A preliminary macroinvertebrate Index of Biotic Integrity for bioassessment of the Kipkaren and Sosiani Rivers, Nzoia River basin, Kenya

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Abstract

Management efforts for the Lake Victoria Basin have been hampered by a lack of clear standards against which to judge the degree of environmental degradation, highlighting the need for a multi-metric approach for this purpose. Indeed, management priorities for the Lake Victoria catchment must be based on reliable assessments of the biological integrity of the inflowing rivers that can potentially influence the ecological functioning of the lake. Accordingly, macroinvertebrate metrics were evaluated for their responsiveness to human impacts, utilizing Pearson's correlations with physico-chemical parameters. The resultant 9 metrics that provided the best discrimination between physico-chemical samples, using the separation power of Mann–Whitney *U* and Kolmogorov–Smirnov tests ($P < 0.05$) from the 21 sampling sites utilized in this study were the: (i) abundances of Ephemeroptera, Plecoptera and Trichoptera; (ii) relative abundances of Diptera; (iii) Ephemeroptera, Plecoptera and Trichoptera:Diptera ratio; (iv) Oligochaeta, Mollusca, Hemiptera, Odonata and the proportions of tolerance taxa; (v) dominant taxa; and (vi) the relative proportions of invertebrates that fall into the gatherer and predator feeding groups, based on the variability they exhibited across the sampling sites. Using the inter-quartile ranges to establish the scoring criteria, the index was able to delineate impacted from less-impacted sites along the rivers, providing preliminary evidence of responses to changes in the ecosystem integrity exhibited by resident macroinvertebrate assemblages in both rivers.

Key words

Index of Biotic Integrity, Kenya, macroinvertebrates, Rivers, water quality.

INTRODUCTION

The global human population is predicted to increase by approximately 2 billion people over the next 25 years, to a total of 8 billion (UN, 1998). The resulting pressures on running (lotic) water systems also will increase dramatically. To this end, although there is a wide spectrum of biotic indices for assessing the ecological integrity of a running water ecosystem, the Index of Biological Integrity (IBI) remains one of the best methods to the present time to obtain a well-rounded perspective of the chemical, physical and biological conditions of a particular stream site (Sabater *et al.* 2004). An IBI is suitable because it satisfies the requirements that an index be relevant, simple and easily understood by managers, scientifically justifiable, quantitative and acceptable in terms of its costs.

Barbour *et al.* (1999) indicated that multi-metric indices are composed of ecologically sound measurements containing known responses to anthropogenic impacts. Thus, when metrics are organized and selected systematically within a regional framework, this concept implies that multi-metric indices can accurately measure changes along disturbance gradients such as agricultural, urbanization and forestry (Karr & Chu 1997). Reference conditions are a suite of sampling points or sites, chosen to represent regional expectations, regardless of the degree of expectations (Barbour *et al.* 1999). Probability-based sampling designs, in concert with knowledge of metric responses to human impacts, are appropriate for the

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random selection of reference conditions (Griffith *et al.* 2005). This observation affirms the use of macroinvertebrate metrics, sampling and reference site used in this study.

Other than for Europe and the United States, the use of IBI to monitor streams and rivers generally has not yet gained momentum for use on the African continent. Nevertheless, various related studies have been conducted in South Africa (Dickens & Graham 2002), Uganda (Kasangaki *et al.* 2006), and Kenya (Masese *et al.* 2009; Raburu *et al.* 2009), utilizing macroinvertebrates as indicators of the health of riverine ecosystems. Such studies have linked land use activities along a gradient of anthropogenic influences with the occurrence of macroinvertebrates in such habitats, as a means of better ascertaining the degree of ecosystem degradation.

To this end, the sampling sites in this study were selected to represent agricultural and urban impacts on stream communities, with less-impacted sites being forests, or swamps dominated by *Cyperus papyrus*. The study sampling design was intended to provide a robust test of the IBI over a wide range of intensities of human impacts, noting that information and data regarding anthropogenic impacts on streams and rivers in this catchment in particular, and Kenya as a whole, are sparse. Knowledge gaps exist regarding the impacts of many human activities and resulting pollution that may stimulate environmental degradation with far-reaching consequences to these valuable ecosystems (Postel 1998). Accordingly, this study focuses on providing data to bridge existing knowledge gaps on riverine integrity, by relating macroinvertebrate variables to anthropogenic influences for the Kipkaren and Sosiani River, including development of a multi-metric index for macroinvertebrate communities, utilizing metrics that correspond to the range of conditions found in these rivers. This study was designed to provide necessary data to ultimately improve the quality of the effluents discharged into these watercourses from human activities that threaten the diversity of aquatic fauna and health in the riverine environments within the Lake Victoria Basin.

MATERIALS AND METHODS

Study area

This study was conducted on the Sosiani and River Kipkaren Rivers, both being tributaries of the Nzoia River in the Lake Victoria Basin, which lies between latitude 1°30′N and 0°05′S and longitude 34°15′W and 35°45′E, at an altitude of 2000–2180 m above sea level (Fig. 1). The

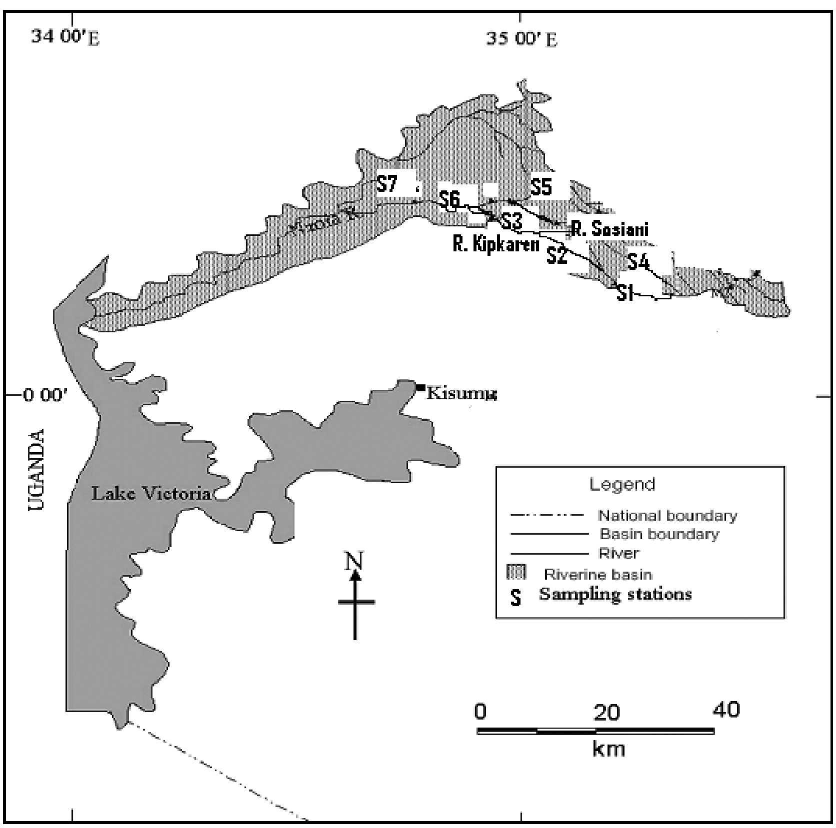

Fig. 1. Sampling stations (each station comprised of riffle, pool and run) on Kipkaren and Sosiani Rivers during study period.

area has a mean annual rainfall of 1200 mm and an average temperature of 18 °C (Jaetzold & Schmidt 1983). The catchment of these two rivers is under pressure from various human activities that lower the ecological integrity of rivers in the upper reaches of Lake Victoria Basin (Table 1; Njiru *et al.* 2008). Macroinvertebrate and selected water quality data were collected from December 2006 to May 2007. This period corresponds largely to the dry season for this region, when rivers and streams generally experience base-flow conditions, as well as the early part of the rainy season (April and May).

Sampling and analyses

Land use characteristics and bank vegetation were recorded for each of the three microhabitats comprising sampling stations, summarized to provide an overall description of each station. Each station had three sampling sites, including riffle, pool and run, randomly picked to avoid bias related to spatial variations, at a distance of approximately 0.5 km from one another, giving a total of 21 sampling sites. Triplicate water physico-chemical parameters were measured at each riffle, pool and run (microhabitat) site (a total of 63 samples), followed by a similar number of macroinvertebrate samples collected from each site using a scoop net (1 m^2, 0.5 mm mesh size). The electrical conductivity of the water was measured *in situ* before 1000 h, using a conductivity meter (Model WD-35607-10; OAKTONR, Singapore). The water temperature and pH also measured *in situ* before 1000 h, using a combined pH-and-temperature-meter (Model pH/Mv/°C METER; OAKTONR). The dissolved oxygen (DO) concentration was determined, using the Winkler Method (APHA, 2000). Triplicate water samples were collected at each site for total nitrogen and total phosphorus concentrations, and subsequently analysed according to the method of Wetzel and Likens (2000). The physico-parameter values for the three samples taken from each microhabitat comprising a sampling station were averaged to obtain a representative water quality measure for each station. A total of 21 macroinvertebrate samples from all the (microhabitat) sampling sites were hand-sorted, preserved in 70% alcohol and identified with a stereoscope to the genus level, according to the method of Merritt and Cummins (1997) and Mathooko (1998), in relation to the local conditions. Variations in water quality, as a function of sampling site categories and sampling dates, were examined, using a 2-way ANOVA with the sites and dates as the main effects. The parameters exhibiting significant effects ($P < 0.05$) were correlated with macroinvertebrate metrics for each site to determine the reference site among the stations sampled for development of the IBI.

Table 1. Location, physical characteristics and land use in Nzoia River Basin catchments, and at sampling stations (stations = riffles, pools and runs summarized from microhabitats into habitats) in Kipkaren and Sosiani Rivers during study period

Station	Altitude (m above sea level)	Land use
S1	2180	Swamp and grassland
S2	2160	Forestry, agriculture and tarmac road
S3	2150	Before confluence, dense bank vegetation
S4	2120	Eldoret-Huruma Sewage and urban centre
S5	2100	Sewage and Turbo urban centre, agriculture
S6	2050	Organic farming and bank vegetation
S7	2000	Kipkaren Urban centre, agro-forestry and agriculture

Macroinvertebrate Index of Biotic Integrity (IBI)

Functional feeding groups were assigned, using literature information (Merritt & Cummins 1997; IFM, 2006), and also suited to the local conditions. The macroinvertebrate community composition at each site, in terms of numbers, density, diversity and percentages of individuals belonging to Ephemeroptera, Trichoptera, Plecoptera, Hemiroptera and functional feeding groups were considered as metrics. For the purpose of this study, a metric is defined as an attribute with empirical change in value being based on ones' study, along a gradient of human disturbance or environmental condition change (Mason 2002). The selected metrics in this study acted as indicator attributes for assessing the status of macroinvertebrate assemblages in response to human perturbations.

Table 2 contains the full list of candidate metrics that fell into the four groups of: (i) taxa richness; (ii) composition attributes; (iii) taxa tolerance; and (iv) trophic function. Taxa richness refers to the total number of species at a specific station in a stream, which represents the simplest way to measure macroinvertebrate diversity at a station in a stream. The orders sensitive to organic pollution, namely Ephemeroptera, Plecoptera and Trichoptera (EPT), were used (Karr & Chu 1997). The numbers of genera belonging to the EPT were evaluated in relation to each macrohabitat. These measures have been identified as an effective metric for use in macroinvertebrates studies for the purpose of IBI development (Masese *et al.* 2009; Raburu *et al.* 2009).

Table 2. Macroinvertebrate metrics considered for assessing Index of Biotic Integrity (IBI) for Kipkaren and Sosiani River sampling sites during study period

Taxa richness (number)	Composition attributes (%)	Taxa tolerance (%)	Trophic function (%)
Ephemeroptera taxa	Diptera	Tolerant taxa	Filterers
Plecoptera	Ephemeroptera, Plecoptera and Trichoptera:Diptera	5 Dominant taxa	Predators
Trichoptera taxa	Mollusca		Gatherers
	Hemiptera		Shredders
	Odonata		
	Oligochaeta		

The composition attributes focus on relative abundance and dominance, to provide information on the makeup of the macroinvertebrate assemblage by assessing their relative contribution to the total fauna (Masese *et al.* 2009). According to Griffith *et al.* (2005), it is always assumed there are changing patterns of dominance associated with pollution, with the few dominant genera contributing a larger proportion of the total noted at the polluted station. In this respect, the percentage of the 5 dominant genera in every order is commonly used as a measure of dominance and evenness. Genera composition measures as metrics that were tested here included the percent of Ephemeroptera, Plecoptera, Trichoptera, Diptera, Mollusca, Oligochaeta, Odonata and Hemiptera, as well as the ratio of the percent EPT to percent Diptera. As a macroinvertebrate order, Diptera is considered pollution-insensitive taxa, in contrast to the EPT group, which is said to be pollution-intolerant as they cannot withstand pollution-derived stresses (Merritt & Cummins 1997).

Taxa tolerance attributes were intended to be representative of sensitivity to perturbation, and includes numbers of pollution-tolerant and pollution-intolerant genera, or percentage composition of macroinvertebrates (Raburu *et al.* 2009). Only those species considered as tolerant or intolerant by a consensus of most researchers were designated as tolerant and intolerant in this study (Karr & Chu 1997; Merritt & Cummins 1997), although acknowledging there is still significant debate on the taxa tolerance of macroinvertebrates to pollution. Taxa considered intolerant to perturbation include the genera from the orders of Ephemeroptera, Plecoptera and Trichoptera (EPT group). Those taxa considered tolerant included most genera belonging to the orders of Diptera, Oligochaeta and Hirudinea. This was evident in the study area, noting that these two groups (tolerant and intolerant) were present in large numbers at the stations that were labelled as degraded based on the sampled macroinvertebrates. The metrics under the "tolerant attributes" included percent tolerant taxa, and the percent of the 5 dominant taxa at each station. Intolerant species disappear in the early stages of degradation, as a response to high suspended solids concentrations, and increased nutrient and dissolved oxygen concentrations (Griffith *et al.* 2005).

Trophic function encompasses functional feeding groups, providing information on the balance of feeding strategies in macroinvertebrate assemblages (Karr & Chu 1997). These functional feeding groups are surrogates of such complex processes as trophic interaction, production and food resource availability (Karr & Chu 1997). Trophic measures as metrics considered included percentage filterers, predators, gatherers and shredders.

Macroinvertebrate metrics were evaluated for responsiveness to human influences by Pearson's correlations, utilizing parameters exhibiting spatial significance differences ($P < 0.05$), including electrical conductivity and dissolved oxygen and total nitrogen concentration, to establish a reference site. The reference station was defined as an area subjected to minimal anthropogenic disturbance, based on thresholds established in this study for water chemistry. The station at the source of the River Kipkaren was chosen as the reference locality in this study, as the macroinvertebrate metrics that decrease with degradation were positively correlated ($r = 0.10$; $P < 0.05$) with the dissolved oxygen concentration, and negatively correlated ($r = -0.21$; $P > 0.05$) with electrical conductivity, and total nitrogen and total phosphorus concentrations. Completely undisturbed stations are virtually nonexistent, however, and even remote waters are impacted by such factors as atmospheric pollution and the presence of households (Mason 2002). After determination of the reference site, the separation power of the Mann–Whitney U test and the Kolmogorov–Smirnov test (as a confirmatory test of Mann–Whitney test) were used to eliminate the resulting metrics that exhibited no significant differences ($P > 0.05$) after pairwise comparison of the metrics for the reference site with those of the impaired sites. A scoring system of 1, 3 and 5, with the thresholds of median-ranges for each metric of 25th and 75th percentiles to the reference station, was used. This system is commonly used in developing fish and macroinvertebrate IBIs (Karr & Chu 1997; Barbour *et al.* 1999; and Karr 1999), as selection of a scoring method has a vital role in increasing the confidence of bio-assessment results, thereby representing a pivotal assessment tool (Blocksom 2003).

As all streams in the study region are considered degraded in one way or another (Kibichii *et al.* 2007), the best attainable values for each metric were used as a reference (Karr & Chu 1997). For each metric that was expected to decrease with increasing degradation, values below the 25th percentile were scored as 1, as they exhibited the greatest deviation from the reference station. Values between the 25th and 75th percentiles were scored as 3, as they fell short of the expected values for the reference station. Values above the 75th percentile were scored as 5. The scoring was reversed for the metrics expected to increase with increasing degradation (Karr & Chu 1997).

It is noted that a pure discrete scoring system also was used for comparison purposes, utilizing a trisection method. For positive metrics (i.e. those that increased with improving conditions), the highest value of a metric across all sites was trisected (Barbour *et al.* 1999). Values above the upper one-third received a score of 5, while those in the middle received a score of 3, and those in the lower one-third received a score of 1. These scores corresponded to unimpaired, intermediate and impaired biota respectively (Barbour *et al.* 1999). For negative metrics, which decreased with improving conditions, the metric was trisected, but scoring done in reverse (i.e. values above the upper one-third received a score of 1, those in the middle range a score of 3 and those in the lower one-third received a score of 5). To develop the final IBI value for each sampling site, the scores for each metric were summed. The highest expected value of 45 points served as a benchmark for the inter-quartile ranges for qualitative assessments of the final IBI scores, in accordance with the methods of Barbour *et al.* (1999) and Griffith *et al.* (2005), although modified to suit local conditions (Table 3). The latter included the status of the riverbank, the environmental conditions of the buffer zone and the adjacent land use. To validate and strengthen the results of the final IBI, the mean IBI value for each site was plotted against the mean value for the dissolved oxygen concentration, electrical conductivity and total nitrogen and total phosphorus concentration (Fig. 2).

RESULTS

Physico-chemical parameters

The highest temperature was recorded at station S2 (mean of 22.2 ± 0 °C), while the lowest was recorded at station S3 (mean of 19.8 ± 0 °C). There was no significant difference between the stations and sampling dates. The lowest mean pH value of 6.8 ± 0.5 was recorded at station

Table 3. Integrity classes for final Index of Biotic Integrity (IBI) development, illustrating classification level and ranges for Kipkaren and Sosiani River sampling sites during study period (EPT, Ephemeroptera, Plecoptera and Trichoptera)

Class of integrity	IBI ranges
Excellent	
No human activity within 100 m of the riparian zone; natural vegetation intact; % EPT >50%; % Diptera <20%; No intolerant taxa >14. Water clear (can see bottom)	36–45
Good	
No human activity within 50 m of the riparian zone; % EPT>50%; % Diptera <20%; no intolerant taxa >10; bottom substrate dominated by stones and vegetal materials; Water clear, as bottom can be seen	28–35
Fair	
Riparian zone >20 m wide with minimal human activity; natural vegetation maintained along reach, with instream cover >50%; % EPT>50%; % Diptera <30%; mainly stone substrate	21–27
Poor	
Riparian zone <20 m; collapsed and eroded riverbanks; human activities include agriculture, water abstractions, urbanization and deforestation; % EPT <30%; % tolerant taxa >30%, and dominated by chironomids and oligochaetes; bottom dominated by sand and organic materials, water turbid (cannot see bottom)	12–20
Very poor	
Riparian zone <10 m; collapsed river banks without vegetation; riparian zone under agriculture or urbanization or industry; human activities include animal watering, water abstraction, bathing, washing and sand harvesting; %EPT <20%; % tolerant taxa >60%, and dominated by chironomids and oligochaetes; number of intolerant taxa <8; bottom composed of sand, mud and organic wastes; water turbid	<12

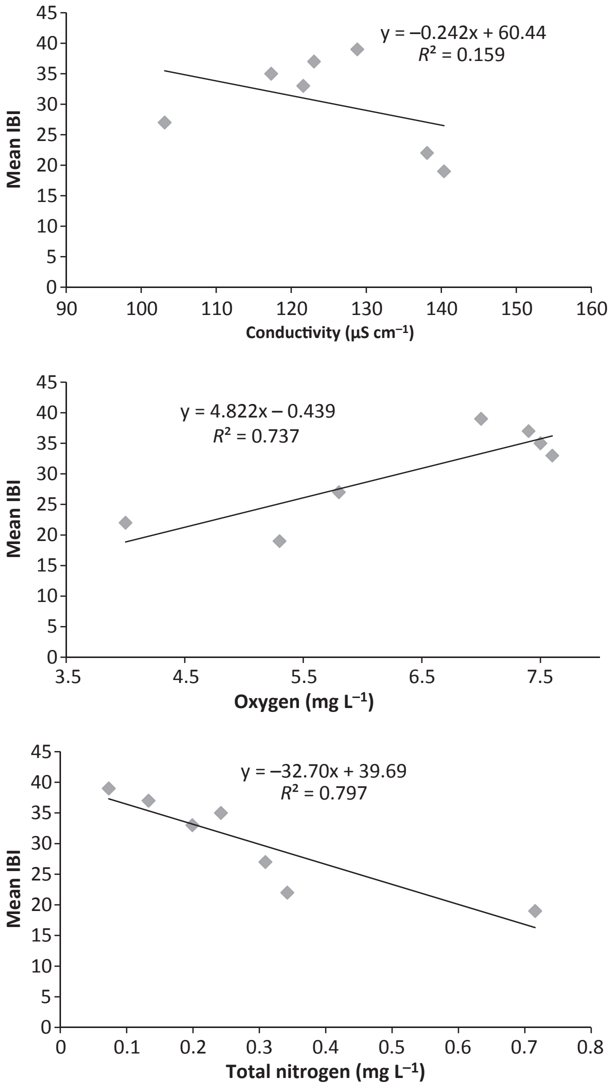

Fig. 2. Plots for validating and strengthening final Index of Biotic Integrity (IBI) scores with final IBI values against dissolved oxygen concentration, electrical conductivity and total nitrogen and total phosphorus concentrations for Kipkaren and Sosiani Rivers during study period.

S3, whereas the highest mean pH value was recorded at station S4 (7.1 ± 0.3). As noted with the temperature, there was no significant difference in pH between sampling stations and sampling dates. The highest mean electrical conductivity of 121.8 ± 8 µS cm^{-1} was recorded at station S4, while the lowest mean value of 101 ± 4 µS cm^{-1} was recorded at station S1. Significant differences in electrical conductivity occurred between stations (F = 16.8; $P < 0.05$), although not between the sampling dates. The highest mean dissolved oxygen concentration of 7.6 ± 0.02 mg L^{-1} was observed at station S2 and the lowest (4.0 ± 0.01 mg L^{-1}) recorded at station S4. The dissolved oxygen concentration differed significantly between the stations (F = 3.6; $P < 0.05$), but not between sampling dates. The total phosphorus (TP) concentration did not differ spatially or temporally during the study. Station S4 in the River Sosiani, however, exhibited the highest TP concentration of 0.54 ± 0.23 mg L^{-1}, while the lowest TP concentration of 0.05 ± 0.02 mg L^{-1} was recorded at station S1. Unlike the TP concentration, the total nitrogen (TN) concentration varied significantly among the stations (F = 629.52; d.f. = 6; P = 0.00), but not temporally. The highest TN concentration of 0.72 ± 0.03 mg L^{-1} was recorded at station S4, and the lowest at station S1 (0.07 ± 0.04 mg L^{-1}).

Macroinvertebrate composition

A total of 1499 macroinvertebrates, belonging to 13 orders, 28 families and 31 genera were sampled. The orders Ephemeroptera, Hemiptera and Coleoptera were the most diverse taxa, consisting of four families each. *Baetis* sp., which was dominant in most of the riffles, dominated station S1, with a relative mean abundance of 29.10 ± 0.21. *Chironomus* sp., which dominated most of the pools, exhibited the lowest relative mean abundance of 0.33 ± 0.01 at the same station. Station S3 experienced a high relative abundance of *Caenis* sp. (23.12 ± 0.63), that also dominated in all the sampling trips, except for station S7. The station, however, exhibited the lowest mean relative abundance of *Pisidium* sp. (0.86 ± 0.02). The highest relative mean values of 19.34 ± 0.09 and 26.73 ± 0.96 for *Lumbricus* sp. were exhibited for stations S4 and S5 respectively, dominating in most pools. *Heptagenia* sp. and *Elmis* sp. were the least dominant at the same stations, with relative mean abundances of 0.56 ± 0.05 and 0.87 ± 0.03 respectively. *Baetis* sp. exhibited the highest relative mean abundance of 27.78 ± 0.95, whereas *Polycentropus* sp. exhibited the lowest relative mean abundance value of 0.28 ± 0.06 at station S2 in the Kipkaren River. Station S7 was dominated by *Chironomus* sp., with a mean relative abundance of 26.1 ± 0.12, whereas *Heptagenia* sp. exhibited the lowest relative mean abundance of 0.74 ± 0.31. *Tubifex* sp., with a relative mean abundance of 27.56 ± 0.07, dominated at station S6, while *Elmis* sp. exhibited the lowest relative mean abundance (0.74 ± 0.01).

Macroinvertebrate index of biotic integrity

As noteworthy observation is that both the combined discrete and continuous scoring methods with a pure discrete method produced similar scoring ranges and scores for the metrics. Of the 15 macroinvertebrate metrics listed in Table 4, the values for 9 metrics differed significantly between sampling sites, thereby allowing for

Table 4. Results of Mann–Whitney *U* and Kolmogorov–Smirnov tests for metrics value of 21 sampling sites in Kipkaren and Sosiani Rivers during study period (*indicates $P < 0.05$; EPT, Ephemeroptera, Plecoptera and Trichoptera)

Metrics	Mann–Whitney *P*-value	Kolmogorov–Smirnov *P*-value
Genera richness (number)		
Ephemeroptera taxa	<0.01*	0.001*
Plecoptera taxa	0.001*	0.01*
Trichoptera taxa	<0.01*	0.02*
Composition (%)		
Diptera	0.025*	0.025*
EPT:Diptera	0.01*	0.01*
Oligochaeta	0.12	0.07
Mollusca	<0.001*	<0.001
Hemiptera	0.23	0.35
Odonata	0.42	0.25
Tolerance (%)		
Tolerant taxa	0.01*	0.02*
Dominant taxon	0.02*	0.01*
5 Dominant taxa	0.25	0.1
Trophic function (%)		
Filterers	0.1	0.2
Gatherers	<0.001*	<0.001*
Predators	0.01*	0.01*
Shredders	0.20	0.15

discrimination between them. These metrics were then used to create an IBI score for each site, and an average IBI per station or locality. The metrics that were similar between the sites were the percent of Hemiptera and Odonata, the percent of the 5 dominant taxa, shredders and filterers. These metrics were not used in calculating the final IBI, the final values of which are summarized in Table 5. The riffles generally exhibited the higher IBI scores, followed by the runs and the pools. Station S2 on River Kipkaren exhibited the highest average Macroinvertebrate IBI (37 points), whereas station S4 exhibited the lowest IBI (19 points). In validating the mean IBI scores per station, in relation to the physico-chemical parameters with spatial significant variations, a negative relationship ($P > 0.05$) between IBI and electrical conductivity and total nitrogen concentration mean values was observed, as was a positive relationship ($P < 0.05$) for dissolved oxygen concentrations (Fig. 2).

DISCUSSION

Anthropogenic activities can cause longitudinal changes in water quality and habitat conditions (Allan 2004). Along the Kipkaren and Sosiani Rivers, the over-use of the riparian areas, sewage discharges and agricultural activities affected the quality of the riparian zones, banks and substrate quality, as reflected in the measured water quality at the sampling stations. The macroinvertebrate

Table 5. Metrics used, scoring criteria, individual sampling site scores. And overall mean IBI per station for Kipkaren and Sosiani Rivers during study period (IBI, Index of Biotic Integrity; S, Site; R, Riffle; P, Pool; Ru, Run; EPT, Ephemeroptera, Plecoptera and Trichoptera; maximum score = 45 points)

Stations	S1			S2			S3			S4			S5			S6			S7			Scoring criteria		
Metric for IBI/Sites	R	P	Ru	R	P	Ru	R	P	Ru	R	P	Ru	R	P	Ru	R	P	Ru	Ri	P	Ru	5	3	1
# Ephemeroptera taxa	5	5	5	5	5	5	5	3	5	5	5	1	5	3	1	5	5	3	5	5	1	18–11	11–6	<6
# Plecoptera taxa	5	3	5	3	5	5	3	3	3	3	1	1	1	1	1	3	3	5	1	1	3	10- 6	6–3	<3
# Trichoptera taxa	5	5	5	5	5	3	5	3	3	5	3	3	5	5	5	3	3	5	1	5	3	6–4	4–2	2–1
% Diptera	3	5	5	5	3	3	5	3	3	1	1	1	1	1	1	5	5	3	1	1	1	<4.6	4.6–8.8	>8.8
% EPT:Diptera	5	5	5	5	3	5	3	3	3	1	1	1	1	1	3	3	3	3	5	5	3	>3.8	1.6–3.8	<1.6
% Mollusca	5	3	3	3	3	5	3	3	3	1	1	3	5	1	3	3	5	3	3	1	3	<5	5–10	>10
% Tolerant taxa	3	3	5	3	5	3	3	5	3	3	1	1	1	3	1	5	3	3	5	1	3	<35	35–42	>42
% Gatherers	5	3	3	5	5	3	5	5	3	1	3	3	1	5	3	5	3	5	3	5	5	>30	15–30	<15
% Predators	5	5	3	5	3	5	3	5	5	1	1	5	3	1	5	5	3	5	5	1	5	>10	6–10	<6
Total IBI Score	41	37	39	39	37	37	35	33	31	21	17	19	23	21	22	37	33	35	29	25	27			
Average score per station		39			37			33			19			22			35			27				

communities in the river also responded to these influences, as reflected in the spatial variability of functional and structural metrics used as degradation indicators in this study. Metric variability and the responses of metrics to impaired sites indicated this IBI responded to the resident macroinvertebrate assemblages found in this ecoregion. These metrics also followed the predicted ecological dose-response relationships with perturbations, using the sub-set (pair-wise) of impaired sites (Barbour *et al.* 1999).

The occurrence of macroinvertebrate communities indicated that headwater stations were dominated by taxa associated with pristine waters (mostly EPT). In contrast, further downstream, and in most pools, sensitive taxa were replaced by the groups of Hemiptera and Odonata, *Chironomus* sp., *Lumbricus* sp. and oligochaetes. The most abundant functional feeding groups in decreasing order were filterers, shredders, predators, scrapers and gatherers. These results are similar to those of Masese *et al.* (2009) in their development of a preliminary IBI for the Moiben River in the Nzoia River basin. These researchers also noted a generally high contribution of scores by riffles and runs in their developed IBI. The dominant occurrence of Hemiptera, Odonata, filterers and shredders in the downstream region could have contributed to the metrics being similar and therefore were eliminated in the final IBI development. Similar results were obtained in Uganda (Kasangaki *et al.* 2008), where sites in agricultural areas, pools, and locations downstream of deforested areas were dominated by tolerant macroinvertebrate taxa that are less sensitive in such habitats. In a stream that flows through human settlements, and agricultural and urbanized areas, chironomids and oligochaetes were positively correlated with poor water quality. In contrast, Ephemeroptera, Plecoptera and Trichoptera displayed a negative response under these conditions (i.e. they were negatively impacted by such conditions; Ndaruga *et al.* 2004).

Based on the calculated mean IBI, station S4 exhibited a mean of 19 points, while station S2 exhibited a mean of 37 points, out of a total of 45 possible points. Based on the integrity classes, station S2 was in the first category (excellent water quality), while station S4 was in the fourth category (poor water quality). The difference in water quality among station S2, and stations S4 and S5, could be partly attributed to the intense urban discharges from Turbo Town, Huruma Estates and Eldoret Town, from industrial discharges and effluents from Ken Knit, Coca Cola, Kenya Cooperative Creameries, Rupa and Raiply into the lower Sosiani River, and from agricultural farms. Station S3 exhibited good water quality (mean of 33 points), probably because of a dilution of the pollutants as a result of the increased water volume observed in the area. Another reason might be the uncultivated farmland, and dense vegetation that forms the riparian zone of the area, which might buffer any runoff into the river to some degree. Station S6 exhibited excellent water quality (mean of 35 points). This finding results probably from the organic farming, and the dense bank vegetation, both of which minimize nutrient and other pollutant discharges into the river. The urban discharges at the town of Kipkaren, along with agricultural runoff in the area could probably be diluted by the increased water volume in the river (Carpenter *et al.* 1998), which might be the reason for its fair water quality (mean of 27 points). The stations for the Kipkaren River were likely less affected by urbanization and agricultural activities because of the presence of a single urban centre (Kipkaren) with no major industries, as well as the presence of uncultivated riparian zones, swamps and vegetation closer to, or around, the river. Thus, the calculated IBI suggests that Kipkaren River water is of good quality, while that in the lower Sosiani River is of fair-to-poor quality.

The IBI calculated in this study is also similar to those IBI scores that have successfully correlated with human activities such as urbanization and agriculture (Carpenter *et al.* 1998; Griffith *et al.* 2005), sewage effluents (Karr & Chu 1997; Harding *et al.* 1998), and destruction of riparian areas (Griffith *et al.* 2005). This indicates that the index probably provides a preliminary estimate of the current biotic integrity of all the sites and stations, and for both rivers, especially during the period of short rains. The 9 metrics considered descriptive of the macroinvertebrate community structure and function varied across a gradient of human influences, which is a key ingredient in biological assessment and monitoring methods (Karr 1999). Their validity also was supported by the strong positive relationship between the overall IBI and the mean dissolved oxygen concentrations, and the negative relationship with electrical conductivity and total nitrogen concentration (Fig. 2), suggesting that the observed variation could be congruent with habitat and water quality of both rivers. In this regard, the index developed in this study was able to identify sources of impairment, and to assess the level of degradation arising from human activities. That no site in the Kipkaren and Sosiani Rivers scored the maximum values for all metrics suggests that even areas considered relatively unimpaired were already experiencing effects of degradation.

In considering management of the Nzoia River basin, the metric scores and integrity classes are indicative of a changing environment being influenced by human activities. With increasing human population in the catchment, this situation is likely to be exacerbated over time. Thus, the primary challenge is to mitigate the current trends and to improve the IBI scores for all the sites and stations by improving both water and habitat quality. This goal can be facilitated by maintaining forest buffers and/or by riparian zone restoration, both of which have been found useful in improving river integrity (Kasangaki *et al.* 2006). Thus, there is a need to adopt this index for monitoring this river, mainly because it is reliable not only for identifying sources of impairment, but also for assessing restoration success. Inadequate reference information, necessary to develop scoring criteria, has handicapped development of river health indices, including the lack of 'baseline' historical research on un-impacted rivers in the region. Thus, development and application of an IBI must address the challenge of a lack of historical information depicting pristine conditions, examples being the structural and functional organization of aquatic biota in most aquatic ecosystems.

As a noteworthy first step towards the development of an IBI for the upper reaches of the Nzoia River region, the index developed in this study is adequate for monitoring the Kipkaren and Sosiani Rivers, as well as others within the upper catchment of the Nzoia River Basin that exhibit similar environmental conditions. Further refinement, incorporating data from minimally impacted rivers and streams in the region, also will strengthen this IBI. Further testing of the metrics, however, should be carried out in these and other river systems, using both the discrete and continuous scoring methods for comparison purposes before the indices are adopted for use in monitoring the entire Lake Victoria Basin.

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