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DEVELOPMENT OF A FISH-BASED INDEX OF BIOTIC INTEGRITY (FIBI) FOR MONITORING RIVERINE ECOSYSTEMS IN THE LAKE VICTORIA DRAINAGE BASIN, KENYA

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ABSTRACT

The long term monitoring of aquatic ecosystems based on chemical analysis is expensive resulting in a lack of time series data for management purposes thus necessitating the need for new cost effective methodologies. This study developed a fish-based index of biotic integrity (FIBI) for monitoring environmental conditions in riverine ecosystems within the Lake Victoria Basin, Kenya. The fish fauna in the basin is poorly studied, less diverse and ecologically specialized than the temperate fauna that provided the origins of the Index of Biotic Integrity. Fish samples were collected by electrofishing from 24 sites during baseflow periods in February, March and July 2004. Validation data were collected from 7 sites with varying levels of degradation. Fish samples were identified, counted and grouped into different trophic groups, relative tolerance to pollution, habitat guild and whether exotic or native to riverine environment. Thirty-three candidate metrics were evaluated for responsiveness to habitat quality and twelve were selected for inclusion in the final index. The index classified 6 of the 7 validation sites according to their levels of degradation. As a bioassessment tool, the index was useful in laying the basis for long-term monitoring of rivers in the Lake Victoria drainage basin. Copyright © 2010 John Wiley & Sons, Ltd.

KEY WORDS: community health; habitat quality; metric selection; fish integrity index; rivers

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INTRODUCTION

Recent advances in the monitoring of surface waters have shifted from measurement of physicochemical parameters to the use of biological indicators as early warning signals of ecosystem degradation. Fishes possess a suite of advantages (Karr, 1981; Karr *et al*., 1986; Fausch *et al*., 1990; Barbour *et al*., 1999) which have made them to be widely used for measuring a wide range of human impact types on aquatic environments. By studying their dynamics using biological metrics (Cairns, 1974; Karr, 1981) and examining their ecological preferences and pollution tolerances, the presence, absence and proportionate abundance of fish can be used to indicate the quality of physical, chemical and biological conditions of aquatic environments in which they live.

The index of biotic integrity (IBI) was originally developed for fish assemblages in small streams in midwestern United States of America (Karr, 1981; Karr *et al*., 1986). The IBI uses attributes of the fish assemblage in a stream reach to assess the condition of a stream and its catchment, relative to ecoregional standards. The IBI integrates land-water linkages, physical habitat quality, hydrological regime, energy inputs, biological interactions and water quality (Karr *et al*., 1986; Steedman, 1988). In it original form, the IBI was designed to combine information from individual, population, assemblage and ecosystem levels into a numerical indicator and quality rating for water bodies (Karr *et al*., 1986). The IBI combines 12 fish assemblage attributes or metrics classified into groups of richness and composition, trophic composition, abundance and health or condition (Karr, 1981). Each metric is an expression of a known influence of human activities on different aspects of the fish assemblage which responds in a different manner to aquatic ecosystem stressors (Fausch *et al*., 1990).

The Lake Victoria and its tributaries are recorded to have been rich in ichthyofauna, with the lake itself supporting more than 200 endemic species, including 4 genera of cichlids and more than 150 *Haplochromis* species (Lowe-McConnell, 1987). However, the lake has witnessed mass biodiversity loss of endemic haplochromines in the recent past due to the introduction of exotic species (Ogutu-Ohwayo, 1990; Mboya *et al*., 2005). Other factors believed to have exacerbated the problem include declines in water quality (Okungu and Opango, 2005), habitat modifications (Raburu *et al*., 2009) and poor fishing methods practiced in the basin (Graham, 1929; Whitehead, 1959; Cadwalladr, 1965), which have brought the once diverse riverine fish

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species to the brink of elimination (Ojuok, 2005; Ojwang *et al*., 2007). This has restructured the fish communities to the current status dominated by few exotic and generalist species, particularly in the lower reaches of major rivers and in the lake itself (Ochumba and Manyala, 1992; Mboya *et al*., 2005; Ojwang *et al*., 2007).

Since environmental pressures in the basin continue, there is a need to develop a biological criteria for monitoring ecological integrity of riverine ecosystems. In working towards addressing similar need elsewhere (e.g. Ganasan and Hughes, 1998; Kleynhans, 1999; Toham and Teugels, 1999), it has been demonstrated that the original IBI (Karr, 1981) is versatile to modifications and by maintaining the conceptual framework, IBI has witnessed wide adoption and application with acceptable results. In its applications in different parts of the world, metrics have been modified, deleted or new ones added to reflect regional differences in fish distribution and assemblage structure (Hughes and Oberdorff, 1999). The basic ecological information needed to modify the IBI for a new region includes knowledge of which species are native and exotic, their trophic and habitat guilds, and their relative tolerance to environmental degradation (Ganasan and Hughes, 1998).

Because the IBI assesses biotic attributes of a river reach in comparison to those expected for a similar-sized reach that is in the same ecoregion and where human activities have been minimal, identification of reference expectations is very important. Ideally, undisturbed stream reference sites would provide a standard against which all other comparable sites of the particular region could be directly assessed. Where identification of 'least-disturbed' sites that can act as reference (e.g. Steedman, 1988; Hughes, 1995) is not possible, because of widespread degradation, an alternative approach is to sample across a gradient of human disturbance to provide a representation of the region (Simon and Lyons, 1995). The best values observed then define the expectations for each biotic attribute (e.g. Fausch *et al*., 1984; Karr *et al*., 1986; Ganasan and Hughes, 1998).

Development of a fish based IBI for the Lake Victoria Basin faces a major drawback due to, (i) a lack of historical data that quantify how various attributes of fish assemblages in streams and rivers have been modified by the past environmental changes, (ii) the fact that low order streams in the basin are naturally species poor (Raburu, 2003, unpublished), which may limit the range and sensitivity of metrics that can be identified and (iii) widespread degradation that makes it difficult to identify 'least degraded' sites that can act as a reference. Despite these challenges, an important part of development and testing of a fish-based IBI for the Lake Victoria Basin is its ability to assess river condition using assessments of the biotic integrity of a species poor fish fauna, which is poorly studied. This fauna is considerably less diverse and ecologically specialized than the North American fauna that provided the origins of the IBI (Karr, 1981; Karr *et al*., 1986).

This study built on what has been done on riverine ecosystems in the basin (Raburu, 2003, unpublished) and elsewhere in Africa. Information in grey literature and local knowledge was also useful in understanding fish distribution and assemblage characteristics within the basin. Metrics were modified to reflect unique attributes of local riverine fish assemblages in the basin. Compositional, structural and functional metrics were identified that accurately reflected the biotic integrity of study sites. The precise expectations for each metric were then derived such that a single index score representing relative biotic integrity was calculated for each site. This was followed by validation of the developed index by evaluating how well it corresponded with environmental conditions of a new set of targeted sites.

MATERIALS AND METHODS

Study area

The Kenyan side of the Lake Victoria Basin straddles the equator with an elevation ranging from 2600 m a.s.l. in the upper catchments to 1134 m a.s.l. at the lakeshore floodplains (Figure 1). The mean annual rainfall, which ranges from about 1100 to 1600 m, displays a bimodal distribution with two distinct short and long rainy and dry seasons, respectively. The rainy season occurs from March to June, with a peak in May, and the short rainy season from September to November. The long and short dry spells occur between December and March, and between July and August respectively (Raburu *et al*., 2009).

On the Kenyan side, six major rivers drain into the Lake Victoria, including the Kuja-Migori (6600 km^2), Nyando (3652 km^2), Nzoia (12 842 km^2), Sio (1437 km^2), Sondu-Miriu (3508 km^2) and Yala (3357 km^2). Most tributaries in the upper reaches of the catchment are rocky, with coarse substrate often covered in decomposing leaf litter. Steep hydrological gradients occur in these areas with long slopes in excess of 20° inclination. Some have minimally disturbed natural habitats and good water quality, whereas others have suffered from a combination of excessive livestock grazing, human settlement and poor agriculture practices (Raburu *et al*., 2009). In the floodplains of the rivers the gradient drastically reduces, and for some, like the Nyando and Nzoia (gradient 0.5–0.8) flooding is a key feature during the heavy rains (LBDA, 1987). Deforestation of the catchment areas and wastewater discharge from agro-industrial activities within the basin (UNEP, 2003; Okungu and Opango, 2005; GEF, 2007) threaten the integrity of both riverine and lacustrine ecosystems.

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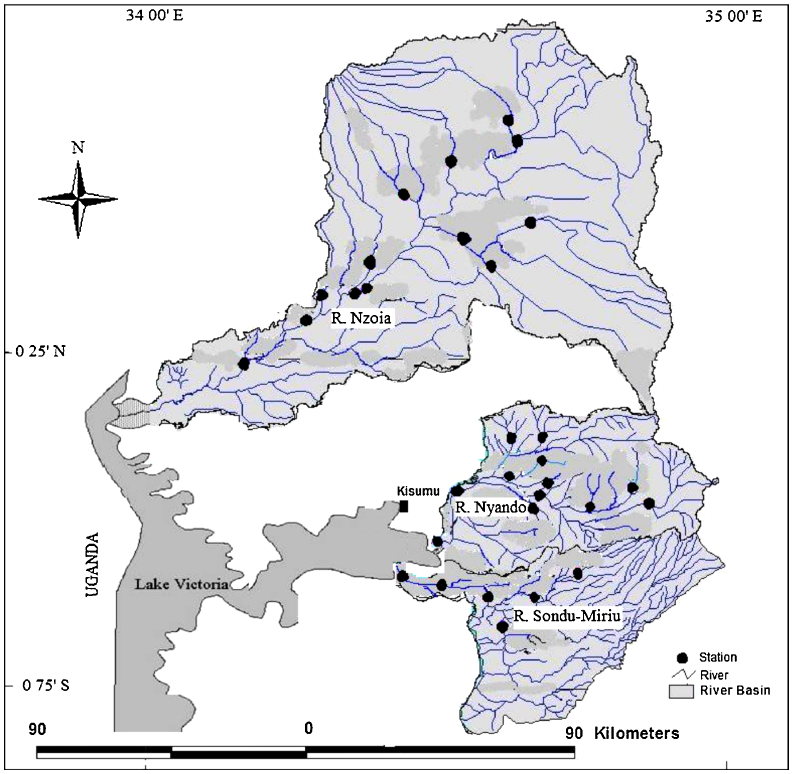

Figure 1. Map of the Kenyan side of Lake Victoria basin showing the position of sampling sites for fish in the three river systems considered for the study

SAMPLING DESIGN

Selection of sampling sites

Site selection was done by delineating all possible access points (bridges and roads) using topographic maps (1:50 000) and then selecting a stratified random sample ($n = 24$; Table I), according to Barbour *et al.* (1999). Stratification was based on stream size whereby sites were selected based on the relative abundance of the different stream orders (Strahler, 1957) in the basin, and the influence of human activities arising from different land uses. To capture the effects of point sources of pollution from industrial wastewater discharges sites were located both upstream and downstream of the discharge point for comparison of fish assemblage characteristics. Since first order streams in the basin are species poor (Raburu, 2003, unpublished results), they were not sampled because they are dominated by one species, *Barbus neumayeri*. We sampled six second-order, four third-order, six fourth-order, five fifth-order and lastly, three sixth-order streams/rivers. More sites were sampled in the fourth and fifth order streams because these streams in the middle reaches of the basin are those most affected by a wide range of human activities including industrialization, urbanization, row crop agriculture and habitat loss by unrestricted animal access. This increased the representation of all impact types occurring within the basin. In addition to the random sites, seven targeted sites were sampled representing varying degrees of impairment from least impacted to severely impacted

Table I. Number of random sites used for index development and targeted sites used for index validation per stream order. General condition of the sites and potential sources of impairment are also presented

Stream order	Number of random sites	Number of targeted sites	Comments
1	Not sampled	Not sampled	Species poor
2	6	2	Most in forested upper reaches with minimal human activity
3	4	1	Most sites affected
4	6	2	by human activities –
5	5	1	industrialization, urbanization, rowcrop agriculture and habitat loss by unrestricted animal access
6	3	1	Sites affected by municipal wastes, and habitat (sand mining, animal and human access)

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(Table I). These targeted sites were used for index validation only.

Physical habitat and riparian disturbance

To assess the level of degradation at the sampling sites, a habitat quality index (HQI) was developed following the U.S. Environmental Protection Agency's Rapid Bioassessment Protocols (RBPs; Barbour *et al*., 1999). Habitat quality was assessed qualitatively at a reach scale of 40 times the mean wetted stream width to encompass about three meander sequences (Wang *et al*., 1996; Barbour *et al*., 1999). For the purpose of this study a reach is defined as a section of stream with roughly a homogenous slope, discharge, habitat, channel type and riparian features (Barbour *et al*., 1999). Habitat quality characteristics assessed at each sampling station included stream width, depth, velocity, discharge, substrate and instream cover, bank erosion, channel stability and sinuosity, channel morphology and modifications, riparian zone and floodplain quality and microhabitat quality (pool, riffle and run depth, substrate type and velocity). Habitat quality assessment was done at the reach scale where fish sampling was undertaken. These characteristics were used as metrics to develop a habitat quality index (HQI) for each sampling station according to Herschy (1978), Rankin (1995) and Barbour *et al*. (1999) with modifications to suit conditions in the Lake Victoria Basin ecoregion.

In the modified index for the Lake Victoria ecoregion (Raburu, 2003, unpublished; Masese *et al*., 2009), the origin of the substrate was excluded from the substrate metric since the assessment was carried out within the same ecological zone. This reduced the total score for the substrate metric to 15 from 20. For the instream cover metric, the scores for the amount of instream cover were changed to range from 1 to 10 instead of 1 to 11 in the original index and deep pools were considered to be those with a depth greater than 1 m. Channelisation was excluded for the channel morphology metric because it was absent in the study area, as in most riverine ecosystems in the region. Modifications of the channel morphology were included and each given a score of -1. These included watering of cattle, bathing, swimming, laundry, sand mining and dumping of wastes. These activities are predominant in affecting the river channel and its banks. The maximum score for channel morphology reduced to 15 from 20 in the original index by Rankin (1995). The riparian zone, bank erosion, pool-run-riffle quality metrics were scored as in the original index, while the gradient metric was not included in the current study because the streams and rivers in the region have not yet been classified in this regard. The habitat quality metrics were grouped into five broad categories and tested for variability across the study sites using one-sample *t*-tests.

Sampling for fish

Fish samples were collected from the 24 randomly selected and 7 targeted sites where habitat assessment had been done using a generator-powered bank electrofisher (Smith-Root Type VI-A) during baseflow periods in February, March and June 2004. The generator was a Honda GX 240 8 HP that produced a current at 400 V and 10 A. The power of the electrofisher was adjusted depending on the conductivity of water at the sampling site (range 41.7–337.8 $\mu S\,cm^{-1}$). Sampling was done during daylight hours whereby one person collected all of the fish seen using a hand net, 17 mm mesh-size. At each sampling station a river reach equivalent to 40 times the width of the river was sampled starting from the downstream end and the time taken noted. Whereas this was the standard distance sampled, to ensure a representative sample was collected, fish caught in each 50-m stretch were noted until no additional species was encountered. Efforts were made to sample all habits available relative to their abundance.

The fish caught were identified and counted. The fish were then dissected to remove the gastrointestinal system, which was preserved immediately in 4% formaldehyde solution. In the laboratory, the stomach contents were examined using the frequency of occurrence method (Corbet, 1961). Information from stomach content analysis was used to assign fish species to one of the four trophic groups: (1) herbivore, diet usually more than 75% plant material; (2) omnivore, diet usually more than 25% plant material and more than 25% animal material (Karr, 1981; Karr *et al*., 1986); (3) carnivore, diet usually more than 75% animal material and (4) detritivore, diet usually composed of detritus on the stream bed. Where results from stomach content analysis were not conclusive, information available from literature (Corbet, 1961; Okedi, 1971; Balirwa, 1979) was used to classify fish into the different trophic groups.

Fish were categorized according to their origin, typical position in the water column and tolerance to environmental degradation (Table II). For origin, information from literature was used to determine if species were either native or exotic, including some species that have invaded riverine ecosystems from the lake where they were introduced (Ogutu-Ohwayo, 1990; Ochumba and Manyala, 1992; Mboya *et al*., 2005). For position in the water column, the different fish species were grouped as either benthic or water column based on direct observation of their usual position in relation to the stream bed. According to flow requirements, rheophilic species were also identified. Information on tolerance limits of common African taxa relied on literature (Hocutt *et al*., 1994; Hay *et al*., 1996; Hugueny *et al*., 1996; Toham and Teugels, 1998, 1999; Kouamelan *et al*., 2003; Raburu, 2003, unpublished), and professional judgment by drawing from the occurrence and

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Table II. Classification of fish assemblages encountered during the study in terms of origin, tolerance to environmental pollution, structural and functional groups

Family and species	Origin	Habitat guild	Tolerance	Trophic group
Cichlidae				
Oreochromis niloticus (L., 1757)	E	NI	T	G
O. variabilis (Boulenger {Blgr.}, 1906)	N	NI	S	V
O. leucostictus (Trewavas, 1933)	E	NI	T	H
Tilapia zillii (Garvais, 1848)	E	NI	T	H
Haplochromis multicolor (Hilgendorf, 1888)	N	NI	M	D
Haplochromis sp. (Hilgendorf, 1888)	N	NI	M	D
Pseudocrenilabrus multicor	N	NI	M	D
Cyprinidae				
Barbus neumayeri (Fischer, 1884)	N	NI	S	V
B. altianalis (Blgr., 1900)	N	NI	S	V
B. apleurograma (Blgr., 1911)	N	NI	M	V
B. cercops (Whitehead)	N	NI	M	I
B. jacksoni (Günther, 1889)	N	NI	M	I
B. kerstenii (Peters, 1968)	N	NI	M	I
B. nyanzae (Whitehead)	N	NI	M	I
B. paludinosus (Peters, 1852)	N	NI	M	I
Labeo victorianus (Blgr, 1901)	N	NI	M	I
L. cylindricus (Peters, 1852)	N	NI	M	I
L. worthingtoni	N	NI	M	D
Rastreonobola argentea (Pellegrin, 1904)	E	NI	M	D
Bagridae				
Bagrus docmak (Forsskäl, 1775)	N	R	S	P
Schilbidae				
Schlibe mystus (Ruppell, 1832)	N	B	S	P
Mochokidae				
Chiloglanis sp. (Peters, 1868)	N	R	M	D
Synontis afrofisheri (Hilhendorf, 1888)	N	B	M	I
S. victoriae (Blgr., 1906)	N	B	M	I
Centropomidae				
Lates niloticus (L., 1758)	E	NI	M	H
Mormyridae				
Gnathonesmus longibarbis (Hilgendorf, 1888)	N	WC/R	S	I
Mormyrus kanumme (Forsskäl, 1775)	N	WC/R	S	I
Clariidae				
Clarias alluaudi (Blgr., 1906)	N	NI	T	G
C. gariepinus (Burchell, 1815)	N	NI	T	G
C. theodorae (Weber, 1897)	N	NI	M	I
Mastacembelidae				
Afromastacembelus frenatus (Blgr., 1901)	N	B	R	I
Protopteriidae				
Protopterus aethiopicus (Heckel, 1851)	N	B	T	P
Amphiliidae			M	
Leptoglanis sp. (Blgr, 1902)	N	R	M	D
Amphilius sp. (Günther, 1864)	N	B	M	I
Poecilidae		NI		
Aplocheilichthys sp. (Ahl, 1924)	N	NI	M	I

Letter designations: origin (N = native, E = exotic); position in water (B = benthic, WC = Water column); flow requirements (R = rheophilic, NI = Not included among the three groups); tolerance (S = sensitive, M = moderately sensitive, T = tolerant); feeding (P = predator, I = insectivore, D = detritivore or benthiphore, G = generalist, H = herbivore, V = variable – changes with site).

distribution of fish species within the basin (Ojuok, 2005) with respect to different levels of degradation (Okungu and Opango, 2005; Raburu *et al*., 2009). Different species were designated as sensitive if they only occurred in sites with good water and habitat quality. Good quality sites according to the regional standards are defined as those with no human activity within 50 m of the riparian zone and no point sources of pollution. This also includes sites occurring in

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catchmnents with 100% forest cover with minimal human activity in the riparian zone and in the river (also see Raburu *et al*., 2009). Conversely, tolerant species were those that occurred at a wide range of sites, including some with signs of heavy degradation, high levels of sedimentation and turbidity and extensively damaged habitat.

INDEX DEVELOPMENT

Metrics selection

Metrics in this study were chosen to reflect major fish community attributes classified under five categories, four of them in the original index by Karr (1981): (i) species richness and composition, (ii) indicator species or guilds, (iii) trophic function, (iv) reproductive function and, (v) abundance and condition (see also Karr *et al*., 1986). From among these classes, metrics that have been applied in developing fish based indices for African Rivers were selected (Hay *et al*., 1996; Hugueny *et al*., 1996; Kleynhans, 1999; Toham and Teugels, 1999; Raburu, 2003, unpublished) and modified to suit local fish assemblages. In addition, new metrics were selected for evaluation. In total 35 metrics were investigated to determine their suitability in assessing ecological condition of the rivers (Table III).

Species richness and composition. Species richness and faunal composition were assessed by metrics designed to monitor overall fish diversity and habitat-specific fish assemblages. Metrics under this category are either modifications of the original index by Karr (1981) or ones that have been used previously in developing fish indices in Africa. New metrics included number and per cent *Barbus*, cichlid and clariid species. Cichlids were included because of their rich diversity in the basin. Cichlids have also been found to be tolerant to pollution (Fausch *et al*., 1984; Hugueny *et al*., 1996; Toham and Teugels, 1999). Equally, genus *Barbus* is the most abundant and widely distributed in the Lake Victoria basin and thus display varied tolerance limits to different levels and types of degradation (Raburu, 2003, unpublished). Clariids are considered to be tolerant to pollution and high numbers and dominance at a site is an indication of water quality and habitat degradation (Toham and Teugels, 1999; Raburu, 2003, unpublished).

Indicator species or guilds. To identify indicator species, fishes were classified into tolerant, moderately tolerant and intolerant groups (Table II). Most of the metrics under this category are new. 'Number intolerant species' is the only metric in the original index by Karr (1981) retained. Intolerant species disappear early in the degradation sequence associated with land use change that is associated high sedimentation, increased temperature and decreased dissolved oxygen. The metric distinguishes moderate quality from high quality conditions (Karr *et al*., 1986).

Table III. Potential metrics that were considered for development of a fish-based index for monitoring rivers in the Lake Victoria drainage basin, Kenya, their source, predicted responses to pollution and whether they passed the screening process or not

Metrics	Predicted response	Passed test
Species richness and composition		
Number of native species[a,b,c,d,]	Decrease	√
Number *Barbus* species[b]	Decrease	
Number catfish species[b]	Variable	
Number cichlid species[d]	Decrease	
Number cyprinid species[b]	Decrease	
Number of rheophilic species[b]	Decrease	√
Per cent *Barbus* species[c]	Decrease	
Per cent catfish species[c]	Variable	
Per cent cichlid species[d]	Increase	
Per cent clariid species[c]	Increase	
Indicator species		
Number benthic species (excluding clarriids)[d]	Decrease	
Per cent benthic species (excluding clariids)[b]	Decrease	√
Per cent Barbus individuals[d]	Decrease	
Per cent benthic individuals[d]	Decrease	
Per cent catfish individuals[d]	Increase	
Per cent clariid individuals[d]	Increase	
Per cent cichlid individuals[d]	Increase	
Per cent cyprinid individuals[d]	Decrease	
Per cent cyprinid species[d]	Decrease	√
Number of exotic species[c]	Increase	√
Per cent exotic species[d]	Increase	
Number intolerant species[a,b]	Decrease	√
Per cent intolerant species[c]	Decrease	
Per cent tolerant individuals[d]	Increase	√
Per cent tolerant species[b]	Increase	
Trophic metrics		
Proportion as detritivore individuals[c]	Variable	√
Proportion as carnivores[a,b]	Decrease	
Proportion as insectivores[a,b,c]	Decrease	√
Proportion as omnivores[a,b,c]	Increase	√
Reproductive function		
Proportion as mature individuals[c]	Decrease	
Abundance and condition		
Total number of individuals[a,b,c]	Decrease	
Number of individuals per 50 m of sampling[b,c]	Decrease	√
Modified index of well-being[c]	Decrease	√

The hysterics gives the source of the metrics: (a) Karr (1981), (b) Toham and Teugels (1999), (c) Raburu (2003), unpublished and (d) new metric. √ designate metrics included in the final index.

Benthic species (excluding tolerants) are sensitive to siltation, turbidity, reduced oxygen content and toxic chemicals. Increased diversity and overall quality of benthic habitats is associated with increased richness of benthic species (Karr *et al*., 1986; Toham and Teugels, 1999). 'Number of exotic species' was included as a measure of the

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degree to which introduced or invasive species dominate the assemblage. Exotic species are more successful where native species are depauperate or in anthropogenically modified systems (Ross, 1991). The importance of this metric is rendered more pertinent considering the loss of biodiversity associated with introduced fish species in Lake Victoria (Witte *et al*., 1992; Witte *et al*., 1999). Due to lack of information on indictor fish species in the basin, many taxa and groups were evaluated to identify the potential ones that responded to the degradation gradient.

Trophic function. Metrics under this category were evaluated to measure the divergence from expected production and consumption patterns resulting in alterations of river quality that, in turn, modify the food base of the fish assemblages (Ganasan and Hughes, 1998). In this study, all the three metrics in the original index (Karr, 1981) plus a new one, relative abundance of detritivore individuals, were evaluated. This trophic group feeds on detritus and algae at the stream bed. It was, therefore, hypothesized, following Toham and Teugels (1998) and Kouamelan *et al*. (2003), that habitat degradation from erosion is likely to result in the development of muddy substrate and suspended solids, which may drastically affect detritivorous species.

Reproductive function. As a measure of reproductive success of a fish community, reproduction function metrics have not been commonly used in Africa, except by Toham and Teugels (1999) who used different size classes of select fish species to assess the suitability of habitats for reproduction success. This is caused by lack of information on the reproductive ecology and spawning behaviour of most African fishes. In this study, the proportion of mature individuals was used because it was expected that this would indicate the potential of the habitat to support growth and development of fishes.

Abundance and condition. Abundance metrics in the original index have also been modified to include total number of individuals per 100 m of sampling (Toham and Teugels, 1999). In this study, total number of individuals per 50 m of sampling was evaluated. Though widely used, abundance as a metric has been found to vary in relation to levels of degradation by being higher at intermediate levels, caused by nutrient enrichment, and lowest at severe levels (e.g. Steedman, 1988). To assess fish condition, the proportion of diseased and deformed individuals has been retained as a metric in most versions of fish IBIs. Most studies include only conspicuous external anomalies such as deformities, eroded fins, lesions and tumours (DELTs) (e.g. Oberdorff and Hughes, 1992). This metric was used in Africa but no data were available for its scoring (Toham and Teugels, 1999). In the Lake Victoria drainage basin, the modified index of well-being (Miwb) has been used as a substitute (Raburu, 2003, unpublished) on the basis that it is useful for assessing fish health and condition (Yoder and Rankin, 1995). The Miwb was calculated for each site from the formula:

$$\mathrm{Miwb} = 0.51nN + 0.5\ \ln B + \overline{H}_{\mathrm{N}} + \overline{H}_{\mathrm{B}}$$

where N is the number of individuals caught per unit distance sampled, B the biomass individuals caught per unit distance excluding tolerant and exotic species, $\overline{H}_{\mathrm{N}}$ the Shannon diversity index based on numbers and $\overline{H}_{\mathrm{B}}$ is the Shannon diversity index based on biomass.

Metric screening

Metrics were screened for range, response to environmental degradation and redundancy. For the range test, all richness metrics with a range of 5 or less were eliminated, except the number of introduced species which are not expected in natural sites, while percentage metrics with a range of less than 10% were also eliminated. Retained metrics were examined for response to environmental degradation by correlations with habitat quality variables and the habitat quality index. Redundancy was evaluated by correlation coefficients and visual inspection of scatter plots (Clarke and Ainsworth, 1993). Metrics with a correlation coefficient $(r) \geq 0.85$ were considered to be too closely related to act as single metrics. Only one metric from a group of redundant metrics was retained for the final index. Metrics were evaluated as a function of stream order using scatter plots for developing a maximum species richness lines (MSRL; Fausch *et al*., 1984; Karr *et al*., 1986), based on collected data from the 24 randomly selected sites. Before statistical analysis, all count and score data were log-transformed while percentage data were arcsine transformed for normality (Zar, 2001). All analyses were run using SPSS statistical software (Version 13.0, SPSS Inc., Chicago, IL) and tests were considered significant at the $p \leq 0.05$ level.

Reference conditions

Reference sites ideally are set in areas with minimal anthropogenic disturbance, based on thresholds established for water chemistry, physical habitat and land use upstream of the sampling site. Despite the fact that fish assemblages are known to respond strongly to habitat disturbances (Barbour *et al*., 1999), the habitat quality ratings in this study may not have accurately measured some types of environmental degradation, such as water quality degradation or highly episodic toxic pollution and altered seasonal hydrologic regimes. Moreover, our sample size of sites was fairly small, particularly for relatively undegraded large rivers and heavily degraded streams. This is because most large rivers are already degraded and most streams occur in forested upper reaches with intact habitat conditions. As a result, we might fail to identify certain appropriate indicators of biotic integrity if reference sites are used to

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establish the scoring criteria. Because of these considerations, reference sites were not used to establish the scoring criteria. Instead, sites were sampled across a range of human influence within the basin as a means of detecting signals about resource condition. This approach is recommended in situations where no pristine conditions can be identified (Simon and Lyons, 1995), and expectations for each attribute are based on best observed values (Fausch *et al*., 1984; Oberdorff and Hughes, 1992; Ganasan and Hughes, 1998; Kestemont *et al*., 2000). However, though considered to be less subjective (e.g. Kestemont *et al*., 2000), the use of best observed values greatly underestimate potential biological integrity, especially in studies done in highly degraded conditions. Future research focusing on less disturbed rivers in the Lake Victoria Basin may provide more accurate measures of potential condition.

Scaling and scoring criteria

We used a 1, 3, 5 scaling system, which is common in developing fish IBIs. Scoring criteria were developed by trisections of maximum obtained values considered indicative of least disturbed condition. For positive metrics (i.e. those that increased with improving conditions), the upper expectation was the highest value of a metric across all sites. The metric was then trisected and values above the upper one-third received a score of 5, those in the middle received a score of 3 while those in the lower one-third received a score of 1, corresponding to unimpaired, intermediate and impaired metrics respectively (Karr *et al*., 1986). Adjustments were made for metrics which increased as a function of stream order depending on the value of the MSRL. For each stream order, the MSRL was trisected to give the scoring criteria. For negative metrics that decreased with improving condition, the highest value for the metric across all sites were trisected but the scoring was done in reverse. Since no exotic species should be present in a biologically undisturbed water body, and because only six species of fish in riverine ecosystems in the Lake Victoria drainage basin are considered exotic, the scoring criteria was 5 for no exotics, 3 for 1 or 2 exotics and 1 for more than 2 exotics. Because few fish were collected at some sites, some scoring modifications were made. When fewer than 20 fish were collected, each fish represents too great a proportion of the entire sample, generating a potential false positive or Type I sampling error especially when dealing with degraded sites. Scoring modifications similar to those proposed by Rankin and Yoder (1999) were used whereby all sites with less than 20 fish were automatically scored a '1' for all percentage metrics. After scoring each of the metrics and combining scores to obtain the final FIBI score for each station, integrity classes were then determined with five categories of excellent, good, fair, poor and very poor if the final score ranged from 58–60, 48–52, 40–44, 28–34 and 12–22, respectively (Karr *et al*., 1986).

RESULTS

Fish community characteristics

During the survey, 2393 individuals of fish were collected belonging to 13 families and 35 species. First order streams were dominated by *Barbus* species, especially *Barbus altinialis* and *B. neumayeri*, and in most cases only the two species were encountered. The two species represented the highest numerical abundance in the entire basin. Family Cyprinidae dominated in middle and upper sites, both with number of species and relative abundance. In the lower reaches no family was particularly dominant in terms of abundance but that of Cichlidae increased compared to other river sections. Overall, species richness was higher downstream compared to the upper reaches. Five exotic species were encountered in the rivers, mostly in the lower reaches; *Oreochromis niloticus*, *O. leucostictus*, *Tilapia zillii*, *Lates niloticus* and *Rastreonobola argentea* – a lacustrine cyprinid species. Genera *Leptoglanis* sp. and *Chiloglanis* sp. (Amphiliidae) and *Aplocheilithys* sp. (Poeciliidae) observed in the river basins have not been reported within the main lake.

Environmental conditions

The scores of the habitat index developed in this study showed significant variations ($p < 0.05$) among the sampling sites (Table IV). In low order streams, human activities which affected habitat quality and were expected to affect fish species included deforestation, rowcrop agriculture on the riparian zones and human settlement. In the middle reaches, additional activities included municipal and industrial discharges and sand mining. Other activities such as rowcrop agriculture occurred along the whole gradient of the rivers. However, the composition of crops varied along the gradient with upstream areas under tea, coffee, maize and wheat while sugarcane featured in most of the sub-basins in the middle reaches. Other activities that occurred across the gradient were water abstraction, bathing and watering of animals.

Metric selection and scoring criteria

During metric screening, numbers of benthic fish species (excluding clariids), cichlid species, clariid species and per cent predator individuals were eliminated because they failed the range test. Because exotic fish species are normally not expected to occur at least impacted sites, the number of exotic species metric was therefore retained even after failing the range test. Of the 29 metrics remaining,

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Table IV. One-sample t-test ($n = 24$) for habitat variables and the final habitat quality index (HQI) showing the highest and lowest score values for all random sites used in index development

Habitat variables	Mean ± SE	Highest values	Lowest value	p-value
Substrate	9.7 ± 1.2	15	2	<0.01*
Instream cover	8.3 ± 0.9	18	4	<0.01*
Channel morphology and modifications	6.5 ± 0.5	10	3	<0.01*
Riparian zone and bank erosion	5.6 ± 0.5	9.5	2	<0.01*
Riffle/pool/run quality	12.0 ± 0.3	17	7	<0.01*
Habitat quality index (HQI)	42.1 ± 2.6	60.5	22	<0.01*

Asterisk (*) indicates significant differences.

those eliminated due to lack of significant relationship with any one of the habitat quality variables include number of *Barbus* species, per cent *Barbus* species, per cent benthic fish individuals, per cent catfish individuals and species, per cent exotic species, per cent tolerant species, per cent mature individuals and per cent herbivore individuals. After redundancy tests on the remaining 21 metrics, the following were included in the final index because they were not redundant with each other; total number of native species, intolerant species and rheophilic species, per cent benthic species, insectivore individuals, detritivore individuals and the Miwb. Redundant metrics comprised of the following groups:

- per cent *Barbus* individuals and number of individuals per 50 m of sampling;
- per cent cichlid individuals, exotic individuals, cichlid species and number of exotic species;
- per cent individuals of clariids, tolerants and generalists, and per cent clariid species; and
- per cent cyprinid individuals, cyprinid species and intolerant species.

For metrics that were redundant, a single metric was chosen to represent the correlated metric group thus eliminating redundancy (Clarke and Ainsworth, 1993). Consideration was given to ones with ecological significance, wide response to habitat variables, interpretability and wider range across a gradient of human disturbance. We chose number of individuals per 50 m of sampling and number of exotic species for inclusion in the final index. Even though per cent tolerant individuals and generalist individuals were redundant with one another, both were included in the final index. This was because of the different information they display, one being a measure of tolerance to pollution and the other representing changes in fish feeding habits following degradation. According to Karr *et al*. (1986) redundant metrics can be included in the final index, especially those that are sensitive across the range of integrity, because some are only sensitive to a portion of that range.

In total 12 metrics were selected for the final index (Table V) of which five were responding to changes in stream order and the MSRLs were drawn showing a sloping relationship with 95% of the data below the line (Figure 2). The remaining area below the MSRL was then trisected to obtain the scoring values. Scoring values were ascending for nine positive metrics and descending for three negative metrics. Final FIBI scores for the entire basin were based on a scale of 12–60. This scale derives from the 12 metrics in the final index and ranges from 12, which is the total score for a site that scores a value of '1' for all the 12 metrics, and 60 if a site scores a value of '5' for all the 12 metrics. Scores for this study ranged from 20 to 55.

Metric response to degradation

Most of the metrics responded to a number of impact types caused by human activities (Table VI). However, to avoid over-reliance on the habitat index as the only predictor of fish integrity, some metrics like the number of rheophilic species, total number of individuals per 50 m of sampling and modified index of well-being, were included in the final index even when they didn't show any significant relationship with any of the habitat metrics. Inclusion of former two metrics was based on the wide use of their derivatives in developing fish IBIs in Africa (e.g. Hugueny *et al*., 1996; Kleynhans, 1999; Toham and Teugels, 1999) and around the world (e.g. Karr *et al*., 1986; Ganasan and Hughes, 1998; Oberdorff *et al*., 2002). The Miwb metric was variable across the sites and in the absence of a replacement metric to assess fish condition, it was retained for this study. The FIBI derived showed a significant relationship with the habitat quality index based on Spearman's correlation coefficient ($p < 0.05$; Figure 3), demonstrating its ability to respond to overall degradation.

Condition categories and metric response to degradation

All sites in this study were grouped into five condition category classes according to Karr *et al*. (1986): excellent,

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Table V. Component metrics of the fish index of biotic integrity for the Lake Victoria basin and the scoring criteria

Final metrics	Scores and scoring criteria		
	1	3	5
Number of native species[a]	Expectations vary with stream order and are discussed in the text		
Number of intolerant species[a]			
Number of rheophilic species[a]			
Total individuals per 50 m[a]			
Per cent benthic species (excluding clariids)[a]			
Number exotic species	≥2	1	0
Per cent cyprinid individuals	<33.3	33.3–66.7	>66.7
Per cent tolerant individuals	>33.4	16.7–33.4	<16.7
Per cent insectivore individuals	<33.3	33.3–66.7	>66.7
Per cent detritivore individuals	<15	15–30	>30
Per cent generalists individuals	>45	20–45	<20
Modified index of well-being	<3.2	3.2–6.4	>6.4

[a]Metrics for which scoring was adjusted to reflect increase in stream order; see Figure 2 for details.

good, fair, poor, and very poor depending on whether the final FIBI score was within 58–60, 48–52, 40–44, 28–34 and 12–22, respectively (Table VII). We interpreted biological responses to human influence, establishing descriptions using individual metrics, final FIBI scores and habitat quality status for each class (Table VI). A notable response was the association of habitat modifications caused by animal watering, sand harvesting and agriculture on the riparian zone with either low numbers of intolerant taxa or high numbers and dominance of tolerant taxa. Clariids were the dominant groups at 'poor' and 'very poor' sites. These sites were mostly located below industrial discharge points and in municipal areas that received organic wastes from towns on the riparian zone.

FIBI values for the validation data set

The independent validation data set indicated that the FIBI could predict human influence at six of the seven sites. One site with a FIBI value of 51 under the 'good' condition category was located in the lower reaches in a section of the river that had an intact riparian zone, no human activity within 100 m upstream and instream habitat was intact. Four sites with 46, 44, 38 and 37 FIBI scores under the 'fair' category were located in agricultural areas. However, the sites had maintained riparian areas and no human activity in the river. One site, with a score of 37 was located below the irrigation outflow of rice paddies. The other site under the 'poor' category with a FIBI score of 30 was located in the upper reaches in an area that had experienced deforestation. The riparian zone was bare and the substrate was of fine sand. A FIBI value of 51 was higher than expected for Mbogo, a site located below a discharge point of a sugar factory.

DISCUSSION

The fish index developed here consists of 12 metrics which best delineated the differences in biotic integrity among different sites. Most of our metrics were the same or similar to metrics already in use for other African versions. However, modifications were made to some to reflect differences in fish community characteristics. The number of native species metric is widely used and considered to be most informative of water quality impairment (Ganasan and Hughes, 1998; Toham and Teugels, 1999; Morris *et al*., 2007). This metric assesses local species excluding exotics which are considered to reduce the integrity of a site. Normally a reduction in species richness is expected along a degradation gradient.

Numbers of intolerant and rheophilic species metrics are also common in Fish IBIs. Fish species considered intolerant to pollution included *Mormyrus kannume*, *Gnathonesmus longibarbis*, *B. neumayeri*, *B. altinialis*, *Oreochromis variabilis*, *Schilbe mystus* and *Bagrus docmak*. Mormyrids are known to be sensitive to degradation, especially sedimentation, which affects their stream bed habitat (Hugueny *et al*., 1996; Toham and Teugels, 1998). In the study area, their distribution was linked to high levels of pollutants reported in the rivers (Okungu and Opango, 2005). The predominance of *B. neumayeri*, and *B. altinialis* at the forested and near natural streams in the upper reaches and their decline downstream suggests that they are sensitive to poor water quality and habitat degradation. This can also

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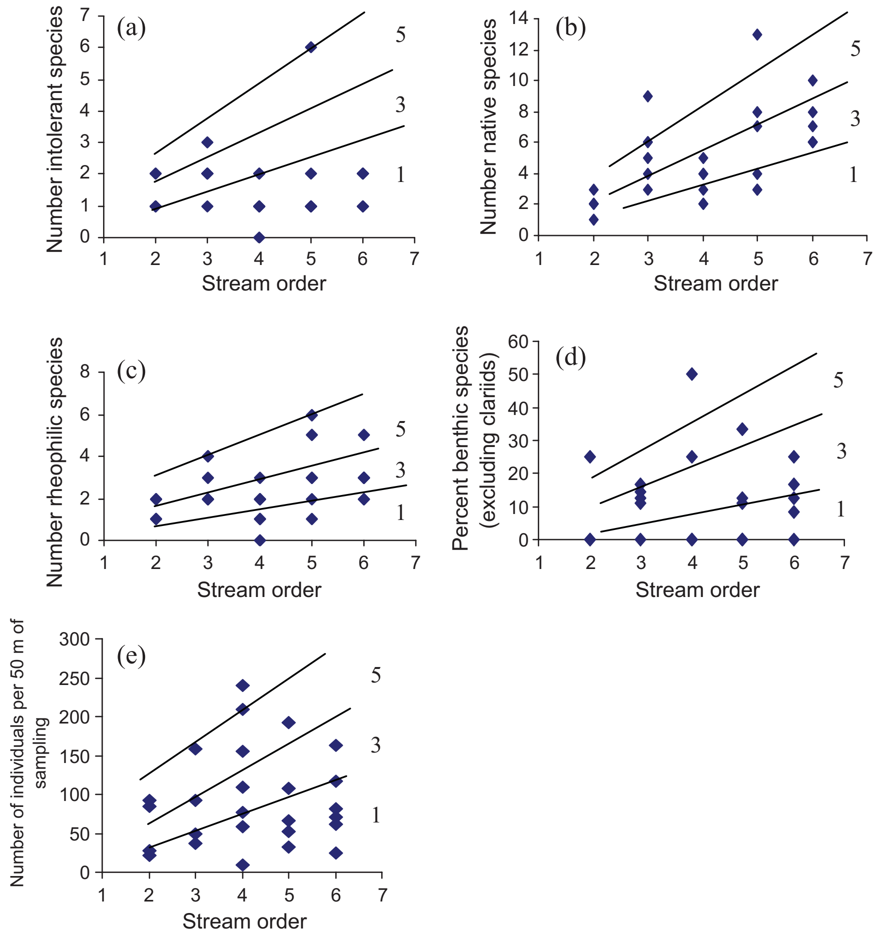

Figure 2. Tentative maximum species richness lines (MSRL) resulting from a scatter plot of the stream order (size) against: (a) number of intolerant species, (b) total number of native speices, (c) number rheophilic species, (d) per cent benthic species (excluding clariids) and (e) number of individuals per 50 m of sampling

be verified by their occurrence in certain rivers like Sio, Awach and Sondu-Miriu, which are among the least degraded in the basin, and in some clean tributaries of Rivers Nzoia and Nyando, which are among the most degraded (Okungu and Opango, 2005). Even though electrolocation in mormyrids has been shown not to be affected by changes in electrical conductivity of the water environment (Kramer and Kuhn, 1993; Baier, 2008) the implications of sustained increases in conductivity compounded by high sedimentation levels, following severe degradation, on the breeding and ecology of the fishes in the Lake Victoria basin is yet unknown. Genus *Oreochromis* is generally considered to be tolerant to physico-chemical changes. However, in the Lake Victoria Basin *O. variabilis* has become one of the most rare and threatened species because of degradation of its habitat (Ogutu-Ohwayo, 1990; Kaufman, 1992); contrary to its earlier wide distribution and high abundance (Balirwa and Bugenyi, 1980; Greboval and Mannini, 1992). This has necessitated the need to restore its numbers through aquaculture (Maithya *et al*., 2005). Equally, *S. mystus* and *B. docmak* have been declining in the lake, a condition attributed to declining water quality (Ogutu-Ohwayo, 1990). Moreover, as carnivores, *S. mystus* and *B. docmak* will be affected by environmental changes that will impact on their food base.

The number of rheophilic species metric is useful in assessing effects of poor agricultural practices and deforestation in the basin, which cause sedimentation and loss of habitat diversity and heterogeneity (Hocutt *et al*., 1994; Ganasan and Hughes, 1998; Toham and Teugels, 1999). To capture the effects of sedimentation, the relative abundance of benthic species (excluding clariids) was also used. Clariids were eliminated from the metric because they are known to be tolerant to pollution (Toham and Teugels, 1999) and this could have compromised the sensitivity of the metric to degradation. Contrary, per cent tolerant individuals, which included clariids, proliferated at highly polluted sites below industrial outfalls and in urban areas. Tolerant

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Table VI. Pearson's correlation coefficients between habitat variables and fish metrics and the final index (FIBI) for the Lake Victoria drainage basin

Fish metrics	Habitat variables					
	Substrate quality	Instream cover	Channel morphology and modifications	Riparian zone and bank erosi on quality	Riffle/pool/ run quality	HQI
Number of native species	−0.03	−0.40	−0.49*	−0.09	−0.22	−0.29
Number intolerant species	0.52*	−0.37	0.15	−0.04	0.26	0.23
Number rheophilic species	0.10	−0.21	−0.21	−0.24	−0.10	−0.14
Number per 50 m of sampling	0.26	0.28	0.26	0.07	0.02	0.28
Per cent benthic species (excluding clariids)	0.47*	−0.30	0.35	−0.01	0.44*	0.30
Per cent cyprinid individuals	0.68*	−0.55*	0.19	0.21	0.52*	0.36
Per cent tolerant individuals	−0.66*	0.05	−0.35	−0.22	−0.47*	−0.52*
Number exotic species	−0.41*	−0.22	0. 71*	−0.47*	−0.50*	−0.59*
Per cent insectivore individuals	0.47*	0.25	−0.51*	0.27	0.50*	0.58*
Per cent detritivore individuals	−0.10	−0.52*	−0.01	−0.08	−0.11	−0.06
Per cent generalist individuals	−0.65*	0.07	−0.35	−0.10	−0.50*	−0.49*
Modified index of well-being	0.33	−0.09	−0.02	0.13	0.12	0.17
FIBI	0.71*	−0.17	0.31	0.25	0.44*	0.51*

*Significant relationship at $p \leq 0.05$.

species were widely distributed from the upper reaches to the lower reaches, making them useful indicators of poor water and environmental quality.

As a measure of abundance, the number of individuals per 50 m of sampling metric, was retained despite a lack of relationship with the assessed habitat variables. Total number of individuals is a gross measure of fish production with low numbers recorded in highly degraded systems and nutrient-poor waters (Karr, 1981; Ganasan and Hughes, 1998). In this study, sampling sites with obvious point and non-point sources of pollution needed more sampling effort to obtain sufficient number of fish. As earlier reported, habitat quality is only one among many indicators of degradation. For instance, sites located below effluent discharge points from Muhoroni Agro-Chemical and Pan Paper Mills Industries had intact habitat but reduced fish abundance, possibly due to poor water quality, but not habitat quality.

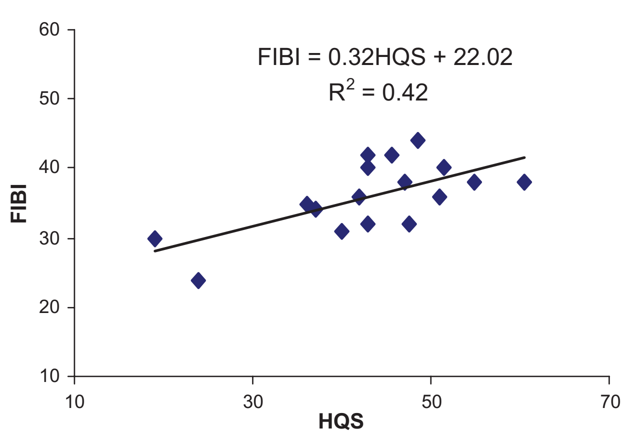

Figure 3. The relationship between the derived Fish Index of Biotic Integrity for Lake Victoria drainage basin and the habitat quality scores (HQS)

Per cent cyprinid species metric was useful in delineating degradation levels among the studied sites. Cyprinids were widely distributed from the mouth to the source of the rivers, but are conspicuously absent in severely degraded areas. In sites with good water and habitat quality, it was the dominant group encountered and its wide distribution made it suitable as an indicator of environmental quality in the whole basin. In tropical West African streams, Toham and Teugels (1998, 1999) proposed cyprinids as useful indicators of ecosystem degradation due to their relatively high species richness and broad geographical distribution over a wide range of conditions.

In the Lake Victoria Basin, the number exotic species metric proved to be important in assessing fish assemblage diversity. Exotic species were recorded mostly at the lower reaches and this explains the high number of cichlid species in the lower reaches, as opposed to the upper reaches; since three of the six cichlids encountered were exotic. Moreover, in the wake of increased degradation resulting from human population growth in the catchment areas, the discrimination potential of this metric can be utilized by considering the potential and likely impact of the different introduced species concerned. For instance, the capture of *Lates niloticus* upstream of the Nzoia River is worrying considering the extirpations of native haplochromines it

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Table VII. Total FIBI scores, integrity classes and description of their attributes specific to the Lake Victoria Basin, Kenya

Total FIBI score (sum of 12 metric ratings)	Integrity class	Description
58–60	Excellent	Similar to unimpacted sites in the region with whole catchment under natural forest with minimal or no human activity in the riparian zone and in the river. Fish composition dominated by intolerant taxa with number of insectivores more than 66.7%
48–52	Good	No human activity within 100 m of the riparian zone, number of intolerant fish species >2, stream bed substrate stable. No point source of pollution
40–44	Fair	Riparian zone >20 m wide with minimal human activity that include settlement, natural vegetation maintained along the river. No rowcrop agriculture and industrial activity or urban centre on the riparian zone
28–34	Poor	Collapsed and eroded river banks, rowcrops act as riparian zones, human activity include agriculture, animal watering points and water abstraction, urbanization and industrial activity with 100 m of the riparian zone. Stream bed dominated by sand and organic materials, water turbid (cannot see the stream bed). Obvious point and non-point sources of pollution. No intolerant taxa and tolerant ones form more than 80% of the total composition
12–22	Very poor	Riparian zone <5 m or human activity up to the edge of the river, collapsed river banks without vegetation, riparian zone under agriculture or urbanization or industry, human activity include animal watering, water abstraction, bathing, washing and sand mining. Point-source pollution from municipal and industrial discharges, stream bed composed of sand, mud and organic wastes. Water turbid and only tolerant clariid fish species occur at the site

has caused in the lake (Witte *et al*., 1992, 1999). However, its earlier detection in Sondu-Miriu (Ochumba and Manyala, 1992) and absence of it during this survey means that it may not fully establish itself in the rivers. This is partly due to the fact that the fish is sensitive to low oxygen levels (Chapman *et al*., 1996; Schofield and Chapman, 2000). Long-term studies on riverine fish assemblages, which are currently lacking, should be able to present the potential impacts posed by exotic species.

Alterations in water quality or habitat conditions can result in fish communities changing because of the fluctuating food resources (Karr *et al*., 1986). Three metrics under trophic group category that met the test criteria in this study were per cent insectivore, omnivore and detritivore individuals. Disruptions in the food base caused by degradation have been found to lead to higher percentage of omnivores (generalists) and a decrease in the proportions of insectivores and carnivores (Karr, 1981; Karr *et al*., 1986; Morris *et al*., 2007). Omnivores were consistently higher in degraded sites receiving point and non-point sources of pollution while proportion of insectivores was low in degraded sites. It was, however, important to note that the same species of fish could exhibit different feeding preferences depending on the environmental condition of the site inhabited, as also recorded by Raburu (2003, unpublished) in the Lake Victoria basin. In the Ntem River Basin, the proportion of invertivores and omnivores responded to deforestation and were, therefore, useful in assessing degradation (Toham and Teugels, 1999). Hugueny *et al*. (1996) also observed an increase in percentage of omnivores and a decrease in invertivores at disturbed sites, attributing it to changes in food supply. The top carnivore metric common in fish IBIs did not meet the test criteria but per cent detritivores did. There are few carnivorous fish in the basin and the three that were encountered, *S. mystus*, *B. docmak* and *Protopterus aethiopicus*, practiced food switching by feeding on insects in the rivers. This behaviour is different from the ontogenic size related diet change. For instance, Corbet (1961) indicated that the diet for some fish varied with season and availability of food.

Because data on fish anomalies were not collected, the modified index of well-being was used as a metric to assess fish condition. This metric is based on fish abundance and biomass measures and is a useful tool for assessing fish assemblages in rivers (Yoder and Rankin, 1995). This metric replaces the per cent individuals with deformities, eroded fins, lesions, and tumours (DELTs) metric used in North America (Karr *et al*., 1986). Studies in Africa have rarely used fish condition metrics because of a lack of data on its scoring. It has, however, been retained in the final indices (e.g. Hugueny *et al*., 1996; Toham and Teugels, 1999) pending future investigations.

Index performance and validation

Many of the FIBI metrics were significantly correlated with substrate quality, riffle quality and the final HQI score. The weak relationship between the FIBI and HQI can be explained by the fact that other factors were influencing fish assemblage characteristics which were not captured by

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habitat assessment. These include water quality, flow regime, biotic interactions and energy sources. However, the fact that the relationship was significant implies that widespread land-use disturbance affected the sites and fish assemblage characteristics. This can be explained by the fact that agriculture dominates most of the catchments, accounting for more than 75% of the land area. However, instream habitat quality significantly influenced the FIBI, demonstrating that the fish index was able to register near-stream and instream human activities like sand harvesting and watering of animals in rivers.

Validation of the FIBI was done by applying it to assess targeted sites of known quality to evaluate how well it could predict human influence on a new set of sites. The validation data set indicated that the FIBI could predict human influence at six of the seven sites. The River Mbogo site, below a sugar factory discharge point, had a good FIBI value of 51. However, there was high habitat heterogeneity at the site which could have increased fish diversity and abundance. Another reason could be attributed to the efficient treatment of the factory wastewater before release into the river (Tonderski *et al*., 2007). Further evidence is the low FIBI value belonging to the 'very poor' condition category recorded below the Muhoroni Agro-Chemical factory effluent site indicating that the index was sensitive to wastewater from the industry.

CONCLUSIONS

The FIBI developed in this study has demonstrated its reliability in identifying sources of impairment and the potential of the ecosystems to support healthy fish assemblages. The index clearly indicates that wastewater from agro-based industries, municipalities and poor agricultural practices were key contributors to serious declines of environmental condition. This provides scientific evidence on the influence of perturbations on riverine fish assemblages in the Lake Victoria Basin. The assessment tool developed here gives water resource managers a scientifically defensible rationale for reducing riverine habitat degradation and pollutants from point and non-point sources.

Considering that almost all aquatic environments within the Lake Victoria drainage basin have been altered in one way or another, it is difficult to get 'least impacted' sites that can act as a reference. This is more so the case in the lower reaches where pollutants from upstream affect water quality and human activities along the rivers affect habitat quality. The risk, therefore, is that disturbed sites can be used as a reference with the effect that the scoring criteria are too easily met resulting in high FIBI scores and qualitative evaluations that might not encourage conservation or restoration (Hughes, 1995). To avert this risk, reference sites were not used for developing the scoring criteria and the highest values for a metric across all sites was used as a reference (Karr and Chu, 1999). This was possible because all the sites sampled fall within the same ecoregion (see also Raburu *et al*., 2009) with comparable fish assemblages and human impact types. In so doing, the logical foundations of indices of biotic integrity were found to be adaptable for our situation in the Lake Victoria drainage basin, Kenya. Given that the FIBI was able to delineate different sites according to the level of degradation, its use is encouraged to identify river reaches with potential problems where interventions are needed to avoid further degradation to ecosystem integrity. However, modifications can be done to improve the sensitivity of the metrics selected as more information on sensitivity of the different fish species to different types of degradation is generated.

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