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Effect of Water Quality on the Diversity and Distribution of Benthic Insects in Kiwunya Stream, Kampala

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ABSTRACT
A study was conducted to assess the composition and distribution of the benthic insects at selected sites along Kiwunya Stream. The benthic insects were collected by the using a Hess sampler with a mesh size of 250µm. The samples were preserved with 5% formalin before identification. Selected factors affecting the distribution were analyzed using standard limnological methods. The distribution of benthic insects was heterogeneous. Six orders and eighteen species were found in the river. Order Ephemeroptera (mayflies) were the most dominant (45%) component of the benthic insect community and were found in all sites. They contributed more than 40% to the total biomass. Chironomids occurred in large numbers at site 3. Orders Odonata, Coleoptera and Hemiptera were the least abundant. The nature of the substratum, change in current turbulence, vegetation and effluent discharge were important factors in selecting the kinds and density of benthic insects in the stream. The highest density of insects was recorded at the vegetated downstream in site (4) while the upstream sandy substratum had the lowest density in site (3). The benthic insects were less abundant on rainy days compared to dry times.
Keywords: Water Quality, Benthic, Insects.

INTRODUCTION

Water pollution is the degradation of water quality as measured by physical, chemical or biological criteria. These criteria take into consideration the intended use for the water, departure from the norm, effect on public health, and ecological impacts. Many factors can affect water quality. The conditions of a river or lake can fluctuate periodically, so water quality must be measured periodically to look for trends. Water that is determined to be safe for one use may be unacceptable for another purpose or species. It is therefore important to use biological, chemical and physical measurements to determine the health of a body of water. The major water pollutants are oxygen-demanding waste, measured by biochemical oxygen demand (BOD) pathogens, measured by the faecal coliform bacteria count; nutrients that lead to eutrophication, in which overgrowth of algae deprives water oxygen and sunlight; oil; toxic substances, including synthetic organic and inorganic compounds, heavy metals, and radioactive materials; heat; and sediments.

Common physical tests of water include temperature, solids concentrations (e.g., total suspended solids (TSS)) and turbidity Water samples may be examined using the principles of analytical chemistry. Many published test methods are available for both organic and inorganic compounds.

Frequently used methods include pH, biochemical oxygen demand (BOD), chemical oxygen demand (COD), nutrients (nitrate and phosphorus compounds), metals (including copper, zinc, cadmium, lead and mercury), oil and grease, total petroleum hydrocarbons (TPH), and pesticides. Biological testing involves the use of plant, animal, and microbial indicators to monitor the health of an aquatic ecosystem (Welch *et al.*, 2004).

Benthic insects are aquatic insects, worms and crustaceans most often found in the substrate of streams. They are vital to lotic systems as essential members of detritus food webs that biodegrade organic matter and serve as food for both aquatic life, such as fish and terrestrial life, such as birds (Barbour *et al*., 1999). Fluctuations in physicochemical parameters can cause a variation in the number, morphology, physiology or behaviour of those organisms (Thorpe *et al*., 1999).

Bio-indicator methodology detects the susceptibility of particular species, i.e., algae, benthic macroinvertebrates, and fish (Lenat *et al*., 1993), to changes in their habitat (Kasangaki et al., 2006). The concept of bio-indicator has been defined as a species, population, or community that has specific environmental requirements. An ideal indicator is one that has a low tolerance to environmental fluctuations (Kinyua and Pacini, 1991) that could affect the community structure of the river.

Besides, surface water runoffs that drain to River Kiwunya come from multiple use catchments, which include urban drains, petrol stations, garbage, sewage, washing bays, agricultural and recreational activities as the river passes through the slums. These further places pressure on this water resource and impacts on water quality. Thus there is therefore a need to carry out a study using benthic insects as bio-indicators, to assess urban impacts on the stream water quality. Despite the rich and diverse biodiversity, existing in the Kiwunya river ecosystem very little/no assessment of the river biodiversity *visa a vie* its water quality deterioration as a result of urban development has been done. Most of the research concerns and initiatives have been focused on the physiochemical water quality parameters, and community benefits derived from the various resources along the river. By assessing the biological pollution of the river, the progress or deterioration of the Kiwunya River can be verified. After assessing the deterioration the overall goal of the study is to determine the composition and abundance of benthic insects as bio-indicators of the urban impact on the ecological integrity of the Kiwunya River.

The numbers of different insects far outnumbers all the other species of animals and plants put together (Richards and Davis, 1977). A large proportion of benthic hexapods are attached to or resting on the bottom of water sediments. They dominate the macroinvertebrate fauna in lotic habitat communities (Mason, 2002). Although the species composition in aquatic insect groups performing the same ecosystem function differs among rivers separated geographically, a marked similarity exists at the lower taxonomic levels. The distribution of the benthic insects is a result of an assemblage of several factors (Sabramanian et al., 2005). Changes in the physical and chemical characteristics of the stream are reflected in the changes in diversity and density of the benthic fauna. Benthic insects process and utilize the energy entering streams from either autochthonous periphyton sources such as leaves and other particulate matter from vegetation or organic wastes from humans or other animals in the watershed. Investigations on lotic waters, particularly from the ecological point of view have lagged behind those of lentic waters. Most of the studies on benthic organisms have dealt with lake-based benthic communities and concentrated on their ecological role on lake productivity dynamics. Therefore, fundamental data concerning the functioning of stream ecosystems is scarce. This restricts the role of a biologist in interpreting the factors that regulate the spatio-temporal distribution of riverine flora and fauna. In Uganda, few limnological studies have been conducted on streams. Kizito (1986) evaluated the pollution levels of Nakivubo Channel. Matagi (1996) focused on the benthic macroinvertebrates of the same channel and found a diverse group of macrozoobenthic invertebrates.

MATERIALS AND METHODS

Study area

Kiwunya Stream is one of the main tributaries of River Lubigi.River. Lubigi is part of the complex network of rivers and streams draining into Lake Victoria. Kiwunya River is located between latitudes 0°20'N-0°21'N and longitudes 32°33'E-32°34'E in Kampala, Uganda. It originates from the valley, which is at the foothills of Kasubi, Kawaala and Makerere. The riverbed is about 1.5 m wide and its depth varies with seasons, becoming deeper during the rainy seasons. Eucalyptus trees, grasses and herbs characterize vegetated areas along the river. Many insects gather at the waterside, giving evidence of the extraordinary abundance of biodiversity (Merimba, 2004).

The mean annual rainfall of 1475mm is bimodally distributed, received on an average of 166 days per year. There are two rainy seasons occurring from March through May and from September through November (Figure 1). The dry seasons are in the months of December to February and June to August. But the latter is hotter than the former (Merimba, 2004). The daily mean minimum and maximum air temperatures are 12.7 and 25.5 respectively lower than those in lowland equatorial regions. The mean annual temperature is 22°C with a maximum of 26.8°C and a minimum of 11.9°C. The soils are predominantly red, well drained soils of the "Ferralitic" group, consisting sandy loams and sandy clay loams. Langdale -Brown *et al*. (1969).

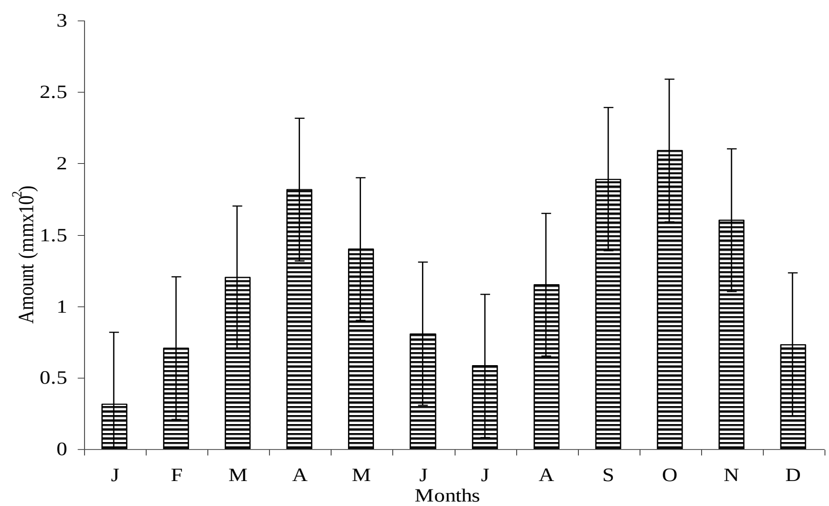

Figure 1: Rainfall for F ort Portal (1950-2002)

Sampling of Benthic insects

Quantitative sampling for the benthic insects was done by the use of a Hess sampler (Welch *et al*., 2004) with a mesh size of 250 µm. The samples were preserved with 5% formalin. In the laboratory, the samples were washed through a 250-µm sieve. The benthic insects were preserved in 70% ethanol. They were identified using standard keys like that of Watson-Ferguson *et al*. (2006) and counted under a binocular microscope.

Water Temperature Measurement

Water temperature was measured using a thermometer. It was lowered into the water and to record temperature data (readable to 0.01°C).

Dissolved oxygen Measurement

The modified Winkler's method was used to determine dissolved oxygen concentration. Water was siphoned into 250ml BOD bottles. The sample was fixed by using 2mls of manganese sulphate followed by 2mls of sodium azide solutions. Titration of 100 mls of sample (using a digital titrator) with 0.0125N sodium thiosulphate solution using 1% starch indicator gave a titre that was used in the calculation of dissolved oxygen (DO) concentration as follows:

$$\text{DO (Mgl}^{-1}\text{)} = \frac{100\text{x}v\text{x}0.1}{V}$$

Where

v = volume of sodium thiosulphate titrated

V = volume of water sample used in the titration.

Temperature and dissolved oxygen was measured using appropriate probes. Ammonia-nitrogen and nitrate-nitrogen were determined following the procedures described by Wetzel and Likens (1994). The water velocity was determined by measuring two metres between two points along the river. The rate of water flow was got by dividing the measured distance by the time the float took to move from the first point to the second point. The water depth was measured using a metre rule.

Data Analysis

Both descriptive statistics and inferential statistics were used. Data were summarised in form of tables and graphs. The chi-square test was used to analyse the relationship between the observed frequencies and expected frequencies of the benthic insects. One-way ANOVA was used to analyse the means of quantitative parameters.

RESULTS

The benthic insects in Kiwunya River were diverse and represented by six orders (Table 1, Figure 1). Many of the insect forms found in the stream are the young stages that closely resemble or differ from the adults. Ephemeroptera, Trichoptera and Diptera occurred in relatively large numbers. Ephemeroptera was the most abundant group accounting for over 45% (Figure 2) of the total number of insects in the stream. It was well represented in all the four sampling sites. The dipterans were dominated by chironomids, which made up more than 90% of the total density in that group. Chironomid larvae formed the largest proportion of benthic insects at site 3. Odonata, Coleoptera and Hemiptera contributed small numbers to the overall density. Hemiptera formed the smallest component of the benthic insects. In terms of total abundance among the sites, site 4 had the highest number of individuals per m^2 while site 1 had the lowest. In terms of diversity, site 4 supported the largest number of taxa while site 3 had the smallest. Samples that were collected on wet days had less insects compared to those collected on dry days. Sites 1, 2, and 3 that lacked riparian vegetation had lower densities of insects compared to vegetated area (site 4). More insects occurred in the substratum with plants than that without plants. The mud site had high species abundance and species diversity than the sand substratum.

Site 4 had the highest concentration of oxygen with an average of 4.55 mg l^{-1}. The concentration of dissolved oxygen was lowest in site 3 (average = 1.24 mg l^{-1}). High dissolved oxygen concentrations were observed on rainy days while low values were observed in dry days. Although dissolved concentration was low in station 3, samples taken after downpours showed increased concentrations. Ammonia concentration in the stream site was high during the dry days.

In the upstream site the concentrations were low. Its concentration ranged from 0.61-3.39 mg l^{-1}(Table 2). The highest concentration was recorded at site 3 while the lowest was recorded at site 4. The highest concentration of nitrate-nitrogen was recorded at site 4. The lowest concentration was recorded at site 3. On dry days the water velocity did not vary much among the four stations. It ranged between 0.24 m s^{-1} and 0.54 m s^{-1} with an average of 0.36 m s^{-1}. Marked variations in water velocity were observed on wet days. The impact of water velocity was greatest on the chironomid larvae. Increase in water velocity greatly affected the number of chironomids.

Table 1: Benthic insects (individuals m^{-2})

Order/Site	1	2	3	4
Ephemeroptera	345	964	54	1116
Trichoptera	294	501	20	547
Diptera	152	93	925	118
Coleoptera	16	50	5	115
Odonata	6	28	0	75
Hemiptera	30	0	7	8

Table 2: Physico-chemical characteristics

Parameter/Site	1	2	3	4
Temperature (˚C)	25.3	26.2	26.8	26.1
Velocity (m s^{-1})	0.59	0.39	0.28	0.21
Depth (cm)	8.7	9.7	7.5	5.7
DO (mg l^{-1})	4.38	3.29	1.24	6.55
Ammonia (mg l^{-1})	0.74	1.15	3.39	0.61
Nitrate (µg l^{-1})	6.25	5.34	0.49	7.28

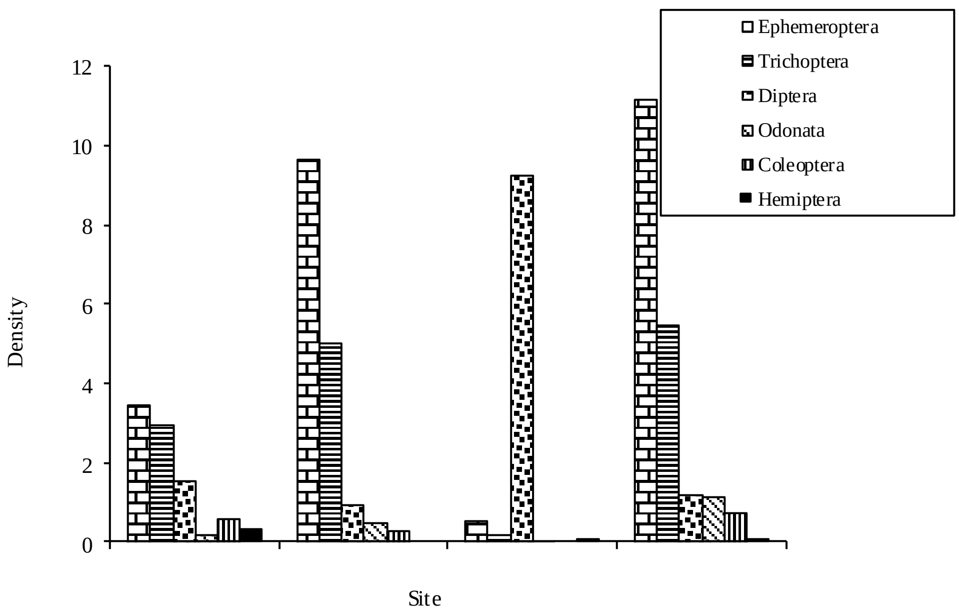

Figure 2: Taxa distribution (individuals $m^{-1}x10^{2}$) of the benthic insects in the sampling sites of Kiwunya

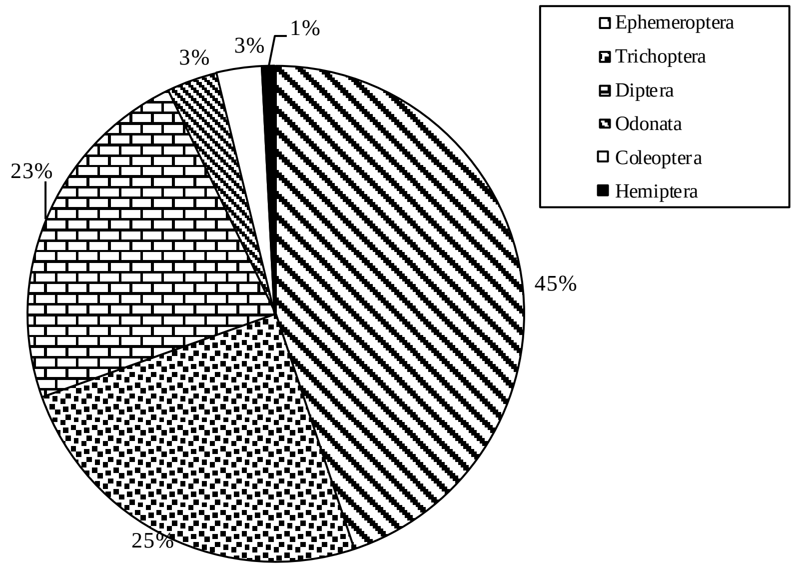

Figure 3: Percentage contribution of the taxa to the overall density of the benthic insects of Kiwunya Stream.

DISCUSSIONS

The density of benthic macro invertebrates can be influenced by many factors among them the organic matter content in sediments, physical anthropogenic disturbances and the density of the riparian vegetation. Most of the changes that occur in streams are of natural or anthropogenic origin and they often impose stress on these ecosystems. Kiwunya River is one of the streams, which experience anthropogenic of disturbance. The impacts of anthropogenic activities on streams have been described in detail by Kasangaki *et al*. (2006) and are common to urban streams in other East African countries (Kinywa & Pacini, 1991; Mavuti, 2003). Organic matter input along rivers is known to occur more in canopied sites than open sites. In this study, there was low density of benthic insects in sites 1 and 2, which is less vegetated. The dominance of immature (larval and nymphal) stages in benthic insect community of Kiwunya River is in line with the observations made by Welch *et al*. (2004).

The low numbers of benthic insects in sites 2 and 3 were due to the clearance of the vegetation by humans. Since the plants were removed, many insects had no surfaces where to cling especially under situations of increased water velocity (during rainfall). Site 1 (sandy substratum) had the least density of benthic insects due to the low content of particulate organic matter (food) resulting from the scarcity of vegetation. Because the sandy substratum is usually clean and its interstices have less organic sediment, it tends to have few benthic organisms (Townsend and Hildrew, 1994). The physical nature of substratum influenced the distribution of benthic insects. For example, the burrowing nymphs of the dragonfly and damselflies require a substratum of fine particles into which their modified front legs can dig effectively. This explains why the densities of *Libellula* and *Aeshna* were very low in site 1. Dragonfly and damselfly nymphs have stout claws with which they cling to objects including vegetation. That is why most of them occurred in the vegetated site. The presence of mud coupled with the availability of vegetation favour the highest density of benthic insects at site 4.

Riparian vegetation affects the patterns of organic matter inputs, thus indirectly affecting the density and species composition. Numerous benthic insects flourished at sites 4 due to enrichment as s result of input of fine particulate from vegetation. These largely feed on fine particulate organic matter. Vegetation acted as a source of organic matter, which furnished the food supply. In addition, vegetation provides surfaces upon which benthic insects can cling. The scarcity of vegetation along streams due anthropogenic influence tends to lead to low densities of benthic macroinvertebrates.

Organic loading indicated by both low dissolved oxygen concentration and high ammonia concentration at site 3 are attributed to the input of disposable organic matter from the effluent. However high oxygen concentrations observed at the same site on rainy days is a result of aeration due to turbulence and dilution. The plants at site 4 contribute to the concentration of dissolved oxygen through photosynthesis. Macrophytes have been found to supplement atmospheric supply of dissolved oxygen through their photosynthetic activities (Nyakoojo and Byarujali, 2009). Generally, taxa other than chironomids are intolerant to low dissolved oxygen. Thus, the dominance of these insects in respective sites indicates relatively clean water especially in respect to organic waste. Samples from site 3 consisted of many chironomids of Family Chironomidae (and Subfamily Chironomini). This group is known for the preference of strata that are rich in organic substances and have high tolerance to low oxygen levels. The blood of *Chironomus* has haemoglobin, which has a high affinity for oxygen and acts as a carrier for the gas at low oxygen tensions (Mason, 2002). Their haemoglobin has a great affinity for oxygen and loads up more easily under low oxygen tension. This characteristic accounts for their high density at site 3. Field investigations that have been conducted on stream macroinvertebrates reveal that chironomid larvae dominate at low oxygen levels (Mason, 2002). The principal reason for the reduction in species abundance in site 3 that insufficient oxygen eliminates intolerant taxa. The remaining taxon (chironomids) flourished because of increased survival as a result of the reduction of the intolerant predators e.g. dragonflies and a more favourable food supply from the organic input from the effluent (Welch *et*. *al*., 2004). Therefore the low oxygen tension is responsible for the low species diversity at this site. Loading streams with organic matter tends to decrease diversity (Townsend and Hildrew, 1994). Organic loading indicated by low dissolved oxygen and high ammonia concentrations at site 3 are attributed to the input of disposable organic matter from the effluent. However, high oxygen concentration observed at the same site on rainy days is a result of aeration due to turbulence and dilution.

Higher concentrations of ammonia in site 3 are a result of the bacterially mediated degradation of organic matter and animal excretion (Harper, 1996). Heterotrophic bacteria produce ammonia as a primary end product of organic matter from proteins and other organic compounds. The low nitrate-nitrogen concentration recorded at site 3 is attributed to the low dissolved oxygen concentration, which enhances denitrification (Harper.1996). Following deoxygenation (due to rapid uptake and low rate of diffusion into the sediments), nitrate-nitrogen becomes the next electron acceptor for carbon oxidation and microbial denitrification to nitrogen occurs. This process depletes a significant proportion of nitrate-nitrogen. The hydraulic effect of rainwater runoff dislodges and washes way the benthos. The tendency of benthic macroinvertebrates to increase in dry conditions and decline during the wet season appears to be a general characteristic of perennial streams and rivers in the tropics (Harper, 1996).

There was reduction in density of benthic insects on wet days due to the hydraulic effects of rainwater runoff. Rain results increased water velocity that dislodge and wash away the benthos (Welch *et*. *al*., 2004). This explains why an increase in water velocity resulted in a general decrease in the number of benthos. The impact of velocity was greatest on the chironomid larvae because they do not have attachment organs and are easily washed away. The numbers of these dipteran insects were quite high under reduced water velocities. Rainfall is one of the most important factors that influence the ecosystems of tropical rivers and streams (Welch *et*. *al*., 2004). Rainfall affected the benthic insects of Kiwunya Stream by affecting the water velocity. The impact of velocity on the distribution of benthic insects was observed on wet days, when higher water velocities were recorded. The impact of rain on water velocity and distribution of benthic macro invertebrates in east African rivers has been stressed by other limnologists like Matagi (1996).

CONCLUSIONS

The study having focussed on effect of water quality on the diversity and distribution of benthic insects in Kiwunya stream, and specifically to determine the spatial variations of the benthic insects along the stream gradient and analyse relationships between water quality, taxa composition and abundance of benthic insects; it was noted that the Ephemeroptera, Trichoptera and Diptera occurred in relatively large numbers in the stream but in young stages that closely resemble or differ from the adults, where the Ephemeroptera was the most abundant group accounting for over 45% of the total number of insects.

It is also therefore noted that the density of benthic macroinvertebrates can be influenced by many factors; among them the natural anthropogenic disturbances organic matter content in sediments, and the density of the riparian vegetation. Most of the changes that occur in streams are of natural or anthropogenic origin and they often impose stress on these ecosystems. Kiwunya river is one of the streams, which experience anthropogenic of disturbance. Benthic insects are good indicators of ecosystems and these change as the ecosystems too. In kiwunya stream, abudance of ephemeroptera in particular cause a downstream in Diptera, and presence outbreak of Trichoptera are attributed to stable flow ring conditions. However, the impacts of human activities are manifested through water quality, land use, elimination of aliens and decline in number of benthic insects.

RECOMMENDATIONS

- Environmental Education to the communities should be taken seriously.
- An effective environmental policy among the poor needs to have an element of economic incentive, for them to be supportive.
- Appropriate technologies in line with aquaculture need to be explored.
- NGOs are important links between local authorities and CBOs.

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