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Relative abundance of mosquitoes and snails associated with water hyacinth and hippo grass in the Nyanza gulf of Lake Victoria

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Abstract

This study was conducted from September to December 2008 to investigate the relative abundance of malaria vectors and schistosomiasis host snails associated with aquatic weeds in Nyanza Gulf (Lake Victoria). Larval and adult's stages of mosquitoes, lakeflies and snails were collected and identified with standard entomological and malacological techniques. The relative species composition and abundance of fish associated with macrophytes were also determined. Physico-chemical parameters were determined with standard analytical methods. Community-based surveys were also conducted, using standard questionnaires, focused group discussions and direct observations. The results of this study indicated that the abundance of malaria-causing mosquitoes was low, accounting for only 0.4% of the total number of mosquitoes and lake flies collected from the gulf. Lake flies (*Chaoborus* and *Chironomus* spp.) were the most abundant flying insects associated with aquatic macrophytes (84.2%), followed by Culicines *Culex* spp. (12.2%) and *Aedes* spp. mosquitoes (3.2%). *Biomphalaria sudanica* and *Bulinus africanus*, the two most common hosts for schistosomiasis in the gulf, were detected in both types of macrophytes, but were most significantly attached to water hyacinth ($P < 0.0001$) and hippo grass ($P = 0.0003$). There were significantly fewer snails attached to the hippo grass, compared with those unattached in the open water ($P < 0.05$, GENMOD). Different habitats exhibited low Secchi disc transparency values, but elevated total phosphorous (TP), total nitrogen (TN), chlorophyll-*a* concentrations, as well as algal cell counts. Furthermore, *Oreochromis niloticus* and Haplochromine fishes were more abundant in water hyacinth mats compared with hippo grass mats and open-water habitats. The low mosquito abundance indicated that the sampled habitats were unsuitable for mosquito breeding, likely attributable to water turbulence and/or predation by larvivorous fish. The strong association between *B. sudanica* and *B. africanus* and aquatic macrophytes, and the observation that local communities perform many lakeshore-related activities that bring them into contact with water, can potentially lead to a higher prevalence of schistosomiasis in the Nyanza Gulf region.

Key words

aquatic macrophytes, lake flies, Lake Victoria, malaria mosquitoes, Nyanza gulf, schistosomiasis snails.

INTRODUCTION

Water hyacinth *Eichhornia crassipes* (Mart.) Solms – Laubach, of South American origin, gained attention in the past as an ornamental plant because of its attractive purple flowers. It was first distributed by gardeners and horticulturists more than a century ago. Because of its extremely fast growth rate, however, it soon became the major floating waterweed of tropical and subtropical regions worldwide, dispersing easily, displacing indigenous floras, increasing waterborne diseases, and creating problems in reservoirs, fisheries, irrigation schemes and transportation routes (Timmer & Weldon 1967; Mitchell & Thomas 1972; Gopal 1987; Epstein 1998; Levy 2004; Ogwang & Molo 2004). Communities living around Lake Victoria have a high dependency on the lake, with many of their daily activities closely linked to it. Questions regarding relationships between human health and water

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hyacinth are of great interest not only to health managers and researchers but also to communities around the lake. There are many anecdotal suggestions from community inhabitants regarding the links between water hyacinth and diseases in the communities.

Invasive plants such as water hyacinth and other aquatic macrophytes can change the ecological conditions in their habitats, which can lead to an increased transmission of human diseases. Based on previous reports, water hyacinth can form microhabitats for a variety of disease vectors, including malaria, cholera, encephalitis, schistomiasis and lymphatic filariasis (de Groot 1993; Twongo *et al.* 1995). The prevalence of malaria in the western Kenya region bordering Lake Victoria is estimated to be 16% (KMIS 2007), and clusters with prevalence rates as high as 50% do occur during high transmission seasons. Schistosomiasis is widespread in the Lake Victoria region, with the intermediate hosts being snails. Previous studies indicate that the prevalence and intensity of schistosomiasis are inversely related to the distance from the lake. According to Handzel *et al.* (2003), the mean prevalence of *Shistosoma mansoni* infection in school children was 16.3%, with their proximity to the lake and their contact with lake water being associated with infection levels. The same can be said for specific water-related activities, including swimming, fishing and collecting water. Karanja *et al.* (1997) reported that persons employed as vehicle washers in the town of Kisumu, Kenya, are exposed for several hours daily to water in Lake Victoria that contains *S. mansoni*-infected *Biomphalaria pheifferi* snails, resulting in a focus of high endemicity for schistosomiasis in the Lake Victoria region. There are two types of schistosomiasis in the region, *S. mansoni* and *Schistosoma haematobium*. Both species are distributed around the lake, with their intermediate hosts being *Biomphalaria sudanica* and *Bulinus africanus*, respectively. The seasonal fluctuation in the population density of *B. sudanica* elsewhere is reported to be highly associated with rainfall, lake water level, availability of vegetation and abundance (Handzel *et al.* 2003).

It has been hypothesized that water hyacinth in tropical countries contributes to increased snail populations that transmit schistosomiasis, a disease that afflicts 83 million people globally (Gay 1960; Dazo *et al.* 1966; Batanouny & El-Fiky 1975; Bond & Roberts 1978; WHO 1985; Ntiba *et al.* 2001). Many schistosome snail species thrive in the presence of aquatic vegetation (Odei 1973; Klumpp & Chu 1980; Ndifon & Ukoli 1989; Woolhouse & Chandiwana 1989), and/or prefer the low water velocities and light intensities that occur under dense, mat-forming vegetation (WHO 1957; Malek 1958; Muirhead-Thomson 1958; Mitchell & Thomas 1972). Schistosome host snail species, however, can vary widely in their ecologic requirements. In Lake Victoria, East Africa, for example, *B. sudanica* prefers still (non-flowing), shallow waters with muddy substrates and vegetation, whereas *Biomphalaria choanomphala* prefers deeper, sandy, non-vegetated offshore waters (Webbe 1966; Baalawy 1971; Magendantz 1972; McCullough *et al.* 1972; Brown 1980). The *B. africanus* group of snails in Kenya is represented by *B.* (*africanus*) *globosus*, *B.* (*a.*) *africanus*, *B.* (*a.*) *nasutus*, and *B.* (*a.*) *ugandae*, and other than *B.* (*a.*) *ugandae*, are important hosts of *S. haematobium* in Kenya (Kariuki *et al.* 2004).

Several previous reports pointed out that aquatic weeds are associated with increased mosquito abundance. Volta Lake in Ghana, West Africa, contains *Pistia*, which was found to harbour many mosquito larvae, with *Aedomyia africana* dominating 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 also commonly found associated with *Pistia* sp. in Volta Lake (Obeng 1969). Water hyacinth in Malaysia, where this plant is widespread, have been observed to harbour insect vectors of filariasis (e.g. *Mansonia uniformis*, *Mansonia indiana* and *Mansonia annulifera*) (Bakar *et al.* 1984).

The extent of human population infestation by schistosomiasis can be seen for Volta Lake, a manmade impoundment in West Africa. In 1965, when Volta Lake was 1 year old, *Pistia stratiotes* supported *Bulinus forskalii* populations, which is not a host of *S. haematobium* (Petr 1968). In the second year, however, *Bulinus truncatus rohlfsi* was found both on *Pistia* sp. and *Ceratophyllum* sp., while *B. forskali* was diminishing in numbers. While pre-impoundment studies indicated the prevalence of schistosomiasis infection in villages and townships situated on the Volta River ranging between 1% and 3% (with one locality on a tributary having 8%), the disease was endemic in the Volta delta, affecting many villages, and between 80% and 90% of the school children (Paperna 1970). Infections in some lakeshore communities on Volta Lake reached 99% by 1968.

Ceratophyllum sp. was the major habitat for *Bulinus tropicana rohlfsi* in Volta lake in the 1970s (Odei 1979), with snails also found on many other substrata, including lake bottom, stones, twigs and particularly palm leaves used to make fish traps. The snails were being dispersed by a number of human activities, particularly fishing. Nets often become entangled and fouled with weeds, with cleaning of the nets near villages bringing in the snails. Odei (1979) observed a rapid snail build-up on reflooded drawdown areas of the lake. Where there was no offshore *Ceratophyllum* sp., however, there usually was a marked decrease during the dry season, as previously reported by Paperna (1969, 1970).

The results of past studies on macrophyte–vector associations have been contradictory. According to Pope *et al.* (2005), *Typha domingensis* marsh and flooded forest are habitats of immature *Anopheles vestitipennis. Eleocharis* spp. marsh is the habitat for immature *Anopheles albimanus.* In a study carried out in Cameroon, Kengne *et al.* (2003) reported that although macrophyte-based wastewater treatment systems dominated by *P. stratiotes* permitted the fixation of a great number of larvae to the macrophyte roots, only 0.02% of captured imagoes were *Anopheles gambiae*, suggesting that macrophyte-based wastewater treatment systems do not significantly contribute to the development of malaria vectors. In a study to determine qualitatively the macrophyte–mosquito larvae association, members of *Culex vishnui* subgroup were associated with most of the macrophytes, with *E. crassipes*, *Marsilea quadrifolia* and *Spirodella polyrhiza* exhibiting a high potential for mosquito breeding, and *Azolla* sp. exhibiting a very low potential for both anophelines and culicines (Victor *et al.* 1991).

A form of ecological succession (the progressive displacement of one or more species of plants by other species) has been observed in Lake Victoria, in which stationary mats of water hyacinth along the shores and banks of rivers were replaced by other aquatic plants such as hippo grass (*Vossia cuspidata*), other aquatic sedges such as *Cyperus papyrus* and climbing plants such as *Ipomoea aquatica* (Othina *et al.* 2003; Omondi & Kusewa 2006; LVBC 2008; Twongo & Okurut 2008), creating concern among stakeholders in the region.

This study was designed to investigate the relative abundance of malaria vectors and schistosomiasis host snails associated with the aquatic weeds water hyacinth and hippo grass, either alone or as a mixture, at different sites within the open lake waters and lakeside shorelines of Nyanza Gulf. The abundance of other dipteran lake flies associated with the macrophytes was also determined, as they can easily be mistaken for mosquitoes by non-entomologists and some community members.

MATERIALS AND METHODS

Study location and habitat types

The study was conducted between September and December 2008, and covered the entire Nyanza Gulf. The sampling sites are illustrated in Figure 1 and Table 1. Water sampling was done from the following sites: Kisat, Hippo Point, Kiwasco, Dunga, Kibos, Sondu Miriu, Homa Bay, Lwanda Gembe and Asembo Bay. The location of the sampling sites was marked with a GPS Garmin GPS II Plus. Table 1 also highlighted the types of sampled habitats and characteristics of associated aquatic vegetation.

Subjective and quantitative techniques were utilized to map aquatic vegetation or macrophyte types. Transects were taken at different zones, with percentage cover being estimated with 1 × 1 m quadrats. Plants with diagnostic features (e.g. flowers, fruits, shoots, rhizomes) were collected, pressed and labelled with a brief habitat description and associated taxa. Macrophyte species occurring at the various sampling sites were recorded, with their locations being marked by GPS. Photographs were also taken using a HSC50 Sony digital camera, USA. Macrophyte identification was carried out with the keys of Agnew and Agnew (1994), Cook *et al.* (1974), Kokwaro and Johns (1998) and Sainty and Jacobs (1994).

The aquatic macrophyte profile of the Nyanza Gulf shoreline was highly diverse, including shores with clear pristine waters and muddy shorelines. Although many types of macrophytes, principally water hyacinth, hippo grass and other aquatic vegetation (*P. stratiotes*, *I. aquatica*, *C. papyrus*, *Aeschyonomene elaphroxylon*, etc.) were observed, the inshore coverage of water hyacinth was low. The three different aquatic vegetation (habitat) types (pure water hyacinth, hippo grass, a mixture of hyacinth and hippo grass) observed are highlighted in Figures 2–4, respectively.

Determination of physico-chemical parameters and phytoplankton biomass

Turbidity and pH were measured using a 2100 P Hach turbidimeter (Hach company, Loveland, Colo, USA) and a WTW 315i pH meter (WTW GmbH, Weilheim, Germany), respectively. Secchi depth was measured with a black and white Secchi disc (20 cm diameter). Water samples were collected with a Van Dorn sampler. Nutrient analyses were carried out according to the methods outlined by Wetzel and Likens (1991). Total nitrogen (TN) was analysed by digestion of unfiltered water samples with concentrated sulphuric acid (autoclave procedure) to convert organic nitrogen to ammonium nitrogen. Phosphate phosphorus was measured with the ascorbic acid method. For total phosphorus (TP) concentrations, the unfiltered water samples were oxidized with hot 5% potassium persulphate ($K_2S_2O_8$) in distilled water. The tubes (samples, standards and blanks) were autoclaved for 30 min. They were further cooled at room temperatures with the caps slightly loosened. The total phosphate was then determined by the methods described above for inorganic phosphate.

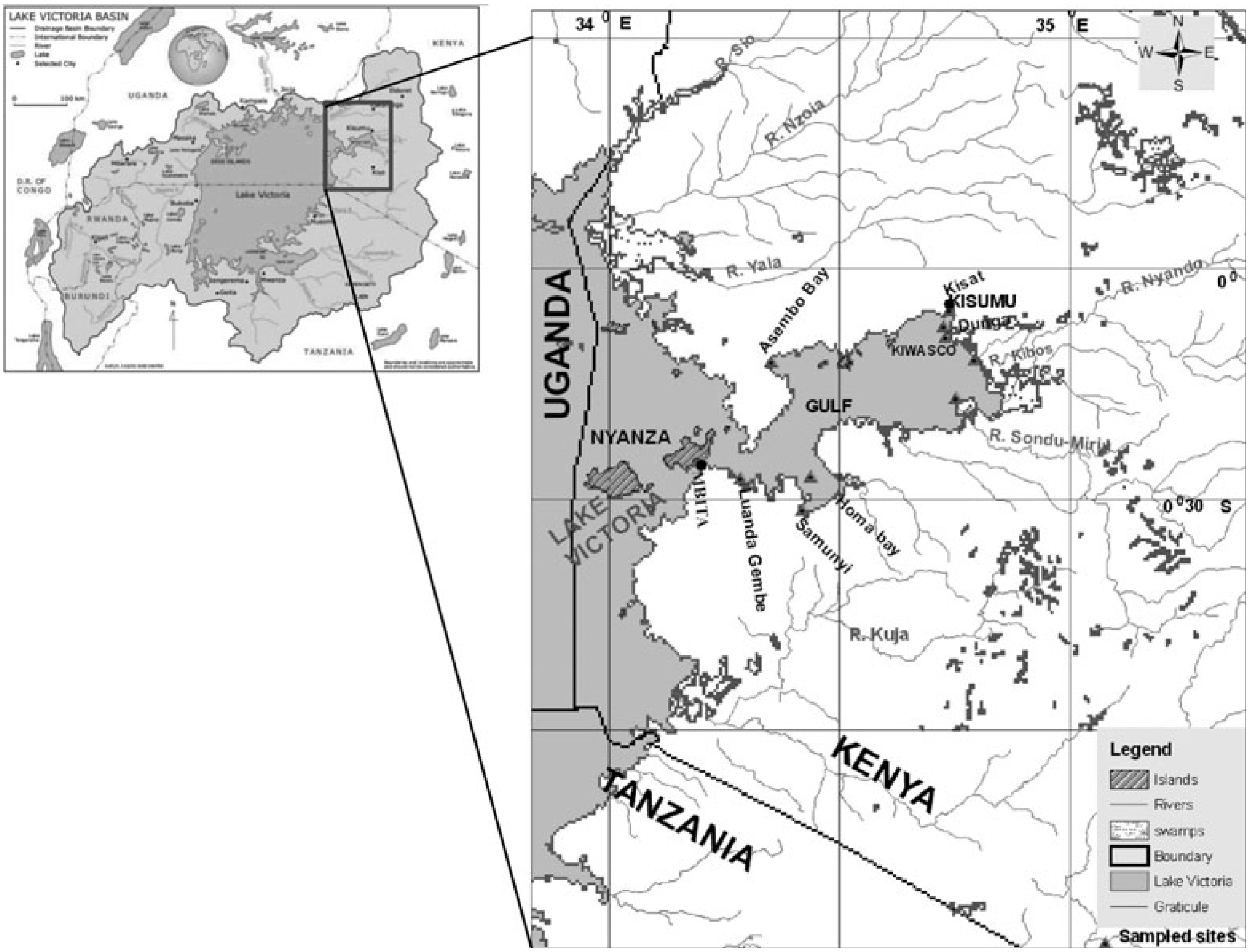

Fig. 1. Map of Nyanza Gulf (Lake Victoria), illustrating sampled sites.

Phytoplankton were determined from samples collected from 5 cm below the water surface. The water samples (25 mL) were preserved in acidic Lugol's solution. A phytoplankton sub-sample (1 mL) was placed in a rafter-cell chamber and allowed to settle. Representative numbers of strips were counted for quantitative algal abundance. An inverted microscope (400× magnification) was used for phytoplankton species identification and enumeration. Phytoplankton taxa were identified, utilizing the methods of Huber-Pestalozzi (1968). Phytoplankton densities were estimated by counting all the individuals, whether single cells, colonies or filaments. The resulting counts were used to calculate algal density, expressed in cells mL^{-1}. The methods outlined by Strickand and Parsons (1972) were used to quantify the chlorophyll-*a* content, expressed as $\mu g\ L^{-1}$, while algal densities were expressed in number per litre.

Mosquitoes and lake fly samples

Mosquito larvae were sampled with a standard 350 mL dipper ladle, while adult mosquitoes or lake flies were sampled with a conical sweep cloth. Five dips were made at each site, with the water being collected on a white plastic tray, and examined for the presence of mosquito larvae. All larvae were transferred into labelled vials and taken to the laboratory for taxonomic identification. Adult insects, including lake flies, were sampled by sweeping over the macrophyte vegetation, or the open water, for five minutes at each site. The mosquitoes and lake flies were identified with the taxonomic keys of Gillies and Coetzee (1987) and Pennak (1978), respectively.

Snail samples

To sample the snails associated with the aquatic vegetation, a 'kick-net' (30 × 30 cm; 0.5 mm mesh size) was used to sweep under the hyacinth mats or hippo grass macrophytes. The kick-net also was used to sample the open waters and along the shoreline. Snails associated with the root masses of the vegetation were sampled by manually uprooting five plants from each site. Any snails were then separated from the collected root mass by vigorously shaking each root sample in a bucket containing

Table 1. Study location, sampling sties, habitats and associated aquatic vegetation in the Nyanza Gulf, Lake Victoria

Study location	Study sites	GPS coordinates	Habitat	Observations on associated aquatic vegetation
Dunga	Dunga Beach, next to Osienala Headquarters	00°08.779′S 034°44.127′E	Hippo grass	Shoreline covered by hippo grass, some *Pisitia stratiotes* and decomposing organic matter
Kibos	Kibos	00°09.235′S 034°43.598′E	Open waters	–
Sondu Miriu	Sondu Miriu Site A	00°18.985′S 034°45.362′E	Mixed hippo grass and water hyacinth	Water hyacinth mixed with decomposing hippo grass and papyrus floating in the water. Rotting smell of vegetation. Emergent vegetation mainly papyrus. Hippo grass growing between papyrus and water hyacinth. Algal blooms apparent.
	Sondu Miriu Site B	00°19.000′S 034°45.364′E	Hippo grass	Mostly hippo grass, with few water hyacinth in the fringes
	Sondu Miriu Site C	00°19.007′S 034°45.336′E	Open waters	–
Homa Bay	Homa Bay (at Uwi beach)	00°28.458′S 034°24.340′E	Mixed Hippo grass and water hyacinth	Interphase of hippo grass (dominant), papyrus (stationary) near the lake shore. Few patches of water hyacinth.
	Homa Bay (at Uwi beach) – behind the Soklo hill at Baylet	00°28.455′S 034°24.336′E	Water hyacinth	Stationary water hyacinth mat close to the shoreline. Little or no hippo grass. Fringed by *Aeschyonmene elaphroxylon.* Some algal blooms present
	Homa Bay (Near Soklo)	00°27.174′S 034°25.00′E	Open waters	–
	Homa Bay (At Soklo)	00°27.144′S 034°24.934′E	Mixed Hippo grass and water hyacinth	Within the floating mats of hippo grass and water hyacinth. Small populations of *Ipomoea aquatica*
	Homa Bay (at Uwi beach)	00°28.458′S 034°24.500′E	Water hyacinth	Pure water hyacinth mat floating on water.
	Homa Bay at Samunyi Site A	00°31.840′S 034°25.081′E	Mixed Hippo grass and Water hyacinth	Clear zonation with small fragments of papyrus–landwards. Thick mats of hippo grass and water hyacinth bordering the lake
	Homa Bay at Samunyi – B	00°31.801′S 034°25.051′E	Open waters	–
	Homa Bay at Samunyi Site C	00°31.770′S 034°24.900′E	Mixed Hippo grass and water hyacinth	A clear zonation of water hyacinth and hippo grass lakeward and papyrus on the landward side. The zone is fringed by *A. elaphroxylon*
	Homa Bay at Samunyi Site D	00°31.476′S 034°24.895′E	Water hyacinth	Water hyacinth-only zone. Thick algal scum
	Homa Bay at Oluchi river mouth	00°27.617′S 034°29.930′E	Hippo grass	Zone dominated by hippo grass, with some tufts of *A. elaphroxylon* fringing the shoreline

Table 1. (*Continued*)

Study location	Study sites	GPS coordinates	Habitat	Observations on associated aquatic vegetation
Luanda Gembe	Luanda Gembe – A	00°27.470 S 034°16.930 E	Water hyacinth	Pure water hyacinth zone with thick mats on the lakeward side. Landward side is fringed by some tufts of woody plants and papyrus. Algal blooms present
	Luanda Gembe – B	00°27.489′S 034°16.941′E	Open waters	–
	Luanda Gembe – C	00°27.932′S 034°16.895′E	Mixed Hippo grass and water hyacinth	Area dominated by water hyacinth and hippo grass. Algal bloom present
	Luanda Gembe – D	00°27.918′S 034°16.894′E	Open waters	–
Asembo Bay	Asembo Bay – A	00°14.1019′S 034°21.609′E	Hippo grass	Area dominated by hippo grass. Area fringed by some populations of *A. elaphroxylon*. Some climbing plants (e.g. *I. aquatica)* and algal blooms present. Intensive hippo grass harvesting by local community to allow harvesting of *Clarias gariepinus* fingerlings
	Asembo Bay – B	00°14.895′S 034°21.309′E	Open water s	–
	Asembo Bay – C	00°11.314′S 034°23.285′E	Water hyacinth	Mainly healthy water hyacinth. Clear zonation with abundant water hyacinth lakewards. Area fringed by *A. elaphroxylon*
	Asembo Bay – D	00°11.231′S 034°24.281′E	Open waters	–

10% isopropyl alcohol, which causes the snails to detach from the roots. The snail samples were sorted in a white plastic tray with clear water, and identified using the taxonomic reference keys of Kristensen (1987).

Fish associated with macrophytes

Assessment of the relative abundance, composition and sizes of fish associated with the macrophytes was done with an electro-fisher. Electro-fishing was carried out with a Septa model unit (discharge voltages of up to 600 volts; accompanying amperes between 5 and 30 amps). A pulsed mode of discharge was adopted for electrocution, lasting 10 min at each attempt. Species identification was done based on the descriptions given by Witte and van Oijen (1990), using morphometric and meristic characteristics. Biometric data were recorded for all species obtained in the sampling effort. Length measurements were recorded to the nearest centimetre for large specimens, and to the nearest millimetre for smaller specimens (e.g. Haplochromines). Fish also were dissected, and the stomach contents identified based on the methods of Witte and van Dansen (1995).

Fig. 2. Pure population of water hyacinth.

Community-based studies and observations

The knowledge of lakeshore communities on Nyanza Gulf regarding the effects of aquatic macrophytes on their health also was assessed. Activities which could

Fig. 3. Single population of hippo grass.

Fig. 4. Water hyacinth mat mixed with hippo grass.

expose community members to health risks also were documented, especially for contracting schistosomiasis from contacts with snail-infested water. Information from community members was collected based on the following methods: (i) Survey of primary stakeholders affected, or with the potential to be affected, by water hyacinth and other macrophytes; (ii) key informant interviews with both open-ended and semi-structured questionnaires of community leaders, government workers, NGOs and CBOs; and (iii) focus group discussions with community groups. Selection of study locations was purposive, being based on areas where aquatic macrophytes were normally present. Respondents at the beach were randomly selected, especially those present at the time of the interview. Various community members were included in the surveys, the majority being fishermen, followed by fish traders. Also interviewed were farmers, small scale traders, car washers, crews, hotel operators, railway transporters, and Kisumu Water and Sewerage Company personnel. A total of 41 people were interviewed, 56% being female and 44% male. Direct observations of the water activities of the lake communities (i.e. fishing, watering animals, bathing, etc.) in relation to aquatic macrophytes and risk from waterborne diseases (especially schistosomiasis) were also documented.

Data analysis

Physico-chemical data and differences in number of mosquitoes sampled within the different habitats (water hyacinth, hippo grass, mixed hippo grass and hyacinth, open water) were analysed with ANOVA (SPSS version 11, SPSS Inc., (Nasdaq/SPSS) Chicago, IL, USA). The differences in the number of snails found attached to either water hyacinth or hippo grass or unattached and floating in the open water also were analysed, using the generalized estimating equations procedure (GENMOD) in SAS version 9.1 (SAS Institute, Cary, NC, USA). *P*-values <0.05 were considered significant.

RESULTS

Physico-chemical parameters

The sampled sites from the different habitats exhibited low Secchi disc readings, and elevated turbidity, TP, TN and chlorophyll-*a* concentrations and algal counts (Table 2). The mean temperatures were 28.5 °C in the water hyacinth habitats, 26.8 °C in the hippo grass habitats, 26.8 °C in the mixed water hyacinth and hippo grass habitats and 27.7 °C in the open water habitats. The mean pH values were 7.8, 7.4, 7.6 and 7.8 in the same respective habitats. There were no statistical differences in the mean temperature and pH in the various habitats ($P > 0.05$, one way ANOVA). The hippo grass habitats exhibited higher turbidity, however, compared with the water hyacinth and open water habitats.

Abundance of mosquitoes and lake flies associated with aquatic macrophytes

Figure 5 illustrates the relative abundance of mosquitoes and lake flies in different habitats associated with water hyacinth and hippo grass. Although the study results indicated a relatively low abundance of mosquitoes, there was a marked association between the aquatic macrophyte habitats (whether water hyacinth, hippo grass, or a mixture of the two) and the insects (mostly lake flies and few mosquito larval or adult stages), compared with open lake waters.

Very few adult stages of mosquitoes, or their larvae, were found within the Dunga, Sondu Miriu and Kibos sampling sites. Only one *Anopheles* spp. mosquito larvae was found within the relatively sheltered hippo grass habitat in the shoreline within Dunga. The habitat also

Table 2. Variations (mean ± SD) of physico-chemical parameters measured from different aquatic habitats in the Nyanza Gulf, Lake Victoria

Habitat Parameter	Water hyacinth	Hippo grass	Mixed (water hyacinth and hippo grass)	Open waters
Secchi depth (m)	0.35 ± 0.13 (0.10–0.45)	0.23 ± 0.10 (0.15–0.35)	0.31 ± 0.14 (0.15–0.45)	0.42 ± 0.12 (0.25–0.60)
Temperature (°C)	28.50 ± 2.39 (25.7–31.9)	26.8 ± 2.33 (24.2–28.7)	28 ± 1.77 (25.9–30.2)	27.7 ± 2.10 (25.5–31.8)
pH (standard units)	7.80 ± 0.82 (6.6–8.8)	7.4 ± 1.36 (5.9–8.5)	7.6 ± 0.4 (7.2–8.1)	7.8 ± 0.47 (7.2–8.5)
Turbidity (NTU)	112.20 ± 111.79 (54.0–339.0)	461.3 ± 360.13 (77–791)	152.80 ± 121.89 (78.3–335)	71.1 ± 24.51 (47.3–115)
Total phosphorus (μg P L^{-1})	538.7 ± 823.37 (146.9–2216.9)	486.9 ± 444.77 (179.7–996.9)	391.9 ± 147.04 (179.7–511.1)	208.1 ± 47.78 (149.7–284)
Total nitrogen (μg N L^{-1})	975.2 ± 796.49 (750.4–2584.2)	542.4 ± 139.30 (517.3–692.5)	587.8 ± 157.18 (396.3–726.7)	633.3 ± 118.73 (485.7–834.6)
Chlorophyll-*a* (μg L^{-1})	1045.9 ± 1045 (9.9–5.989.4)	231.9 ± 367.83 (19.4–656.7)	301.80 ± 245.82 (11.2–612.3)	89.95 ± 76.81 (9.9–200.2)
Algal densities (number L^{-1})	12 172.5 ± 16 177.38 (700–36 120)	6914.67 ± 9340.42 (1493–17 700)	8058.25 ± 5731.59 (1652–15 522)	4772.12 ± 4264.31 (1116–13 638)

Values in parenthesis indicate range.

was associated with *P. stratiotes* weed and decomposing matter. Only three adult culicine (*Culex* spp.) mosquitoes were observed within the mixed hippo grass and water hyacinth habitat, and one culicine adult mosquito in the pure hippo grass habitat of Sondu Miriu. No mosquito was sampled in the open waters of the same site. One culicine mosquito was sampled offshore, however, in the open lake waters of Kibos.

Numerous lake flies (dipteran insects of *Chaoborus* and *Chironomus* spp.), and some adult culicine and *Aedes* spp. mosquitoes, were sampled inshore in the mixed hippo grass and water hyacinth habitats, and in the hippo grass habitats, as well as in the pure water offshore floating hyacinth and hippo grass habitats in the lake waters in Homa bay. Offshore open waters off Kibos, Sondu Miriu, Homa Bay (near Soklo), Homa Bay (at Samunyi B), Luanda Gembe at sites B and D, however, and Asembo bay at sites B and D were associated with very few or no insects. There were very few or no lake flies, whether inshore or offshore, in all the habitats sampled on some particular days. Other aquatic vegetation or macrophytes species (e.g. *P. stratiotes*, *I. aquatica*, *C. papyrus* and *A. elaphroxylon*) occurring together with water hyacinth or hippo grass, and the presence of algal blooms, did not seem to increase the abundance of mosquitoes or lake flies.

Of the total of 279 collected insects, 235 (84.2%) were adult lake flies, while 44 (15.8%) were different stages and species of mosquitoes associated with aquatic macrophytes at the sampled sites within Nyanza Gulf (Fig. 5); 147 (52.7%) insects (lake flies, and different stages of mosquito species combined) were sampled in the mixed hippo grass and water hyacinth habitats, followed by 67 (24.0%) from the water hyacinth habitats, and then 64 (22.9%) from the hippo grass habitats, compared with only one (0.4%) insect sampled from the open lake water habitats. Statistical analysis indicated that there were more mosquitoes (whether larvae or adults of the different species) in the mixed hippo grass and water hyacinth habitats, compared with the other habitats, but even more so compared with open water habitats (one-way ANOVA, $P = 0.01$).

Abundance of snails associated with the aquatic macrophytes

Figure 6 illustrates the results of sampling for snails associated with aquatic macrophytes at various study sites and habitats. Sampled snail species included *B. sudanica* and *B. africanus*, which are the two most common hosts of schistosomiasis in the Nyanza Gulf. *Biomphalaria sudanica*, the host for *S. mansoni*, was the most frequently collected species of snail in Homa Bay, followed by

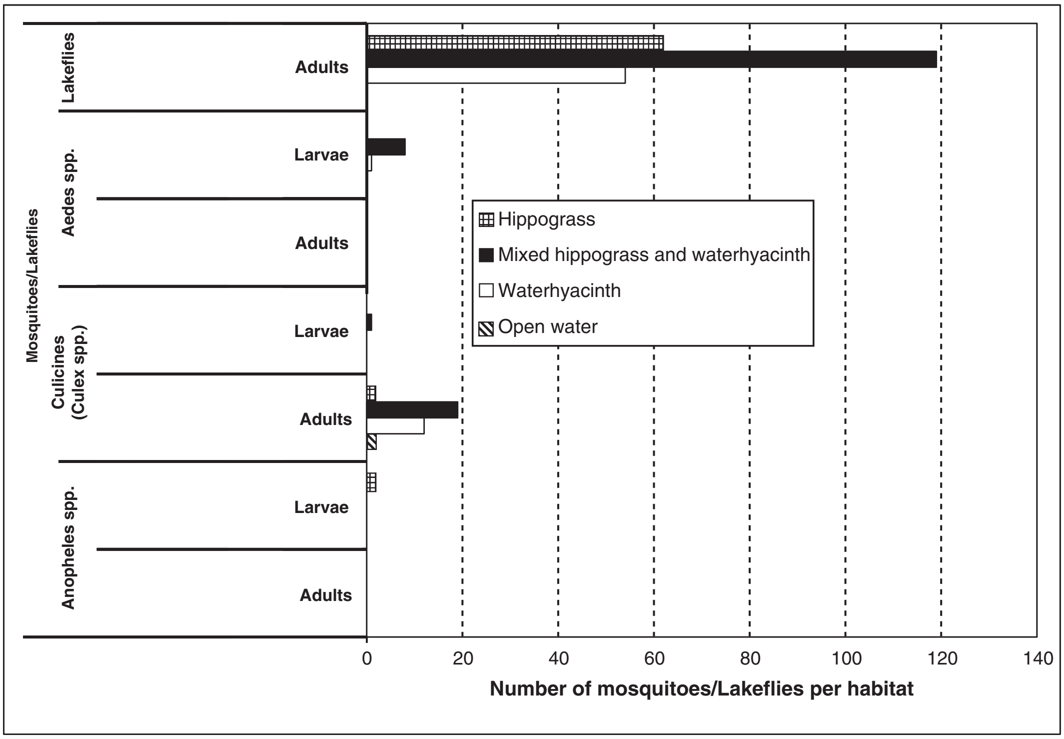

Fig. 5. Relative abundance of mosquitoes and lake flies in different habitats associated with water hyacinth and hippo grass in sampling sites in Lake Victoria.

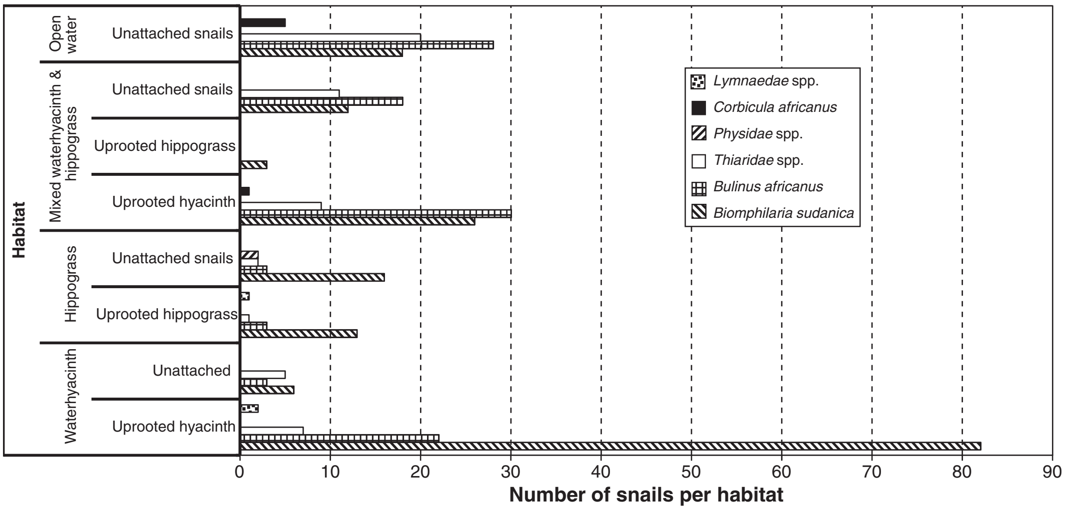

Fig. 6. Relative abundance of different snails species collected in water hyacinth (*Eichhornia crassipes*) and hippo grass (*Vossia cuspidata*) habitats, or in open water at different sampling sites within Nyanza Gulf, Lake Victoria.

B. africanus, the host for *S. haematobium* in the same region. Other non-host species identified were *Thiaridae* spp., *Physidae* spp., *Lymnaeidae* spp. and *Corbicula africanus*. There were more *B. africanus* snails than *B. sudanica*. in the Luanda Gembe area. Snails were found in all types of macrophytes, but were most significantly attached to the water hyacinth ($P < 0.0001$) and to hippo grass ($P = 0.0003$) compared with the unattached snails floating in the open waters, as determined by GENMOD statistical procedure. There were also significantly fewer snails attached to the hippo grass, compared with those unattached in the open waters ($P < 0.05$, GENMOD procedure). Both water hyacinth and hippo grass had a significantly lower number of attached non-vector snails (*Corbicula* sp., *Thiaridae* sp. and *Physidae* spp.) compared with those unattached in the open waters ($P < 0.01$, GENMOD procedure). Snails also were found both inshore and offshore, sometimes freely drifting and floating on open lake waters preceding stormy rainy episodes over the lake. Interestingly, there were no schistosomiasis host snails isolated from Sondu Miriu, except the non-host snails of *C. africanu*s, *Thiaridae* spp. and *Physidae* spp.

Species composition and abundance of fish associated with aquatic macrophytes

Table 3 highlights the relative species composition, abundance and sizes of fish collected from different aquatic habitats (water hyacinth; hippo grass; open lake waters) within Winam Bay of lake Victoria. *Oreochromis niloticus* and Haplochromines fish were more abundant in the water hyacinth mats compared with the hippo grass and open water habitats. There also were more fingerlings of *O. niloticus* and Haplochromines within the water hyacinth mats (length ranges being 1.9–6.2 and 1.8–4.6 cm, respectively) compared with the same species within the hippo grass habitats (4.9–10.6 and 5.2–11.9 cm, respectively) and in the open waters (2.0–14.5 and 4.5–75 cm, respectively). Fish diversity, however, was highest within the hippo grass habitat compared with the water hyacinth and open water habitats. The stomach contents of fish collected in the aquatic habitats included insect remains, as well as algae, crustaceans, mollusks, etc. as illustrated in Table 3.

Community-based responses and observations

Members of the community reported increases in waterborne diseases such as malaria, typhoid, amoeba and bilharzias (schistosomiasis). However, contrary to community members' responses that water hyacinth and other macrophytes in Lake Victoria waters are associated with high incidences of malaria in the basin, the study results indicated the abundance of malaria-causing mosquitoes was very low (only one *Anopheles* larvae was collected out of 23 sampled sites within the gulf). Observations on the activities of lake community populations indicated that harvesting of hippo grass (Fig. 7) for animal feed, and *Clarias gariepinus* fish (commonly known as 'nyapus,' by the local community; Fig. 8) for

Fig. 7. Harvesting of hippo grass.

Table 3. Relative species composition, abundance and feeding habits of fish collected from different aquatic habitats in Nyanza Gulf, Lake Victoria

Aquatic habitat	Fish species	Number of species	Length range (cm)	Stomach contents
Water hyacinth	*Oreochromis niloticus*	124	1.9–6.2	Algae, insects, crustaceans, bacteria
	Haplochromines	62	1.8–4.6	Insects remains
	Clarias gariepinus	2	37–45	Insect larvae, molluscs, fish remains
Hippo grass	*O. niloticus*	30	4.9–10.6	Algae (mainly diatoms), insects
	Haplochromines	18	5.2–11.9	Insects remains
	C. gariepinus	5	8.0–13.2	Insect larvae, molluscs
	Labeo victorianus	16	6.2–14.0	Slime, rotifers, fungi, insects, mud, plant debris
	Lates niloticus	1	8.0	Invertebrates (e.g. *Caridina nilotica*), insect larvae,
Open waters	*O. niloticus*	74	2.0–14.5	Algae, insects, crustaceans, bacteria
	Haplochromines	31	4.5–7.5	Insects remains
	C. gariepinus	6	6.5–12.5	Insect larvae, molluscs

Fig. 8. Harvesting *Clarias gariepinus* fingerlings ('nyapus').

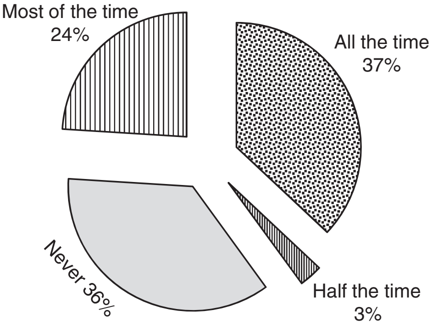

Fig. 9. Proportion of lake water use for livestock watering.

fishing bait, were activities that could expose community members to schistosomiasis infection.

Community-based responses also showed that about 62.5% of households used lake water for washing clothes, utensils and for bathing, with 32.5% of households using it all the time, 17.5% using it most of the time and 12.5% using it just a few times. Of households, 64% normally used lake water for livestock watering. Of this, 32.5% using it all the time, 24% used it most of the time and 3% used it about half of the time (Fig. 9).

DISCUSSION

Mosquito larval habitat ecology is important in determining larval densities and species assemblage which, in turn, can influence malaria transmission in a given area (Mwangangi *et al.* 2007). Although statistical analysis demonstrated that there were more mosquitoes (whether larvae or adults of the different species) in the mixed hippo grass and water hyacinth habitats compared with the open water habitats, this study generally exhibited a low abundance of malaria mosquitoes (i.e. *Anopheles* spp.) associated with water hyacinth and other macrophytes in the Nyanza Gulf of Lake Victoria. These results are contrary to the common belief and previous anecdotal reports that water hyacinth in Lake Victoria is associated with high incidences of malaria in the Lake Victoria basin (Twongo *et al.* 1995; Mailu *et al.* 1998). These results are not surprising, however, as anopheline mosquitoes are traditionally known to prefer breeding in small open habitats compared with permanent large aquatic habitats such as open lake waters. The larval stages of *A. gambiae*, for example, the common mosquito that transmits malaria in the Lake Victoria basin, often occur in newly formed temporary pools and puddles (Bentley & Day 1989; Munga *et al.* 2006). When the habitats age increases, the populations of anopheline larvae have been shown to decline (Gimnig *et al.* 2001, 2002).

Previous studies show that algae are the main food source for *A. gambiae* ss (Gimnig *et al.* 2002). The results of this study did not establish any association between algal blooms and abundance of mosquito larvae in the macrophyte habitats in the lake, however, suggesting the need for future investigations in more controlled experimental studies in the lake waters directed towards determining if algal blooms and chlorophyll levels in the lake waters can increase the abundance of mosquito larvae. The temperature and pH ranges in the sampled habitats were found to be within the optimum ranges suitable for mosquito breeding (Clements 2000). Other physico-chemical parameters also did not seem to influence mosquito abundance, noting that the values of these parameters (other than for turbidity) were more or less similar between the habitats, as statistically determined by one-way ANOVA. According to Minakawa *et al.* (2008) the recent reductions in the Lake Victoria water level have increased the amount of available habitat for *A. funestus*. This may pose an emerging threat of malaria transmission by anopheline mosquitoes which can breed in the aquatic macrophyte habitats occurring along the shoreline. Land-based observations also indicated that several *Anopheles* mosquito larvae were found very close to the shoreline, being located in footprints and depressions created by human activities.

The low abundance of mosquitoes associated with the macrophytes also could be attributed to turbulent lake waters, which are unsuitable for anopheline mosquito breeding. It also could be attributed to predation by larvivorous fish that tend to breed in higher numbers within aquatic macrophyte areas. As previously mentioned, the production of adult *A. gambiae s.* occurs in small, temporary, sunlit, turbid water pools (Gimnig *et al.* 2002). Although the larvae can exist in a wide range of habitats, most species prefer clean, unpolluted water.

Most mosquito species do not prefer flowing waters (e.g. creeks; turbulent open lake waters) for breeding purposes (Gillies & De Meillon 1968; Gillies & Coetzee 1987; Clements 2000). In this study, *Anopheles* spp. mosquito larvae were only found within relatively sheltered hippo grass habitats in the shoreline area within Dunga. Previous studies by Sunahara *et al.* (2002) also have indicated that habitat size is a factor determining the opportunity for encounters between mosquito larvae and aquatic predators. Thus, mosquito larvae are more exposed to predation in the larger, permanent lake water habitats.

Regarding predation by fish, results of this study indicated that *O. niloticus* and Haplochromines fish were more abundant in the water hyacinth mats compared with hippo grass and open water habitats. There also were more fingerlings of *O. niloticus* and Haplochromines within the water hyacinth mats compared with the same species within the hippo grass habitats and in the open waters. This finding illustrates that the aquatic mats in the lake waters were harbouring abundant fish that do predate on the mosquito larvae, since insect remains were found in the stomach contents of the fish caught in these habitats. The larvivorous nature of *O. niloticus* is reported by Njiru *et al.* (2004), for where zooplankton and insects form the main food component during all seasons (long dry; short dry; short rainy; long rainy). *Clarias gariepinus* fingerlings also have been reported to feed on insects, including mosquito larvae/pupae (Britz & Hecht 1988), thereby acting as biological control agents (Ghosh *et al.* 2005). Greenwood (1981) reported that Haplochromines (astatotilapia) feed primarily on larval and adult insects, further reinforcing the role these fish species can play in controlling mosquito populations in water habitats. Fingerlings of fish such as *O. niloticus*, and other species in this study that can feed on mosquito larvae found under the macrophytes, also can explain the low number of mosquitoes in the habitats. Thus, the presence of larvorous fish in aquatic habitats can provide a simple, inexpensive and reasonably effective means of mosquito control (Howard *et al.* 2007). Fish selection preference, however, should be given to native fish species to avoid possible undesirable implications that could be caused by the introduction of non-native fish species (WHO 1981).

This study has demonstrated that lake flies were abundant within the lake's aquatic habitats, and highly associated with the aquatic macrophytes. Lake flies (*Chaoborus* and *Chironomus* spp.) are dipteran insects that can sometimes form huge swarms over Lake Victoria waters, often being mistaken for mosquitoes by the local population or inexperienced 'entomologists'. Swarms of synchronously emerging flies also have been observed in other East African lakes (e.g. Lake Malawi; Lake Nyasa) (Corbet 1958). The fly larvae, called 'glassworms' because of their transparent bodies, live on the lake bottom where they feed on plankton. When they form pupae, they rise from the lake bottom, utilizing air sacs at the anterior end of their pupa. Many of these lake fly pupa are eaten by fish on their way to the surface, possibly attracting fish in lakes where they occur.

Contrary to the results of physical studies reporting a low abundance of malaria mosquitoes associated with the aquatic weeds in Lake Victoria, respondents of the parallel community-based surveys and other previous anecdotal studies have reported that water hyacinth and other aquatic weeds in the lake waters lead to high incidences of malaria in the people in the Lake Victoria region. Reports by Mailu *et al.* (1998), on the impacts of water hyacinth on malaria incidences in the lake region communities, for example, only examined disease trends in lakeside districts based on hospitals' or health centre medical records, which cannot provide an accurate physical picture of the association between aquatic weeds in the lake and incidences of human diseases on the surrounding land surface. Thus, community surveys (based on questionnaires, focus group discussions, key informant interviews and health records alone) may be unreliable for determining the exact physical ecological conditions influencing the incidence of diseases or other emerging threats in the lake communities. In a previous community-based study by Mutuku *et al.* (2006) on the description and local knowledge of larval habitats of *A. gambiae* s.l. in a village in western Kenya, which also employed focus group discussions and in-depth interviews with villagers, it was reported that the participants did not associate specific habitats with anopheline larvae, and expressed reluctance to eliminate habitats as they were sources of domestic water supply, while at the same time, indicating a willingness to participate in a source-reduction programme if appropriate support was provided. These findings indicate that community members are usually ill-equipped with scientific knowledge needed to understand important ecological issues that may affect their lives and livelihoods.

Results from this study also illustrated that *B. sudanica* and *B. africanus*, the two most common snail hosts of schistosomiasis in the Nyanza Gulf, were found associated with the aquatic macrophytes in the lake waters. Schistosomiasis snail hosts were more associated with water hyacinth than with hippo grass. High turbidity water in the hippo grass habitats, probably associated with hippo grass-derived organic decomposition and humic acids, could have influenced snail abundance, although this suggestion requires confirmation in future studies. Although the study has demonstrated an association between the aquatic macrophytes and schistosomiasis snails, the study results did not establish the extent to which this association impacts the lakeshore communities. Schistosomiasis is a focal disease and the association of its hosts with floating mats of water hyacinth and other macrophytes has the potential to introduce the disease to sites and beaches initially devoid of the disease (Munda 2001). Results of this study illustrated that many schistosomiasis-related snails were freely drifting in the open waters of the lake, especially after stormy rainy spells in the lake region. This study also demonstrated that hippo grass (*Vossia*) is also a habitat for these snails (although not as suitable as water hyacinth), and that this association may lead to the permanent establishment of snails following their introduction and movement with water hyacinth through ecological succession. Plummer (2005) examined whether or not water hyacinth (*E. crassipes*) had an effect on *B. sudanica* and *B. choanomphala*. Utilizing eight 16 m^2 enclosures established in shallow shoreline areas, and paired for water depth, substrate, detritus buildup, and distance from rooted vegetation, agricultural runoff, and human activity, the study suggested that *B. sudanica* density was significantly higher in enclosures containing water hyacinth. Plummer's study, however, did not determine if this situation is replicated under natural conditions, a condition examined in this present study.

Many previous studies also have reported associations between aquatic macrophytes and schistosomiasis snails. Bailey and Litterick (1993), for example, reported that the fringing hyacinth in Lake Wutchtung in the Sudd region contained large numbers of gastropods, including *B. forskalii*, *B. truncatus*, *Biomphalaria pfeifferi* and *B. sudanica.* Surprisingly, this study found no schistosomiasis host snails from around Sondu Miriu area, but rather only the non-host snails of *C. africanus*, *Thiaridae* spp. and *Physidae* spp. This finding should be investigated in future studies. Future studies also should focus on determining whether or not schistosomiasis snails associated with the macrophytes in the lake can be biologically controlled by predator fish. In Sudan, the introduced grass carp was reported to ingest vast numbers of *Biomphalaria* snails, along with *Potamogeton* spp., on which it normally feeds (WHO 1985). The use of grass carp in irrigation and drainage canals in sub-tropical countries, and in fish ponds, is known to reduce maintenance costs by clearing weeds, and also reduces snails as well as mosquito breeding through increased water flows and/or predation (WHO 1981, 1982, 1985). The latter types of environments, particularly in the Lake Victoria Basin, could be ideal for investigating the effects of integrated management of both schistosomiasis and malaria mosquitoes.

In the community-based surveys, respondents reported an increased incidence of Bilharzia as a result of aquatic weeds infestation, confirming the physical observations made in this current study. The community members, however, also pointed out some advantages of aquatic macrophytes infestations, such as increased catches of indigenous fish species such as *C. gariepinus* and *Protopterus* sp., the utilization of hyacinth for making crafts and the use of hippo grass as animal fodder. In addition, more people were being employed in harvesting *C. gariepinus* fingerlings, with an estimated 1000 people reported engaged in this activity, which can lead to increased schistosomiasis infection. The community-based responses also indicated that many households used lake water for washing clothes, cleaning utensils, bathing and stock watering, all being activities that can lead to schistosomiasis infection. These community responses were also corroborated by physical observations of community members engaged in these risky water contact activities.

The results of this study have highlighted the importance of understanding the habitat ecology of disease vectors and hosts, which can help in determining the potential occurrence of diseases associated with aquatic macrophytes in Lake Victoria and its basin. They also can facilitate the design of effective control programmes, including those for malaria, schistosomiasis, or other water-related diseases. Thus, describing habitat characteristics in terms of environmental attributes, and identifying relationships between biotic and abiotic factors, should be included in future studies of Lake Victoria and its basin. Although the numerous anecdotal fears related to presumed links between water hyacinth and malaria was not necessarily borne out by the results of this study, future horizontal studies should be conducted to evaluate seasonal variations within the lake region, before it can be firmly concluded that water hyacinth and associated macrophytes in the waters of Lake Victoria do not pose any significant threats of increased malaria incidences among the human populations in basin communities.

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REFERENCES

Agnew A. D. Q. & Agnew S. (1994) Upland Kenya Wild Flowers: A Flora of the Ferns and Herbaceous Flowering Plants of Upland Kenya, 2nd edn. East African Natural History Society, Nairobi, Kenya, p. 374.

Baalawy S. S. (1971) Some observations on the role of Lake Victoria in the transmission of *Schistosoma mansoni*. *East Afr. Med. J.* **48**, 385–8.

Bailey R. G. & Litterick M. R. (1993) The macroinvertebrate fauna of water hyacinth fringes in the Sudd swamps (River Nile, southern Sudan). *Hydrobiologia* **250**, 97–103.

Bakar B. B., Amin S. M. & Yusof E. B. (1984) Water hyacinth (*Eichhornia crassipes* (Mart.) (Solms) in Malaysia: status and distribution, problems and control. In: Proceedings of International Conference on Water Hyacinth (ed. G. Thyagarajan), pp. 944–58. UNEP, Nairobi.

Batanouny K. H. & El-Fiky A. M. (1975) The water hyacinth in Egypt distribution and problem magnitude. In: Proceedings of the International Conference on Water Hyacinth (ed. G. Thygarajan), pp. 127–44. UNEP, Nairobi, Kenya.

Bentley M. D. & Day J. F. (1989) Chemical ecology and behavioral aspects of mosquito oviposition. *Annu. Rev. Entomol.* **34**, 401–21.

Bond W. J. & Roberts M. G. (1978) The colonization of Cabora Bassa, Mocambique, a new man-made lake, by floating African macrophytes. *Hydrobiologia* **60**, 243–59.

Britz P. J. & Hecht T. (1988) Artificial and fry production. In: The Culture of Sharptooth Catfish Clarias gariepinus in South Africa (eds T. Hecht, W. Uys & P. J. Britz), pp. 36–56. South African National Scientific Programs Report No. 153 CSIR, Pretoria.

Brown D. S. (1980) Fresh Water Snails of Africa and Their Medical Importance. CRC Press, 1994. ISBN 0748400265. Taylor and Francis, London, 487 p. ISBN 0-85066-145-5.

Clements A. N. (2000) The Biology of Mosquitoes. Volume 1: Development, Nutrition and Reproduction. CABI Publishing, Oxon. ISBN 0-85199-374-5.

Cook C. D. K., Gut B. J., Rix E. M., Schneller J. & Seitz M. (1974) Water Plants of the World: A Manual of the Identification of the Genera of Freshwater Plants. Dr. W Junk Publishers, The Hague, The Netherlands.

Corbet P. S. (1958) Lunar periodicity of aquatic insects in Lake Victoria. *Nature* **182**, 330–1.

Dazo B. C., Hairston N. G. & Dawood I. K. (1966) The ecology of *Bulinus truncatus* and *Biomphalaria alexandrina*, and its implications for the control of bilharziasis in the Egypt-49 Project area. *Bull. World Health Organ.* **35**, 339–56.

Epstein P. (1998) Weeds bring disease to the East African waterways. *Lancet* **351**, 577.

Gay P. A. (1960) Ecological studies of *Eichhornia crassipes* Solms. In the Sudan. I. Analysis of spread in the Nile. *J. Ecol.* **48**, 183–91.

Ghosh A., Mandal S., Bhattacharjee I. & Chandra G. (2005) Biological control of vector mosquitoes by some common exotic fish predators. *Turk. J. Biol.* **29**, 167–71.

Gillies M. T. & Coetzee B. (1987) A supplement to Anophelinae of Africa South of Sahara (Afro-tropical region). South Africa Institute of Medical Research **55**, 1–143.

Gillies M. T. & De Meillon B. (1968) The Anophelinae of Africa South of the Sahara, 2nd edn. South Africa Institute of Medical Research, Johannesburg, South Africa, p. 54.

Gimnig J. E., Ombok M., Kamau L. & Hawley W. (2001) Characteristics of larval anopheline (Diptera: Culicidae) habitats in Western Kenya. *J. Med. Entomol.* **38**(2), 282–8.

Gimnig J. E., Ombok M., Otieno S., Kaufman M. G., Vulule J. M. & Walker E. D. (2002) Density-dependent development of *Anopheles gambiae* (Diptera: Culicidae) larvae in artificial habitats. *J. Med. Entomol.* **39**(1), 162–72.

Gopal B. (1987) Aquatic Plant Studies 1. Elsevier, Amsterdam.

Greenwood P. H. (1981) The Haplochromine Fishes of the East African Lakes. Department of Zoology, British Museum Natural History, Cornell University Press, Ithaca, New York, p. 839.

de Groot P. J. (1993) Introduction and summary. In: "Control of Africa's Floating Water Weeds" (eds A. Greathead & P. J. de Groot), p. 187. Commonwealth Science Council, Series no. CSC (93) AGR-18, Proceedings 295.

Handzel T., Karanja D. M. S., David G. A. *et al.* (2003) Geographic distribution of schistosomiasis and soil-transmitted helminthes in Western Kenya: implications for anthelminthic mass treatment. *Am. J. Trop. Med. Hyg.* **69**(3), 318–23.

Howard A. F., Zhou G. & Omlin F. X. (2007) Malaria mosquito control using edible fish in western Kenya: preliminary findings of a controlled study. *BMC Public Health* **7**(147), 199.

Huber-Pestalozzi G. (1968) Das Phytoplankton des Subwassers, 2nd edn, Part 3: Cryptophyceae, Chloromonadophyceae, Dinophyceae. Schwetzerbart, Stuttgart.

Karanja D. M. S., Colley D. G., Nahlen B. L., Ouma J. H. & Secor W. E. (1997) Studies on schistosomiasis in western Kenya: I. Evidence for immune-facilitated excretion of schistosome eggs from patients with *Schistosoma mansoni* and human immunodeficiency virus coinfections. *Am. J. Trop. Med. Hyg.* **56**, 515–21.

Kariuki H., Curtis J. A., Clennon M. S. *et al.* (2004) Distribution patterns and cercarial shedding of *Bulinus nasutus* and other snails in the Msambweni area, Coast Province, Kenya. *Am. J. Trop. Med. Hyg.* **70**(4), 449–56.

Kengne I. M., Brissaud F., Akoa A. *et al.* (2003) Mosquito development in a macrophyte-based wastewater treatment plant in Cameroon (Central Africa). *Ecol. Eng.* **21**, 53–61.

Klumpp R. K. & Chu K. Y. (1980) Importance of the aquatic weed *Ceratophyllum* to the transmission of *Schistosoma haemotobium* in the Volta Lake, Ghana. *Bull. World Health Organ.* **58**, 791–8.

KMIS (2007) Kenya Malaria Indicator Survey. Division of Malaria Control and Sanitation. Ministry of Public Health and Sanitation, Government of Kenya, 2009. Available from URL: http://www.nmcp.or.ke, http://www.kmis.org/DOMC.htm. Accessed 9 March 2010.

Kokwaro J. O. & Johns T. (1998) Luo Biological Dictionary. East African Educational Publishers, Nairobi. ISBN 9966468412.

Kristensen T. K. (1987) A field Guide to African Freshwater Snails. 2: East African Species, 2nd edn. Danish Bilharziasis Laboratory, Charlottenund.

Levy K. (2004) Neglected consequences: role of introduced aquatic species in the spread of infectious diseases. *EcoHealth* **1**, 296–305.

LVBC (2008) Studies on rapid assessment of the ecological succession and the dynamic status of Water Hyacinth *Eichhornia crassipes* (Mart.) Solms- Laubach in the Nyanza Gulf of Lake Victoria, Kenya. Support from Lake Victoria Basin Partnership Fund.

Magendantz M. (1972) The biology of *Biomphalaria choanomphala* and *B. sudanica* in relation to their role in the transmission of *Schistosoma mansoni* in Lake Victoria at Mwanza Tanzania. *Bull. World Health Organ.* **47**, 331–42.

Mailu A. M., Ochiel G. R. S., Gitonga W. & Njoka S. W. (1998) Water Hyacinth: an environmental disaster in the Winam Gulf of Lake Victoria and its control. In: First IOBC Global Working Group Meeting for the Biological Control and Integrated Control of Water Hyacinth (eds M. Hill, M. Julien & T. Center), pp. 101–5. Harara, Zimbabwe.

Malek E. A. (1958) Factors conditioning the habitat of bilharziasis intermediate hosts of the family Planorbidae. *Bull. World Health Organ.* **18**, 785–818.

McCullough F. S., Webbe G., Baalawy S. S. & Maselle S. (1972) An analysis of factors influencing the epidemiology and control of human schistosome infections in Mwanza, Tanzania. *East Afr. Med. J.* **49**, 568–82.

Minakawa N., Sonye G., Dida G. O., Futami K. & Kaneko S. (2008) Recent reduction in the water level of Lake Victoria has created more habitats for *Anopheles funestus*. *Malar. J.* **7**, 117.

Mitchell D. S. & Thomas P. A. (1972) Ecology of Water Weeds in the Neotropics: An Ecological Survey of the Aquatic Weeds Eichhornia crassipes and Salvinia species, and their Natural Enemies in the Neotropics. UNESCO, Paris.

Muirhead-Thomson R. C. (1958) The ecology of vector snail habitats and mosquito breeding-places: the experimental approach to basic problems. *Bull. World Health Organ.*, **19**, 637–59.

Munda S. (2001) The effects of water hyacinth (*Eichhonia crassipes* Mart Solms) on diversity and abundance of aquatic macro-invertebrates especially disease vectors in Winam Gulf, Lake Victoria, Kenya. (MSc thesis) Moi University, Eldoret, Kenya.

Munga S., Minakawa N., Zhou G. *et al.* (2006) Association between land cover and habitat productivity of malaria vectors in western Kenyan highlands. *Am. J. Trop. Med. Hyg.* **74**(1), 69–75.

Mutuku F. M., Alaii J. A., Bayou N. *et al.* (2006) Distribution, description, and local knowledge of larval habitats of *Anopheles gambiae* s.l. in a village in western Kenya. *Am. J. Trop. Med. Hyg.* **74**(1), 44–53.

Mwangangi J. M., Mbogo C. M., Muturi E. J. *et al.* (2007) Spatial distribution and habitat characterisation of *Anopheles* larvae along the Kenyan coast. *J. Vector Borne Dis.* **44**, 44–51.

Ndifon G. T. & Ukoli F. M. A. (1989) Ecology of freshwater snails in South-western Nigeria. I: distribution and habitat preference. *Hydrobiologia* **171**, 231–53.

Njiru M., Okeyo J. B., Muchiri M. & Cowx G. (2004) Shifts in the food of Nile tilapia, *Oreochromis niloticus* (L.) in Lake Victoria, Kenya. *Afr. J. Ecol.* **42**, 163–70.

Ntiba M. J., Kudoja W. M. & Mukasa C. T. (2001) Management issues in the Lake Victoria watershed. *Lakes Reserv. Res. Manage.* **6**, 211–6.

Obeng L. E. (1969) The invertebrate fauna of aquatic plants of the Volta Lake in relation to the spread of helminth parasites. In: Man-Made Lakes: The Accra Symposium (ed. L. E. Obeng), pp. 320–5. Ghana University Press, Accra.

Odei M. A. (1973) Observations on some weeds of malacological importance in the Volta Lake. *Bulletin de l'Institut francçais d'Afrique noire* **45**, 57–66.

Odei M. A. (1979) Some ecological factors influencing the distribution of snail hosts of schistosomiasis in the Volta Lake. In: Proc. Int. Conf. On Kainji Lake and River Basin Development in Africa, Ibadan, Kainji Lake Research Institute, **2**, 588–93.

Ogwang J. A. & Molo R. (2004) Threat of water hyacinth resurgence after a successful biological control program. *Biocontrol Sci. Technol.* **14**, 623–6.

Omondi R. & Kusewa M. (2006) Macrophytes of Lake Victoria, Kenya and succession after invasion of water hyacinth. In: Proceedings of the 11th World Lakes Conference 31st Oct–4th Nov 2005 (ed. Odada E. O., Olago D. O., Ochola W., Ntiba M., Wandiga S., Gichuki N. S. & Ojieke H.), pp. 600–2. Nairobi, Kenya. November 2005.

Othina A., Omondi R., Gichuki J., Masai D. & Ogari J. (2003) Impact of water hyacinth, *Eichhornia crassipes*, (Liliales: Ponteridiaceae) on other macrophytes and Fisheries in the Nyanza Gulf of Lake Victoria. In: Lake Victoria Fisheries: Status, Biodiversity and Management (eds M. Van der Knaap & M. Munawar) Aquatic Ecosystem health and Management Society, Available from URL: http://www.aehms.org/glow_lake_victoria.html. Accessed 10 March 2010.

Paperna I. (1969) Aquatic weeds, snails and transmission of bilharzia in the new man-made Volta lake in Ghana. *Bulletin de l'I.F.A.N.* **30**(ser. A), 487–99.

Paperna I. (1970) Study of an outbreak of schistosomiasis in the newly formed Volta Lake in Ghana. *Z. Tropenmedizin u. Parasitologie* **21**, 411–25.

Pennak R. W. (1978) Freshwater Invertebrates of the United States, 2nd edn. Wiley Intersceince Publication ISB 0-471-04249-8. New York, Chichester, Brisbane and Toronto, p. 798.

Petr T. (1968) Population changes in aquatic invertebrates living on two water plants in a tropical man-made lake. *Hydrobiologia* **32**, 449–85.

Plummer M. L. (2005) Impact of Invasive Water Hyacinth (*Eichhornia crassipes*) on Snail Hosts of Schistosomiasis in Lake Victoria, East Africa. *EcoHealth* **2**(1), 81–6.

Pope K., Masuoka P., Rejmankova E., Grieco J., Johnson S. & Roberts D. (2005) Mosquito Habitats, Land Use, and Malaria Risk in Belize from Satellite Imagery. *Ecol. Appl.* **15**(4), 1223–32.

Sainty G. R. & Jacobs S. W. L. (1994) Waterplants in Australia: A Field Guide, 4th edn. Sainty and Associates, 2003, Potts Point, NSW. ISBN 0958105510, 0958105510 (hbk).

Strickand J. D. H. & Parsons T. R. (1972) A Practical Handbook of Sea Water Analysis, 2nd edn. *J. Fish. Res. Bd. Canada* **167**, 311.

Sunahara T., Ishizaka K. & Mogi M. (2002) Habitat size: a factor determining the opportunity for encounters between mosquito larvae and aquatic predators. *J. Vector Ecol.* **27**, 8–20.

Timmer C. E. & Weldon L. W. (1967) Evapotranspiration and pollution of water by water hyacinth. *Hyacinth Control J.* **6**, 34–7.

Twongo T. & Okurut T. O. (2008) Control of water hyacinth in Lake Victoria, challenges in the resurgence succession. Paper presented at the Science Policy linkages workshop 24–26 September 2008. Imperial Botanical Gardens, Entebbe, Uganda. Sponsored by the UNU-INWEH in collaboration with the LVBC.

Twongo T., Bugenyi F. W. B. & Wanda F. (1995) The potential for further proliferation of water hyacinth in Lakes Victoria, Kyoga and Kwania and some urgent aspects for research. *Afr. J. Trop. Hydrobiol. Fish.* **6**, 1–10.

Victor T. J., Marimuthu S. & Sivaramakrishnan K. G. (1991) Aquatic macrophytes and the associated mosquitoes in and around Madurai City (Tamil Nadu). *Indian J. Malariol.* **28**(3), 151–5.

Webbe G. (1966) The effect of water velocities on the infection of *Biomphalaria sudanica tanganyicensis* exposed to different numbers of *Schistosoma mansoni* miracidia. *Ann. Trop. Med. Parasitol.* **60**, 85–9.

Wetzel R. G. & Likens G. E. (1991) Limnological Analyses, 2nd edn. Springer-Verlag, New York, p. 391. ISBN 387-9733-1.

WHO (1957) Study group on the ecology of intermediate snail hosts of bilharziasis: report. *WHO Tech. Rep. Ser.* **120**, 1–38.

WHO (1981) Report of the International Seminar on Integrated Control of Mosquito Vectors, Adana, Turkey, 2–14 November 1981, p. 59.

WHO (1982) Report of the Sixth Meeting of the Scientific Working Group on Biological Control of Vectors, Geneva, 13–16 September 1982., p. 46.

WHO (1985) The control of Schistosomiasis: report of a WHO expert committee. *WHO Tech. Rep. Ser.* **728**, 1–113.

Witte F. & van Dansen L. T. (1995) Fish Stocks and Fisheries of Lake Victoria: A Handbook of Field Observations. Samara Publishing, Cardigan, UK, p. 404.

Witte F. & van Oijen M. J. P. (1990) Taxonomy, ecology and fishery of Lake Victoria Haplochromine trophic groups. *Zool. Verh. Leiden* **262**, 1–47.

Woolhouse M. E. J. & Chandiwana S. K. (1989) Spatial and temporal heterogeneity in the population dynamics of *Bulinus globosus* and *Biomphalaria pfeifferi* and in the epidemiology of their infection with schistosomes. *Parasitology* **98**, 21–34.