Development of a Fish Index of Biotic Integrity (IBI) for satellite lakes within Yala Swamp, Lake Victoria Basin, Kenya

By:

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DECLARATIONS

Declaration by the candidate

This thesis is my original work and has not been submitted for a degree award in any other University.

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DEDICATION

To my late mum and uncle, Phelesiah and Wellington, respectively without whom I may not have seen nor regarded the value of education, to my dad Omuhaya for parental motivation, to my fiancée Rose for continued encouragement and to all my dear friends for timely encouragement to carry on and to all my family members for their relentless concerns. God be with you all.

ABSTRACT

This study evaluated and tested ten fish community attributes for use in developing a fish-based Index of Biotic Integrity (IBI) for assessing the biotic integrity of Lakes Kanyaboli and Sare in Yala Swamp within Lake Victoria basin, Kenya. Fish assemblages were sampled for a period of three months using beach seining at sampling stations selected from the two sites. Physico-chemical water quality parameters were determined for the two lakes and correlated with fish attributes. Nine out of the ten fish community attributes evaluated showed significant correlations ($p<0.05$) with the physico-chemical parameters and therefore qualified as metrics for development of the fish IBI for each site. These metrics were mean number of individuals per seine haul, percentage of individuals as *Oreochromis esculentus*, percentage proportion as planktivores, percentage proportion as generalists, percentage proportion as introduced individuals, percentage proportion as carnivores, percentage proportion as natives, total number of species and Shannon-Wiener diversity index. Historical fish data from previous studies was used to develop reference baseline conditions for the two lakes while metrics not in the historical data were scored following trisection technique. Lake Kanyaboli was categorized as being of fair biotic integrity (overall IBI score = 33) and Lake Sare was classified as being of poor biotic integrity with a score of 23 out of the maximum expected score of 45. It is concluded that the Index of Biotic Integrity (IBI) method can be used to assess the ecological health and biotic integrity of the two satellite lakes and other aquatic habitats within the Lake Victoria basin. However the IBI developed in this study

based on fish assemblages will need further validation and refinement in order to eliminate the confounding effects of anthropogenic influences such as overfishing.

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ABBREVIATIONS, ACRONYMS AND DEFINITION OF TERMS

List of Acronyms

BINU- Biological Indicators for National Use

BMWP- Biological Monitoring Working Party

FBI- Family Biotic Index

GoK- Government of Kenya

IBI- Index of Biotic Integrity

KLA- Kenya Land Alliance

KWS- Kenya Wildlife Service

LBDA- Lake Basin Development Authority

MCI- Macroinvertebrate Community Index

NJDEP- New Jersey Department of Environmental Protection

OSIENALA- Friends of Lake Victoria

SSP- Species Survival Programme

USEPA- United States Environmental Protection Agency

Definition of terms

Assemblage: An association of interacting populations of organisms in a wetland or habitat.

Attribute: A measurable component of a biological assemblage. In the context of biological assessments, attributes include the ecological processes or characteristics of an individual or assemblage of species that are expected, but not empirically shown to respond to a gradient of human disturbance or environmental perturbation.

Biological assessment: The use of biomonitoring data of samples of living organisms to evaluate the condition or health of a place (e.g., a stream, wetland or lake).

Biological integrity: The ability of an aquatic ecosystem to support and maintain a balanced, adaptive community of organisms having a species composition, diversity and functional organization comparable to that of natural habitats within a region (Karr and Dudley, 1981).

Biological monitoring: Sampling the biota of a place (e.g., a stream, lake or a wetland).

Index of Biotic integrity (IBI): An integrative expression of the biological condition of a site across multiple metrics often composed of at least seven metrics (Karr and Chu, 1999).

Metric: An attribute with empirical change in value along a gradient of human disturbance or environmental condition change.

Trisecting: The division into three parts of a range of data for scoring a metric (USEPA, 2002b).

Reference conditions: Conditions during which the study sites had minimal exposure to human activities or disturbances and are representative of the water body type and region of interest (Hughes *et al.* 1986).

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God bless them all.

CHAPTER 1

1.0 INTRODUCTION

Aquatic ecosystems have historically been monitored for pollution and ecological status primarily through chemical means (Karr, 1981; NJDEP, 2004; USEPA, 2005; Groom *et al.* 2006). Unfortunately, chemical monitoring provides only a "snapshot" of conditions at the time of sampling and may therefore fail to detect acute pollution events such as runoff from heavy rains, spills and non-chemical effects such as habitat alteration, overfishing and species introductions (Karr, 1991; Simon and Stewart, 1998; NJDEP, 2004).

Biological assessment is based on the premise that biological communities are shaped by long-term conditions of their environment and therefore reflect the health of an ecosystem (Karr *et al.* 1986; Barbour *et al.* 1999; USEPA, 2002a, 2002b; Raburu, 2003; Groom *et al.* 2006). This method is widely used in the bioassessment and monitoring of aquatic systems. The principal evaluation mechanism of biological assessment utilizes the technical framework of the Index of Biotic Integrity (IBI), a fish assemblage approach first developed by Karr (1981). Although initially developed for North American streams (Karr, 1981), the IBI has consequently been modified and applied to virtually all other aquatic ecosystems including; coldwater streams (Leonard and Orth, 1986; Karr *et al.* 1986; Lyons *et al.* 1996), large rivers (Hay *et al.* 1996; Ganasan and Hughes, 1998; Kleynhans, 1999), lakes (Minns *et al.* 1994; Whittier, 1999; Drake and Pereira, 2002), wetlands (Gernes and Helgen, 1999), reservoirs (Jennings *et al.* 1995; McDonald and Hickman, 1999), estuaries (Whitfield, 1996; Whitfield and Elliot, 2002) and highly modified habitats (Simon, 2000). It has also been adapted for use in diverse geographical areas (Fausch *et al.* 1984; Leonard and Orth, 1986; Karr, 1991; Hay *et al.* 1996; Kleynhans, 1999; Raburu, 2003). There is therefore, a growing interest in the use of biological communities to assess the ecological status of water resources (Deegan *et. al*., 1997; Bain *et. al*., 2000; Simon, 2000; Raburu, 2003). This makes the IBI a widely used multi-metric index for assessing the biological health of fish communities (Lyons *et al.* 1995, 1996; Barbour *et al.* 1999). It incorporates the zoogeographic, ecosystem, community and population aspects of the fish assemblage into a single ecologically based index (Karr, 1981; Leonard and Orth, 1986; USEPA, 2002a, 2002c) which may be used to detect degradation or changes in biotic integrity, identify the causes of such changes, and determine community recovery (Okeyo-Owuor, 1998). The IBI has been preferred to biological diversity indices for use in assessment of ecosystem health (Angermeier and Karr, 1994).

Fish assemblages can be stand-alone indicators of a water body's health and/or biotic integrity (Jennings *et al.* 1995; Soto-Galera *et al.* 1998; NJDEP, 2004). However, they may be combined with other biological and chemical indicators to assist in characterizing ecological significance of water bodies (Simon *et al.* 2000; Volstad *et al.* 2003). Also, fish assemblages are usually affected by human alterations of the physical, chemical or biological properties of aquatic systems (Karr, 1981, 1991; Groom *et al.* 2006). Fish have also been successfully used as indicators of aquatic environmental quality changes and have numerous advantages as indicator organisms for bioassessment and biomonitoring programmes (Karr *et al.* 1986; Whitfield, 1996; Whittier, 1999; Raburu, 2003).

Lakes Kanyaboli and Sare are significant wetland habitats with a variety of floral and faunal species (Mavuti, 1989; Opiyo, 1991; Opiyo and Dadzie, 1994; Aloo, 2003). Furthermore, wetlands are the vital link between water and land and are among the most biologically productive ecosystems in the world (Mitsch and Gosselink, 2000). They provide a wide variety of ecosystem functions and services such as water storage, water quality improvement, reducing flood damage, preventing bank and shoreline erosion, and recharging ground and surface water supplies (Mitsch and Gosselink, 1993). They also provide vital ecological habitats for fish and wildlife, offering opportunities for recreation, ecotourism, education and research, producing food, forest and fuel products (Aloo, 2003; Abila, 2003). They also perform important ecosystem functions such as providing carbon storage, biogeochemical transformations and aquifer recharge (Mitsch and Gosselink, 1993). They constitute a vital life support and natural asset that should be conserved for the benefit of their human and non-human dependants (Mitsch and Gosselink, 2000).

Biological communities in wetlands like in other systems are dependent on water quality and quantity to exhibit biological integrity and sustain ecological functions (Simon *et. al.*, 2000). Developing an IBI for fish communities in wetlands can therefore be a useful tool towards bioassessment of the biological integrity of these habitats.

Previous studies carried out in Yala Swamp recommended that the swamp be reclaimed and developed into a small holder irrigation scheme that would provide increased food and cash crop production (Gibb, 1954; ILACO, 1975). Consequently, approximately 2,300 ha of the swamp were reclaimed from mid 1960s to early 1970s under a project sponsored by UNDP and FAO (GoK, 1987; OSIENALA, 1998). Currently approximately 4,600 ha of the swamp has been reclaimed and is undergoing agricultural development to produce cotton, rice and horticultural products under the Dominion Farms Limited through a lease agreement with the Siaya and Bondo Districts Local Authorities (Simonit and Perrings, 2004). According to a Japan International Cooperation Agency (JICA) survey, it was suggested that the reclaimed land could support commercial fish production in fish ponds and cages installed in the running water channels, estimated to produce up to 60 Metric tons of fish per year (JICA, 1987). Reports however indicate that swamp reclamation would result in ecological problems such as lower water quality, decreased species diversity and increased pressure on the resources of the remaining wetland (OSIENALA, 1998: Aloo, 2003).

Given the anticipated ecological changes that may result from Yala wetland reclamation, it was important to come up with a bioassessment and monitoring method before these wetlands are degraded. The development of an IBI would therefore be useful in providing a means for rapid assessment and monitoring of the ecosystem integrity of the Yala Swamp lakes, which are facing threats of reclamation for large-scale agricultural development.

1.1 Objectives

1.1.1 Overall Objective

The overall objective of this study was to develop an Index of Biotic Integrity (IBI) based on fish assemblage metrics and physico-chemical parameters.

1.1.2 Specific Objectives

The specific objectives of this study were:

i. To document the ichthyofauna of Lakes Kanyaboli and Sare.
ii. To determine the physico-chemical water quality of Lakes Kanyaboli and Sare.
iii. To determine the correlations between fish assemblage attributes and water quality parameters for Lakes Kanyaboli, and Sare.
iv. To develop an Index of Biotic Integrity (IBI) for Lake Kanyaboli and Lake Sare.

1.2 Research Hypotheses

This work was guided by the following working hypotheses:

H_o 1: Fish community attributes do not differ significantly between Lake Kanyaboli and Lake Sare.

H_o 2: The physico-chemical water quality parameters do not differ significantly between Lake Kanyaboli and Lake Sare.

H_o 3: Fish community attributes within Lakes Kanyaboli and Sare are not correlated to the physico-chemical parameters within these lakes.

H_o 4: The IBI metric scores do not differ significantly between Lake Kanyaboli and Lake Sare.

1.3 Problem Statement and Justification

The Yala wetland complex, including the satellite lakes Kanyaboli and Sare, is faced with threats such as habitat alteration, agricultural reclamation, human encroachment, fishing pressure and species introductions (Opiyo, 1991; Aloo, 2003; Ikiara *et al.* 2004; Simonit and Perrings, 2004). The swamp has been affected by human development such as reclamation since mid 1960s leading to approximately 2,300 ha of the swamp being drained (GoK, 1987). Currently, approximately 4,600 ha of the swamp has been reclaimed and is undergoing agricultural development to produce cotton, rice and horticultural products under Dominion Farms (K) Limited (Ikiara *et al.* 2004; KLA, 2005). Such human alterations of the physical, chemical and/or biological properties of aquatic systems usually result in changes in the distribution and structure of fish assemblages.

Raburu (2003) noted that wetland systems in Kenya have not been adequately studied to enable their classification chemically or biologically. Thus no reproducible standardized biotic or water quality indices are available for monitoring aquatic resources in Kenya. There is also lack of basic data on the biodiversity and distribution of aquatic organisms and their relationship to abiotic and other human induced factors such as pollutant loads (Okeyo-Owuor, 1998). In Lakes Kanyaboli and Sare, the concept of biological indicators has not been explored in monitoring and assessing their ecological changes. The same applies to the whole of Lake Victoria

Basin (LVB) except for the pioneer study by Raburu (2003) that developed an Index Biotic Integrity (IBI) for biomonitoring of River Nyando. The use of IBI in monitoring ecosystem health and integrity is therefore generally lacking in Kenya. Hence there is need for development of bioassessment and monitoring tools towards achieving sustainable utilization of wetland resources and biodiversity conservation in Kenya.

Bioassessment and monitoring involves use of biota of aquatic ecosystems to detect anthropogenic impacts (Davis and Simon, 1995). This concept is attaining greater importance in efforts towards restoring and maintaining physical, chemical and biological integrity of waters in the United States (USEPA, 1990; USEPA, 2005) and other parts of the world (Hay *et al.* 1996; Barbour *et al.* 1999; Raburu, 2003). This concept is also under consideration for use in Africa and has been applied in South Africa and Namibia (Hay *et al.* 1996; Kleynhans, 1999) and in Cameroon (Toham and Teugels, 1999). In Kenya, the Kenya Wildlife Service (KWS) is in the process of exploring the potential of developing biological indicators for national use (BINU, 2005) through the Yala Swamp Task Force. This study is therefore an additional effort to develop bioassessment and monitoring tools for Kenya's aquatic resources.

Lakes Kanyaboli and Sare form part of the open water bodies in Yala Swamp. They were targeted for this study since they were experiencing the effects of Yala Swamp reclamation and yet they have been pointed out as being of great ecological significance and need to be conserved at all costs (Mavuti, 1989; Opiyo, 1991; Harper and Mavuti, 1996; OSIENALA, 1998; Aloo, 2003). Bioassessment and monitoring of

Lakes Kanyaboli and Sare using fish as indicators of biotic integrity was based on the fact that most of the fish species such as *O. esculentus*, which previously formed the mainstay of the commercial fishery of Lake Victoria, are still found in these lakes. Therefore, documenting changes in fish assemblages in these lakes would provide important information on water resource quality and the biotic integrity of these freshwater systems, hence the need for the current study. This is because wetlands are amongst the most degraded of ecosystems and losses have been estimated at 50% of the original global wetland area (Gardiner, 1994; Jones *et al.* 1995). Further, wetlands in Kenya have been classified and noted for their importance for conservation and productivity (Mavuti, 1989). Thus this study was focused on development of a wetland bioassessment and monitoring index based on fish IBI to evaluate the biological integrity of these wetlands.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 Biological Assessment and Biomonitoring

Biological assessment has been defined as the evaluation of the biological condition of a habitat, based on surveys of the diversity, composition, and functional organization of the community of the resident biota such as macroinvertebrates, plants, amphibians, fish, algae and birds (Karr *et al.* 1986; Barbour *et al.* 1999; USEPA, 2002a, 2002c). Bioassessments often include the collection of physical and chemical data (USEPA, 2002a). Biomonitoring on the other hand is the periodic sampling of biota of a site or habitat such as a stream or wetland (USEPA, 2002a). The use of biota in the monitoring and assessment of aquatic systems is gaining greater importance in detecting anthropogenic impacts (Davis and Simon, 1995). Bioassesments are based on the premise that the community of plants and animals living in the aquatic habitat will reflect the ecological health and integrity of the habitat (Karr, 1981).

When the habitat is damaged, the diversity of plants and animals often decreases and the composition of species change (Karr and Dudley, 1981; USEPA, 2002b). Therefore estimating ecosystem health and integrity through bioassessment may be the best way to assess the total effects of damage to aquatic environments (Karr, 1991). For example, the Lake Victoria ecosystem has been particularly affected by the introduction of the Nile perch, *Lates niloticus,* in the 1950s and the water hyacinth, *Eichhornia crassipes,* in 1990s (Ogutu-Ohwayo and Hecky, 1991). The consequences of such introductions have been suggested to be detrimental to the lake's biodiversity, especially fish fauna, leading to a shift in the fishery from a multi-species fishery to one dominated by only two major exotic species, Nile perch, *L. niloticus* and Nile tilapia, *Oreochromis niloticus* and one native species "omena" *Ratrineobola argentea* (Ogutu-Ohwayo and Hecky, 1991).

In an ideal situation, the quality of aquatic habitats should be assessed by the use of physical, chemical and biological parameters in order to provide a complete spectrum of information for appropriate water management (Iliopoulou-Georgudaki *et. al*., 2003). However, such a study needs much more time and resources than the study of the biological parameters, which as is widely accepted and can give reliably all the information about habitat quality or condition (Iliopoulou-Georgudaki *et. al*., 2003).

Environmental indicators can be defined as physical, chemical, biological or socio-economic measures that best represent the key elements of a complex ecosystem or environmental issue (Whitfield, 1996). Biological indicators show changes if deterioration or improvement of their ecosystem occurs (Whitfield, 1996). Environmental indicators can be qualitative or quantitative although, the latter is more useful if used for management actions (Whitfield, 1996).

Water quality assessment and monitoring programmes are designed to assess aquatic ecosystems' condition with statistical rigor while maximizing the use of available management resources (USEPA, 2002a). At the broadest level, monitoring should include: detecting and characterizing the ambient condition of existing aquatic systems, describing whether their condition is improving, degrading or staying the same, defining seasonal patterns in their condition and identifying thresholds for system stressors (USEPA, 2002a). Therefore, monitoring programmes should be designed to answer questions such as how, when, where and at what levels do acceptable aquatic habitats condition occur (USEPA, 2002a). Biological assessments are therefore carried out and data obtained from the assemblages used to evaluate the aquatic habitats' condition and that of the specific sites (USEPA 2002a). Typically, the organisms that are intolerant to the disturbances die and organisms that are more tolerant to the disturbance make up a larger proportion of the individuals. Ideally therefore, bioassessment results should show if a wetland is damaged in any way or if it is improving (USEPA 2002a).

2.2 Aquatic Ecological Health and Integrity

Ecological health has been defined as the ability of an aquatic ecosystem to supply goods and services required by both human and non-human residents sustainably (Karr, 1991). Therefore an environment is healthy when the supply of goods and services required by both human and non-human residents is sustained (Karr and Dudley, 1981; Karr, 1987). To be healthy, a wetland should thus be in good condition and able to provide goods and services sustainably. Ecological integrity of a site or habitat on the other hand refers to its ability to support a biota that is a product of evolutionary and biogeographic processes (Karr and Dudley, 1981; Karr, 1991). Biological integrity therefore, is the ability of an aquatic ecosystem to support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity and functional organization comparable to the natural habitats of a region (Karr and Dudley, 1981; Barbour and Yoder, 2000).

Several biological assessment techniques have been used successfully to measure the effects of human activities on the biotic integrity of aquatic systems (Siligato and Bohmer, 2002). Although different taxonomic groups may serve as assessment tools, fish (Faush *et al.* 1990; Moyle and Randall, 1998; Roth *et al.* 1998) and macroinvertebrates (Kerans and Karr, 1994; Bailey *et al.* 1998) have been mainly used as biocriteria to assess the integrity of surface water resources. Iliopoulou-Georgudaki *et al*. (2003) also noted that biological quality can be assessed using other organisms such as; diatoms, riparian and aquatic vegetation.

In many parts of the world, biotic indices have been applied to stream macroinvertebrate community data in order to detect and monitor water pollution and other forms of human impact. These include the Biological Monitoring Working Party (BMWP) score system used in Great Britain (Armitage *et al.* 1983), Stark`s (1985) New Zealand Macroinvertebrate Community Index (MCI), Wisconsin Biotic Index (BI) (Hilsenhoff, 1987) and Family Biotic Index (FBI) (Hilsenhoff, 1988). Indices of this type are calculated by assigning numerical values to individual taxa (species, genera, or families) that reflect their inferred sensitivities or tolerances, and then summing or averaging the values for all taxa or individuals in a sample (Karr *et al.* 1986). Such indices are becoming increasingly popular because they are responsive to different types of anthropogenic impacts (Barton and Metcalfe-Smith, 1992; Carmago, 1993; Resh and Jackson, 1993; Growns *et al.* 1995).

In Europe and U.S.A., the major pieces of legislation protecting the water environment and its component species, biotopes, habitats and ecosystems are increasingly including measures of biological integrity (European Commission, 1992; Kurtz *et al.* 2001). The Water Framework Directive and the Habitats and Species Directive of the European Commission of 1992 highlight a set of estuarine species whose integrity should be protected (Elliott and Hemingway, 2002). Similar technical guidelines to evaluate the suitability of ecological indicators for monitoring programmes in the U.S.A. have been prepared by the Environmental Protection Agency's Office of Research and Development (Kurtz *et al*. 2001).

Multi-metric indices have been defined as numbers that integrate several biological metrics to indicate a site's condition (Karr *et al.* 1986). They are designed to be sensitive to a wide range of characters (physical, chemical and biological) that stress biological systems, and are relatively easy to interpret (Karr and Chu, 1999). Through a multi-metric approach, each metric is given a rating according to whether its value deviates weakly or strongly from values measured in least disturbed ecosystems or sites of a particular type within a region (Karr, 1981; Karr *et al.* 1986; USEPA, 2002a). These ratings (e.g., excellent, moderate, fair and poor) can be used to make decisions on whether the wetland condition indicates that aquatic life is being supported (USEPA, 2002a). The success of multi-metric indexes is largely dependent on choice of metrics that reflects diverse responses of biological systems to human actions (Karr and Chu, 1999). Therefore, the best multi-metric indices combine measures of condition in the individuals, populations, communities, ecosystems, and landscapes (Karr *et al.* 1986).

2.3 Index of Biotic Integrity (IBI)

The Index of biotic integrity (IBI) is an integrative expression of a site's biological condition across multiple metrics and is often composed of at least seven metrics (Karr and Chu, 1999). However, with many different versions now in existence, the IBI is best thought of as a family of related indices rather than a single index (Barbour *et al.* 1999; USEPA, 2002b). The IBI includes attributes of the biota and ranges from individual health to population, community, and ecosystem levels (Karr, 1991). Therefore, IBI can be broadly defined as any index that is based on the sum or ratings of several different measures, termed metrics, with the rating of each metric based on quantitative expectations of what comprises high biotic integrity (Simon and Lyons, 1995). Fish IBIs are therefore models comprising attributes of fish species assemblages, termed as metrics that are used as measures of human disturbances (Fausch *et al.* 1984; Karr *et al.* 1986).

The development and use of indices of biological integrity in evaluation of aquatic habitats' health and integrity date back to 1981 following its use in the assessment of the biological health of fish communities in warm water streams in central Illinois and Indiana (Karr, 1981). The original version had 12 metrics that reflected fish species richness and composition, number and abundance of indicator species, trophic organization and function, reproductive behavior, fish abundance and condition of individual fish (Karr, 1981). Each metric received a score of 5 points if it had a value similar to that expected for a fish community characteristic of a system with little human influence, a score of 1 if it had a value similar to that expected for a fish community that departs significantly from the reference condition, and a score of 3 if it had an intermediate value (Karr, 1981).

This original version of the IBI quickly became popular and has been used by many investigators (Lyons, 1992; Gerritsen *et al.* 1998; McDonough and Hickman, 1999; Karr and Chu 1999; Raburu, 2003; NJDEP, 2004). As the IBI became more widely used, different versions were developed for different regions and different ecosystems. These new versions had a multimetric structure, but differed from the original version in the number, identity, and scoring of metrics (USEPA, 2002b).

New versions were developed for streams and rivers in the central United States, but generally retained most of the metrics used in the original IBI and modified only those few that proved insensitive to environmental degradation in a particular geographic area or type of stream (e.g., Whittier *et al.* 1987; Simon, 1992; Lyons, 1992; Yoder and Rankin, 1995). New versions of IBI developed for streams and rivers in France, Canada, and the eastern and western United States tended to have a different set of metrics (e.g., Steedman, 1988; Oberdoff and Hughes, 1992; Goldstein *et al.* 1994). These reflected the substantial differences in fish fauna between these regions and the Central United States. Similarly, the metrics used in IBI versions developed for other types of ecosystems, such as estuaries, impoundments, and natural lakes, usually bore only a limited resemblance to those of the original version (Hughes *et al.* 1986; Hay *et al.* 1996; Jennings *et al.* 1999; Whittier, 1999) yet retained the ecological structure of the original IBI metrics.

The IBI development procedure using fish assemblages was first used for riverine ecosystems in Kenya by Raburu (2003) and was explored in the present study for lacustrine/wetland ecosystems of Lake Kanyaboli and Lake Sare to come up with metric scores and an overall IBI per lake for their bioassessment and monitoring.

2.4 Bioassessment Assemblages

Indicator species for surveillance need to be able to register subtle, rather than gross and obvious effects of pollution (Mason, 2002). Use of assemblages of organisms allows this more subtle approach. For a biological system to be suitable for a broad survey or monitoring programme, it should exhibit several features including the presence or absence of an organism, which must be related to water quality rather than other ecological factors (Karr, 1991; Mason, 2002). Numerical abundance at some sites, widespread distribution and well-documented ecology are also important factors to take into account in selecting a group of organisms for water quality assessments (Mason, 2002).

Bioassessment in streams indicate that valuable multi-metric indices typically use one or more assemblages for evaluating stream condition, such as macroinvertebrates, fish, and/or periphyton (Barbour *et al.* 1999). Results from wetland IBI development indicate that monitoring a combination of assemblages (e.g., plants and macroinvertebrates) may increase the power of bioassessments in wetlands (Gernes and Helgen, 1999). Wetland bioassessment studies are exploring the use of several assemblages, including algae, amphibians, birds, fish, macroinvertebrates and vascular plants since it is not yet clear which assemblages would work best (USEPA, 2002b). A variety of indicator species have been used to assess wetlands (Danielson, 1998); however, only a few have actually been used to develop and calibrate an IBI (Simon *et al.* 2000).

Resident fish within a wetland ecosystem often play a pivotal role within it, directly and indirectly affecting each other and the organisms on which they prey (Kneib, 1986) and those which feed on them (Lafferty and Morris, 1996). Additionally, residence marsh ichthyofauna play a role in the transfer of energy and nutrients off the marsh surface (Kneib, 1997). Karr (1981) developed an IBI for fish communities in the United States, which included measures of abundance, total species richness, number of various fish functional groups, number of sensitive and tolerant species, trophic composition and a measure of fish condition. A total of 12 metrics were given values of 1, 3 and 5 (trisected) and then summed to produce the IBI, which ranged from 12 to 60. The overall score was considered a measure of the health and integrity of the entire fish community. Later workers have used fish extensively in evaluating aquatic habitats (Simon and Lyons, 1995; Simon and Stewart, 1998).

According to Karr (1987), the qualifications that make wetland ichthyofauna useful as bioindicators are their readily available life history information, their representation of various trophic classes and use of foods from the aquatic and terrestrial sources which provides an integrated view of the catchment and their easy identification with minimal training. Other considerations include the fact that biological integrity can be evaluated rapidly using fish community metrics, the general public can easily interpret the results on fish communities, and that results allow direct assessment of economic resources. Also, acute toxicity (missing fish) and stress effects (depressed growth or reproductive success) can be evaluated. Further, fish are primarily affected by macro-environmental influences, unlike algae and macroinvertebrates that are affected by both micro- and macro-environmental influences and the fact that fish are relatively long-lived; hence provide temporal integration in assessments (Karr, 1987).

Fishes have been successfully used as indicators of environmental quality changes in a wide variety of aquatic habitats (Hickman and McDonough, 1996; Whitfield, 1996; Soto-Galera *et al*. 1998; Kleynhans, 1999; Raburu, 2003). Whitfield (1996) and Soto-Galera *et al.* (1998) outlined numerous advantages of using fish as indicator organisms for environmental bioassessment and monitoring programmes. These includes that fish are typically present in all aquatic systems with the exception of highly polluted waters and the fact that there is extensive life history and environmental response information available for most species. They also suggested that fishes are relatively easy to identify and most samples can be processed in the field with the fishes being returned to the water (non-destructive sampling). Also fish communities usually include a range of species that represent a variety of trophic levels including foods of both aquatic and terrestrial origin. Fishes are also comparatively long-lived and therefore provide a long-term record of environmental stress; they contain many life forms and functional guilds and thus are likely to cover all components of aquatic ecosystems affected by anthropogenic disturbance. They are both sedentary and mobile and thus will reflect stressors within one area as well as providing groups to give a broader assessment of effects. Acute toxicity and stress effects can be evaluated in the laboratory using selected species, some of which may be missing from the study system. Fish have a high public awareness value such that the general public is more likely to relate to information about the condition of the fish community than data on invertebrates or aquatic plants. Societal costs of environmental degradation, including cost-benefit analyses, are more readily evaluated because of the economic, aesthetic and conservation values attached to fishes (Whitfield, 1996; Soto-Galera *et. al*., 1998).

The use of fishes as indicators of biological integrity, however, does pose some difficulties and problems. Whitfield (1996) and Soto-Galera *et al*. (1998) cited the selective nature of sampling gear for certain habitats, sizes and species of fishes, fish mobility on seasonal and diel time scales, which may lead to sampling bias and relative tolerance by fish to substances chemically harmful to other life forms. Also, fishes can swim away from an anthropogenic disturbance, thus avoiding localized exposure to pollutants or adverse environmental conditions while aquatic environments that have been physically altered by humans may still contain diverse fish assemblages. Many of the disadvantages described above are out-weighed by the widespread advantages of using fish as an indicator of biological integrity (Whitfield, 1996). In addition, it should be noted that a number of the negative aspects also applies to other taxonomic groups (e.g., invertebrates) that may be used in biological monitoring of the aquatic environment (Whitfield, 1996; Soto-Galera *et. al*., 1998).

2.5 Reference Conditions

Reference conditions are defined as those conditions during which the sites had minimal exposure to human activities or disturbances and are representative of the water body type and region of interest (Hughes *et. al.*, 1986). They have also been defined as a set of selected measurements or conditions of minimally impaired water bodies, characteristic of a water body type in a region (Lyons *et al.* 1995). More specifically, reference sites may have criteria for *in situ* physical and chemical conditions, riparian conditions, and land use that dictate their inclusion within a reference database. These criteria, which can exclude sites from consideration as reference, vary by water body type and region can be developed either *a priori* or *a posteriori* (Gibson *et al.* 1996). The database of reference sites and the analyses performed in developing and calibrating reference conditions provide an objective framework for determining ecological impairment of the habitats (Stribling *et. al.*, 1998).

The use of historical fisheries data for development of regional reference conditions has been discussed elsewhere (Kurtenbach, 1994). Metrics not included in these data were scored using trisection technique such that the best values observed for each metric, even if they do not come from the highest quality sites are used to develop the expectations and set the scoring criteria (Karr, 1981; Fausch *et al.* 1984; Lyons, 1992). That is, for metrics without reference data, they were delineated such that the best values observed for each metric, even if they did not come from the highest quality sites were used to define the reference expectations and setting the scoring criteria. The method has been found to work best when it has been difficult or impractical to identify least impacted sites (Simon and Lyons, 1995).

2.6 Criticism of the IBI

There has been considerable debate regarding how the IBI or other biological measures can be used to measure impacts on aquatic habitats and what the limitations of these methods are (Yoder and Rankin, 1995). A number of thoughtful criticisms have been drawn on the concept of the IBI on various grounds (Suter, 1993; Yoder and Rankin, 1995). Some of these criticisms relevant to the IBI and counter arguments for the use of the IBI include the concepts of ambiguity, eclipsing, lack of diagnostic results and improper analogy to other indices (Karr *et al.* 1986; Ohio EPA, 1987; Simon and Lyons, 1995). These points are briefly reviewed below.

2.6.1 Ambiguity

It has been argued that indices such as the IBI are too ambiguous to determine why an index value is high or low (Suter, 1993; Yoder and Rankin, 1995). In contrast, the IBI has been suggested to utilize multiple metrics to evaluate the water resource status. The greatest advantage of IBI is that the site score can be dissected to reveal patterns exhibited at the specific reach compared to the reference community (Ohio EPA, 1987). Also, overall site quality can be determined from both the composite score and evaluation of each of the individual metrics, which reduces ambiguity as compared to single metric indices such as the Shannon-Wiener Diversity Index (Simon and Lyons, 1995).

2.6.2 Eclipsing

Index of Biotic Integrity has been suggested to have the inherent likelihood of eclipsing (i.e., metrics canceling each other) between different metrics (Suter, 1993).

Eclipsing of low values of one metric can be dampened by the high values of another metric (Suter, 1993). For example, the density and disease linkage in epidemiology is an interrelated effect, and when toxic chemicals are involved, the disease factor may not be reflective of the density or quality of an otherwise unimpaired community (Suter, 1993). Studies by Ohio EPA (1987) and Karr *et al.* (1986) however, have shown that when the IBI is assessed properly each metric provides relevant information, which determines the position along a continuum of water resource quality. Thus some sites may score well in some areas but poorly in other metrics depending on levels of degradation. Thus the reference condition is critical in determining the least impacted condition for the region (Simon and Lyons, 1995).

2.6.3 No Diagnostic Results

Suter (1993) suggested that one of the most important uses of biological survey data is to determine the cause of changes in ecosystem properties. He further suggested that combining the individual metrics into a single value can result to loss of resolution particularly when attempting to diagnose the responsible entity. However, it has been counter argued that the greatest use of IBI is the ability to discern differences in individual metrics and determine cause and effect using additional information such as habitat, chemical water quality and toxicity information (Karr *et al.* 1986). The inverse however is not apparent when attempting to reduce chemical water quality and toxicity test information into simple predictions of biological integrity based on complex interactions (Simon and Lyons, 1995).

2.6.4 Improper Analogy to other Indices

Since environmental health as a concept has been compared to an economic index, authors have argued that the environmental indices are generally comprehensible and require an act of faith to make informed judgements or decisions (Yoder and Rankin, 1995). In a counter argument, Simon and Lyons (1995) argue that the IBI has greatly improved the decision-making process by removing the subjective nature of past biological assessments. They suggest that by using quantitative criteria (biological criteria) to determine goals of the Clean Water Act (attainable goals and designated uses) the generally comprehensible goals of the IBI enable a linkage between water resource status and biological integrity. This does not require an act of faith; rather it broadens the tools available to water resource managers for screening water body status and trends (Simon and Lyons, 1995).

2.7 Justification for use of the Index of Biotic Integrity (IBI)

Despite these criticisms, IBI is still the most widely used multimetric index in the assessment of biological health of fish communities (Karr *et al.* 1986; Simon, 1998; Barbour *et al.* 1999; Volstad *et al.* 2003) and other assemblage organisms such as invertebrates, amphibians, birds, algae and macrophytes (USEPA, 2002b). Simon (1998) modified and calibrated IBI to assess wetland quality of dunal, palustrine wetlands along the southern shore of Lake Michigan. He examined 36 attributes of wetland fish communities to derive a dunal, palustrine IBI using 12 metrics. He observed that, there was need for modification of IBI for assessment of a particular wetland type, dependent on class, source of human disturbance and the biological reference conditions. Simon, *et al.* (2000) developed an IBI based on crayfish, fish, and amphibian assemblages to assess vernal ponds and palustrine wetland habitats along the southern shore of Lake Michigan. They found out that the modified IBI based on three crayfish, twelve fish and seven amphibian species collected during their survey provided a more complete assessment than one based on any single taxonomic group. Simon and Stewarts (1998) used a newly modified IBI for assessing biological integrity of fish communities in dunal, palustrine wetlands to assess the non-point source influence of an industrial landfill on the Grand Calumet Lagoons (landfill being primarily an iron and steel manufacturers slag waste). They established that the IBI provided an accurate description of the Grand Calumet Lagoons.

Central to many issues facing environmental managers is estimation of habitat quality/condition or the ability of a habitat to support various living resources, both commercial and noncommercial species (Diaz *et. al.*, 2003). The development of fish IBI for Lakes Kanyaboli and Sare was therefore carried out because bioassessment with the use of bioindicators offers the advantage that biological communities reflect overall biological and ecological quality of the aquatic system. Fish also integrate the effects of different stressors, providing a measure of their impact and an ecological measurement of fluctuating environmental conditions (Karr *et al.* 1986).

CHAPTER 3

3.0 MATERIALS AND METHODS

3.1 Description of the study area

This study was carried out in two satellite lakes located within the Lake Victoria basin, Western Kenya, East Africa. The two lakes (Lake Kanyaboli and Lake Sare) form part of the open water bodies in Yala Swamp complex (Figures 1 and 2). Yala Swamp (Figure 1) is an expansive wetland covering an area of approximately 160 km^2 and is located in Bondo, Siaya and Busia Districts (GoK, 1987). It is drained by Hwiro River to the north and Yala River to the south and is separated from Lake Victoria by a sand bar through which the Yala River cuts in many deltaic outflows into the lake. The swamp was formed by the deposition of silt from the Yala River at the point where the river flows into Lake Victoria (GoK, 1987). This freshwater wetland is a combination of seasonally and permanently covered grassland, marshes dominated by a wide range of herbaceous plants and floodplains. It is the largest papyrus swamp in the Kenya section of Lake Victoria (Nasirwa and Njoroge, 1997).

The swamp is inhabited by many fish species, all of which breed within the swamp (Aloo, 2003). These include *Clarias gariepinus, Protopterus aethiopicus, Labeo victorianus* and *Barbus sp.,* but they occur in low numbers (Aloo, 2003). The common rooted vegetation of the swamp is *Cyperus papyrus* and *Phragmites mauritanius*. A rich community of invertebrates and birds is found in the Yala River outlet into Lake Victoria (Mavuti, 1989).

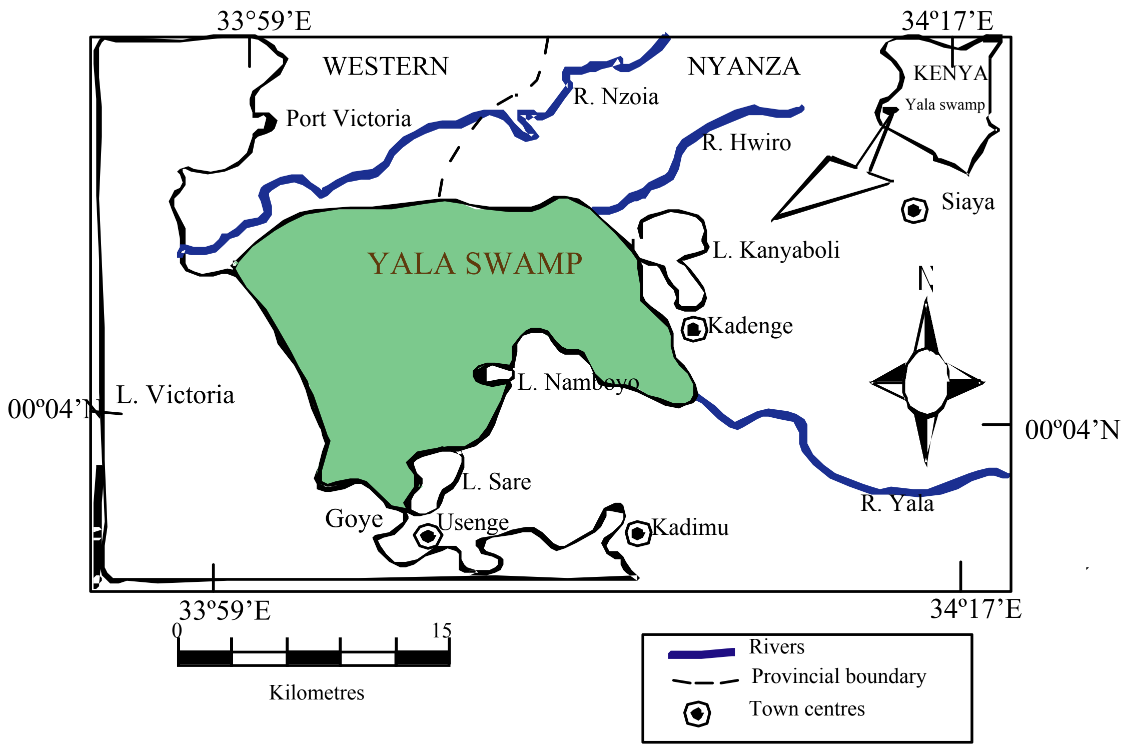


Figure 1. Map of the Yala Swamp and satellite Lakes Kanyaboli and Sare (Adapted from Simonit and Perrings, 2004)

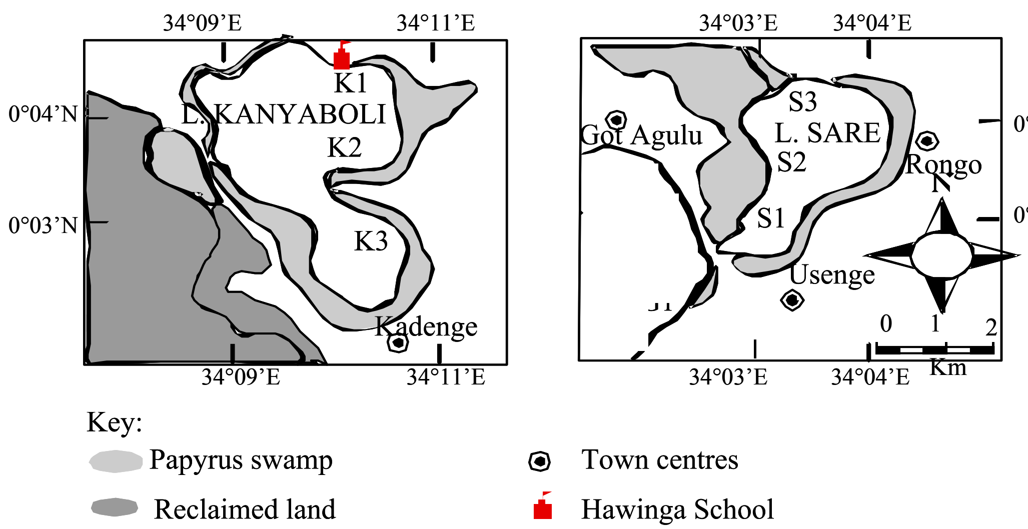


Figure 2. The location of the sampling stations within Lakes Kanyaboli and Sare (Redrawn from Aloo, 2003); K1, K2, K3 are sampling stations within L. Kanyaboli while S1, S2, S3 are sampling stations within Lake Sare.

Threats to the swamp have been noticed to include the draining of the swamp for agricultural production, which is currently being carried out by the Dominion Group of Companies and intensive human pressure to over-use its resources (Ikiara *et al.* 2004).

3.1.1 Lake Kanyaboli

Lake Kanyaboli is a small lake with an area of approximately 10.5 km^2 and a mean depth of 2.7 m (Figure 2). It lies between latitudes 0º05'N and 0º02'N and longitudes 34º09'E and 34º11'E and is located in the northeastern extreme of Yala swamp at an altitude of about 1156 m above sea level (Aloo, 2003). The fish fauna of this lake are unique, being composed of fish species that populated Lake Victoria before the introduction of the *L. niloticus* (Mavuti, 1989). A thick papyrus swamp surrounds the lake, with characteristic floating papyrus islands. Threats to the lake include water hyacinth patches, which have been observed within Yala swamp and could find their way into this lake (Species Survival Programme-SSP, 1994). Others include pressure to over-use its fishery resources through over-fishing and fishing using illegal gears (Aloo, 2003). The lake receives water from its catchment area west of Siaya town, the River Hwiro and back seepage from designated areas of the Yala Swamp (Aloo, 2003). Sampling stations in this lake were selected based on their proximity to the Yala swamp reclaimed area, accessibility and fishers knowledge of the fishing grounds. Three stations K1, K2 and K3 approximately 300-500 m apart were selected in the lake (Figure 2).

3.1.2 Lake Sare

Lake Sare forms part of the outlet of Yala River into Lake Victoria (Figure 1). The lake is about 5 km^2 in area with a mean depth of 1.8 m (Aloo, 2003). It lies between latitude 0º03'S and 0º02'S and longitudes 34º03'E and 34º04'E and is located at an altitude of 1140 m above sea level (Opiyo, 1991). It is also surrounded by papyrus swamp, which merges with the main Yala swamp. The fish fauna of this lake is said to be not as rich as that of Lake Kanyaboli (Aloo, 2003).

The lake receives water from its catchment area within Usenge and direct entry from River Yala. It is faced with similar threats as those faced by Lake Kanyaboli and Yala swamp in general. Sampling stations in the lake were selected based on the same criteria as for L. Kanyaboli. Three stations S1, S2 and S3 approximately 300-500 m apart were selected in this lake (Figure 2).

3.2 Sampling Methods and Laboratory Analyses

Fish samples were collected from all stations in each lake monthly during the short rainy season between mid-October and mid-November 2004 and during the dry season in mid-March 2005.

3.2.1 Fish Sampling

Fish samples were collected from each of the stations at the two lakes using a seine net of 25 mm-mesh size, 2 m deep and 200 m long. Four seine hauls were conducted per station during each sampling. Fish captured were identified to the lowest taxonomic level possible and counted. Fish that were not identified in the field were preserved in 80% ethanol and stored for later identification in the laboratory using appropriate keys (De Vos *et al.* 2003).

In the field, all fish were dissected to remove their stomachs and the stomachs preserved in 80% ethanol in labeled plastic vials. These stomachs were later dissected for gut content analysis in the laboratory. The stomach contents stored in the vials for each fish were emptied onto a petridish and mixed into a homogenous solution using 10ml of distilled water. 1ml of this solution was pipetted into a Sedgewick-Rafter cell for identification of the food items under a light microscope at X100 magnification. Identification of food items was done using appropriate keys for algae (Bellinger, 1992; Sze, 1993), insects (Merrit and Cumins, 1996) and non-insect invertebrates (Webb *et al.* 1978). Percentage frequency of occurrence of the food items was determined according to Hynes (1950) as:

$$\text{\% Frequency of occurrence of food item} = \frac{\text{Number of stomachs with the food item}}{\text{Total number of stomachs analyzed}} * 100$$

The fish were then broadly assigned trophic categories as either generalists, planktivores, insectivores or carnivores based on frequency of occurrence of the food items following the classification criteria of Skriver (2005). Fish were categorized as; planktivores if frequency of occurrence of algae, zooplankton and detritus was greater than 50%, generalists if more than 50% of individuals fed on a variety of food items, insectivores if frequency of occurrence of insects was greater than 50% and carnivore if more than 50% of individuals fed on other fishes.

3.2.2 Physico-chemical Parameters

Three replicate readings of water physico-chemical parameters were taken *in situ* at each station of the two lakes using a digital dissolved oxygen meter (YSI 55) for dissolved oxygen, Secchi disc for Secchi depth, conductivity meter (Model HI 8033) for conductivity and digital thermometer for temperature. Water depth at sampling stations was measured using a calibrated rope. All readings were taken just before seining operation was carried out.

3.3 Fish Community Structure

Fish community structure was assessed using ten fish community attributes under the major categories of: (i) fish abundance, (ii) species composition and diversity, and (iii) trophic composition. The attributes are listed in Table 1.

The following is a description of the components of each of the attributes:

3.3.1 Mean Number of Individuals per Seine Haul

Total number of individuals caught per four seine hauls was determined by enumeration and expressed as number of individuals caught per seine haul at each study site using the equation:

$$\text{Mean no. of individuals per seine haul} = \frac{\text{Total no. of individuals caught in 4 seine hauls}}{\text{4 (No. of seine hauls)}}$$

This metric gives a gross measure of fish production within a site and evaluates population abundance (Raburu, 2003). Generally, sites with lower biotic integrity are associated with fewer individuals hence sites with fewer individuals per seine haul score lower values than those with more individuals.

Table 1. Fish community attributes used to assess the fish community structure of Lakes Kanyaboli and Sare.

Attributes
Fish abundance
1. Number of individuals per seine haul
2. Percentage proportion as *O. esculentus*
3. Percentage proportion as introduced individuals
4. Percentage proportion as native individuals
Species composition and diversity
5. Total number of species
6. Shannon wiener species diversity index (H')
Trophic composition
7. Percent proportion of individuals as planktivores
8. Percent proportion of individuals as generalists
9. Percent proportion of individuals as carnivores
10. Percent proportion of individuals as insectivores

3.3.2 Percentage Proportion as *Oreochromis esculentus*

This was determined by counting the number of *O. esculentus* individuals per seine haul per site per sampling. This was then multiplied by 100 and divided by the total number of individuals caught, to obtain percent proportion as *O. esculentus*. This metric was adopted as a measure of the relative abundance of *O. esculentus*. This species is especially vulnerable to Nile perch predation and competition from introduced tilapiines (Siddique, 1977; Welcomme, 1984). It is indigenous to the satellite lakes. The absence of some fish species in a habitat occurs due to subtle environmental changes caused by anthropogenic disturbances. The historical distribution of *O. esculentus* is significantly greater than that of presently occurring populations and has been currently restricted to satellite lakes where Nile perch has not been introduced and which have fewer introduced tilapiines (Nagayi, 1999). Thus a reduction in the percentage proportion of this species in the catch is associated with low biotic integrity and vice versa.

3.3.3 Percentage Proportion as Introduced Individuals

Introduced species are those that are known not to be native to the Lake Victoria basin and include *Lates niloticus, Oreochromis niloticus, O. leucostictus* and *Tilapia zillii* (Ogutu-Ohwayo, 1990; Ogutu-Ohwayo and Hecky, 1991).

The proportion of introduced individuals in the catches was determined by multiplying the number of introduced individuals by 100 and dividing by the total number of individuals caught to get the percent proportion of introduced individuals. The significance of this attribute for use as a metric is that non-native fishes are generally more successful where native species are depauperate or in anthropogenically altered systems (Barbour et. al., 1999). It is therefore a direct measure of loss of species segregation. Thus an increase in proportions of introduced individuals is associated with lower IBI scores while sites with no introductions get maximum score (Karr, 1991).

3.3.4 Percentage Proportion of Native Individuals

The proportion of native individuals in the catches was determined by multiplying the number of natives by 100 and dividing by the total number of individuals caught to get the percent proportion of native individuals. A higher percentage proportion of native individuals are indicative of an undisturbed or less disturbed ecosystem (Karr *et al.* 1986; Ganasan and Hughes, 1998). Therefore a decline in the relative abundance of native fish translates into a site with a lower biotic integrity while the opposite holds for site with higher proportions of native fishes in the catch.

3.3.5 Total Number of Species

This was determined as a numerical count of the number of fish species represented in a sample collection per site. Thus this metric is simply a measure of the total number of fish species identified from a sample collection. The significance of this metric is that a reduction of taxonomic richness may indicate pollution effects (e.g., organic enrichment, toxicity) and/or physical habitat loss or degradation (Karr *et al.* 1986; Raburu, 2003). Fish species with the least tolerance to environmental change, typically are the first to become absent when environmental degradation occurs. Therefore sites with fewer species have low biotic integrity than sites with more species representations.

3.3.6 Shannon-Wiener Diversity Index (H')

Shannon's index of diversity was calculated using Magurran's (1988) equation:

$$H' = -\sum Ni/N \ln Ni/N$$

Where H'= Shannon-Wiener diversity index

N= Total number of individuals of all species collected,

Ni= Number of individuals belonging to the i^{th} species.

Shannon-wiener diversity index (H') has been suggested to have values usually ranging between 1.5 and 3.5, rarely rising above 4.5 (Magurran, 1988). Lower values of H' are generally characteristic of polluted or stressful conditions, where a few tolerant species dominate the community and higher values are recorded from unpolluted waters (Mason, 2002). Therefore sites that show low Shannon-wiener diversity index values receive a lower score and vice versa.

3.3.7 Percent Proportion of Individuals as Planktivores

The number of planktivores was recorded, divided by total number of individuals caught per site and multiplied by 100 to get percent proportion as planktivores. This metric was used as it is expected to decrease with increased habitat disturbance because it includes species that feed on both phytoplankton and zooplankton which are food to most of the native cichlids in the satellite lakes (Opiyo, 1991; Opiyo and Dadzie, 1994). A lower biotic integrity rating would therefore be associated with a decline in the proportion of planktivorous species and vice versa.

3.3.8 Percent Proportion of Individuals as Generalists

Generalists referred to species that feed on substantial proportion of plants and animal material or on what is more available in their habitat irrespective of their normal food preference. The numbers of generalist individuals per sample were enumerated and divided by the total number of individuals caught per site and multiplied by 100 to get the percent proportion as generalists. This metric is expected to increase with increasing disturbance to the ecosystem reflecting changes in preferred food availability and hence representing lower biotic integrity. Therefore low biotic integrity would be associated with sites having higher proportions of generalists.

3.3.9 Percent Proportion of Individuals as Carnivores

The numbers of carnivores were counted, divided by total number of individuals caught per site and multiplied by 100 to get percent proportion as carnivores. The percentage of individuals as carnivorous species was based on the number of *L. niloticus* that made up the total catch, as it was the only species in this trophic grouping. This metric corresponds to the metric of proportion as piscivores used by Schulz *et al.* (1999) for Florida lakes IBI. An increase in the proportion of carnivorous individuals caught indicate a disturbance to the ecosystem such as native species loss due to predation, or effect of species introductions and hence a lower biotic integrity.

3.3.10 Percent Proportion of Individuals as Insectivores

The numbers of fish that feed on insects were counted, divided by total number of individuals caught per site and multiplied by 100 to get percent proportion as insectivores. Generally, a decline in number or proportion of insectivores indicates impairment to the system. Thus sites with higher proportion of insectivores have higher biotic integrity than those with lower proportions of insectivorous fishes.

3.4 Reference Condition Development

The reference conditions developed and used in this study were obtained from previous studies (Okemwa, 1981; GoK, 1987; Mavuti, 1989; Magurran, 1988). Fish community metrics taken as the reference conditions in the present study are presented in Table 2.

Fish community metrics for which no reference condition was established using historical data were trisected and scored accordingly (see section 3.5.1) assuming that the ranges established included data from disturbed, moderate and undisturbed conditions (Karr, 1981; Fausch *et al.* 1984; Lyons, 1992). That is, metrics without reference data were delineated such that the best values observed for each metric, even if they did not come from the highest quality sites, were used to define the reference expectations and setting the scoring criteria. The method has been found to work best when it has been difficult or impractical to identify least impacted sites (Simon and Lyons, 1995).

3.5 Data Analyses

Functional relationships between fish assemblage attributes and physico-chemical parameters were investigated using Pearson's correlation analysis. This allowed elimination of non-responsive attributes as candidate metrics. That is, an attribute was considered a candidate metric for the IBI development if it related either positively or negatively to the physical and chemical parameters and exhibited significant r-values. Differences in physico-chemical parameters between the lakes was analyzed using pair-wise student t tests with statistical significance being accepted at $p<0.05$.

Table 2. Reference conditions for the fish community attributes as obtained from past studies

Attributes	Reference/baseline condition value	Source
1. Total number of species	23	Okemwa, 1981; Mavuti, 1989.
2. Percentage proportion as *O. esculentus*	64.4	Okemwa, 1981; GoK, 1987.
3. Percentage proportion as Native individuals	100	Lowe-McConnell, 1987
4. Percentage proportion as Introduced individuals	0.00	Expected
5. Shannon-wiener diversity index (H')	3.5	Magurran, 1988

Statistical analysis for t-tests and correlations were done using the MINITAB™ statistical software package (Minitab Version 13.1). Due to heterogeneity of variance in the data (Levene's test, $p<0.05$) and lack of normality (Shapiro-Wilk W test, $p<0.05$) the limnological data was first logarithmically transformed before analysis to meet the statistical requirement of homogeneity of variance and normality. Fish count data and percentage proportions were analyzed for differences between the lakes using non-parametric 2-Sample Wilcoxon tests (Grafen and Hails, 2002) in the Statistical Package for Social Sciences (SPSS) Version 10.0. All statistical analysis followed Zar (1996).

3.5.1 Metric Trisecting and Scoring

Attributes that showed strong and significant correlations with the physico-chemical data qualified as candidate metrics for incorporation in the fish IBI. These were converted into the uneven metric scores of 1, 3 and 5 depending on whether they fell within <33%, 33-67% or >67% of the reference/baseline values or best values observed/expected for each metric respectively. Metrics whose increase in value resulted in decreased biotic integrity (reverse metrics/ negative metrics) were scored such that values in the <33% received a score of 5, values between 33-67%, 3 and values in the top >67% a score of 1. This approach follows that being explored for use in developing biological indictors for national use by the Yala Wetland Task Force (Raburu, 2003). Since no introduced individuals should be present in a biologically undisturbed system, the scoring criterion was set for no introduced individuals as 5, for 1-10% as 3 and greater than 10% non-natives as 1 (Raburu, 2003). The same criterion was applied for carnivores since they were expected to be absent in undisturbed systems in the present study because the metric was based on the introduced *L. niloticus*.

After scoring each of the metrics, the metric scores were summed up to obtain the final IBI score. Habitat integrity classes were then determined with five categories of excellent, good, fair, poor and very poor if the final score fell within 96-100%, 85-95%, 54-84%, 33-53% or <33% of the total expected final IBI score respectively (Simon, 1998; Simon *et al.* 2000).

CHAPTER 4

4.0 RESULTS

4.1 Fish Fauna in Lakes Kanyaboli and Sare

A total of thirteen fish species belonging to seven families were recorded in the two lakes (Table 3). A total of nine species were recorded in Lake Kanyaboli, of which six belonged to family Cichlidae, two to family Clariidae and one to family Protopteridae. Similarly, nine species were recorded in Lake Sare, of which four belonged to family Cichlidae while each of the rest belonged to its own different family as indicated in Table 3.

4.2 Physico-chemical Parameters in Lakes Kanyaboli and Sare

Mean dissolved oxygen (D.O) levels of 7.18±0.09mg/l and 6.79±0.07mg/l were recorded in Lakes Kanyaboli and Sare respectively (Table 4). There were no significant differences in D.O levels between the lakes ($t=-1.8$, $p>0.05$). Secchi depth values indicated that L. Kanyaboli was significantly ($t=93.99$, $p<0.05$) more turbid (0.45±0.01m) than Lake Sare (0.68±0.01m). Conductivity was significantly higher in Lake Kanyaboli (282.2±17.2µS/cm) than in Lake Sare which had lower conductivity of 160.23±5.40µS/cm. Mean temperature values of 24.91±0.38^{o}C and 25.76±0.39^{o}C were recorded in L. Kanyaboli and L. Sare respectively. There was no significant difference in mean temperature between the lakes ($t=0.69$, $p>0.05$). There were significant differences in the mean depth between the lakes ($t=9.89$, $p<0.05$) with Lake Sare being deeper (2.74±0.15m) than Lake Kanyaboli (1.85±0.09m).

Table 3. A checklist of fish fauna sampled in Lake Kanyaboli and Lake Sare during the study period, √- present x- absent from the study site. * indicates introduced species while the rest are natives.

Family	Species	Lake Kanyaboli	Lake Sare
Cichlidae	*Astatoreochromis alluaudi*	√	√
	Astatotilapia nubila	√	√
	Haplochromis maxillaris	√	√
	Oreochromis esculentus	√	x
	*Oreochromis niloticus**	√	√
	Oreochromis variabilis	√	x
Clariidae	*Clarius gariepinus*	√	x
	Clarias leucocephalus	√	x
Protopteridae	*Protopterus aethiopicus*	√	√
Characidae	*Brycinus jacksonii*	x	√
Centropomidae	*Lates niloticus**	x	√
Mochokidae	*Synodontis afrofischeri*	x	√
Mormyridae	*Gnathonemus longibarbis*	x	√

Table 4. Comparison of the physico-chemical parameters between Lake Kanyaboli and Lake Sare for the entire sampling period; ± indicate standard error of the mean (sem)

Parameter	L. Kanyaboli	L. Sare	t-value	p-value
Dissolved oxygen (D.O) (mg/l)	7.18±0.09	6.79±0.07	-1.80	ns
Conductivity (µS/cm)	282.2±17.2	160.23±5.40	21.76	0.0003
Secchi depth (m)	0.45±0.01	0.68±0.01	93.99	0.0001
Temperature (°C)	24.91±0.38	25.76±0.39	0.69	ns
Depth (m)	2.74±0.15	1.85±0.09	9.89	0.006

4.3 Fish Community Attribute Evaluation

A total of nine fish community attributes qualified as candidate metrics following correlation analysis to determine their responsiveness to the physico-chemical water quality data ($p<0.05$; Table 5).

The attribute of percentage proportion as insectivores did not to qualify as a metric because it did not correlate significantly with the physico-chemical parameters (Table 5). Of the nine metrics which qualified, four had significant negative correlations to Secchi depth while three showed significant positive correlations with Secchi depth ($p<0.05$; Table 5). Only three metrics showed significant correlations with conductivity, all being positively correlated except Shannon-Wiener diversity index while three metrics were significantly correlated with depth, of which one (proportion as generalists) showed negative correlation ($p<0.05$; Table 5). Percentage proportion as generalists and total number of species significantly correlated with dissolved oxygen ($p<0.05$; Table 5).

4.3.1 Fish Abundance

4.3.1.1 Mean Number of Individuals per Seine Haul

Lake Kanyaboli recorded the highest mean number of individuals per seine haul (26.22±3.68) while Lake Sare recorded 9.11±0.8 (Figure 3). There was significant difference in the number of individuals per seine haul between Lake Kanyaboli and Lake Sare (Wilcoxon Z=-3.53, $p<0.05$).

Table 5. Pearson's correlation coefficients (r) and p-values for the correlation of fish attributes with physico-chemical parameters at Lakes Kanyaboli and Sare. Superscripts 1, 2, 3, 4, 5 correspond to D.O, Secchi depth, conductivity, depth and temperature respectively, ns indicates not significant.

Attributes	Pearson's r	p-value
Fish abundance		
1. Number of individuals per seine haul	-0.757^{2}	0.003^{2}
2. Percent proportion as *O. esculentus*	-0.883^{2}, 0.741^{3}, 0.665^{4}	0.000^{2}, 0.000^{3}, 0.002^{4}
3. Percent proportion as introduced individuals	0.592^{2}	0.009^{2}
4. Percent proportion as natives	-0.592^{2}	0.009^{2}
Species composition and diversity		
5. Total number of species	0.559^{1}	0.02^{1}
6. Shannon-Wiener diversity index (H')	-0.485^{3}	0.04^{3}
Trophic composition		
7. Percent proportion as planktivores	-0.706^{2}, 0.577^{3}	0.001^{2}, 0.012^{3}
8. Percent proportion as generalists	0.618^{2}, -0.548^{4}, 0.577^{1}	0.001^{2}, 0.02^{4}, 0.01^{1} ,
9. Percent proportion as carnivores	0.738^{2}	0.004^{2}
10. Percentage proportion as insectivores	0.04^{1}, 0.41^{2}, -0.31^{3}, 0.12^{4},0.30^{5}	$\text{ns}^{1,2,3,4,5}$

Mean number of individuals per seine haul showed significant correlations with Secchi depth ($r = -0.757$, $p<0.05$) (Table 5). Lake Kanyaboli scored a value of 3 for this metric while Lake Sare received a score of 1 out of the expected score of 5 (Tables 6 and 7).

4.3.1.2 Percentage Proportion of Individuals as *Oreochromis esculentus*

Oreochromis esculentus was recorded in Lake Kanyaboli only making up a proportion of 59.13% of the total catch in the lake.

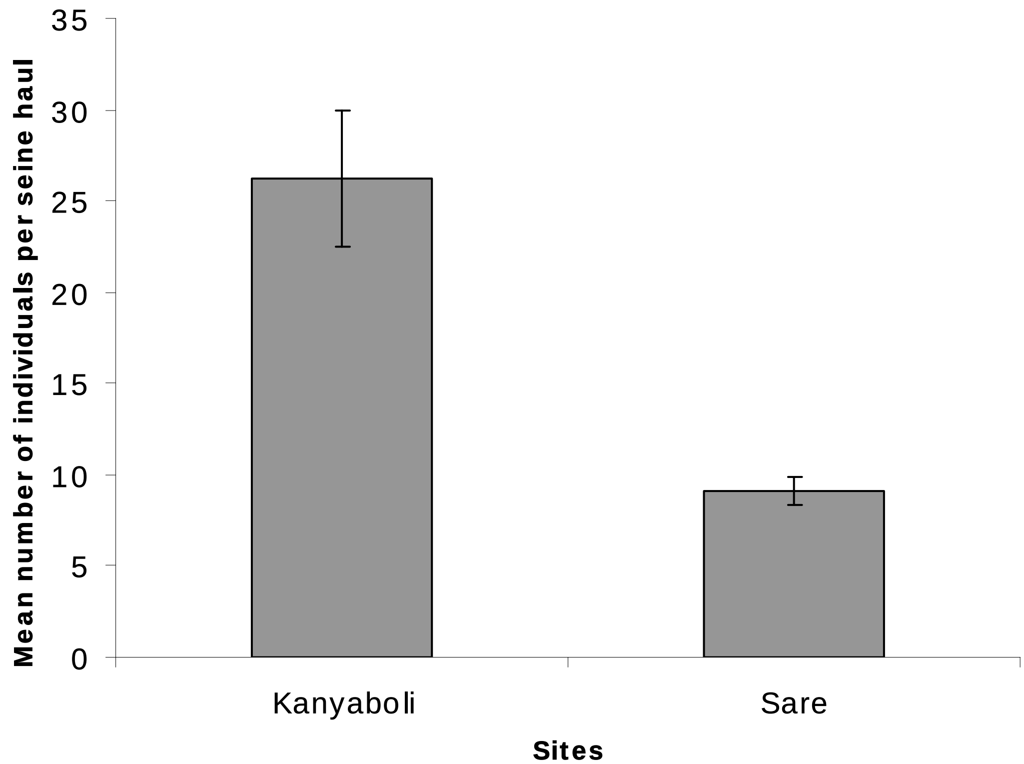


Figure 3. Mean number of individuals per seine haul at Lake Kanyaboli and Lake Sare (error bars represent ± standard error of the mean)

Table 6. Metrics, reference values, scoring criteria, individual score per metric and overall IBI score for Lake Kanyaboli

Metric	**Current value**	**Reference value**	**SCORING CRITERIA 1**	**3**	**5**	**IBI SCORE**	**Total expected score**
Fish abundance							
1. Number of individuals per seine haul	26	42	<14	14-28	>28	3	5
2. Percentage individuals as *O. esculentus*	59.13	68.12	<33	33-67	>67	3	5
3.Percentage of individuals as introduced	2.45	0.00	>10	1-10	0.00	3	5
4. Percentage of individuals as natives	97.55	100	<33	33-67	>67	5	5
Species composition and diversity							
5. Total number of species	9	23	<8	8-15	>15	3	5
6. Shannon-Wiener Diversity (H')	1.00	3.5	<1.2	1.2-2.3	>2.3	1	5
Trophic composition							
7. Percentage as planktivores	96.04	94	<33	33-67	>67	5	5
8. Percentage as generalists	3.96	3.96	>67	33-67	<33	5	5
9. Percentage as carnivores	0.00	0.00	>10	1-10	0.00	5	5
TOTAL IBI SCORE						**33**	**45**

Table 7. Metrics, reference values, scoring criteria, individual score per metric and overall IBI score for Lake Sare

Metric	**Current value**	**Reference value**	**SCORING CRITERIA 1**	**3**	**5**	**IBI SCORE**	**Total expected score**
Fish abundance							
1. Number of individuals per seine haul	9	42	<14	14-28	>28	1	5
2. Percentage individuals as *O. esculentus*	0.00	68.12	<33	33-67	>67	1	5
3. Percentage of individuals as introduced	24.1	0.00	>10	1-10	0.00	1	5
4. Percentage of individuals as natives	75.9	100	<33	33-67	>67	5	5
Species composition and diversity							
5. Total number of species	9	23	<8	8-15	>15	3	5
6. Shannon-Wiener Diversity index (H')	1.24	3.5	<1.2	1.2-2.3	>2.3	3	5
Trophic composition							
7. Percentage as planktivores	41.8	94	<33	33-67	>67	3	5
8. Percentage as generalists	15.5	3.96	>67	33-67	<33	5	5
9. Percentage as carnivores	20.7	0.00	>10	1-10	0.00	1	5
TOTAL IBI SCORE						**23**	**45**

Pearson's correlation analysis indicated significant correlation between percentage proportion as *O. esculentus* and Secchi depth (r=-0.883, p<0.05), depth (r=0.665, p<0.05) and conductivity (r= 0.741, p<0.05) (Table 5). Lake Kanyaboli scored 3 while Lake Sare received a score of 1 for this metric (Tables 6 and 7).

4.3.1.3 Percent Proportion as Introduced Individuals

Lakes Sare and Kanyaboli recorded 24.1% and 2.45% as introduced individuals respectively (Figure 4). Percentage proportion as introduced individuals differed significantly between the two lakes (Wilcoxon Z=2.77, p<0.05). There was significant correlation between percent individuals as introduced and Secchi depth (r=0.592, p<0.05). Lake Kanyaboli scored 3 and Lake Sare scored 1 for this metric (Tables 6 and 7).

4.3.1.4 Percent Proportion as Native Individuals

The native species recorded in Lake Kanyaboli included *O. esculentus, O. variabilis, Haplochromis maxillaris, Astatotilapia nubila, Astatoreochromis alluaudi, Clarias gariepinus* and *Protopterus aethiopicus* (Table 3). Together, all natives made up 97.55% of the total catch in the lake (Figure 4). Lake Sare recorded percentage proportion as native individuals of 75.9%. These consisted of *Brycinus jacksonii, H. maxillaris, A. nubila, Synodontis afrofischeri,* and *Protopterus aethiopicus* (Table 3).

Percentage of individuals as natives differed significantly between the sites (Wilcoxon Z=-2.77, p<0.05).

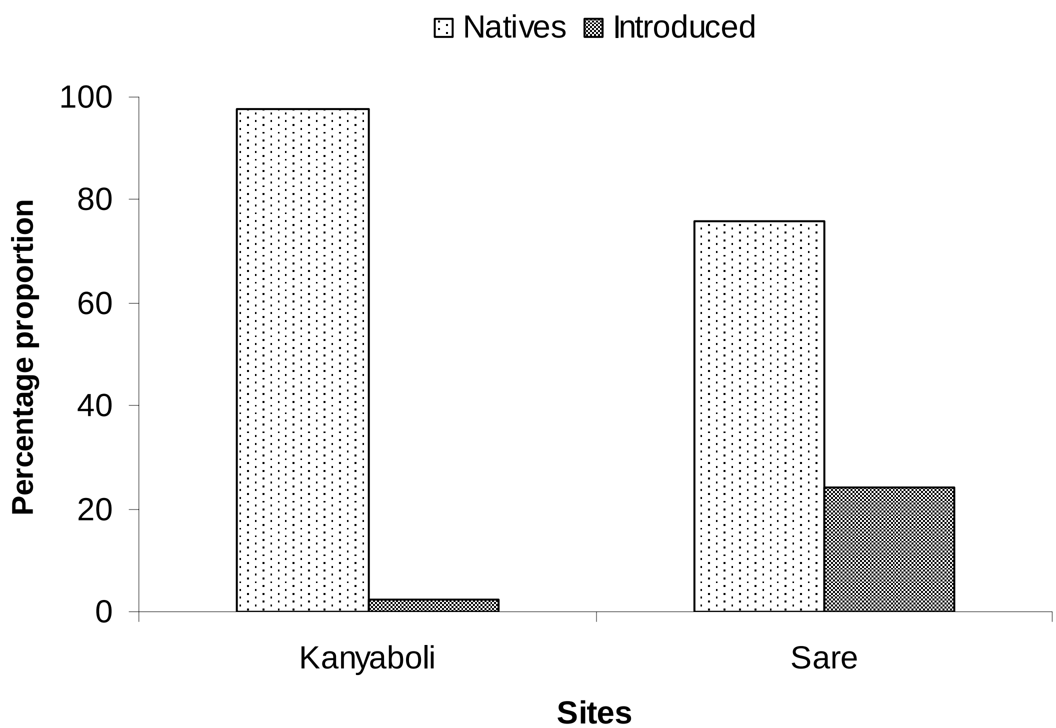


Figure 4. Percentage proportion of catch as introduced and native individuals at Lake Kanyaboli and Sare

There was significant correlation between percent individuals as natives and Secchi depth ($r=-0.592$, $p<0.05$) and depth ($r=-0.514$, $p<0.05$) (Table 3). Lakes Kanyaboli and Sare scored IBI values of 5 each for this metric (Tables 6 and 7).

4.3.2 Species Composition and Diversity

4.3.2.1 Total Number of Species

A total of 9 fish species were recorded from Lakes Kanyaboli and Sare. Total number of species indicated significant correlation with dissolved oxygen ($r=0.559$, $p<0.05$; Table 5). Lakes Kanyaboli and Sare scored 3 each for this metric (Tables 6 and 7).

4.3.2.2 Shannon's Diversity Index (H')

Lake Sare had a higher Shannon-Wiener diversity index of 1.24 while L. Kanyaboli had a value of 0.99. Pearson's correlation analysis indicated significant correlation between Shannon-Wiener diversity index and conductivity ($r=-0.485$, $p<0.05$; Table 5). Lake Sare scored 3 while Lake Kanyaboli scored 1 for the metric (Tables 6 and 7).

4.3.3 Trophic Structure

Fish species from the two study sites fell into one of the four main trophic categories of planktivores, generalists, insectivores or carnivores (Table 8). *Oreochromis esculentus*, *Haplochromis maxillaris*, *Astatotilapia nubila*, and *Astatoreochromis alluaudi* were categorized as planktivores; *Oreochromis niloticus* and *Clarias gariepinus* as generalists; *Brycinus jacksonii* and *Synodontis afrofischeri* as insectivores; and *Lates niloticus* as carnivore (Table 8).

Table 8. Trophic categories of the fish species sampled from all the sites during the study period

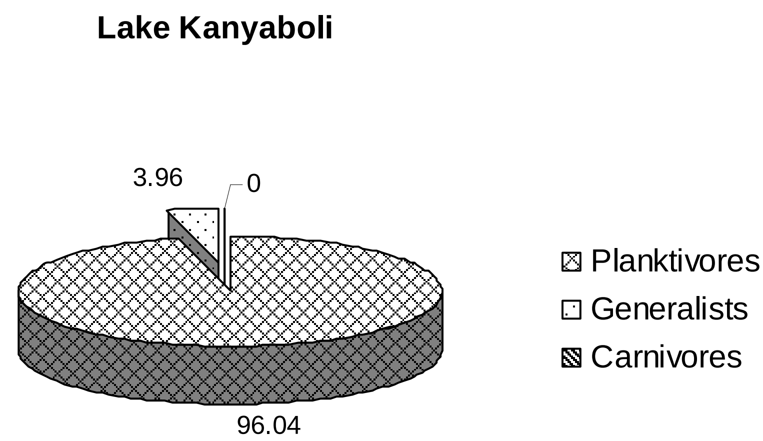
Fish species	Frequency of occurrence of the food items, %							Sample size, n
	Algae	Detritus	Zooplankton	Other fish	Insects	Molluscs	Category	
Oreochromis esculentus	100.00	100.00	71.43	0.00	28.57	0.00	Planktivore	35
Oreochromis niloticus	100.00	100.00	41.33	63.22	40.44	49.44	Generalist	60
Haplochromis maxillaris	100.00	100.00	63.88	12.50	32.38	0.00	Planktivore	68
Astatotilapia nubila	100.00	100.00	85.00	0.00	75.00	0.00	Planktivore	30
Astatoreochromis alluaudi	100.00	100.00	83.33	0.00	35.83	0.00	Planktivore	22
Brycinus jacksonii	31.43	22.86	37.14	0.00	100.00	0.00	Insectivore	35
Clarias gariepinus	100.00	100.00	60.00	80.00	100.00	60.00	Generalist	5
Lates niloticus	11.76	58.82	100.00	76.47	70.59	82.35	Carnivore	17
Synodontis afrofischeri	25.00	83.33	91.67	0.00	100.00	0.00	Insectivore	12

4.3.3.1 Percentage Proportion as Planktivores

A higher proportion of catch as planktivores (96.04%) was recorded in Lake Kanyaboli while Lake Sare recorded 41.8% (Figure 5). Percentage proportion as planktivores differed significantly between the lakes (Wilcoxon Z= -2.83, $p<0.05$). Pearson's correlation analysis indicated significant correlations between percent proportion as planktivorous individuals and Secchi depth ($r= -0.706$, $p<0.05$) and conductivity ($r=0.577$, $p<0.05$) (Table 5). Lake Kanyaboli scored a value of 5 while Lake Sare scored a 3 (Tables 6 and 7).

4.3.3.2 Percentage Proportion as Generalists

Lake Sare and Kanyaboli had 15.5% and 3.96% of catch as generalists respectively (Figure 5). There were significant differences between the lakes (Wilcoxon Z=3.44, $p<0.05$). Percentage proportion as generalists showed significant correlation with Secchi depth ($r= 0.618$, $p<0.05$), depth ($r=-0.548$, $p<0.05$) and dissolved oxygen ($r=0.571$, $p<0.05$) (Table 5).



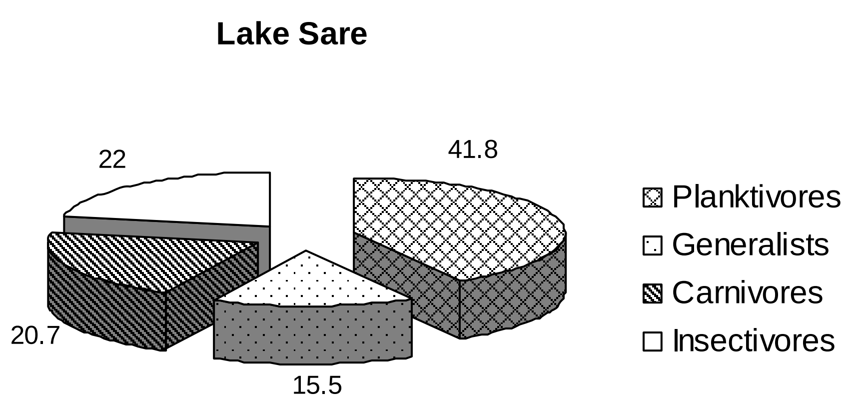


Figure 5. Fish trophic composition of Lake Kanyaboli and Lake Sare based on the trophic categories that were established in this study. The values shown indicate percentage proportions based on individuals at each site

Lakes Kanyaboli and Sare scored the expected metric score value of 5 for this metric (Tables 6 and 7).

4.3.3.3 Percentage Proportion as Carnivores

Lake Sare recorded a higher proportion as carnivores (20.7%) while Lake Kanyaboli had no carnivorous species (Figure 5). There was significant correlation between percent proportion as carnivores and Secchi depth ($r= 0.776, p<0.05$) (Table 5). Lake Kanyaboli scored a value of 5 and Lake Sare 1 for this metric (Tables 6 and 7).

4.3.3.4 Percentage Proportion as Insectivores

Insectivorous fish were recorded in Lake Sare only and constituted 22% of the catch in this lake (Figure 5). There was no significant correlation between percent proportion as insectivores and any of the physico-chemical parameters (Table 5). Therefore this attribute was not used in IBI development.

4.4 Index of Biotic Integrity (IBI) Score Rating and Integrity Classes

Following the individual metric scores and the final IBI score by site as presented in Tables 6 and 7, a higher overall IBI score value of 33 was recorded for Lake Kanyaboli out of the maximum expected score value of 45 while for Lake Sare an overall IBI score of 23 was recorded. Five integrity classes and their narrative description as was established in the present study are indicated in Table 9. Lake Kanyaboli fell in the fair biotic integrity class while Lake Sare was categorized in the poor biotic integrity class.

Table 9. Total IBI scores, their integrity classes and narrative description based on the present study

Total IBI score (sum of the nine integrity metric ratings) and sites	**Class**	**Narrative description**
43-45	Excellent	Condition that is comparable to the best situation that may have been there before species introductions and with species that used to populate L. Victoria especially *O. esculentus, O. variabilis* and the haplochromines.
38-42	Good	Condition indicative of low biotic integrity with less than the expected number of species of the native *O. esculentus, O. variabilis* and haplochromines.
24-37 (Lake Kanyaboli, 33)	Fair	Dominance by the native *O. esculentus* and fewer haplochromines and presence of introduced individuals, mainly *O. niloticus*.
15-23 (Lake Sare, 23)	Poor	Dominated by generalist individuals, mainly *O. niloticus*, few top carnivores and lower abundance of native individuals such as haplochromines. No *O. esculentus*
<15	Very poor	Dominated mostly by the introduced *L. niloticus* and *O. niloticus* Complete absence of *O. esculentus* and very few haplochromine species encountered.

CHAPTER 5

5.0 DISCUSSION

Nine fish community metrics were found to be potential indicators for the biotic integrity of Lakes Kanyaboli and Sare. The applicability and limitations of these metrics and the IBI developed herein for bioassessment of the two lakes are discussed below.

5.1 Fish Abundance

5.1.1 Number of Individuals per Seine Haul

The negative association of number of individuals with Secchi depth would be expected, perhaps reflecting the fact that the fish benefits from low turbidity either by increased visibility for visual foragers and/or predator avoidance. Similar correlations have been reported by Jordan and Vaas (2000) in their development of an index of ecosystem integrity for Northern Chesapeake Bay. A decline in the total number of individuals caught per seine haul is a potential indicator of disturbance to the ecosystem such as physical habitat loss, over-fishing, or pollution and hence a lower biotic integrity rating for the system (NJDEP, 2004).

An intermediate score of 3 was recorded in Lake Kanyaboli while Lake Sare recorded a low IBI score value of 1 (Tables 6 and 7). This scenario could be attributed to two possibilities. First, the fact that much of the catch recorded in this study was dominated by the native species, *O. esculentus* and the haplochomines (especially *H. maxillaris*) that dominated Lake Kanyaboli and which were absent or caught in fewer numbers in Lake Sare. Secondly, gear selectivity may account for catch differences between sites, however this option is inapplicable to this study because the same gear was used at all the sites. This study utilized seining technique for sampling since the gear is efficient for sampling a larger percentage of fish (Seegert, 2002a; 2000b) hence gear selectivity cannot account for differences between stations. The first case on dominance by native species confirms earlier studies on biodiversity of these lakes, which indicate that the native *O. esculentus* and some haplochromines that disappeared from Lake Victoria (Bruton, 1990; 1995; Calamari *et al.* 1992; Chapman *et al.* 1996) are still present in the satellite lakes (Chapman *et al.* 1996; De Vos *et al.* 2003). However, Lake Kanyaboli did not score the highest possible score of 5 perhaps due to the effects of fishing pressure (which is uncontrolled) on *O. esculentus* (SSP, 1994; Aloo, 2003).

Therefore the results of this study based on this metric would be reflective of changes in the biotic integrity of the two sites possibly due to factors other than Secchi depth that it correlated with. These may include the effect of *Lates niloticus* that was observed in Lake Sare and over-fishing as has been reported in Lake Kanyaboli (SSP, 1994; Aloo, 2003).

5.1.2 Percentage Proportion as *Oreochromis esculentus*

The percentage proportion of catches as *O. esculentus* correlated negatively and significantly with Secchi depth, but positively with depth and conductivity. The negative association of this species with Secchi depth perhaps reflect the fact that *O. esculentus* (categorized as a planktivore) benefits from low turbidity either by making them less visible to predators (such as the generalist *O. niloticus* and *C. gariepinus* which also feed on other fish) or by indirectly representing higher food concentrations (phytoplankton and zooplankton).

The use of metrics based on fish species presence-absence data has been emphasized for studies examining ecological integrity (Jackson and Harvey, 1997). Some studies on Lake Victoria (Ogutu-Ohwayo, 1990, 1992; Miller, 1989; O'Riordan, 1996) have attributed the absence of *O. esculentus* in Lake Victoria partly to the introduction of *L. niloticus,* during the 1950s and invasion by water hyacinth, *Eichhornia crassipes* in 1990s. Further, *O. esculentus* has been suggested to be easily fed on by *L. niloticus* (Ogutu-Ohwayo, 1991). Therefore their absence in Lake Sare may partly be attributed to the presence of *L. niloticus,* apart from overfishing and competition from the introduced tilapias. Anthropogenic activities such as overfishing and pollution have also been partly held responsible for the decline of the multispecies fishery and ecosystem integrity of Lake Victoria (Craig, 1992; Kaufman and Ochumba, 1993). This may be the case in Lake Kanyaboli, which despite being the only site with *O. esculentus* did not score the maximum score of 5. Therefore absence-presence metrics such as that of percentage proportion as *O. esculentus* provide useful information for evaluating biotic integrity of these lakes.

5.1.3 Percentage Proportion as Introduced Fish

The percent proportion as introduced species correlated positively and significantly with Secchi depth. The positive association of predatory species such as *L. niloticus* with Secchi depth is expected, which could be related to the fact that the fish benefits from high transparency because they are visual predators. Piscivorous fishes have been suggested to detect and attack prey by use of vision (Lowe-McConnell, 1987), therefore high transparency facilitates prey detection and capture. On the other hand, *O. niloticus* being a generalist could probably feed in both turbid and clear waters as it forages for different prey items.

Lake Kanyaboli scored an intermediate value of 3 (Table 6) while Lake Sare recorded a low IBI score of 1 (Tables 7). This could be attributed to the fact that the metric composed of the introduced *O. niloticus* and *L. niloticus* that dominated Lake Sare but which were few or absent in Lake Kanyaboli. Presence of more introduced species can be a sign of loss of biotic integrity due to decline in native fish fauna that used to populate the affected sites. For example, stocks of introduced species were recorded to have increased rapidly between 1971 and 1983 followed by a decline and in some cases total disappearance of some of the native species in Lake Victoria (Ogutu-Ohwayo, 1990, 1992; Witte *et al.* 1992). Also, about 200 out of an estimated 300+ species of haplochromines are believed to have disappeared from the lake, this being attributed to *L. niloticus* as haplochromines formed its main food in Lake Victoria (Gee, 1964, Ogutu-Ohwayo, 1990). This scenario may possibly apply to the observed situation in satellite Lake Sare where *L. niloticus* has been observed and recorded. Therefore the presence of the introduced *L. niloticus* could be associated with a decline in the abundance of natives and hence a lower biotic integrity. This is also supported by the fact that interactions between natives and introduced species have been implicated in extirpations of indigenous fishes in many regions (Rosenfield and Mann, 1992; Welcomme, 1988; Pollard, 1989). In particular, it has been suggested that the introduced and native tilapiines have similar feeding requirements, with the introduced *O. niloticus* having a wider food spectrum than the native tilapiines (Ogutu-Ohwayo, 1990). These species, especially *O. niloticus*, seem to have contributed to the displacement of native tilapiines through competition and/or hybridization with *O. niloticus* displacing other tilapiines from waters to which it has been introduced (Siddique, 1977; Welcomme, 1984).

As earlier indicated, an increase in the total number of introduced species would be indicative of disturbance to the ecosystem that may include physical habitat loss by the native species, predation effects, or change in trophic status for the native fish fauna due to competition from the introduced fish, and hence a lower biotic integrity. This metric has been applied by different researchers using the same premise of low integrity at higher proportions of introduced individuals. For example, Hickman and McDonough (1996) used percent individuals that are exotic species for IBI development for reservoirs in the Tennessee River Valley. Similarly, Minns *et al.* (1994) also modified Karr's (1981) metric of introduced species in developing an IBI for the littoral zone areas of concern in the Great lakes, with the index showing a similar effect of the IBI score declining as the number of exotic fish species increased.

5.1.4 Percent proportion as Native Fish

The negative association of this metric with Secchi depth may be due to the fact that possibly most of the native species benefit from low turbidity either by making them less visible to predators or by indirectly representing higher food concentrations (phytoplankton and zooplankton). Lakes Kanyaboli and Sare scored the expected maximum metric score value of 5. This could be attributed to higher numbers of indigenous species which are still observed in the satellite lakes (Aloo, 2003). A higher percentage proportion of native individuals are indicative of an undisturbed or less disturbed ecosystem (Ganasan and Hughes, 1998). Therefore a decline in the relative abundance of native fish due to factors such as physical habitat loss, predation effects, or change in trophic status for the native fish fauna would result in a lower biotic integrity. Scott and Hall (1997) used the metric of percent individuals that are indigenous species for IBI development for coastal streams in Maryland. They attributed higher quality sites to presence of a more balanced assemblage structure and trophic composition as well as by higher indigenous cyprinid richness and abundance. This premise supports the use of the metric of native individuals in this study with higher numbers of natives being associated with higher biotic integrity. This metric was found to be useful in evaluating the biotic integrity of the sites in this study (see Tables 6 and 7). The metric has been used by various studies towards IBI development (Schulz *et al.* 1999; Ohio EPA, 1987; Steedman, 1988) all attributing a decline in natives to low biotic integrity as was found in the present study. Therefore the use of this metric to diagnose sites with impaired integrity was found to be ecologically relevant.

5.2 Species Composition and Diversity

5.2.1 Total Number of Species

This metric has been suggested to be a measure of the species richness component of diversity (Pielou, 1975). Both Lakes Kanyaboli and Sare scored the intermediate metric score value of 3 which is lower than the expected IBI metric score of 5 suggesting a possible loss of some species from these sites.

It has been hypothesized that a decrease in number of species occurs with increased degradation (Karr *et al.* 1986; Oberdoff and Hughes, 1992). This hypothesis was consistent with the findings of the present study since a reduction in the total number of species was associated with low biotic integrity. The metric of total number of species is common to almost every IBI developed in streams (Karr *et al.* 1986, Leonard and Orth, 1986; Raburu, 2003), lakes (Whittier, 1999; Jennings *et al.* 1999) and reservoirs (Jennings *et al.* 1995). Whittier and Hughes (1998) have successfully used the metric of species richness for lakes in the Northeastern United States. The metric score was found to decline as the species richness reduced and hence a low IBI. Other workers have also applied this metric to running water systems (Karr *et al.* 1986; Fausch *et al.* 1984, 1990; NJDEP, 2004) and wetlands (Gernes and Helgen, 1999). The number of species in a sample is expected to decline or reduce to indicate a disturbance to the ecosystem, thus the use of the metric to indicate degradation. These makes the use of this metric relevant since a loss of species was associated with destructive anthropogenic activities that may include introduction of *L. niloticus*, overfishing and swamp reclamation which impact negatively to the sites' ecological integrity and therefore possible loss of some species.

5.3 Trophic Structure

5.3.1 Percentage Proportion as Planktivores

Percentage proportion of planktivorous species correlated negatively and significantly with Secchi depth and positively with conductivity. The negative association of proportion of planktivores with Secchi depth is expected, perhaps reflecting the fact that planktivorous fish benefits from low/moderate turbidity either by making them less visible to predators (e.g., *Clarias gariepinus*) or by indirectly representing higher food concentrations such as zooplankton and phytoplankton.

The low biotic integrity recorded at Lake Sare for this metric could be attributed to the fact that the metric comprised mainly of *O. esculentus* and *H. maxillaris*, which occurred in higher numbers in Lake Kanyaboli but were less abundant in Lake Sare. The percent of individuals as planktivores was expected to increase as an indicator of no or little disturbance to the ecosystem's biotic integrity. A lower biotic integrity rating would therefore be associated with a decline in the proportion of planktivorous species. This compares well with the specialized insectivore metric where a reduction in these led to low IBI scores in streams (Leonard and Orth, 1986).

5.3.2 Percentage Proportion as Generalists

The proportion of individuals as generalists correlated positively and significantly with Secchi depth and dissolved oxygen but negatively with water depth. The positive association of generalist species with Secchi depth would possibly indicate the fact that fish benefits from high transparency probably by making them see clearly through the water in search of food. The positive association with dissolved oxygen is expected of all fish species, as oxygen is essential for their body functioning and respiration (Lowe-McConnell, 1987). The negative association with depth is likely indicative of how this generalist species prefer clear or fairly transparent waters as evidenced in the positive association with Secchi depth. Lakes Kanyaboli and Sare scored the expected maximum (Tables 6 and 7). This could be attributed to the fact that generalist species were dominated by the introduced *O. niloticus* that were caught in fewer numbers in Lakes Kanyaboli and Sare.

Many researchers have used the metric of percent proportion as generalists in IBI development. For example, it has been applied in streams and rivers (Karr, 1981; Karr *et al.* 1986; Leonard and Orth, 1986; Steedman, 1988), lakes (Minns *et al.* 1994) and reservoirs (Jennings *et al.* 1995). Often, a shift from predominantly specialist groups to generalist groups has been suggested to occur, as water quality becomes degraded (Leonard and Orth, 1986; Ohio EPA, 1987). Due to broad feeding and habitat requirements, species included in this metric are considered tolerant of environmental degradation (Karr, 1981; NJDEP, 2004). This is because generalist groups have broad feeding and habitat requirements; hence their inclusion in the IBI would indicate tolerance to environmental degradation and therefore low IBI scores.

An increase in the percentage of individuals as generalists in this study was an indication of disturbance to the ecosystem such as changes in food availability and hence represented lower biotic integrity. This compares well with a study by Jennings *et al.* (1999) who used the metric of percent of individuals that are generalists for an IBI for inland lakes in Wisconsin where the IBI score declined as the percentage proportion of generalists increased. This metric replaced the omnivore metric used in the original IBI (Karr, 1981).

5.3.3 Percentage Proportion as Carnivores

The percentage proportion as carnivorous species was based on the number of *L. niloticus* that made up the total catch. The percentage of individuals as carnivorous species correlated positively and significantly with Secchi depth. The positive association of carnivores with Secchi depth could be due to the fact that being a visual predator, *L. niloticus* probably benefits from high water transparency by making them see their prey and hence forage efficiently (visual feeders).

A lower biotic integrity based on percentage of individuals as carnivorous species was recorded at Lake Sare while Lake Kanyaboli scored the expected score of 5 (Tables 6 and 7). This could be attributed to the fact that since only *L. niloticus* was used to come up with this metric its presence in Lake Sare could be responsible for the lower biotic integrity compared to Lake Kanyaboli where it was absent. This finding supports studies that have implicated the presence of *L. niloticus* as a possible cause of the absence or elimination of *O. esculentus* and *O. variabilis*, which are still present in Lake Kanyaboli (Okemwa, 1981; Benda, 1981; Opiyo, 1991; Opiyo and Dadzie, 1994; Aloo, 2003). Therefore the presence of *L. niloticus* is a possible indicator of change in the native fish fauna community and hence changes in biotic integrity of the two sites where this species occurred. The ability to discriminate between sites with invasive species (*L. niloticus*) from sites without this species makes this metric ecologically relevant with low scores for sites with more carnivores and vice versa. This metric corresponds to the metric of proportion as piscivores used by Schulz *et al.* (1999) for Florida lakes IBI and that used by NJDEP (2004) for assessment of New Jersey streams. An increase in the proportion of carnivorous individuals caught indicate a disturbance to the ecosystem such as native species loss due to predation, or effect of species introductions and hence a lower biotic integrity, thus the usefulness of this metric.

5.4 Interpretation and Conservation Application of the IBI

The preliminary fish IBI developed in this study and the individual metrics significantly correlated with three of the physico-chemical parameters (i.e. conductivity, Secchi depth, and depth). The IBI could therefore be described as a potential indicator of changes in these parameters, mainly Secchi depth, site depth and conductivity or probably an interaction of these parameters with others that were not explored in this study. This compares well with some of the studies done on natural lakes by Hughes *et al.* (1998), Whittier, (1999) and Drake and Pereira, (2002) to come up with metrics and an IBI for evaluating the biotic integrity using fish communities. It also compares well with studies that have been carried out on streams, which have successfully correlated IBI scores with human activities, including sewage effluent (Karr *et al.* 1986), mining activities (Leonard and Orth, 1986) and urbanization and riparian zone destruction (Steedman, 1988). The index developed in this study based on the nine metrics could therefore be a preliminary estimate of the current biotic integrity of these sites. The overall interpretation of the IBI is that Lake Kanyaboli was described as of fair biotic integrity while Lake Sare was described as being of poor biotic integrity (Table 9).

The management implication of these IBI scores is that although Lake Kanyaboli and Lake Sare have been suggested to contain some of the native fish species that disappeared from Lake Victoria (Opiyo, 1991; Mavuti, 1989; Aloo, 2003), they are still under threat from human activities. Thus L. Sare is more impacted than Lake Kanyaboli. A decline in biotic condition as a result of swamp reclamation and uncontrolled fishing is unavoidable; however it is necessary to develop mitigation programs to improve on the IBI scores of these sites. Therefore the challenge is how to turn around the situation on the ground to reverse continued degradation and improve on the IBI scores of these sites. Development of IBI for tropical ecosystems such as that of the Lake Victoria basin faces the constraint of lack of baseline information from which to construct indices (Okeyo-Owuor, 1998). The application of the IBI in the management of the sites is therefore faced with the limitation of information such as the biology, ecology and systematics of fish in the region, which is inconsistent while information on species sensitivity to general disturbance is missing (Raburu, 2003). The IBI developed in this study for the two lakes may therefore need refining using further studies to establish tolerance limits and associations of the fishes to other limnological parameters to facilitate accurate predictions of biotic integrity. Since there are several expected impacts from reclamation of Yala Swamp for agricultural development activities (Kenya Land Alliance, 2005), the fish based index of biotic integrity (IBI) developed in this study is recommended as a starting point towards bioassessment and monitoring of the satellite lakes towards mitigation process which would result to improvement of their ecological systems hence their biotic integrity.

CHAPTER 6

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

1. This study demonstrated that metrics derived from fish assemblages in the two lakes have potential use in describing the biotic integrity of these aquatic habitats. This is due to the differences observed for the IBI score values for the two sites and hence rejection of the first and fourth null hypotheses. This is a step forward towards IBI development as a bioassessment and monitoring tool for the Lake Victoria basin satellite lakes.
2. The fish index of biotic integrity and its component metrics were sensitive to changes in fish community structure and were capable of detecting differences in some of the physico-chemical parameters especially Secchi depth, depth and conductivity. Thus the rejection of the third null hypothesis for these three that showed significant correlation with the fish community attributes.
3. There was dominance by introduced species in Lake Sare, which recorded low IBI score values than Lake Kanyaboli, which had more native fish thus supporting the hypothesis that fish community attributes differed significantly among the sites. However, it is worth noting that Lake Kanyaboli still scored far below the expected IBI score implying impaired biotic integrity.
4. The main difference between the IBI for Lake Kanyaboli and Lake Sare could be attributed partly to the introduced Nile perch, *L. niloticus*. The implication of this would be that there should be no introduction of this species into Lake Kanyaboli, which is still free of the Nile perch.

5. The IBI developed herein could be incorporated as part of a suite of systems that would lead to more questions towards attempts to solving a particular problem of ecological concern such as the anticipated ecosystem changes that are likely to accompany Yala Swamp reclamation especially now that agricultural developments are ongoing within the swamp.

6.2 Recommendations

Following the results of this study, the recommendations below are advanced:

1. The Index of Biotic Integrity (IBI) method based on fish assemblages should be used to assess health and biotic integrity of other aquatic ecosystems in the whole of Lake Victoria basin. This is because this study has shown that the Index of Biotic Integrity using fish assemblages can be sensitive to habitat quality deterioration.
2. There is need to develop a validation procedure of the metrics developed herein by using a similar method as a necessary step towards biological indicator development for other satellite lakes in the Lake Victoria basin.
3. Modification of this preliminary fish based IBI through combining of different or various taxonomic groups (fish, invertebrates, algae, amphibians) so as to provide a more complete bioassessment tool for the biotic integrity and ecological health of Lakes Kanyaboli and Sare is recommended.

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