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Full Length Research Paper

Macroinvertebrate-based Index of biotic integrity (M-IBI) for monitoring the Nyando River, Lake Victoria Basin, Kenya

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A macroinvertebrate-based Index of Biotic Integrity (M-IBI) was developed to monitor ecological integrity of the Nyando River and its tributaries. Macroinvertebrates were sampled with a scoop net between September and December 1999 from 12 stations selected to correspond with different human activities in the catchment. The samples were hand sorted in the field, preserved in 70% alcohol before transportation to the laboratory for identification and counting. The stations were grouped into three condition categories (reference, moderate and impaired) according to the level of water and habitat quality. Twenty metrics representing the structural and functional organization of macroinvertebrates were evaluated for range, response to disturbance and stream size differences and redundancy with each other. Ten metrics met the test criteria and were used to provide the final scores for developing the M-IBI. Metrics values at both reference and impaired sites were used to establish the scoring criteria using inter-quartile ranges. The metrics displayed variability across the sites and the final index was able to separate reference sites from moderately impaired and impaired sites. There were variations in ecosystem integrity among stations and this was reflected in community composition and structure of resident macroinvertebrates. The index developed can, therefore, be used to monitor the integrity of streams within the Nyando River Basin.

Key words: Bioindicators, bioassessment, metrics, water quality, habitat integrity.

INTRODUCTION

Riverine ecosystems in Lake Victoria drainage basin provide a suite of water use benefits to the riparian communities including water for domestic use, irrigation and industrial use. However, unsustainable land use changes, and their drivers (Odada et al., 2009), pose threats to the integrity of both surface (Okungu and Opango, 2005) and ground water (Simiyu et al., 2009). Among the major human activities that have been identified to degrade water quality include deforestation, agriculture, hydromodification, urban runoff, and discharge of untreated waters from storm sewers (GEF, 2007; Njiru et al., 2008). Nyando River drains an area of vast and varied land use activities ranging from the forested upper reaches to the urban-industrial and agricultural middle and lower reaches (Raburu, 2003). Because of these land-use types, high amount of nutrients and suspended solids have been reported for the river (Okungu and Opango, 2005). This is caused by high effluent loads, both domestic and industrial, entering the river and high doses of phosphorous and nitrogenous fertilizers used in the catchment. Thus, a number of point and non-point source pollutants impact on water quality and the overall ecosystem integrity of the river. Nyando River however still plays an important role as a major source of livelihoods for riparian communities as well as being a major spawning ground for potamodromous fishes (Raburu, 2003).

Land-use activities within a watershed often alter stream morphology and water quality of individual river

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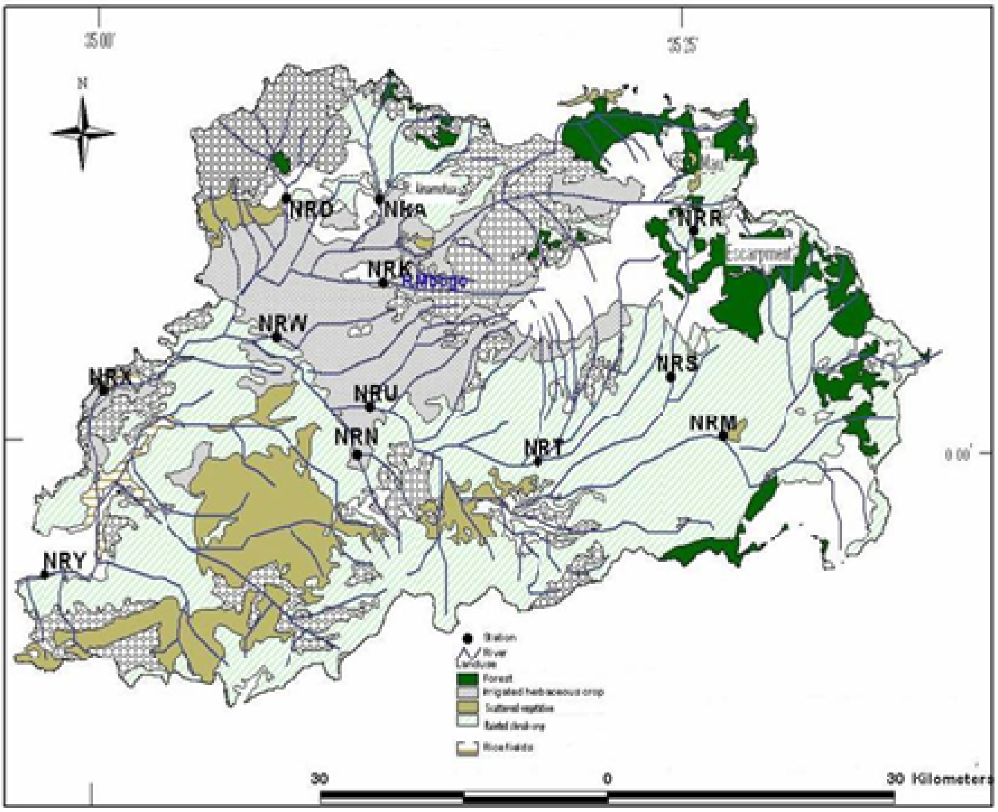

Figure 1. A land use map of Nyando River basin showing the location of sampling stations.

systems that drain it. These activities change the natural balance of flow, sediment movement, temperature, and other important variables, which ultimately impact the physical, chemical and biological processes (Gore and Shields, 1995; Kyriakeas and Watzin, 2006). Unfortunately, the effects of non-point source pollution can be difficult to quantify since most pollution occurs during heavy rain events (Morris et al., 2003). However, aquatic biota provides an integrative measure of water chemistry and physical conditions of their environment (DeShon, 1995; Barbour et al., 1999) forming the basis for their use in biological assessment.

Macroinvertebrate assemblages have been widely used as biondicators of the overall health of riverine ecosystems within the framework of the Index of Biotic Integrity (IBI) (Kerans and Karr, 1994; Thorne and Williams, 1997; Raburu et al., 2009a). The IBI comprise several quantifiable attributes of the biotic assemblage, termed 'metrics', that assess assemblage structure, composition and function (Fore et al., 1996, Karr and Chu, 1999). The IBI as a multimetric approach is effective for evaluating human disturbance, standardizing assessment and communicating the biotic condition of streams (Barbour et al., 1999). An IBI is also useful in developing biological criteria for stream protection (Barbour et al., 2000).

Water quality monitoring in Lake Victoria Basin has always been based on measurement of physico-chemical parameters which is expensive and irregular (Njiru et al., 2008). This study, therefore, set out to develop an integrative and cost-effective multimetric index (Karr and Chu, 1999) for monitoring the ecological integrity of the river. The main objectives were; to classify anthropogenic pressures and evaluate their intensity in relation to identified reference conditions, to select the most sensitive metrics and quantify their deviations from the reference situation, and to evaluate the capacity of the index to quantify the intensity of human pressures along the river.

MATERIALS AND METHODS

Study area

The study was carried out in the Nyando River, which is 153 km long, occupying a total catchment area of 3,450 km2 within Lake Victoria Basin (Figure 1). The river originates from the western side of Mau escarpment, at about 1,700 m.a.s.l. The river confluences with its tributaries, Masaita, Mbogo, Ainamotua and Kundos and gently flows into the swamps before entering Lake Victoria at about 1,135 m.a.s.l. The catchment has high agricultural potential with annual biomodal rainfall pattern averaging between 1,100 and 1,600 mm (Jaetzold and Schmidt, 1983). The River drains large-scale coffee, tea, maize, sugarcane plantations and rice irrigation scheme, which are potential sources of non-point pollution. Agro-based industries within the river catchment contribute the bulk of the point pollution sources. Human activities and the general increase in overall population density downstream impacts negatively on the river water quality (Raburu, 2003).

Sampling design

To capture the effects of different human activities on water quality, sites were objectively selected along the river to allow for comparisons. A total of 12 sites were selected based on representative river network sampling criteria (Figure 1). Station NRR located in the forest is a 1st order stream, stations NRS and NRN, both 2nd order, drain coffee and tea plantations with intact riparian areas while NRM and NRD are located on 3rd order streams that drain a recently deforested area and a tea zone interspersed with forests respectively. Station NRA was located on Ainamotua tributary that drain large-scale tea, coffee and sugarcane farms. Station NRT, the 3rd order, was located in an area where the riparian zones were least impacted with human activity. Stations NRU, NRW and NRK, all on 4th order streams, were located below point sources of pollution emanating from an urban center and two sugarcane factories respectively.

Station NRX was located in the lower basin after all the tributaries confluence next to an urban center with increased human activities including bathing, animal watering and dumping of assorted solid wastes. This was also a sub catchment with minimal vegetation cover. Lastly, station NRY was located within the wetlands at the river mouth.

In each sampling station, macroinvertebrates were sampled and habitat quality characteristics and selected water quality parameters determined. Habitat characteristics assessed included, cover, channel morphology, modifications, riparian quality, bank stability and erosion according to Rankin (1995) and following modifications for Lake Victoria basin (Raburu, 2003; Masese et al., 2009). Water quality variables included nutrients [Phosphate phosphorus (PO_4 – P), nitrate nitrogen (NO_3- N)], biological oxygen demand (BOD), temperature, dissolved oxygen (DO), conductivity, turbidity, alkalinity, salinity and hardness. Water samples for PO4-P, NO_3-N, alkalinity, salinity, hardness and BOD analysis were collected and analyzed according to standard methods (APHA, 1998). Temperature, pH, DO, conductivity and turbidity were measured *in situ* using appropriate meters prior to macroinvertebrate sampling.

At each sampling station, three replicate macroinvertebrate samples were collected from different channel units using a scoop net (1 m^2, 500 µm mesh size). The macroinvertebrates were washed through a 300 µm mesh size sieve, hand sorted in the field and preserved in 70% alcohol. In the laboratory, the preserved macroinvertebrates were identified to genus level according to Stehr, (1991); Merritt and Cummins, (1996) and Quigley (1977), and then counted.

Environmental conditions

Sampling sites were classified into three condition categories; reference, moderately impaired and impaired, based on habitat and water quality. Sites were considered as reference if the stream was in a forested basin, no towns or communities within 100 m upstream, riparian vegetation intact and no detectable effects of grazing or human activity within 100 m upstream and no hydrologic modification in the watershed, and no major wastewater treatment discharges. Impaired sites were identified as those with damaged and eroded riverbanks associated with livestock grazing, recreation- swimming, row crop agriculture, and obvious point and non-point sources of pollution like industrial and municipal discharges within 30 river kilometers upstream. Also the sites had a < 20 m riparian zone. Sites that did not belong to the two categories were considered to belong to the moderate range of conditions.

Metric selection and testing

Successful application of the multimetric index depends on a rigorous process to identify and test metrics (Karr et al., 1986). Metrics can be selected *apriori* to objectively measure a given type of disturbance based on expected response of the assemblage to that particular type of stressor (Weigel et al., 2002) or *posteriori* based on empirical relationships based on statistical correlations with measures of disturbance, like water chemistry and habitat quality (Klemm et al., 2003). Biological response to stress also varies from one region to another as constrained by different biogeographic and climatic differences that drive ecological processes.

The posteriori approach is more common because it offers testing of a large number of metrics, which provide a wider scope and a more rigorous assessment of perturbations, because, if wrongly selected a metric may fail to capture differences in environmental quality. In this way a metric is included in the final index based on demonstrated ability to communicate resource condition in question rather than on its historical performance. In this study we combined the two approaches by objectively selecting some metrics from literature (Kobingi et al., 2009; Masese et al., 2009; Raburu et al., 2009; Weigel et al., 2002), which are known to respond well to some particular stressors similar to the ones in River Nyando and other metrics were selected that corresponded with the different levels of degradation in the catchment.

Twenty metrics were selected to represent the functional and structural compositions of macroinvertebrate assemblages in the study area (Table 1). The final metrics for development of an index of biotic integrity were then selected on the basis of various criteria as follows: first, for each metric, scatter plots were examined for linearity, skewness, and kurtosis (Clarke and Ainsworth, 1993); the metrics were examined for response as a function of stream size/order, followed by determination of metrics' response along a gradient of human influence. We determined metric responses to stream size/order and stressors using a 2-way analysis of variance (ANOVA), with stream size/order and site condition category as main effects (Zar, 2001). For metrics that showed no significant effect of stream order, we ran an ANOVA with site condition category as the main effect. A Bonferroni multiple range test was used to indicate differences among condition categories for each metric. Responsiveness of metrics to disturbance gradients was evaluated against physicochemical parameters and habitat characteristics by using Pearson's correlation coefficient. Disturbance gradients included general disturbance (habitat quality index score, channel morphology habitat score, riparian land use score, riparian zone and bank erosion score), channel alteration (channel modification score). Other disturbances included were sedimentation (embeddedness score, turbidity, substrate quality score), acidity (pH, alkalinity, salinity, conductivity and hardness, nutrients (nitrogen and phosphorus) and decomposition (DO and BOD). Metrics that correlated with at least one of the physicochemical and habitat parameters were further tested for redundancy. Redundancy in the remaining metrics was evaluated by Pearson's correlation coefficient. Metrics with a correlation coefficient (r) ≥ 0.85 were considered redundant (Clarke and Ainsworth, 1993). Only one metric from a group of redundant metrics was included in the final index. Metrics that passed the screening process were included in the final index.

In all cases, the metrics were calculated as proportions and normalized by Arcsin-square root transformations before statistical analyses using SPSS (Version 13.0). Tests were considered significant at the $p \leq 0.05$ level. Generic richness, count data and M-IBI scores were log (x+1) transformed.

Scoring criteria and integrity classes

Natural breaks (stream order) and inter-quartile ranges between the

Table 1. Metrics for macroinvertebrates that were considered for development of an index of biotic integrity and the predicted responses to pollution.

Metric	Metric definition	Predicted response
Simpson richness index	Value of the Simpson richness index	Decrease
Number Ephemeroptera genera	Total number of mayfly genera	Decrease
Number Plecoptera genera	Total number of stonefly genera	Decrease
Number Trichoptera genera	Total number of caddisfly genera	Decrease
Number Ephemeropter-Plecoptera-Trichoptera genera	Total number of taxa from mayfly, stonefly and caddisfly orders	Decrease
Total number of genera	All different genera at a site	Decrease
Percent EPT individuals	% individuals from mayfly, stonefly and caddisfly orders	Decrease
Percent non-insect individuals	% of individuals no belonging to the insect orders	Increase
Percentage Diptera individuals	% midge individuals	Increase
EPT: Diptera individuals ratio	Ratio of individuals belonging to mayfly, stonefly and caddisfly orders to that of midges	Decrease
Percent Coleoptera individuals	% of beetle individuals	Decrease
Shannon diversity index	Value of Shannon diversity index	Decrease
Percent dominant 2 or 3 genera	% of individuals in 2 or 3 most dominant genera	Decrease
Number intolerant genera	Total number of taxa belonging to pollution intolerant genera	Decrease
Percent intolerant individuals	% of individuals in pollution sensitive genera	Decrease
Percent tolerant individuals	% of individuals in pollution tolerant genera	Increase
Percent filterer individuals	Filter fine organic material	Increase
Percent scraper individuals	Feed on algae at the bottom	Decrease
Percent predator individuals	Carnivores- scavangers, engulf or pierce prey	Decrease
Percent gatherer individuals	Collect fine deposited organic material	Increase

site groups dictated scoring criteria for metrics. The interval 1, 3, 5 scoring system used in developing fish and macroinvertebrate IBIs (Karr, 1981; Kerans and Karr, 1994; Barbour et al., 1999) was adopted to normalize the ranges of metrics. For metrics that decreased with impairment, we scored sites as 5 if the value of the metric was >25th percentile of reference site values**;** 3 if the value was between the 25th percentile of reference and the 50th percentile of impaired site values; and 1 if the value was >50th percentile of impaired site values. For metrics that increased with impairment, we scored sites as 5 if the value of the metric was <75th percentile of reference site values; 3 if the value was between the 75th percentile of reference and the 50th percentile of impaired site values; and 1 if the value was >50th percentile of impaired site values. The scored metrics were then summed to obtain the final M-IBI score. Two-way ANOVA was used to determine differences in M-IBI scores among the condition category and stream order interaction term. If there was no interaction, one-way ANOVA was re-run with condition category as the only main effect followed by post hoc Bonferroni tests to identify the condition categories that differed from one another. Three integrity classes, good, fair and poor were defined using total M-IBI scores at reference and impaired sites according to Stevenson et al. (2004).

RESULTS

Site categories and environmental conditions

After conducting habitat and water quality assessments, including floodpalin land use, reference sites occurred in lower stream orders with lower NO_3-N, BOD, temperature, salinity, hardness, and turbidity than impaired sites (Table 2). In total we had three categories of sites, 4 reference, 4 moderate and 4 impaired sites. Human activities were concentrated in the lower reaches and this coincided with an increase in stream order.

Macroinvertebrate assemblage characteristics

We identified 98 macroinvertebrate genera belonging to 13 orders and 65 families. Ephemeroptera, Trichoptera, Odonata, Coleoptera and Diptera were encountered at all stations with Ephemeroptera dominating with at least three families. Hemiptera did not occur at stations NRS, NRD, NRX and NRY. Plecoptera did not occur at stations NRU and NRY. Malacostraca and Gastropoda gained prominence at downstream stations in the middle and lower reaches. The relative abundance of Ephemeroptera was highest at all stations in the upper reaches accounting for more than 50% of all individuals in the samples. The relative abundance of Diptera and Coleoptera did not show much variation downstream but that of Trichoptera and Odonata increased while that of Plecoptera decreased.

In general Ephemeroptera, Diptera and Odonata accounted for more than 80% of total number of individuals at the upper and middle reaches and in the lower

Table 2. Summary statistics of environmental variables for reference and impaired sites in River Nyando.

Reference	Salinity (mg/l)	Hardness (mg/l)	Turbidity (NTUs)	Temperature (ºC)	DO (mg/l)	NO_3-N (mg/l)	Stream order
75th percentile	0.14	157.74	141.60	21.86	8.03	5.55	3
50th percentile	0.13	142.28	100.94	20.69	7.62	5.08	3
25th percentile	0.11	113.63	69.43	18.92	7.42	4.97	2
Impaired							
75th percentile	0.13	129.22	365.43	24.23	6.68	6.07	5
50th percentile	0.12	123.87	295.51	23.90	6.51	5.62	4
25th percentile	0.11	114.98	209.10	23.43	6.15	5.76	4

reaches this declined with Malacotraca, and Coleoptera making for the difference. There was strong correspond-dence between Diptera (Chironomus), Malaco-straca, Baetidae (Ephemeroptera) and Hydropsychidae (Tricho-ptera) with point source pollution while Plecoptera and the other Ephemeroptera and Trichoptera families declined or disappeared at degraded sites.

Metric selection

The 2-way ANOVAs indicated significant stream size/order effects on number of genera, (p < 0.05) and percent tolerant individuals (p < 0.05), but the sites did not cause a significant interaction term on the two metrics. On re-run of the model, with condition category as the only main effect, the following metrics showed significant differences between the three condition cate-gories; total number of genera, and numbers of Ephe-meroptera, Plecoptera, Trichoptera, EPT and intolerant genera, percent individuals belonging to Coleoptera, non-insects, EPT, intolerant, tolerant, scrapers, gatherers and predators. All the above metrics distinguished reference and moderate sites from impaired sites. Similarly, percent EPT individuals, number of genera, number of Plecoptera genera and percent scraper individuals distinguished between moderate and impaired sites, after Bonferroni multiple comparisons of means. The metrics that were eliminated for failing to distinguish between condition categories were; percent 2 or 3 dominant genera, Shannon diversity index, Simpson richness index, percent Diptera individuals, ratio of EPT to Diptera individuals and percent filterer individuals**.** Redundancy test showed that intolerant genera metric was redundant with EPT genera, total genera and Trichoptera genera.

Total genera metric was retained because it distin-guished moderate from impaired sites, while Trichoptera taxa was retained because it was not redundant with total taxa. Finally, percent EPT was redundant with percent intolerant and percent scrapers. However, percent EPT was retained because it distinguished moderate from impaired condition categories. The metrics selected for inclusion in the final index are shown in Table 3. All metrics that distinguished between any of the two condition categories at least correlated with one of the physico-chemical parameters (Table 4).

Scoring criteria

We established M-IBI scoring criteria for each metric based upon the summary statistics (Table 5). Scoring criteria depended upon basin area for total genera metric. Basin size scoring criteria were not used for the other metrics because they primarily responded to differences in the level of degradation among the condition cate-gories.

The final ANOVA model with site condition category as the main effect indicated that M-IBI scores were significantly different among condition categories *(p* < 0.001). Post hoc Bonferroni multiple comparisons showed that while the reference and moderate categories were significantly different, only the reference category was different from the impaired category (Figure 2). A check of M-IBI performance showed that IBI values were significantly correlated with physicochemical parameters (4).

All sites in this study were grouped into three integrity classes good, fair and poor, using percentiles of frequency distributions of M-IBI scores at reference and impaired sites. The 25th percentile (38) of M-IBI at reference sites was used to separate “good” from “fair” conditions while the 25th (26) at impaired sites was used to separate “fair” from “poor” sites (Table 6).

DISCUSSION

Macroinvertebrates assemblages and human activities

The Nyando River watershed experienced a number of human activities, which affected water quality and environmental conditions as reflected in the composition and distribution of macroinvertebrate assemblages. For instance, generic richness was highest in minimally

Table 3. Final metrics selected for developing M-IBI for River Nyando and their ability to discriminate between reference, moderately impaired and impaired conditions at the study sites. The numbers 1, 2 and 3 represent reference, moderately impaired and impaired conditions respectively.

Metrics	Condition categories discriminated
Number Ephemeroptera genera	1 and 2 from 3
Number Plecoptera genera	1 from 2 and 3
Number Trichoptera genera	1 from 2 and 3
Total number of genera	1 and 2 from 3
Percent EPT individuals	1 and 2 from 3
Percent Coleoptera individuals	1 and 2 from 3
Percent tolerant individuals	1 and 2 from 3
Percent gatherer individuals	1 and 2 from 3
Percent predator individuals	1 and 2 from 3
Percent non-insect individuals	1 and 2 from 3

Table 4. Pearson's correlation coefficients between M-IBI and its component metrics and physico-chemical parameters in River Nyando,* designate significant relationship at $p < 0.05$.

Metrics	Salinity (mg/l)	pH	Hardness (mg/l)	Conductivity (µS/cm)	TDS (mg/l)	Turbidity (NTUs)	Temperature (ºC)	DO (mg/l)	BOD (mg/l)	NO_3-N (mg/l)
Number Ephemeroptera genera	-0.02	-0.04	-0.18	-0.10	-0.12	-0.57*	-0.02	0.16	-0.09	-0.02
Number Plecoptera genera	-0.20	0.03	0.01	-0.30	-0.33	-0.60*	-0.50*	0.71*	-0.57*	0.27
Number Trichoptera genera	0.58*	0.58*	0.06	0.46	0.48	-0.13	-0.10	0.30	0.33	0.24
Total number of genera	0.69*	0.20	-0.47	0.72*	0.74*	0.43	0.48	-0.28	-0.14	0.50*
Percent EPT individuals	-0.49	0.33	0.30	-0.28	-0.33	-0.83*	-0.68*	0.64*	0.79*	0.35
Percent Coleoptera individuals	0.03	0.20	0.69*	0.18	0.15	-0.26	0.10	-0.24	-0.10	-0.21
Percent tolerant individuals	0.21	0.00	-0.12	0.00	0.13	0.59*	0.58*	-0.47	0.59*	-0.07
Percent gatherer individuals	-0.05	0.51*	0.84*	0.01	0.06	-0.22	-0.07	-0.15	0.06	-0.34
Percent predator individuals	0.41	-0.58*	-0.36	0.23	0.26	0.75*	0.55*	-0.43	-0.62*	-0.26
Percent non-insect individuals	0.21	-0.47	-0.48	0.08	0.14	0.78*	0.48	-0.32	-0.43	-0.33
M-IBI	-0.09	0.23	-0.05	0.29	0.21	-0.50*	-0.31	0.46	-0.58*	0.29

Table 5. Scoring criteria for component metrics of the macroinvertebrate Index of Biotic Integrity (M-IBI) for River Nyando. Sites were scored on a 1, 3, or 5 scale. Component metric scores are summed to yield a multimetric M-IBI value.

Metric	Scoring criteria		
	5	3	1
Number of Ephemeroptera genera	> 6	4-6	$\leq$ 3
Number of Plecoptera genera	$\geq$ 4	2-3	$\leq$ 1
Number Trichoptera genera	>3	2-3	<2
Total number of genera			
Stream order <3	>40	30-40	<30
Stream order $\geq$3	>46	44-46	<44
Percent EPT individuals	>54	28-54	>28
Percent Coleoptera individuals	>8.4	4.2-8.4	<4.2
Percent tolerant individuals	<27.1	27.1-50.3	>50.3
Percent gatherer individuals	<4.5	4.5-6.4	>6.4
Percentage predator individuals	>31.2	16.5-31.2	<16.5
Percent non-insect individuals	<4.1	4.1-16	>16

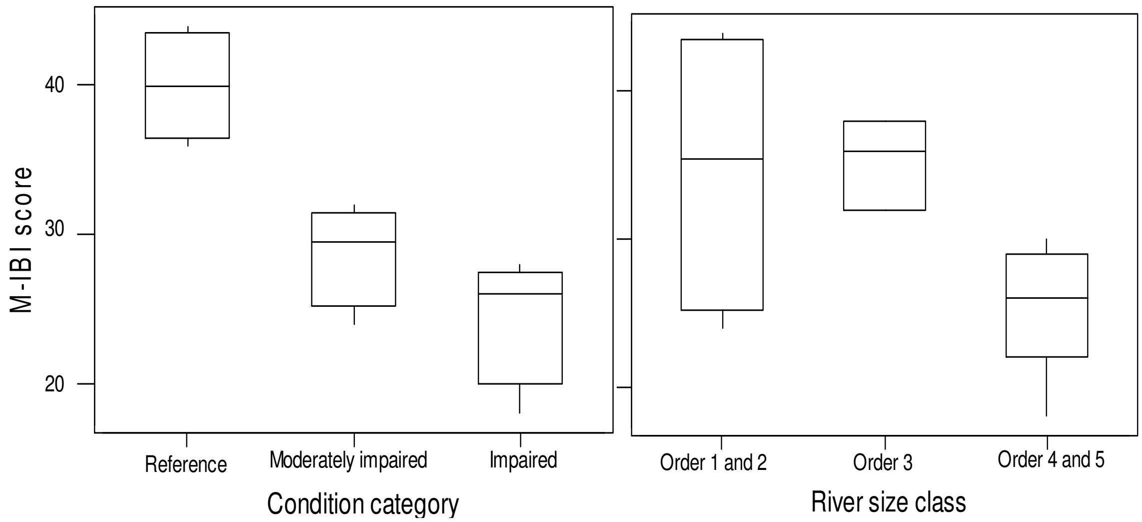

Figure 2. Box plots of Macroinvertebrate Index of Biotic Integrity (M-IBI) values by condition categories and river size. M-IBI distinguished reference from moderate and impaired categories, but moderate and impaired were not statistically different after Bonferroni multiple comparisons. There was no significant stream size or stream size x category interaction effect on M-IBI values.

Table 6. Total M-IBI scores, their integrity classes and narrative description based on environmental conditions found along the Nyando River Basin during the current study.
Reorganize table 6 as follows:

Integrity classes, total M-IBI score and stations	Narrative description based on River Nyando
Good, $\geq$ 38 (NRR, NRS and NRK)	Minimal human activity within 100 m of the riparian zone, natural vegetation intact, macroinvertebrates dominated by EPT, few non-insects, if present gastropods, in-stream substrate dominated by stones, boulders and vegetal material. Water clear (can see the bottom).
Fair, 27-37 (NRT, NRN, NRD, NRA, and NRW)	Minimal human activity within 50m of the riparian zone, BOD <2 mg/l, % EPT 25-50%, % Diptera <20%, in stream cover >75%, bottom substrate dominated by stones and vegetal materials, industry within 100 m of the riparian zone and industrial discharges. Water clear as the bottom can be seen
Poor , 10-26 (NRM, NRU, NRX and NRY)	Riparian zone <30 m, collapsed and eroded river banks, in stream cover <50%, human activity include deforestation, settlement, animal watering points, water abstraction, sand harvesting, dumping of domestic wastes, high sedimentation, row crop subsistence farming/rice irrigation, highest human population density within the basin, BOD >4 mg/l, % EPT <25%, % tolerant taxa >30% and dominated by chironomids and oligochaetes (non-insects), bottom dominated by sand and organic materials, water turbid, (turbidity > 200 NTUs).

impaired stations while lowest among moderately impairred stations. However, this could be attributed to river size/order differences, which had an effect on richness. Additionally, the intermediate disturbance hypothesis (Ward and Stanford, 1983), predicts highest diversity and richness at stations experiencing moderate levels of pollution, a scenario that can explain the higher numbers of taxa at the moderately impaired stations.

There were marked shifts in relative abundance and composition of macroinvertebrate assemblages among the stations. This was reflected in the relative abundance of EPT, which declined downstream. This trend was more vivid at stations located below discharge points of Industrial wastewater and in settlement areas where increase in turbidity as a result of sedimentation affected the groups, as has been observed elsewhere (Kibichii et al., 2007; Masese et al., 2009).

On the other hand, the relative abundance of tolerant groups, like Chironomidae, and non-insects like Gastropoda and Mollusca, increased downstream at degraded sites NRX and NRY. Chironomidae has been found to be tolerant to degradation and dominating at organically polluted sites (Masese et al., 2009) and higher relative abundance of non-insects has been found to be an indication of stress (Klemm et al., 2003).

M-IBI development and performance

The process of testing hypotheses about how Macroinvertebrates in River Nyando responded to different human influence types and developing an index that could register and communicate this response by delineating different sites according to their levels of degradation formed the bulk of this study. Classifying sites according to different levels of degradation enabled us to come up with reference conditions against which the response of macroinvertebrate metrics to environmental conditions was to be assessed. Among the different categories of metrics evaluated, ten passed the screening process and were included in the final index for River Nyando.

The four richness metrics in the final index were able to separate reference from impaired sites. In addition, number of Plecoptera genera and total number of genera metrics separated reference from moderately impaired sites. The EPT metrics have found similar applications in indices where they are separated into individual orders to improve their sensitivity (DeShon, 1995; Klemm et al., 2003). This is because the three orders, though intolerant to pollution, respond differently to degradation with the sensitivity decreasing from Plecoptera to Trichoptera. This was the case in River Nyando where the tolerance of Hydropsychidae (Trichoptera), Baetidae and Caenidae (Ephemeroptera) reduced the sensitivity of the two orders, conforming to results from other studies (Thorne and Williams, 1997). In River Nyando a general decrease in taxa richness downstream was as a result of intensified human activities both in the river and on the riparian areas.

Among the community composition metrics, the relative abundance of EPT individuals met the test criteria. Low values were recorded at degraded sites below industrial outfalls like NRW and NRU and in urban areas like NRX. The metric is useful in registering subtle differences in water quality (Karr and Chu, 1999) and therefore can be used to monitor even low levels of degradation. The relative abundance of Coleoptera individuals metric is not common in most IBIs. However, in the current study it was able to separate impaired from moderately impaired sites. The good performance of Coleoptera can be attributed to the high abundance of elmids in the study area, which are sensitive to pollution (Buss et al., 2002).

In other studies Coleoptera, together with the EPT, have been used as a measure of diversity in French streams (Cereghino et al., 2003) and this show that the group can be a good measure of pollution that affects overall richness. Percent non-insects individuals' metric is not commonly used, except by Klemm et al., (2003), but its variations, such as percent non-Tanytarsini dipterans plus non-insects (DeShon, 1995) and percent oligochaetes (Kerans and Karr, 1994), have been used. In this study, the metric responded more strongly to organic pollution. Oligochaeta, Mollusca and Crustacea were dominant at sites receiving organic wastes like NRK and NRX situated in Muhoroni and Ahero Towns respectively. In addition station NRK receives wastewater from a sugar factory.

Percent tolerant individuals' metric was useful in assessing overall pollution from point and non-point sources. A common substitute for this metric in biological indices is the percent sediment tolerant individuals (Fore et al., 1996) or percent depositional individuals (Weigel et al., 2002) all of which measure the effect of sedimentation caused by row crop agriculture, animal overuse of riparian areas and construction. Other studies have used biotic indices, like the Hilsenhoff biotic index, but mostly for assessing organic pollution. High numbers of pollution tolerant chironomids, oligochaetes, gastropods and belostomatids achieved high numbers at stations below urban centres and industrial discharges than at minimally degraded sites.

Two metrics from the community function category met the test criteria, percent gatherer and predator individuals. Gatherers are generalists that thrive in depositional zones having an abundance of fine particulate organic matter (Stepenuck et al., 2002). Such response was used to assess organic pollution, which emanated from livestock grazing and watering, raw sewage disposal, industrial effluents and dumping of domestic wastes. While the river Continuum Concept (Vannote et al., 1980), predicts high abundance of gatherers in large rivers, the high abundance witnessed in small order streams, like NRM (2^{nd} order), and the low numbers at stations NRX and NRY, both 5^{th} order, indicate some level of degradation that was influencing the distribution of food sources.

On the other hand predators are the only functional feeding group not expected to make significant variations along a river continuum (Karr and Chu, 1999) and because of this, they are widely used in monitoring studies (Weigel et al., 2002; Stepenuck et al., 2002). In this study area, higher percentages of predator indivi-duals were observed at minimally impaired stations as opposed to at impaired sites. Because processing of organic material and turnover of detritivores must be substantial to support the predator populations (Cheshire et al., 2005), degradation that affects detritivores populations also affects that of the predators.

Despite the proven utility of the two functional feeding group metrics in defining the degradation gradient, their response to environmental degradation might have been affected by the fact that we used information from literature, as there is limited published information from East Africa, except that by Dobson et al. (2002) who also mostly relied on literature to assign various taxa to different functional feeding groups.

The ten metrics selected for the M-IBI were relatively independent of one another (correlation coefficients >0.85) and the final index showed variation among condition categories. This shows that the index was an effective tool in assessing river condition. The index responded to a number of human induced stresses that affected both water and habitat quality. The three integrity classes namely ‘good’, ‘fair’ and ‘poor’ helped to quantify the level of human-induced degradation. Overall, there was good correspondence between the results of the multimetric system and the degradation gradient.

Conclusions

The composition and distribution of macroinvertebrate assemblages in River Nyando and its tributaries were primarily influenced by changes in water and habitat quality. Consequently, the ten metrics considered by describe the community structure and function varied across a gradient of human influence, and separated the sites according to their levels of degradation. The responses were clear indications that macroinvertebrate communities were good candidates for assessing overall ecosystem integrity. The fact that the index developed could not separate moderate from impaired sites indicate that there is widespread degradation. Agro-based Industries, poor farming methods, human settlement, animal watering and over-use on riparian areas were the major human activities that affected water and habitat quality. By identifying these sources of impairment the index laid the basis for future monitoring and development of management strategies that can restore the integrity of the river and its catchment.

Even though development of IBIs for Kenyan aquatic ecosystems faces the setback of inadequate studies documenting the composition, distribution and response of macroinvertebrate assemblages to water and habitat degradation, the multimetric developed in this study sets a good basis for developing management strategies for the river. Management efforts should focus on the specific natures of impairment, along with enforcement of existing wastewater discharge standards, restoration of degraded habitats, and mitigation of further degradation, based on accurate assessment and interpretation of component metrics and an understanding of amounts and types of human disturbance. Upon further validation with an independent data set, the index will present a cost-effective means of evaluating the biological integrity of streams and rivers in the basin.

Future studies

Additional reference sites will strengthen the index and lead to a finer classification system within the basin. Further consideration should be given to development of appropriate identification keys for East Africa fauna that can enable identification to the species level and hence increase the sensitivity of the metrics. Tolerance limits also need to be verified for local fauna by qualitative toxicological tests or by direct gradient analysis to identify the various environmental optima for the taxa.

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REFERENCES

APHA (American Public Health Association), (1998). Standard methods for the examination of water and wastewater, 20th edn. Washington, D.C.

Barbour MT, Gerritsen J, Snyder BD, Stribling JB (1999). Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish. EPA-841-B-99-002, U.S. Environmental Protection Agency, Office of Water, Washington, DC.

Barbour MT, Swietlik WF, Jackson SK, Courtemanch DL, Davies SP. Yoder CO (2000). Measuring the attainment of biological integrity in the USA: a critical element of ecological integrity. Hydrobiol. 422/423: 453-464.

Buss DF, Baptista DF, Silveira MP, Nessimian JL, Dorville LFM (2002). Influence of water chemistry and environmental degradation on macroinvertebrate assemblages in a river basin in south-east Brazil. Hydrobiol. 481: 125-136.

Cereghino R, Park Y, Compin A, Lek S (2003). Predicting the species richness of aquatic insects in streams using a limited number of environmental variables. J. N. Am. Benthol. Soc. 22(3): 442-456.

Cheshire K, Boyero L, Pearson RG (2005). Food webs in Tropical Australian streams: shredders are not scarce. Freshwat. Biol. 50: 748-769.

Clarke KR, Ainsworth M (1993). A method of linking multivariate community structure to environmental variables. Marine Ecol. Prog. Ser. 92:205-219.

DeShon JE (1995). Development and application of the invertebrate community index (ICI). In: Davis WS, Simon TP (eds) Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making, CRC Press, Boca Raton, FL, pp. 217-243.

Dobson M, Mathooko JM, Magana A, Ndegwa FK (2002). Detritivores in Kenyan highland streams: more evidence for the paucity of shredders in the tropics? Freshwat. Biol. 47: 909-919.

Fore LS, Karr JR, Wisseman RW (1996). Assessing invertebrate responses to human activities: evaluating alternative approaches. J. Am. Benthol. Soc. 15: 212-231.

Gore JA, Shields D Jr (1995). Can large rivers be restored? Bioscience 45: 142-152.

Jaetzold R, Schmidt H (1983). Farm Management Handbook of Kenya: natural conditions and farm management information - Central Kenya, Vol II/B. Ministry of Agriculture, Kenya, in Cooperation with the Germany Agricultural Team (GAT) of the Germany Agency for Technical Cooperation (GTZ). p. 739.

Karr JR (1981). Assessment of Biotic Integrity Using Fish Communities. Fish. 6: 21-27.

Karr JR Chu EW (1999). Restoring Life in Running Waters. Better Biological Monitoring. Island Press, Washington, D.C.

Karr JR, Fausch K, Angermeier PL, Yant PR, Schlosser IJ (1986). Assessing Biological Integrity in Running Waters: a method and its Rationale. Illinois Natural History Survey special Publication 5, Champaign, Illinois.

Kerans BL, Karr JR (1994). A benthic index of biotic integrity (B-IBI) for rivers of the Tennessee Valley. Ecol. Appl. 4: 768-785.

Kibichii S, Shivoga WA, Muchiri M, Miller SN (2007). Macroinvertebrate assemblages along a land-use gradient in the upper River Njoro watershed of Lake Nakuru drainage basin, Kenya. Lak. Res.: Res. and Manage. 12: 107-117.

Klemm DJ, Blocksom KA, Fulk FA, Herlihy AT, Hughes RM, Kaufmann PR, Peck DV, Stoddard JL, Thoeny WT, Griffith MB, Davis WS (2003). Development and Evaluation of a Macroinvertebrate Biotic Integrity Index (MBII) for Regionally Assessing Mid-Atlantic Highlands Streams. Environ. Manage. 31: 656-669.

Kobingi,N, Raburu PO, Masese FO, Gichuki, J (2009). Assessment of Pollution Impacts on the Ecological Integrity of the Kisian and Kisat Rivers in Lake Victoria Drainage Basin, Kenya. Afr. J. Sci.Tech. Accepted.

Kyriakeas SA, Watzin MC ((2006). Effects of adjacent agricultural activities and watershed characteristics on stream macroinvertebrate communities. J. Am. Wat. Res. Assoc. 42: 425-441.

Masese FO, Raburu PO, Muchiri M (2009). A preliminary benthic macroinvertebrate index of biotic integrity (B-IBI) for monitoring the Moiben River, Lake Victoria Basin, Kenya. Afr. J. Aquat. Sc. 34(1): 1-14.

Merritt, RW., Cummins, KW **(**1996**)**. An introduction to the Aquatic Insects of North America. 3rd edn. Kendall / Hunt Publishing Company, Dubuque, IA.

Morris CC, Jawyer JA, Bennet HH, Robinson CD **(**2003**)**. Effects of Sediment Quality on the Health of Aquatic Ecosystems: A Case Study on Depth of Fines in Coastal Plain Streams in Alabama. In: T.P. Simon (Ed.), Biological Response Signatures: Indicator Patterns Using Aquatic Communities**.** CRC Press, Boca Raton. pp. 113-120.

Njiru M, Kazungu J, Ngugi CC, Gichuki J, Muhoozi L **(**2008**)**. An overview of the current status of Lake Victoria fishery: Opportunities, challenges and management strategies. Lakes Reserv. Res. Manage. 13: 1-2.

Odada EO, Ochola WO, Olago DO (2009). Drivers of ecosystem change and their impacts on human well-being in Lake Victoria basin. Afr. J. Ecol. 47 (1): 46-54.

Okungu J, Opango P **(**2005**)**. Pollution loads into Lake Victoria from the Kenyan catchment. In: C.A., Mallya (Ed.), Knowledge and Experiences gained from Managing The Lake Victoria Ecosystem. Regional Secretariat, Lake Victoria Environmental Management Project (LVEMP). Dar es Salaam. pp. 90-108**.**

Quigley M (1977)**.** Invertebrates of streams and Rivers: a key to identification. Edward Arnold Ltd. London. 84pp.

Raburu PO (2003). Water quality and the status of aquatic macroinvertebrates and ichthyofauna in River Nyando, Kenya. PhD thesis, Moi University, Kenya.

Raburu PO, Masese FO, Mulanda CA (2009). Macroinvertebrate Index of Biotic Integrity (M-IBI) for monitoring rivers in the upper catchment of Lake Victoria Basin, Kenya. Aquat Ecos. Health Manage. In press.

Rankin ET (1995). Habitat Indices in Water Resource Quality Assessments. In: Davis WS, Simon TP (eds) Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making. Lewis Publishers, Boca Raton FL. pp. 181-208.

Simiyu GM, Ngetich J, Esipila TA (2009). Assessment of spring water quality and quantity, and health implications in Tongaren division, Nzoia River catchment, Kenya. Afr. J. Ecol. 47: 99-104.

Stehr FW (1991). Immature Insects. Vol 2. Kendall/Hunt Publishing Company, Dubuque, IA. p. 975.

Stepenuck KF, Crunkilton RL, Wang L (2002). Impacts of urban landuse on Macroinvertebrate communities in southeastern Wisconsin streams. J. Am. Wat. Res. Ass. 38: 1041-1051.

Stevenson RJ, Bailey BC, Harass MC, Hawkins CP, Alba-Tercedor J, Couch C, Dyer S, Fulk FA, Harrington JM, Hunsaker CT, Johnson RK (2004). Interpreting results of ecological assessments. In Barbour MT, Norton SB, Preston HR, Thornton KW (eds) Ecological assessment of aquatic resources: linking science to decision making. Society of Environmental Toxicology and Chemistry, Pensacola, Florida, pp. 85-111.

Thorne RSJ, Williams WP (1997). The response of benthic macroinvertebrates to pollution in developing countries: a multimetric system of bioassessment. Freshwat. Biol. 37: 671-686.

Vannote RL, Minshall GW, Cummins KW, Sedell JR, Cushing CE (1980). The River Continuum Concept. Can. J. Fish. Aquat. Sc. 37: 30-137.

Ward JV, Stanford JA (1983). The Serial Discontinuity Concept of lotic ecosystems. Dynamics of Lotic Ecosystems. Ann Arbor Science, Collingwood, MI. p. 42.

Weigel BM, Henne LJ, Martinez-Rivera LM (2002). Macroinvertebrate-based index of biotic integrity for protection of streams in west-central Mexico. J. N. am. Benthol. Soc. 21: 686-700.

Zar JH (2001). Biostatistical Analysis. Prentice Hall, Englewood Cliff, NJ.