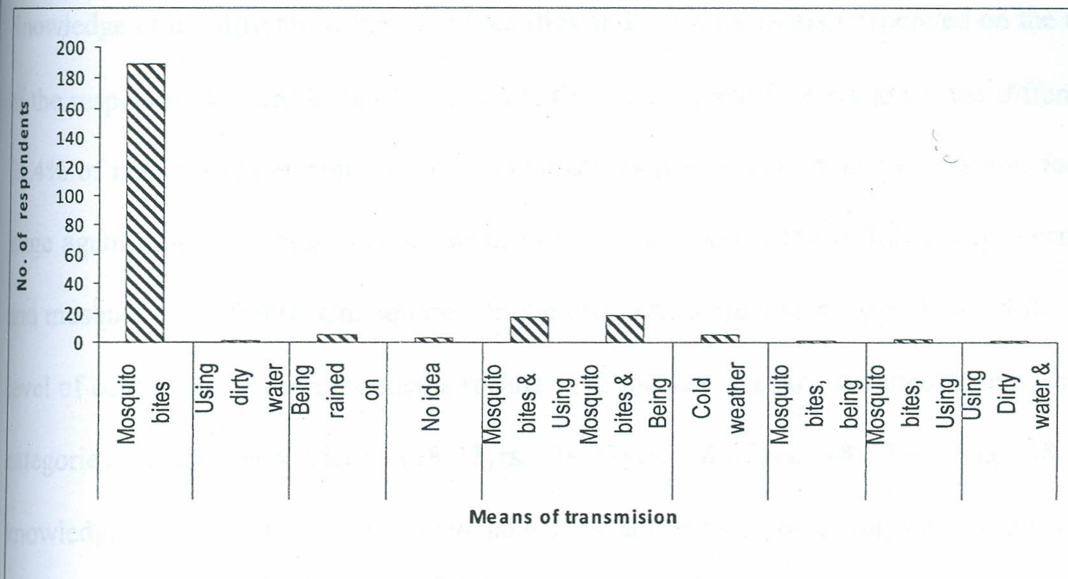

Figure 34. How malaria is transmitted

Since people with less entomological knowledge can easily confuse lake flies and mosquitoes and do think that lake flies are actually mosquitoes which can transmit malaria, questions were asked to find out the respondents knowledge of the difference between lakeflies and mosquitoes. Most male respondents knew the difference between lake flies (Ephemeroptera; Chironomidae: *Povilla adusta*) and mosquitoes compared to female respondents, Table 26. There was a significant relationship between gender and knowledge of the difference between lake flies and mosquitoes, p=0.002, $X^2 = 9.574$.

Table 26. Gender associated knowledge between lake flies and mosquitoes

Gender	Do you know the difference between lake flies and mosquitoes?		
	Yes	No	Total
Male	90 (87.4%)	13 (12.6%)	103 (100%)
Female	96 (70.6%)	40 (29.4%)	136 (100%)
Total	186 (77.8%)	53 (22.2%)	239 (100%)

Knowledge of the difference between lake flies and mosquitoes also depended on the occupation of the respondents. Over 85% of fishermen, fish traders, and farmers knew the difference while 55.4% of respondents engaged in other occupations (retail shop, bicycle operator, food vendor, stage agent, hotel operator, artisan, security guard, etc) knew the difference between lake flies and mosquitoes, $p<0.001$, Chi-square. On the contrary, there was no significant difference in the level of education of the respondents (primary, secondary, tertiary, or uneducated), or in the age categories of the respondents (18-27yrs, 28-37yrs, 38-47yrs, 48-57yrs, and 58-67yrs), on knowledge of the difference between lake flies and mosquitoes. Majority of the respondents (over 77%), knew the difference between lake flies and mosquitoes regardless of their education status or age categories, $p>0.2$, Chi-square test.

On treatment of malaria, 97.5% (237 out of 243) of the respondents stated that malaria is treated using antimalarial drugs (injections and tablets) while a smaller percentage (0.8%) believed that malaria could be treated by local herbs and concoctions, Figure 35.

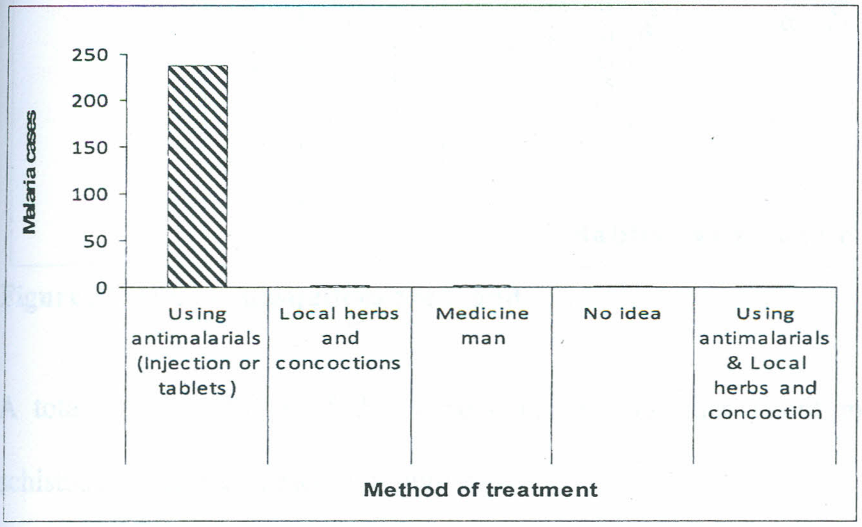

Figure 35. How malaria is treated

A large proportion 66 (27.6%) of the respondents believed that mosquitoes were found solely in the lake, while 37 (15.5 %) believed they are found in the pond, and 24 (10 %) believed they are found in bushy areas. Water bodies comprising of a combination of lake, river and pond were also identified by 19 (7.9 %) of the respondents as malaria vector breeding habitats, Figure 36.

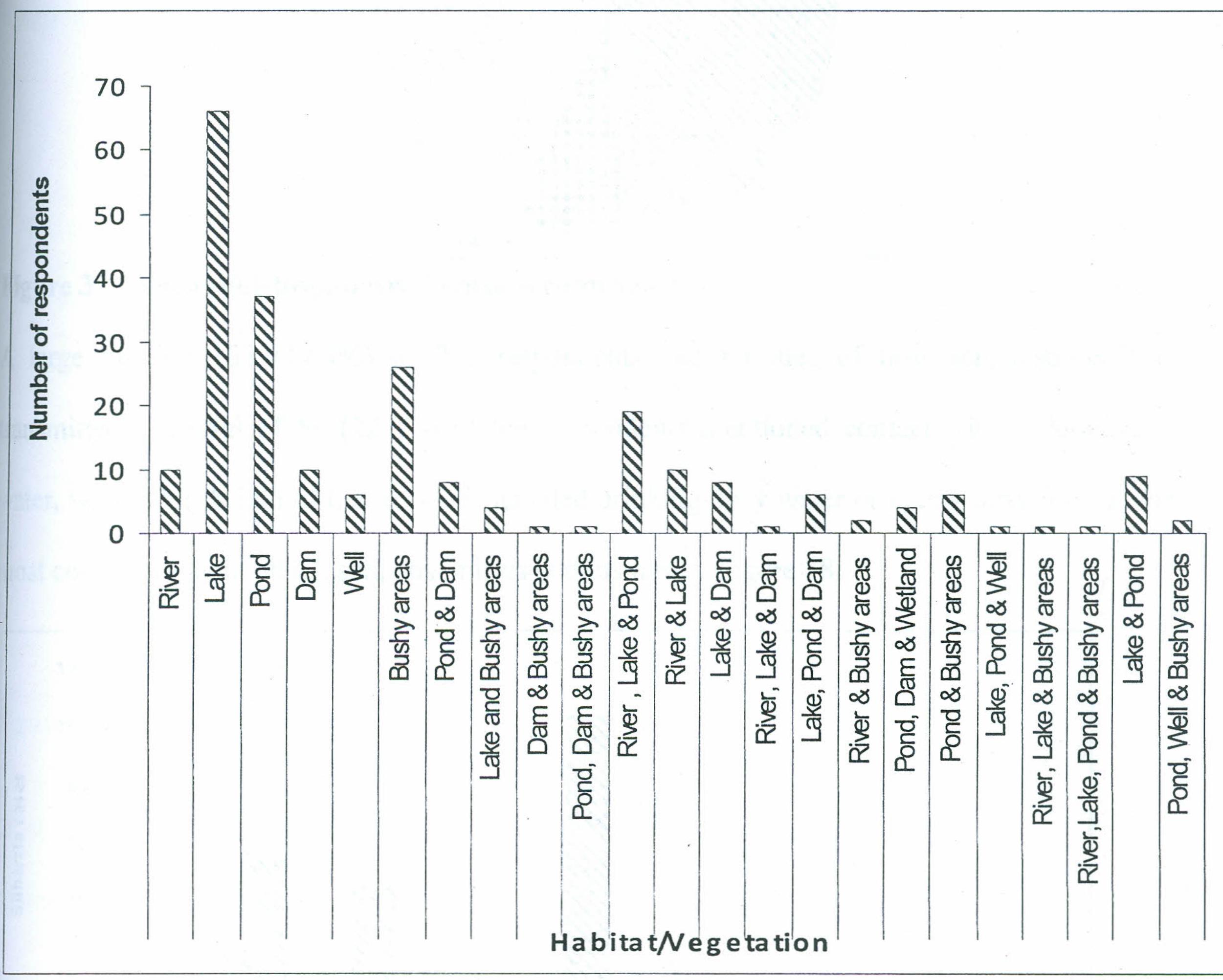

Figure 36. Where mosquitoes are found

A total of 106 (44%) of the respondents had no idea about most probable season when schistosomiasis is contracted, Figure 37.

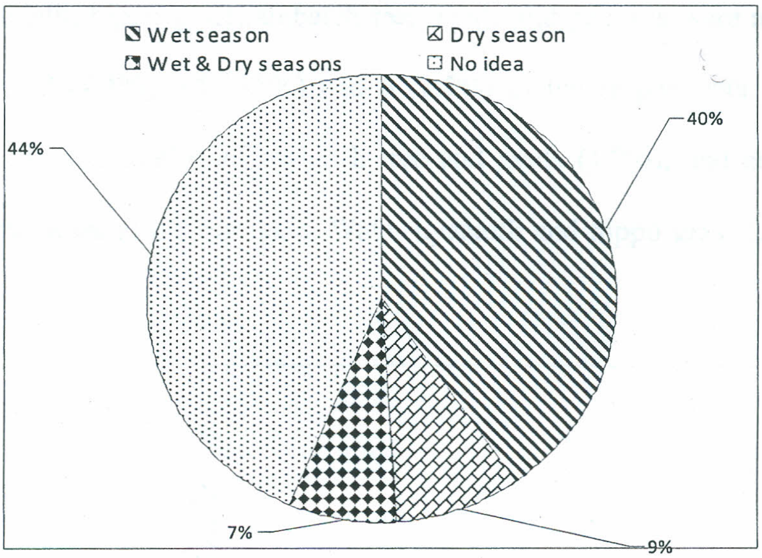

Figure 37. When schistosomiasis disease is contracted

A large number 103 (42.4%) of 243 respondents had no idea of how schistosomiasis is transmitted. A total of 54 (22.2%) of the respondents mentioned contact with contaminated water, while 45 (18.5%) of the respondents cited drinking dirty water or eating dirty food as the most common way in which schistosomiasis is transmitted, Figure 38.

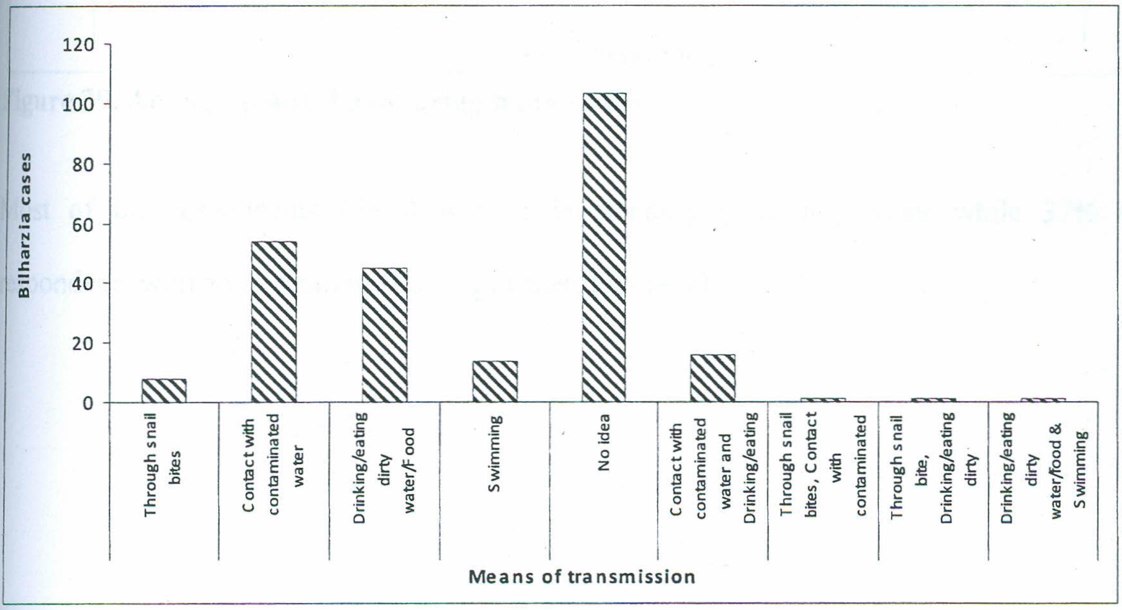

Figure 38. How schistosomiasis is transmitted

A larger percentage (57.2%) of the respondents had no idea of aquatic plants with more snails. However, water hyacinth, hippo grass, ambatch tree, reeds and papyrus were mentioned by 38 (15.6%), 18 (7.4%), 18 (7.4%), 14 (5.8%) and 6 (2.5%) of the respondents, respectively, as having more snails. A combination of ambatch tree and reeds (1.2%), and ambatch tree and water hyacinth (0.4%) were also mentioned. Water hyacinth and hippo grass (2.5%) were also mentioned, Figure 39.

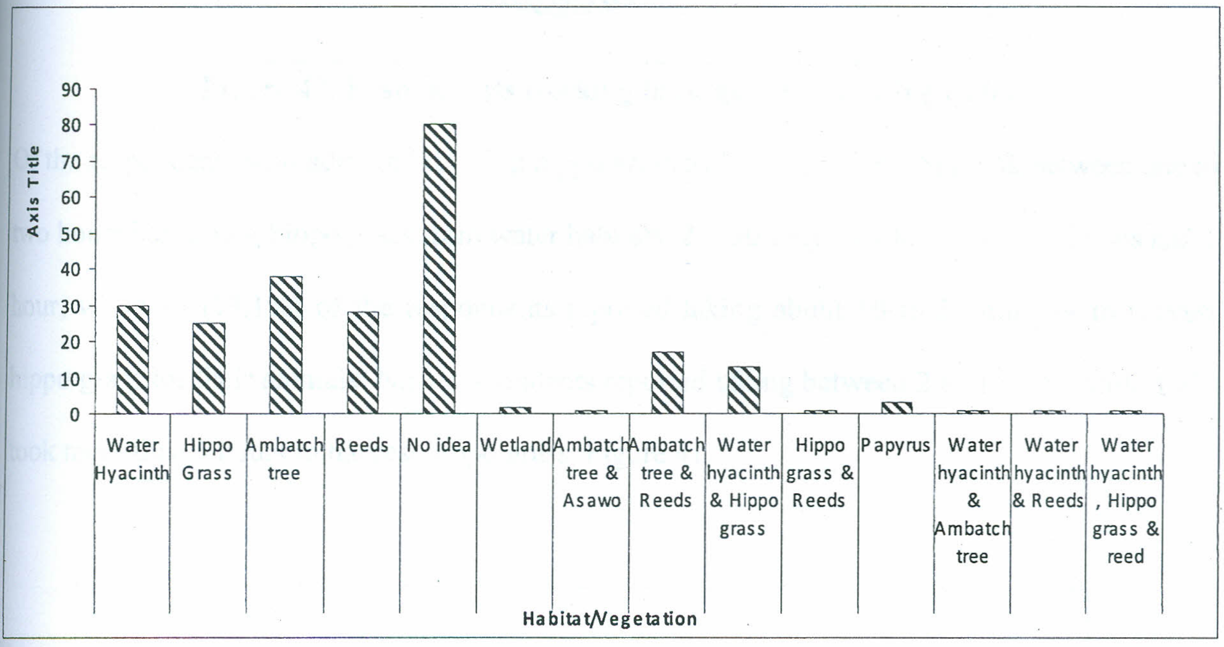

Figure 39. Aquatic plants harbouring more snails

Most of the respondents (63%) worked in standing (stagnant) water while 37% of the respondents worked in running (flowing) water, Figure 40.

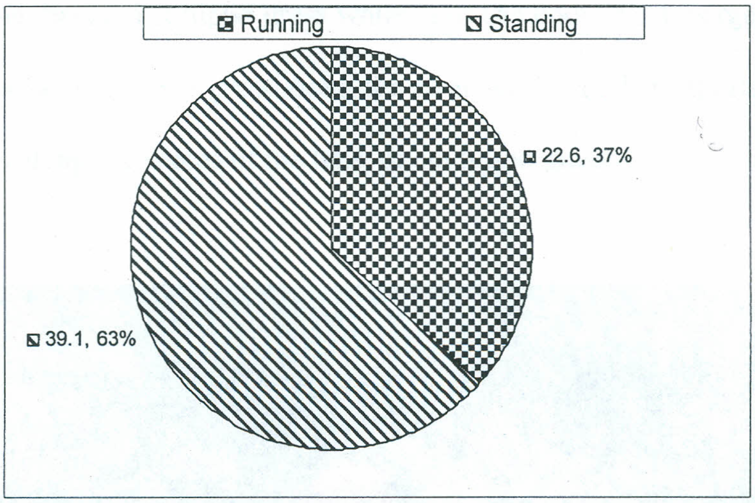

Figure 40. Respondents working in stagnant or flowing water

Of the respondents who admitted to using hippo grass as fodder, 33 (39.8%) took between one to two hours harvesting hippo grass from water habitats, 25 (30.1%) took between 30 minutes and 1 hour, while 15 (18.1%) of the respondents reported taking about 10 to 30 minutes to harvest hippo grass for their animals. Nine respondents reported taking between 2 to 4 hours while 1.2% took more than 5 hours to harvest hippo grass, Figure 41.

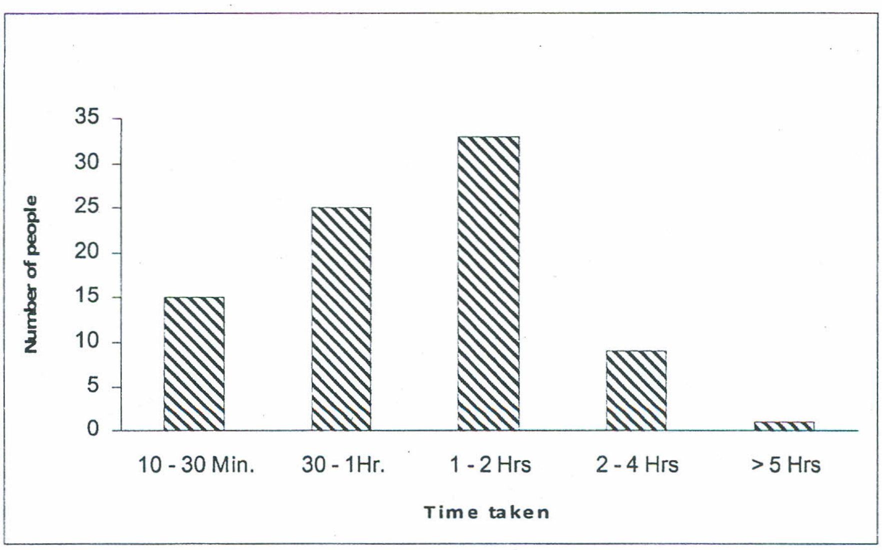

Figure 41. Time taken to harvest hippo grass

ate 12 shows a woman harvesting hippo grass while ½ of the body is submerged in water. One spondent reported harvesting hippo grass along the river while another reported that he feeds imals on hippo grass along the shores of the lake, or cut hippo grass.

Plate 12. Water contact activity, hippo grass harvesting

CHAPTER FIVE

5.0. DISCUSSION

5.1. Introduction

This study determined the abundance and distribution of mosquito and schistosomiasis snails and their relationships with physico-chemical factors, phytoplankton, zooplankton and fish abundance in the Lake Vitoria basin of western Kenya. Gut contents analysis of the fish species were also done, and knowledge and perceptions of community on malaria and schistosomiasis around the lake gulf region were also examined. The results of this study are discussed in the sections that follow.

5.2. Mosquito and Snail Vector Abundance in Lake and Land Locations, Habitats and Vegetation

The results from objective one of the current study have shown that *Anopheles* and *Culex* species of mosquitoes were abundant in different habitat types on land but not in deep inside the lake waters, while *Mansonia* and *Aedes* species of mosquitoes were found in the lake habitats. There were more *Anopheles* mosquitoes on land in dams, streams and swamps, as compared to ponds. These current study's results are in agreement with previous findings by Ofulla *et al.* (2010), which showed low abundance of malaria vectors (*Anopheles* sp) associated with water hyacinth and other macrophytes in the Nyanza gulf of Lake Victoria. The results are also in agreement with established knowledge that *Anopheles* and *Culex* mosquitoes readily breed in the land habitats (Gillies & Coetzee, 1987; Highton, 1983). And more recently, studies by Imbahale *et al.* (2011) showed that permanent aquatic habitats along the river fringe were more important for breeding during the dry season when the water levels reduce and stagnant pools of water suitable for mosquito breeding were created. Imbahale *et al.* (2011) further showed that, when it rained heavily, flooding would occur along the river fringe, erosion pits and within drainage canals rendering the habitats unsuitable for mosquito breeding. The current results, however, do contrast the most recent findings by Minakawa *et al.* (2012) which has shown that *Anopheles* mosquitoes readily breed in the shorelines of Lake Victoria associated with water hyacinth when the lake waters recede during dry spells. The differences could be attributed to mosquito sampling for this current study, which was done off-shore deep inside the lake waters.

Anopheles species and *Culex* species were abundant in different aquatic habitats in different locations on land, while *Aedes* species and *Mansonia* species were absent. Abundance of *Anopheles* species varied significantly in different locations on land. Species assemblages and abundance in specific locations can also be influenced by historical factors and population dynamics mainly, previous colonization or non colonization of the location or area by the particular species, and how population increase or decrease depend on local environmental pressures, which can be true for differential abundance of mosquito species in different locations (Gimnig *et al.,* 2001; Onori et al., 1993; Robert *et al.*, 1998). Therefore, mosquito larval habitat location and ecology is important in determining larval densities and species assemblage which in turn will influence malaria transmission in an area (Mwangangi *et al.,* 2007). Minakawa *et al.* (2002) also reported that the spatial heterogeneity in *An. gambiae* s.l. species composition may be affected either by many other variables, each of which has a small effect, or by other important variables that are yet to be determined under field conditions.

In contrast to the habitats inside the lake, the current study findings clearly showed that *Anopheles* mosquitoes were associated with water hyacinth and hippo grass in the aquatic habitats on land. This is in agreement with several previous studies which showed that mosquito breeding is enhanced by presence of vegetation (Gillies & Coetzee, 1987; McCrae, 1983; Onori *et al.,* 1993; Robert *et al.,* 1998; Service, 1993a). And the most recent study by Minakawa *et al.* (2012) also determined the same. However, this study's results contrast some earlier reports which pointed out that aquatic weeds were associated with increase in abundance of *Anopheles* species of mosquitoes in man-made lakes (Obeng, 1969) probably because the man-made lakes could have been smaller and less turbulent and probably the studies were done when the lakes were still "new" (with few predators) which calls for further research. But clearly, the current results contrast with the common belief and previous reports (Mutuku *et al*., 2006; Twongo *et al*., 1995) that the water hyacinth in Lake Victoria is associated with high incidences of malaria within the Lake Victoria basin.

This study showed that there were more *Biomphalaria sudanica* than *Bulinus africanus* snails in the lake and land locations and habitats within the Lake Victoria basin of Kenya. There were significantly more *Biomphalaria* and *Bulinus* species in Asembo Bay, Kisumu, Usoma Point and Lwanda Gembe. Just like previous results by Ofulla *et al.* (2010), which showed no presence of host snails in the Nyando and Sondu Miriu region, the present study also found out that there were no schistosomiasis host snails in Nyando, Nyakach, Sondu Miriu and Kendu bay. Significantly more *Biomphalaria* spp were however found in Dunga, Kisumu, Homabay/Kendu bay and Auji in land habitats, but were absent in Ahero. No schistosomiasis intermediate host snails were found in lake and land aquatic habitats in Ahero region and yet health records (results not shown in this thesis) showed high prevalence of schistosomiasis in Ahero and Nyando regions. This could probably be due to the fact that sampling of snails was done in dams, ponds and lake waters and not in rice fields and canals where schistosomiasis intermediate host snails have previously been reported to be abundant around Ahero and Nyando regions (WHO/FAO/UNEP, 1988).

In different physical habitats on land, ponds, streams, and swamps, in that order were found to favour *Biomphalaria* and *Bulinus* snails as compared to dams. Similarly, significantly more *Biomphalaria* species were sampled on different locations on land than *Bulinus* species. The findings in this study are similar to those of Opisa *et al.* (2011) which also reported that *Biomphalaria* species were generally abundant than *Bulinus* species in different habitats on land.

In the lake habitats, significantly more *Biomphalaria sudanica* and *Bulinus africanus* snails were found in the ambatch tree zone, hippo grass/water hyacinth zone, hippo grass zone and water hyacinth zone compared to open water, giving a clear indication that aquatic vegetation play an important role in harbouring these snails (Ntiba *et al.*, 2001; Plummer, 2005). In the recent past, water hyacinth that was almost eradicated in the 1990s within the Nyanza gulf has resurged and is now accompanied by other aquatic weeds such as *Vossia cuspidata* (hippo grass), *Phragmites mauritanius,* ambatch tree and *Cyperus papyrus* (Ofulla *et al.*, 2010). Water hyacinth has also spread to smaller water bodies in the marginal terrestrial areas of the Lake Victoria basin hence creating even more suitable habitats for optimal growth of Schistosoma harbouring host snails.

In general, more snails were found in the ambatch tree zone, hippo grass/water hyacinth zone, hippo grass zone and water hyacinth zone compared to open water in the lake. *Biomphalaria sudanica* and *Bulinus africanus* snail abundance showed significant variations in different vegetation habitats in the lake. In addition, there were significantly more *Biomphalaria* spp than *Bulinus* spp in different vegetation habitats in the lake. These findings are consistent with previous studies which showed that many schistosomiasis host snails were associated with water hyacinth followed by hippo grass, though others were free floating especially after heavy storms in the lake which probably dislodges the snails from their attachment to aquatic vegetation (Ofulla *et al.,* 2010). The present study's results are also consistent with findings by Kariuki *et al.* (2004) which reported that snail presence were significantly associated with different vegetation types. It is thus clear that schistosomiasis host snails are clearly associated with different aquatic macrophytes.

5.3. Physico-chemical Parameters Influence on Abundance of Mosquitoes and Snail Vectors in Lake and on Land

Of the physico-chemical parameters analysed (dissolved oxygen (DO), pH, alkalinity, hardness, turbidity, conductivity, temperature and salinity), only temperature was predictive of *Anopheles* species abundance in different locations on land. Past studies have shown that the main abiotic factors favouring mosquito larvae abundance include temperature, water chemical composition, its pH, depth, turbidity (Onori *et al.,* 1993; Robert *et al.,* 1998; Service, 1993a). Also cool, still and clear water with suitable pH, temperature and nutrient composition has been found to encourage breeding of *Anopheles* species (Okogun, 2005; Okorie, 1978). The present study's results may be attributed to the conditions under which the study was done and presence of other environmental abiotic factors yet to be determined under field conditions. However, it is not possible to pin point one physico-chemical parameter as previously reported by Minakawa *et al.* (1999).

Regarding snail vectors, the current study results showed that dissolved oxygen was predictive of *Biomphalaria* species abundance, while pH and turbulence were observed to be predictive of *Bulinus* species abundance in different locations in the lake. This is in congruence with study by Hira (1969) which observed absence of snails from sites with 0.0-0.1 mg/l dissolved oxygen. Hira (1969) also attributed a crash of *Bulinus globosus* population to decrease in oxygen concentration. Low oxygen concentration affects movement, feeding and reproduction activities of snail vectors and could therefore be a limiting factor for distribution of snail (Malek, 1958).

The mean range of pH established by this study was 7.6-8.4. This was fairly consistent with Hira (1969) who observed a range of 5.8-7.8. In addition, Opisa *et al.* (2011) also reported encountering snails in habitats with a wide pH range (6.7 and >11) but suggested that pH may not have much influence on snail abundance. In the current study, there was no habitat with a pH value below 7.6. This was is probably of survival advantage as lower pH values are known to be harmful as they cause mucus coagulation on exposed snail surfaces (Malek, 1958).

5.4. Phytoplankton Abundance and Influences on *Anopheles* Mosquito and Schistosomiasis Snails Abundance in Different Locations on Land and in the Lake

Cyanobacteria abundance varied significantly in different locations on land, while diatoms and dinoflagellates showed significant variations in different locations in the lake. Abundance of phytoplankton (Cyanobacteria, Chlorophyceae, Diatoms, Euglenoids, Zygnematids and

Dinoflagellates) between locations in the lake could be attributed to variation in physico-chemical parameters in different locations and habitats.

Cyanobacteria species have been studied in various mosquito breeding sources (Thiery *et al.*, 1991). These photosynthetic prokaryotes are widely distributed in mosquito habitats and have been found in the guts of mosquito larvae. Cyanobacteria serve as food for mosquito larvae (Khawaled *et al.*, 1989).

Cyanobacteria and Chlorophyceae were shown to be predictive of *Biomphalaria* species abundance in different locations in the lake. These findings compared fairly well with reports of Green (2009), who found out that the phytoplankton of Lake Kyoga Uganda, varied along a gradient from east to west, and was dominated by Cyanobacteria in the east. These findings were however contradictory to studies by Williamson *et al.* (2004) which reported that secondary metabolites from Cyanobacteria are toxic to *Biomphalaria* species.

5.5. Zooplankton Abundance and Influence on *Anopheles* Mosquito and Schistosomiasis Snails Abundance in Different Locations on Land and in the Lake

From the results obtained in this study, abundance of different zooplankton species varied between locations, habitats and vegetation in the lake and on land, $p<0.001$. Abundance of zooplankton between different habitats in the lake only varied for Calanoid, copepoid and *Keratella*, but not for Cyclopoid, $p>0.05$. However, there were significant correlations between abundance of *Anopheles* mosquitoes and Calanoid on land, but no significant correlation between *Anopheles* species and Cyclopoid, *Daphnia, Bosmina*, Calanoid and copepoid, on land, $p > 0.05$. There were significant correlations between abundance of *Anopheles* mosquitoes and

Calanoid on land, but no significant correlation between *Anopheles* species and Cyclopoid, *Daphnia*, *Bosmina*, Calanoid and copepoid, on land, $p > 0.05$. The current study also revealed that there were no significant correlations between *Biomphalaria sudanica* and *Bulinus africanus* snail host abundance with Cyclopoid, Calanoid, *Daphnia* and *Bosmina* in both lake and land, $p > 0.05$, and with *Daphnia* and *Bosmina* in the lake and land.

The zooplankton abundance varied significantly between different locations in the lake, while *Bosmina* spp. was shown to be predictive of *Biomphalaria* species abundance, as well as *Bulinus* species abundance in different locations in the lake, with the relationship being negative. This could imply that *Bosmina* species is either a major food item for the snails or they could be exhibiting secretions that keep the snails away from their habitats. There also could have been toxicological factors and food web efficiency factors that could influence these relationships. *Cyclopoid* species however, were the most prominent zooplankton taxa in different locations in the lake, followed by *Calanoid* species and *Daphnia* species in that order. This is consistent with the results of Green (2009) who reported that the zooplankton were dominated by cyclopoid and copepods in Lake Kyoga, Uganda.

5.6. Fish Abundance and Correlation with *Anopheles, B. sudanica* and *B. africanus*

Abundance

Lake Victoria fish stocks and fisheries have undergone remarkable change over the last two decades. The lake's ecosystem and food web have changed and are in the process of change (Ogutu-Ohwayo, 1990). Increased pollution and clearing of peripheral wetlands, which serve as fish nursery grounds, may be affecting the fisheries and the lake's resource in general (Ogutu-Ohwayo, 1990).

Many fish species such as *Clarias gariepinus*, Butchell *Labeo victorianus* Boulenger and Haplochromines are reduced in numbers. Over the last ten years, even *Lates niloticus* (Nile perch) has shown signs of declining (Ogutu-Ohwayo, 1990; Ochumba, 1990). However, recent studies have shown that the encroachment of the shores and beaches by water hyacinth has resulted in the re-appearance and subsequent increase of some fish species that were reportedly on the decline or threatened with extinction (Njiru *et al.*, 2002).

In the current study, *Oreochromis niloticus* and *Clarias gariepinus* fish species abundance and mean length varied between different locations and habitats in the lake and aquatic habitats in different locations on land. Stomach content analysis showed that *Clarias gariepinus* were more insectivorous compared to other fish species. This is consistent with earlier reports that *Clarias gariepinus* fingerlings feed on insects including mosquito larvae/pupae (Britz & Hecht, 1988), and act as biological control agents (Ghosh *et al.,* 2005). Results from this study and those of previous studies, therefore imply that *Clarias gariepinus* could be a suitable fish for biological control of insects, such as mosquitoes in aquatic habitats, and needs further well designed studies in the Lake Victoria basin.

No significant correlations were found between *Biomphalaria sudanica* and *Bulinus africanus* abundance and *Clarias gariepinus* and *Oreochromis nilotucus* in the lake and between *Biomphalaria sudanica* and *Clarias gariepinus* and *Oreochromis nilotucus* on land. The current study results contrast with studies by Gashawa *et al.* (2008), which showed that the African catfish, *Clarias gariepinus* can also be used as biological control agents against the *Schistosoma* *mansoni* intermediate host *Biomphalaria pfeifferi*, as snail consumption was faster by fish provided with inadequate supplementary food in laboratory ponds. Predation on mosquito larvae and on molluscs by fish may be less efficient in dense underwater meadows or submerged plants. Aquatic plant cover may provide mosquito larvae with refuge from fish predation. Or maybe, in natural environment as in lake and on land aquatic habitats, other ecological factors yet to be determined, hinder the fish from feeding on snails and mosquito larvae.

5.7. Community Perceptions on Malaria and Schistosomiasis Transmission and Control and Relationship with Aquatic Habitats and Vegetation

Results from surveys on knowledge and perceptions are applicable to design or improvement in malaria control programs and to identify indicators for a program's effectiveness (Vijayakumar *et al.,* 2009). Data from this study showed that, along the Kenyan Lake Victoria basin, local community members had a better understanding of malaria causes, symptoms and treatment. However, the findings also showed that 7.8% of the respondents, attributed transmission of malaria to being rained on, dirty water and cold weather. This is consistent with Kenya malaria indicator survey of 2010, where 90 % of mothers with babies under five years old, mentioned that they sought conventional malaria treatment whenever their children had fever (KMIS, 2010).

Most respondents (66.5 %) were able to state the most common symptoms of malaria accurately. However some respondents only mentioned one or two symptoms such as fever and vomiting which could also be attributed to other water borne diseases like typhoid. This has been identified as a major problem since people are likely to take wrong prescriptions of drugs based on wrong diagnosis. Some respondents were not aware of any malaria symptoms, a factor which could be attributed to the high illiteracy levels among communities living within the Lake Victoria basin. No respondent mentioned anaemia and convulsions which are life-threatening, particularly among the under five year olds. Similar observations have been reported from different parts of the world (Ahmed *et al.,* 2009; Hlongwana *et al.,* 2009; Mboera *et al.,* 2007). Earlier studies reported that community members identified malaria mainly on the basis of the symptoms of high body temperature (fever), headache, and general body weakness (De Savigny *et al.,* 2004; Dunyo *et al.,* 2000; Hlongwana *et al.,* 2009).

A majority (97.5%), of respondents knew that treatment of malaria could be achieved by use of conventional anti-malarial drugs. This has major implications for the planning of successful and sustainable community participation in vector control activities. This was consistent with findings from other parts of the world namely Tanzania, India and Bangladesh (Ahmed *et al.,* 2009; De Savigny *et al.*, 2004; Hlongwana *et al.,* 2009; Tuagi *et al.,* 2005).

A considerable number of respondents 66 (27.6%), believed that mosquitoes were found exclusively in the lake. This is a clear case of misperception among the locals, living within the Lake Victoria basin, which could be as a result of low level of education. There could also be confusion by most community members on the difference between lake flies and mosquitoes, as significantly more female respondents did not know the difference between lake flies and mosquitoes. Results of physical studies have previously shown low abundance of malaria mosquitoes associated with various aquatic weeds in the lake and also reported that there could be possible confusion between lake flies and mosquitoes by community members (Ofulla *et al.,* 2010). It was however, worth noting that a few of the respondents knew that mosquitoes were actually abundant in stagnant waters. Habitats mentioned by the respondents were: river, pond, dam, and well.

Despite the high level of awareness on malaria transmission, symptoms and treatment by the local community, low education was identified as a major drawback which can hinder intervention program. It is thus, recommended that information and behaviour change campaigns should be focused at the community level. Detection and control of a disease such as malaria in the Lake Victoria basin therefore calls for major human and material resources, such as intensive research on health issues (including studies on local community members' perceptions on malaria transmission, symptoms, prevalence, treatment and control), in addition to well-equipped health facilities and qualified staff to manage the disease.

This study showed that along the Kenyan Lake Victoria basin, local community members demonstrated poor knowledge of transmission, prevalence and control of schistosomiasis. Fifty two percent (52%) of the respondents had no idea of how schistosomiasis is contracted. This is fairly consistent with the study by Anguzu *et al.* (2007) who found out that 55% of the respondents in Busia, Uganda did not know disease caused by water snails and, community reported mode of transmission of bilharzia as being through drinking dirty water, eating contaminated food or through a wound when one steps in water. The results are also in agreement with a study done by Mengistu *et al.* (2009) where those from intestinal schistosomiasis endemic areas showed low awareness and knowledge of the disease.

The respondents demonstrated poor knowledge of the vectors' habitats in association with aquatic vegetations, as 57% of the respondents, had no idea about aquatic plants harbouring snails, despite of, water hyacinth, ambatch tree, reeds, and papyrus being well known in the study area. This could be attributed to low level of education among these communities as a larger percentage (68%) of the respondents were only educated up to primary school level and the numbers of the uneducated were five times higher than that of tertiary level respondents. This lack of knowledge is unfortunate because previous reports by Ofulla *et al.* (2010) showed that aquatic vegetation particularly water hyacinth and hippo grass harbour schistosomiasis snails along the Kenyan Lake Victoria basin.

The total duration taken in contact with infected water is likely to determine if the person gets infected with schistosomiasis or not. This study found that most of the respondents 63% worked in stagnant waters while 37% of the respondents worked in running water. Thirty five percent (35%), of the respondents reported using hippo grass as fodder for livestock, which they harvested from the shores of the lake or river. The findings are consistent with studies by Ofulla *et al.* (2010) which found that the commonly undertaken activities in the region included harvesting hippo grass, fishing, washing clothes, washing utensils, bathing and many other domestic chores which can expose community members to schistosomiasis infection. The current findings are also consistent with studies done by Anguzu *et al.* (2007), which found that the commonly undertaken activities in Busia, Uganda, included: washing clothes, washing utensils, bathing and playing in lake water. Such risky behaviour should therefore be strongly discouraged as public health strategy against schistosomiasis.

There is need to target the less advantaged members of the community such as women and the uneducated for intense health education strategies aimed at increasing awareness and community participation in the control malaria and schistosomiasis along the Kenyan Lake Victoria Basin. Control measures based on the socio-ecological settings of Kenyan Lake Victoria basin is required while emphasis on further research in this hitherto neglected endemic focus is strongly suggested.

5.8 Study Limitations

Potential limitations noted in this study are:

1. Identification of mosquitoes was based on morphological characters alone. However, future studies may benefit from use of more sensitive molecular techniques such as PCR (Koekemoer *et al.,* 2002) to verify identity of mosquitoes, particularly *Anopheles gambiae* and *Anopheles funestus* cryptic species.

2. Identification of snails in this study was based on both conchological and anatomical (reproductive system) characteristics. Though, this is better than relying on morphological characters of the shell alone, considering the current taxonomic problems associated with separation of the two *Biomphalaria* species i.e. *Biomphalaria pfeifferi* and *Biomphalaria sudanica* (Stensgaard *et al.,* 2005; Brown, 1994) and also in the *Bulinus africanus* group i.e. *Bulimus globosus* and *Bulinus nasutus* (Kane *et al.,* 2008), once again, use of molecular techniques in identification of the vectors is suggested in future studies.

Since this study was mainly on determination of environmental abiotic and biotic factors influencing distribution of mosquitoes and schistosomiasis snails, and also assessing the local community knowledge and perceptions regarding malaria and schistosomiasis along Kenyan Lake Victoria basin, the above mentioned limitations could not affect the authenticity of the study findings. This is because even if one was to use molecular-based identification techniques, first, he or she must identify the vectors using morphological features based on internationally recognized identification keys as was done in this study.

CHAPTER SIX

6.0 SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

6.1. Introduction

Chapter six brings out the summary, conclusions and recommendations of the study for better handling of the problems and challenges in the study. Furthermore, the chapter also calls for suggestions that aid future studies that would be carried on to advance areas that demand more research.

6.2. Summary of Findings

The overall objective of the study was to determine the spatial distribution and habitat characterisation including vegetation types, physico-chemical parameters, and abundance of phytoplankton, zooplankton and fish species on abundance of mosquitoes and snails that transmit schistosomiasis, and also find out community perceptions on transmission dynamics and control of the two diseases, in Lake Victoria basin of western Kenya. From the data collected and analysed, results showed that Anopheline mosquitoes were abundant on land locations and habitats, but not lake habitats and their larvae were associated with different types of vegetation and habitats, there were more *Biomphalaria sudanica* than *Bulinus africanus* snails attached to water hyacinth in the lake and land locations and habitats within Kenyan Lake Victoria, aquatic plants harboured snail vectors for schistosomiasis; temperature was predictive of *Anopheles* species abundance in different locations on land while; dissolved oxygen was predictive of *Biomphalaria* species abundance; Diatom abundance was shown to be predictive of *Anopheles* species in different locations on land while Cyanobacteria and Chlorophyceae were shown to be predictive of *Biomphalaria* species; *Clarias gariepinus* were more insectivorous relative to other fish species; and local community's knowledge on malaria and schistosomiasis vectors' habitats around Lake Victoria was poor.

6.3. Conclusions

(a) *Anopheles* and *Culex* species of mosquitoes were abundant in different habitat types on land but not inside the lake waters, while *Mansonia* and *Aedes* species of mosquitoes were found in the lake habitats.

(b) There were more *Biomphalaria sudanica* than *Bulinus africanus* snails attached to water hyacinth in the lake and land locations and habitats within the Lake Victoria basin of Kenya.

(c) Temperature was predictive of *Anopheles* species abundance in different locations on land. Dissolved oxygen was predictive of *Biomphalaria* species abundance, while pH and turbulence were predictive of *Bulinus* species abundance in different locations in the lake.

(d) Diatom abundance was shown to be predictive of *Anopheles* species in different locations on land, while cyanobacteria, chlorophyceae, and dinoflagellates, were shown to be predictive of *Mansonia* species abundance in different locations in the lake. Cyanobacteria and Chlorophyceae were shown to be predictive of *Biomphalaria* species abundance in different locations in the lake.

(e) *Clarias gariepinus* were more insectivorous compared to other fish species.

(f) Community knowledge on malaria vectors' habitats and aquatic plants harbouring schistosomiasis snails was rather poor.

6.4. Recommendations

(a) There is need for environmental sanitation through elimination of *Anopheles* mosquitoes and snails breeding habitats. Environmental management and sustainable transmission control should be promoted. The measures should aim at reducing people's contact with infested water by supplying safe domestic water and sanitation, and /or at reducing snail breeding by environmental measures.

(b) Removal of water hyacinth from the aquatic habitats both on land and in the lake is needed as they harbour more schistosomiasis transmitting snails.

(c) There is need for determination of pollution levels in different parts of the lake or in aquatic habitats on land. All the physico-chemical parameters analysed (DO, pH, alkalinity, hardness, turbidity, conductivity, temperature, turbulence, depth and salinity) varied between the habitat locations in the lake and on land.

(d) There is also need for determination of cyanobacterial contamination of the Lake.

(e) Concerted effort is needed to scale-up health education and improve the knowledge of the community about mosquitoes and snails and their breeding habitats. Health education should target the less advantaged members of the community such as women, uneducated and subsistence farmers and adapt communication strategies to the local realities, while at the same time aim at increasing participation in the control of malaria and schistosomiasis.

6.5. Suggestions for Future Research

(a) Studies on spatio-temporal distribution of malaria vectors, malaria transmission dynamics and malaria transmission patterns along the Kenyan Lake Victoria basin is needed. This is necessary because the results obtained in the current study could be further enhanced by sampling malaria vectors at different times of the year and determining malaria transmission risk in the area with a view to designing effective intervention measures.

(b) Malacological studies to determine the spatio-temporal distribution of schistosomiasis snails intermediate host and ascertain whether active transmission is occurring along the Kenyan Lake Victoria basin is needed. In an endemic area, such as the Kenyan Lake Victoria basin, animal and human schistosomes may appear together in the same transmission sites, necessitating species identification of schistosome cercariae.

(c) The current study has demonstrated that *Clarias gariepinus* is insectivorous. The challenge now is to conduct further studies under controlled conditions by using same fish species to determine its effectiveness as a bio-control agent against malaria vectors in ponds, dams, and abandoned quarries in areas where the disease is highly endemic such as along the Kenyan Lake Victoria basin.

(d) The abundant availability of *Anopheles* mosquitoes in different vegetation type habitats on land has a high chance of influencing malaria transmission along the Kenyan Lake Victoria basin. This possibility needs to be investigated urgently and appropriate preventive measures put in place

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