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Reliability of the Tanzania river scoring system (TARISS) macroinvertebrate index of water quality: a case study of the river Mpanga system, Uganda

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ABSTRACT

Uganda does not have a biomonitoring system for assessing the water quality of its rivers basing on benthic macroinvertebrates. An alternative system has been suggested in Tanzania. Differences in characteristics between Tanzania and Uganda may contribute to differences in the physical and chemical characteristics of rivers between the two countries, resulting in variations in macroinvertebrate assemblages and sensitivity levels in relation to disturbance. River Mpanga lies along the equator in western Uganda and shows heterogeneity of impacted and non-impacted sites along its course. The disturbance gradient of River Mpanga was determined using habitat integrity scores. The ability of the Tanzania River Scoring System (TARISS) to distinguish test from reference sites using macroinvertebrate assemblages was validated. Both qualitative and quantitative data were obtained through purposive sampling in both the wet and dry seasons. Macroinvertebrates were sampled following a slightly modified TARISS protocol. Canonical analysis of principle coordinates (CAP) showed that macroinvertebrate assemblages vary along a disturbance gradient, grouping test sites distinct from reference sites. Of the TARISS metrics, average score per taxon was able to distinguish between test and reference sites ($p = .009$) among the TARISS metrics. Five taxa not included in TARISS were found in river Mpanga and were assigned sensitivity scores based on CAP predictive model in PERMANOVA. It was concluded that TARISS could be reliable for eastern African river systems but should be updated and/or modified by users in different regions to include missing taxa.

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Introduction

Bioassessment protocols are based on the premise that biotic communities respond to changes in habitat and water quality resulting from anthropogenic disturbance and that

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such community responses are integrated indicators of stream health (Barbour et al. 1999; United States Environmental Protection Agency [USEPA] 2005). Properly developed methods, metrics and reference conditions provide a tool that enables a direct measure of the ecological condition of a water body. Once a bioassessment index is developed for a region, biological monitoring can be relatively inexpensive, and easily performed with standard protocols (USEPA 2005).

Rapid bioassessment methods (RBMs) for assessing ecological conditions in river ecosystems using macroinvertebrates have been developed and used worldwide, for instance in the European Union, Canada, the United States of America, southern Africa and recently in Tanzania (Kaaya et al. 2015). RBMs have been developed in response to the need in water management for quick and cost-effective methods for assessing water quality given the rising negative impact of anthropogenic activities on water systems. Bioassessment provides indications of cumulative impacts of multiple stressors, not just water quality. Biological community condition reflects both short- and long-term effects, and directly evaluates the condition of the water resource (Elias et al. 2014). The macroinvertebrate community at a particular site reflects the organisms which are adapted to the physical structure of the habitat, limnological conditions and ecological interactions.

Despite the undisputable usefulness of bioassessment systems, many regions of the world have not developed these systems. The good news is that bioassessment indices, especially macroinvertebrate-based indices, developed in one region can be applied in other regions with calibration and modification (Dallas et al. 2010; Kaaya et al. 2015). For instance, indices developed from non-tropical countries often need to be modified before they are applied in the tropical countries. The challenge of adapting bioassessment in tropical countries like Uganda, however, is the poorly known taxonomical resolution and sensitivity of macroinvertebrate taxa to pollution (Jacobsen et al. 2008). Even within similar regions, say tropics, considerable variations in seasonality are known. The pattern of climatic seasonality influences almost all aspects of the ecology of stream invertebrates, particularly, their distribution, life histories and timing of life-cycle events (Jacobsen et al. 2008). Therefore, it is very important that bioassessment systems developed are extensively tested within a given region and the taxa and their sensitivities to anthropogenic disturbances updated.

In Africa, six biotic indices based on aquatic macroinvertebrates have been developed, one of which is the Tanzania Rivers Scoring System (TARISS) in Tanzania by Kaaya et al. (2015). The other five including: South African Scoring System (SASS) in South Africa (Dickens and Graham 2002), the Namibian Scoring System (NASS) in Namibia (Palmer and Taylor 2004), the Okavango Assessment System (OKAS) in the Okavango Delta (Dallas 2009) and the Zambia Invertebrate Scoring System (ZISS) in Zambia (Lowe et al. 2013) were all developed in the south African region and therefore are non-tropical systems. SASS has been extensively tested in South Africa and has proven its capability and reliability as an index for the assessment of water quality and general river condition (e.g. Dallas 1997; Dickens and Graham 2002; Dallas et al. 2010). The Tanzanian system, the only tropical system, developed from SASS has been suggested for East African countries by Kaaya et al. (2015) and recently applied in a few Rwandan rivers (Dusabe et al. 2019). However, the system has not been tested for its reliability as a biomonitoring system for the Ugandan rivers including river Mpanga which is located in mid-western Uganda originating from the Rwenzori mountains in the Nile basin. It has been noted in Ojija and Laizer (2016) that differences in climate, geology, longitude and latitude, and other geographic characteristics may contribute to differences in the physical and chemical characteristics of rivers between two countries such as between Tanzania and Uganda. This results in variations in macroinvertebrate assemblages and sensitivity levels in relation to

disturbance and general ecosystem impairment. Such variation might affect the capability, functioning and reliability of the TARISS method when directly applied in Ugandan rivers. It is therefore important that TARISS be tested for its reliability as a cost effective bioassessment system for monitoring the water quality of Ugandan rivers, e.g. river Mpanga, given Uganda is more continental sandwiched in the African rift valley and lying entirely in the Nile basin as opposed to Tanzania.

The aim of this study was therefore to test the reliability of TARISS for use in Ugandan rivers with particular focus on River Mpanga as a case study. The existence of a disturbance gradient from pristine, nearly pristine, moderate to very high disturbance in addition to the location of the river along the equator at the Albertine rift valley makes it a good site for testing TARISS. The ability of TARISS metrics to distinguish between test and reference sites along the anthropogenic disturbance gradient was tested. In addition, the question of whether TARISS taxa were representative of all taxa in river Mpanga was addressed. We discuss general applicability of TARISS for East African riverine systems shedding more light on the need for extensive testing of bioassessment systems developed or adapted within any region of the world.

Materials and methods

Study area

River Mpanga (Figure 1) is located in Midwestern Uganda and flows over a distance of about 200 km, with an altitude ranging from 2124 m in the Rwenzori mountains (source area) to 914 m (Lake George), traversing three different districts of Kabarole, Kyenjojo and Kamwenge. In this area, the annual rainfall ranges from 600 to 1000 mm (PROTOS and MWE 2011).

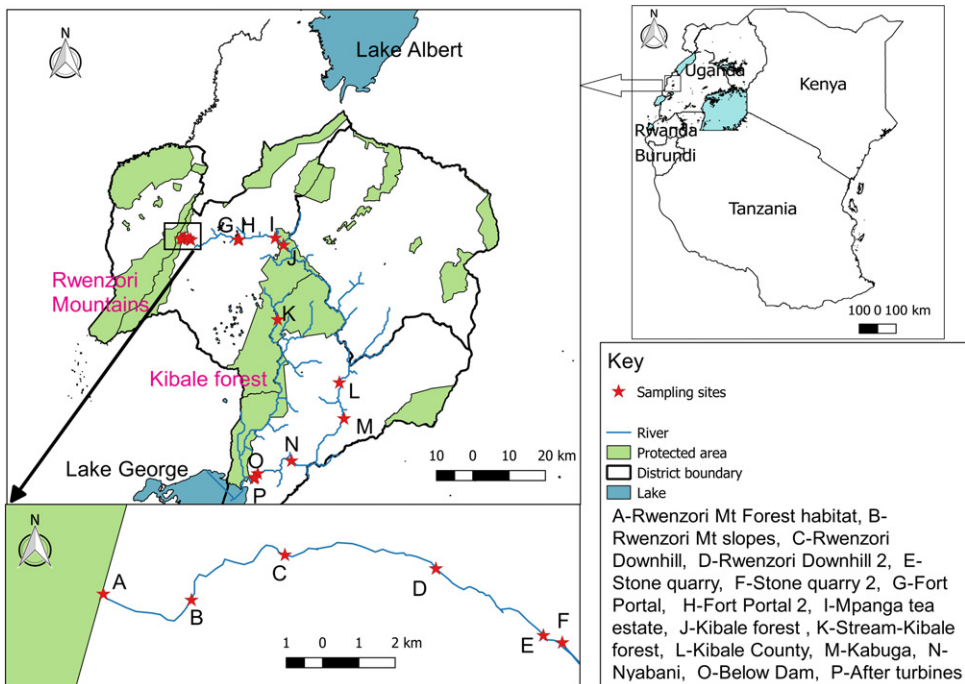


Figure 1. A map of East Africa (right), expanded (left) is part of western Uganda showing the districts, lakes and protected area in the study area where the river Mpanga passes and sampled points (QGIS version 2.6.1-1).

The Mpanga catchment is bound by strong upstream–downstream relationships. The Rwenzori Mountains region is currently under high anthropogenic pressure due to high population growth rate and density (Reinhardt et al. 2018) and suffers a variety of poor land use practices such as deforestation of their steep slopes, mining (sand, gravel and stones) by the local communities (PROTOS and MWE 2011; Reinhardt et al. 2018), water abstraction, poor waste disposal and agriculture. The human activities affect River Mpanga directly and/or indirectly as it flows through Fort Portal town to rural areas with various tea plantations (where large groundwater abstractions are operational) into Kibale Forest. The forest ecosystem is one of the most important indigenous forests still present in Uganda and has high conservation value and Mpanga River plays a key role in its existence and conservation (PROTOS and MWE 2011). The river flows through different wetlands in Kamwenge District towards Lake George where heavy deforestation, cultivation of crops and livestock farming are common along the banks of the river. The red sandy-clay soils of Kiamara series in Mwenge, Kibale, Burahya and Bunyangabo counties and peaty clays along the Mpanga, are the most productive soils in the region (PROTOS and MWE 2011) favouring the cultivation of crops like bananas, yam, sugar cane, vegetables and maize. River Mpanga flows into Lake George over Mpanga falls, a natural habitat for different species of fauna and flora, bordering Queen Elisabeth National Park. At this point, the river joins a wetland system Lake George classified as Ramsar site. The Mpanga Falls Gorge itself is known to be the world only habitat for rare cycad species *Encephalartos whitelockii* (Byaruhanga 2001; Ogwal 2017). At this site a hydropower dam was recently constructed and is operational.

Sampling strategy

Sampling was done in September 2016 through January 2017 to cover both wet and dry seasons. Samples were collected from a total of 18 sites in different zones of the river; upstream, midstream and downstream. In each of the sections, sampling sites were selected to include disturbed (test) and undisturbed/least disturbed (reference) sites. Each of the sections was sampled twice between September to October and December to January though the samples were not collected from necessarily the same points in the dry season since the water levels were low in the upstream at stone quarry site and the river divided into small streams due to siltation. Effort was made to include all forms of human effects on water quality. At each sampling site, latitude, longitude and altitude, were taken using a Garmin GPS IV. Human impact at each site was recorded according to the disturbances (none, domestic, agricultural and industrial waste water, cattle drinking, irrigation, etc.), and by the surrounding habitat (urbanisation, natural forest, wetland, pasture/grassland, agriculture, tree plantation). To minimise inter-observer bias, all estimates were taken by the same person throughout the study period.

Data collection

Disturbance gradient

Data on human activities and ecosystem stressors were collected and weighted at each site and used to develop a disturbance gradient across sites. Local catchment human disturbance score (LCHDS), instream habitat integrity score (IHIS) and riparian zone habitat integrity score (RZHIS) were used as environmental variables for indicating levels of human disturbance across sites. The IHIS and RZHIS are as described by Kleynhans (1996) and the LCHDS were a set of 20 criteria as described by Kaaya et al. (2015). LCHDS are used to give

Table 1. Weighted criteria for instream habitat integrity and riparian zone habitat integrity.

Habitat integrity description	Weight for instream habitat integrity, IHI	Weight for Riparian zone habitat integrity, RZHI weights
Bed modification	13	NA
Channel modification	13	12
Change of extent of inundation	10	11
Flow modification	12	12
Presence of exotic macrophytes	9	NA
Presence of exotic fauna	8	NA
Solid waste disposal	6	NA
Water abstraction	14	13
Change in water quality	14	13
Bank erosion	NA	14
Exotic vegetation	NA	12
Vegetation decrease	NA	13

Source: Kleynhans (1996), NA stands for not applicable.

a quick snapshot of potential reference and test sites. Sites with the LCHDS $\leq 10\%$ were considered to be reference sites. Sites were further reassessed using RZHI and IHI to eliminate sites that had considered reference by LCHDS but had instream and riparian zone stresses not expected of a reference site. Sites with RZHI and IHI $\geq 80\%$ were selected as reference sites in line with Kleynhans (1996) who emphasises that reference sites are natural or largely natural and the modifications are minimal not to cause significant changes in natural habitats and therefore ecosystem functioning is essentially unchanged. The instream and riparian zone habitat integrity weightings of the disturbance impact are shown in Table 1. The total impact score is a result of the assigned impact score multiplied by the weight of the impact divided by the maximum possible impact score (25). The calculated total impacts of all criteria were then summed and expressed as a percentage and subtracted from 100 to give an instream or riparian zone habitat integrity score. Some of the sampled sites are shown (Figure 2). The degrees and type of perturbation varied considerably from one site to another.

Macroinvertebrate sampling

Macroinvertebrates were sampled following a modified sampling protocol adopted from the TARISS sampling protocol (Kaaya 2015). A scoop net (diameter: 30 cm, mesh size: 1 mm) attached to a long handle was placed on the stream bed against the flow and the substrate in front of the net was agitated by simple kicks and steps. Samples were collected in three biotopes, namely stones, vegetation and gravel sand mud (GSM) biotopes. Sampling procedures for each biotope are described below. Sampling times mentioned for each biotope refers to the effective sampling time (kicking, stirring or sweeping).

Stones

The stone biotope comprises samples collected from stones in current (SIC) and out of current (SOOC). In sampling stones in current (SIC), the net was placed close to and downstream of the kicked stones to allow dislodged organisms to be carried into the net by the current. Where necessary, stones were turned over to dislodge organisms. In bed-rock-dominated areas, hands and feet were used to rub off attached organisms. Kicking in loose stones was done for two minutes while kicking in embedded stones, in particular bedrock, was prolonged for up to a maximum of five minutes and sampling time was noted. In stones out of current (SOOC), stones were kicked, scraped, turned or rubbed with hands and feet while the disturbed area was continuously being swept by the scoop net for a period of one minute.

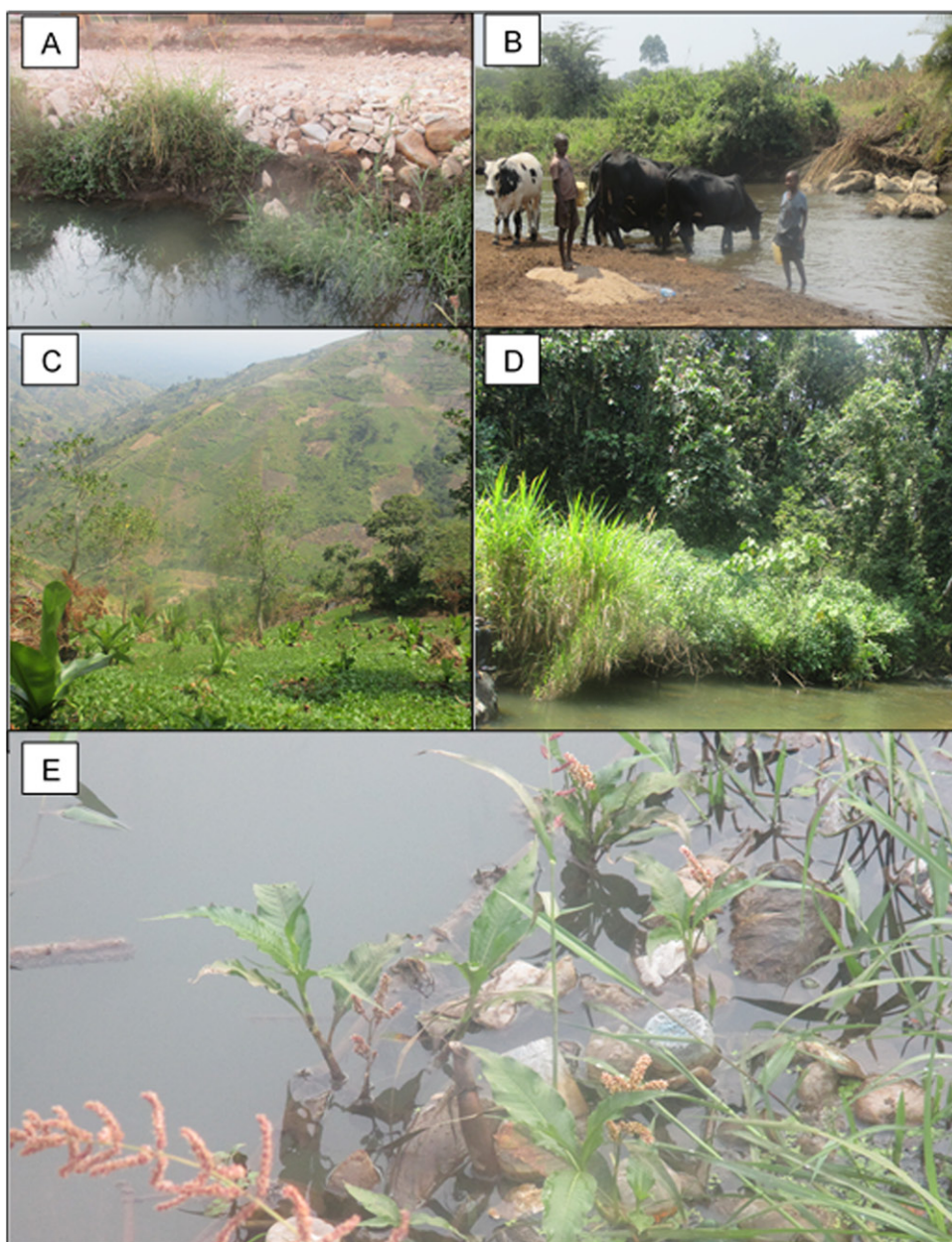


Figure 2. Characteristics of some of the study sites both at site and riparian zone: (A) Construction up at the bank in Fort Portal, (B) Bear bank shared by humans and animals, (C) Crop growing mountain slopes, (D) Pristine Kibale forest and (E) Plastics in water at Fort Portal. Photos taken by Godwin Tumuhairwe during field sampling (C taken on 18/01/2017; A, D, E on 19/01/2017 and B on 20/01/2017).

Vegetation

The vegetation biotope includes marginal and aquatic vegetation, depending on what is present at a site. Marginal vegetation refers to vegetation on the edge of river banks and aquatic vegetation refers to submerged vegetation in the river channel, including filamentous algae and roots and stems of floating vegetation. Approximately 2 m length of

marginal vegetation was sampled. The two-metre length was spread over different locations to allow different types of marginal vegetation to be sampled (reeds, shrubs or grasses) and different flow velocities (fast or slow). The net was vigorously pushed back and forth along the marginal vegetation while moving upstream in order to catch dislodged organisms. When sampling aquatic vegetation, a net was repeatedly pushed through the submerged or floating aquatic vegetation over an area of approximately one square metre.

Gravel, sand and mud (GSM). Samples were collected from gravel (2–16 mm), sand (0.06–2 mm) and mud, silt or clay (<0.06 mm) in different available water currents for a period of one minute. Gravel, sand and mud (GSM) biotopes were stirred by shuffling one's feet while the shuffled area was continuously swept over by a net to catch dislodged organisms. Collection of sand and mud into the net was avoided by sweeping the net sufficiently far from the feet and giving few seconds for large sediment particles to settle before sweeping the net.

Hand-picking and visual observation

Substrate was visually searched for attached organisms especially on the rocks, gravel and submerged decaying wood and any organisms seen were picked up.

The macroinvertebrates collected from the different biotopes were combined and transferred into a container with 70% ethanol using feather-weight forceps for preservation and identified later in the laboratory. Sampling effort was constantly 90 minutes by one person for each site.

Macroinvertebrate identification

Macroinvertebrates were identified to family level except for phylum Annelida whose members were identified to sub-class level. The taxonomic level of identification corresponded to the TARISS taxa. Some keys used included those developed for the East and southern African sub-region (Cape Province to northern Zambia; Day et al. 1999, 2002; Day et al. 2001a, 2001b; Stals and de Moor 2007).

TARISS metrics tested during this study were TARISS scores, Number of Taxa and Average score per taxon (ASPT). The TARISS scores were obtained by adding up the sensitivity scores of the different taxa found at a site with no consideration of abundance. Sensitivity scores were obtained from the score sheet developed by Kaaya (2014), while the new taxa were assigned sensitivity scores following Canonical Analysis of Principal Coordinates (CAP) predictive model (Anderson et al. 2008). ASPT was obtained by dividing the TARISS scores by the number of taxa at a given site.

Data analysis methods

Disturbance gradient

A principal component analysis (PCA) of Local Catchment Human Disturbance Scores (LCHDS), In-stream Habitat Integrity Scores (IHIS) and Riparian Zone Habitat Integrity Scores (RZHIS) was performed and the resulting first PCA axis (PC1 axis) was used as an overall human disturbance gradient across sites using Paleontological statistics (PAST) software (Hammer et al. 2001).

Validating TARISS along the human disturbance gradient

According to Anderson et al. (2008), Canonical Analysis of Principal Coordinates (CAP), which is a constrained ordination, has a high ability to show group differences along a certain dimension. Thus, macroinvertebrate abundance data across different sites were log $(x + 1)$ transformed and a Bray-Curtis resemblance matrix was obtained using Primer version 6 (Anderson et al. 2008). The resultant matrix was analysed along PC1 as the axis for the overall anthropogenic disturbance gradient. This was used to test for the ability of TARISS to distinguish between test and reference sites since the test sites are expected to group differently from reference sites according to Kaaya (2014).

TARISS metrics were correlated with the human disturbance gradient (PC1) to ascertain how TARISS metrics respond to the disturbance continuum in the study area and in the river zones using Primer version 6 (Clarke and Gorley 2006). The TARISS metrics were compared for differences between test and reference sites in the whole study area using Man Whitney U test using SPSS version 20 (Kirkpatrick and Feeney 2012).

Assigning sensitivity scores to new taxa

Assigning sensitivity scores to new taxa was based on the assumption that TARISS macroinvertebrate sensitivity weightings are appropriate reflections of pollution and general disturbance in a river's condition. Thus the TARISS macroinvertebrate sensitivity scale of 1–15 was used. Canonical analysis of principal coordinates (CAP) was used to predict sensitivity weightings of newly identified macroinvertebrate taxa in this study along the gradient of original TARISS sensitivity weightings (1–15). All the taxa that were found and existed in TARISS were used to predict the sensitivity of new taxa. Macroinvertebrate taxa of original SASS sensitivity weightings, used as a model, were presence/absence transformed and analysed by Bray-Curtis coefficient and a resemblance matrix was produced. The number of appropriate PCO axes (m) which explains the model's matrix variability while minimising the chances of misclassifying a new taxon to a wrong group was noted. The number of appropriate PCO's is expected to explain at least 60–80% of the resemblance in a matrix while minimising the residual sum of squares according to Anderson et al. (2008). Another Bray-Curtis resemblance matrix including both model and new macroinvertebrate taxa was produced using the same number of PCO's and sensitivity weightings of new macroinvertebrate taxa were calculated along the original TARISS sensitivity weightings gradient. A CAP ordination was produced showing placement of new taxa along the sensitivity weightings gradient using PERMANOVA + adds on for Primer version 6 software (Anderson et al. 2008).

Results

A disturbance gradient of river Mpanga

A total of 18 sites were sampled of which 17 lie along the course of the river and one is at a stream (tributary) in Kibale forest. Eight sites were considered to be reference sites based on the assessment of Instream Habitat Integrity Scores (IHIS), Riparian Zone Habitat Integrity Scores (RZHIS) and Local Catchment Habitat Disturbance Scores (LCHDS) and 10 were considered as test sites. Habitat integrity changes considerably from the source of the river in Mt. Rwenzori forest which is completely pristine and protected down to Mpanga gorge close to the mouth of the river (Figure 3).

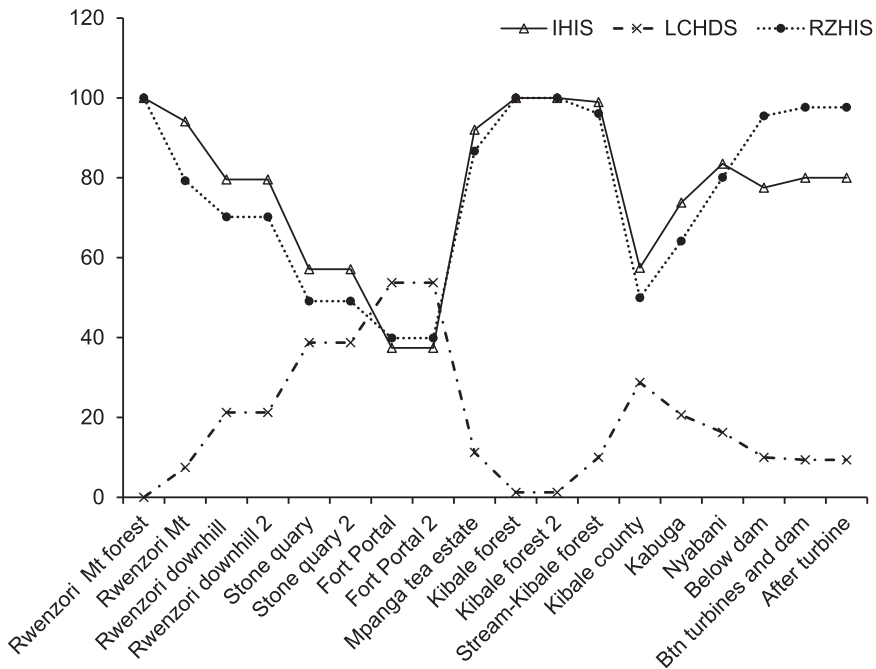


Figure 3. The change in In-stream Habitat Integrity Score (IHIS), Local Catchment Habitat Disturbance Scores (LCHDS) and Riparian Zone Habitat Integrity Scores (RZHIS) of river Mpanga from upstream (left) to downstream (right) obtained during the entire period of study.

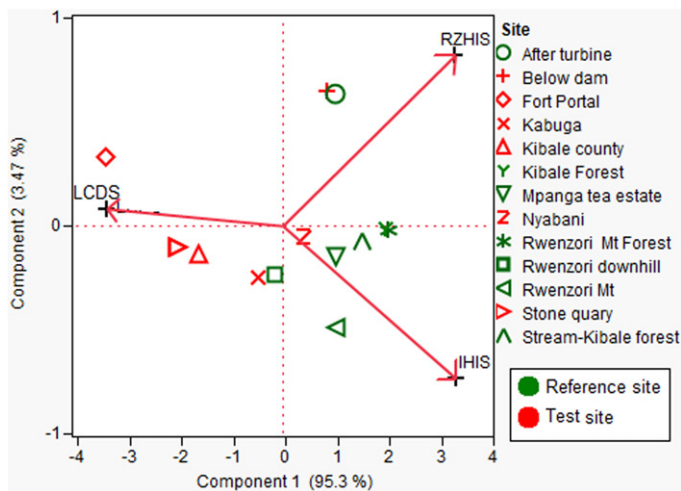


Figure 4. Principle component analysis output of the In-stream Habitat Integrity Score (IHIS), Local Catchment Habitat Disturbance Scores (LCHDS) and Riparian Zone Habitat Integrity Scores (RZHIS) showing the major study sites in relation to human disturbance. The loadings on PC1 are 0.6469, 0.5820, and -0.4928 for RZHIS, IHIS, and LCHDS respectively ($N = 13$. For clarity, repeated sites were not included in the graph).

A Principal component analysis (PCA) of LCDHS, IHIS and RHIS (Figure 4) yielded an overall disturbance gradient of the river (PC1) which explained 95.33% of the disturbance while PC2 represented 3.91%. PC1 was thus considered to be representative of the disturbance gradient of the river and was used for subsequent analysis. All the three

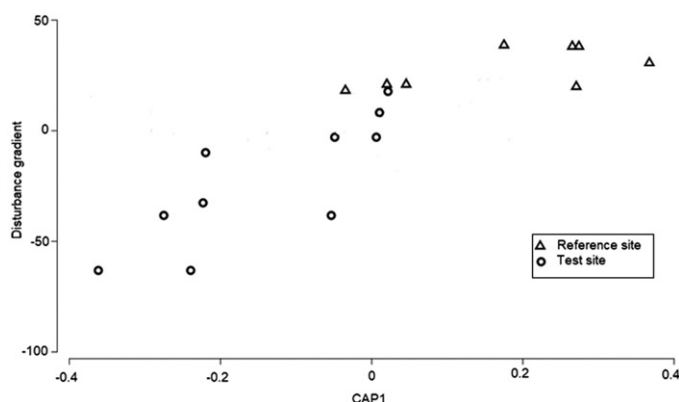


Figure 5. Canonical Analysis of Principle Coordinates (CAP) output showing the grouping of sites along the human disturbance gradient using macroinvertebrate assemblages ($N = 18$).

scores of habitat integrity had a very strong correlation with PC1 (LCDHS = -0.99 , RZHIS = 0.98 and IHIS = 0.97). The more negative end on the axes represents most disturbed sites.

Fort Portal town has the highest degree of anthropogenic disturbance with Mt. Rwenzori forest and Kibale forest having the lowest disturbance. Clearly, urbanization had the greatest negative effect on ecosystem integrity in all aspects. The riparian zone and stream integrity varied according to the intensity and type of human activity as one moves away from the pristine protected area.

Distinction between test and reference site based on TARISS

A canonical analysis of principle coordinates (CAP) was performed to test the hypothesis of no difference in the macroinvertebrate assemblages between test and reference study sites and results indicate that a significant difference in macroinvertebrate assemblages exists ($\delta^2 = 0.75574$, $p = .025$, Figure 5). The positive end of the disturbance gradient represents sites with the least disturbance while increase in the negative end represents increased disturbance. A constrained CAP visualises the distinction between test and reference sites in terms of macroinvertebrate assemblages (Figure 6). The results show that macroinvertebrates in test and reference site are significantly different ($\delta^2 = 0.8157$, $p = .007$) though there are some overlaps. A total of 14 sites (77.8%) were correctly classified and 22.2% were misclassified. Rwenzori Mountain slopes, after turbines in the gorge and between turbines and dam sites were misclassified as reference sites while before stone quarry site was misclassified as test using habitat integrity scores. However, these sites are transition sites between clearly test and reference sites.

TARISS metrics

The TARISS metrics include number of families, ASPT and TARISS score were correlated with disturbance gradient (Table 2). TARISS scores and ASPT values correlate significantly with disturbance gradient ($p = .036$) and ($p = .000$) respectively. ASPT values have a very high positive correlation ($\rho = 0.788$) and TARISS scores show a moderate correlation ($\rho = 0.496$). Highly sensitive taxa to pollution tend to inhabit areas with minimum human disturbance while the least sensitive taxa can tolerate polluted sites as indicated by

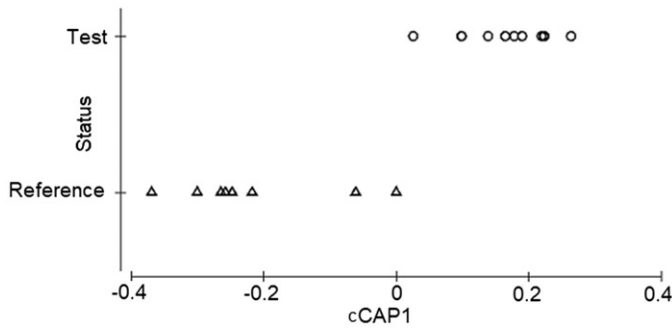


Figure 6. Constrained Canonical Analysis of Principle Coordinates (cCAP) showing how macroinvertebrate assemblages distinguish between test and reference sites on River Mpanga ($N = 18$).

Table 2. TARISS metrics across test and reference site on river Mpanga from upstream to downstream in the dry and wet seasons; highlighted are the sites with low water quality as indicated by Average score per Taxon (ASPT) values, red highlight shows the critically low water quality sites.

Site	TARISS Score	Number of TARISS taxa	ASPT	Status
Rwenzori Mt forest habitat	88	11	8	Reference
Rwenzori Mt slopes	61	10	6.10	Reference
Rwenzori downhill	76	13	5.85	Test
Rwenzori downhill 2	82	14	5.86	Test
Stone quarry	82	14	5.86	Test
Stone quarry 2	84	12	7	Test
Fort Portal	34	8	4.25	Test
Fort Portal 2	44	11	4	Test
Mpanga tea estate	149	20	7.45	Reference
Kibale forest	120	16	7.50	Reference
Kibale forest 2	131	18	7.28	Reference
Stream-Kibale forest	143	18	7.94	Reference
Kibale county	107	19	5.63	Test
Kabuga	165	28	5.89	Test
Nyabani	92	15	6.13	Test
Below dam	136	22	6.18	Test
Btn turbines & dam	99	17	5.82	Reference
After turbine	90	14	6.43	Reference

TARISS scores and ASPT values as. The number of families thus has a small insignificant relationship with degree of disturbance ($\rho = 0.269$, $p = .281$). Fort Portal town has the most polluted water (ASPT = 4) while Rwenzori mountain forest has the least polluted/disturbed water quality (ASPT = 8). The nonparametric Mann Whitney U test shows significant differences in ASPT ($p = .009$) between test and reference sites but insignificant results for TARISS scores and number of taxa.

Assigning sensitivity scores to new taxa

Five new taxa including Chordodidae, Ptilodactylidae, Aspidytidae, Leptopodidae and Paraecnomidae were identified to be missing in the TARISS. Chordodidae (order Gordioidea) was represented by the *Paragordius* sp. found in Fort Portal town where the substrate is mainly mud and macrophytes. Ptilodactylidae and Leptopodidae were found in Mpanga Gorge where the substrate type is exclusive rocks and the water levels generally high. Aspidytidae larvae were found in the pristine Rwenzori mountain forest at an altitude of 2124 m in the cold slow flowing stream whose substrate is mainly sand and decaying organic matter.

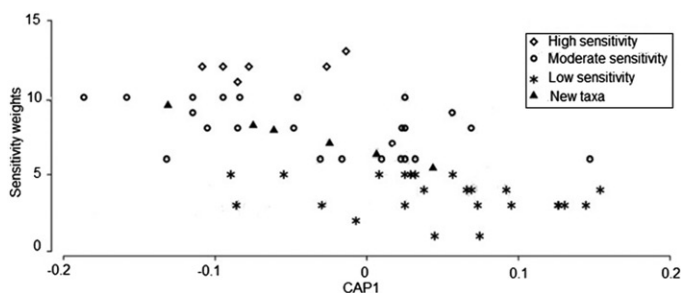


Figure 7. Canonical Analysis of Principle Coordinates (CAP) prediction of sensitivity of new taxa in a cloud of other taxa along the sensitivity gradient ($N = 58$).

When a CAP predictive model was performed, the sensitivity weighting of the new taxa obtained is: Chordodidae (7), Aspidytidae (9), Parecnomidae (8), Leptopodidae (5) and Ptilodactylidae (8), with a correlation square ($\delta^2 = 0.3736$). The appropriate number of principle coordinates (m) was seven which significantly explained the variability in the model by 93.53%. It was thus found that four of the new taxa lie under the moderate sensitivity category while one family (Leptopodidae) lies under the low sensitivity category based on the classification by Gerber and Gabriel (2002). The predicted position of the new taxa in the cloud of other taxa along the sensitivity gradient of the TARISS taxa is shown in Figure 7.

Discussion

Results indicate that macroinvertebrate assemblages differ between test and reference sites with few overlaps along a disturbance gradient. The Tanzania River Scoring System (TARISS) is able to represent the water quality at a given site based on the macroinvertebrate assemblage within the river. However, we found that the TARISS does not contain some of the taxa found in river Mpanga system.

Human activities have varying impact on ecological integrity and ecosystem functioning, a basis on which the different sites should have different integrity scores based on the nature and intensity of the human activity. Discrimination analysis degree of correctness between two categories (e.g. test and reference sites) expected by chance is 50% (Anderson et al. 2008). However, the discrimination correctness obtained in this study was greater than expected by chance (77.78%) suggesting that macroinvertebrates communities are affected by degree of disturbance (Nilsson 1987; Mayfield et al. 2010; Carreño-Rocabado et al. 2012). However, like other biological systems, the difference from reference and test conditions is not discrete but rather a gradual change with intermediate conditions (Whittaker 1956). This explains why there were sites in the transition zone misclassified as either reference or test as shown by the CAP during analysis.

TARISS metrics between test and reference site

Results of the CAP indicate that macroinvertebrate assemblages differ significantly along the anthropogenic disturbance gradient with overlaps in the transition zones. Anthropogenic disturbance therefore results in shift in macroinvertebrate community structure (Feld et al. 2014) with new taxa occupying empty niches along the disturbance gradient. However, this study also shows that some sites overlap between greatly and less

impacted areas along the disturbance gradient in line with the findings of Larsen and Ormerod (2010). The number of taxa, reduction in dominance and diversity are seen to increase initially with the disturbance gradient before reducing to even lower values as disturbance increases. This agrees with Hall et al. (1992) who note that individuals of a species tend to follow a normal distribution pattern within their geographic range. Whittaker et al. (1973) argue that organisms survive in their optimum and suboptimum range, which may indicate that moderately disturbed sites support taxa from undisturbed and highly disturbed niches. Thus moderate anthropogenic disturbance tends to offer better condition for a more varied community structure (Townsend et al. 1997; Stein et al. 2018; Willig and Presley 2018) whereas extremes favour dominant better adapted taxa.

The misclassification of sites within Mpanga gorge after the dam could be attributed to the damming of the river which diverts a very large volume of water from the river course. Whereas other attributes of the study sites qualify them to be reference, damming alone causes major transformation in channel characteristics (Brandt 2000; Granzotti et al. 2018) similar to multiple disturbances.

TARISS metrics

Macroinvertebrate assemblages at a particular site represent the ecological health in relation to anthropogenic disturbance (e.g. Kaaya 2014). Properly assigned sensitivity scores will therefore result in reliable and consistent results of water quality at a given site. This study found that indeed TARISS scores and ASPT correlate significantly with the disturbance gradient. The number of taxa however does not correlate with disturbance gradient. As discussed earlier, Feld et al. (2014) suggest that anthropogenic disturbance results in change of community structure with new taxa replacing others depending on their degree of tolerance to disturbance resulting in an almost uniform community in terms of complexity. The change in community structure is not linear in nature but rather curved with relatively fewer but dominant taxa at extremes of the disturbance gradient. This study also found that critically disturbed sites like Fort Portal had much lower number of taxa than other sites including reference sites.

Of the TARISS metrics therefore, the most reliable is ASPT which describes the average degree of disturbance at the site as indeed is the case with related bioassessment methods of water quality like SASS (Dickens and Graham 2002) and BMWP (Hawkes 1998). Hence, it was able to distinguish between test and reference sites along the anthropogenic disturbance gradient. ASPT combines both TARISS scores and number of families; and the results can be interpreted easily to relate to water quality (Gerber and Gabriel 2002). They classified organisms with sensitivity 1–5 as having low sensitivity, 6–10 moderate sensitivity and 11–15 high sensitivity. Urbanisation was found to have the greatest negative impact on water quality as seen in Fort Portal town. This is because multiple stressors (Freeman and Schorr 2004) such as poor waste management, discharges from abattoirs, runoff from town and washing of vehicles, as discussed earlier, all destroy the integrity of the river ecosystem favouring pollution tolerant taxa which have low scores hence the low ASPT. With reduction in human footprint away from Fort Portal downstream to Kibale forest, the ASPT values recover as the level of disturbance reduces.

Sensitivity scores of new taxa

Bioassessment systems developed in certain regions can be adopted for use in other regions provided they are tested and calibrated accordingly (Dallas et al. 2010). According

to Day and King (1995), factors like geology and climate which vary from one region to another can influence water chemistry there by affecting distribution and sensitivity of related macroinvertebrate assemblages. In this study, five taxa were found to be missing in TARISS; four of these taxa were found to be moderately sensitive to disturbance while one has low sensitivity based on CAP predictive model by Anderson et al. (2008). Aspidytidae is a family of beetles (Coleoptera) described recently in South Africa and China (Balke et al. 1997; Ribera et al. 2002; Alarie and Bilton 2014) and its range and habitat characteristics are barely known. This beetle taxon was found in river Mpanga at its early stages in the pristine Rwenzori mountain forest explaining its high sensitivity weight of 9. Chordodidae (horse-hair worms) are mainly tropical and they are rarely found in temperate regions according to Spiridonov (2003). They are haemocoel parasites of insects like grasshoppers but mature forms reproduce in water. It was found in Fort Portal where the substrate is mainly mud and macrophyte explaining the borderline moderate sensitivity weight of 6 close to low sensitivity. Ptilodactylidae which are believed by Chatzimanolis et al. (2012) to have a worldwide distribution were found in Mpanga gorge downstream which is relatively not greatly modified by human activity given that the diverted water upstream re-joins the river and the area is forested.

Finding of new taxa in river Mpanga not included in TARISS suggests that a bioassessment developed within a given country may not necessarily be applied in other countries within the same region without modifications and/or additions. More taxa could potentially be discovered in other rivers within the region resulting in an improved bioassessment system for the region which will need to be added to the Tanzanian system to form a comprehensive scoring system to be used by East African countries.

Conclusions

Extreme human disturbance resulted in fewer tolerant species while moderate human disturbance resulted in generally higher number of taxa and reduced dominance. Thus moderate disturbance levels provide (temporarily) tolerable conditions for both highly sensitive and less sensitive taxa though at lower populations than in optimum conditions.

TARISS sensitivity weights are reliable and can be used to represent ecosystem health of a river over time since the taxa have adapted to the conditions in the river. However, the list of taxa in TARISS is not exhaustive and may not be applicable to all rivers in East Africa (and Uganda in particular) without revision and modification. The findings of our study are a very important contribution to the development of a critically needed regional scoring system for East African countries that is all inclusive. Bioassessment systems developed for regions or adopted in different region with different characteristics need to be extensively tested and validated before they are used.

Using high taxonomic levels of classification in assessing water quality gives a quick picture of the health of a river but obscures species or generic level differences in sensitivity to disturbance resulting in low levels of precision. Whereas the information obtained can be useful, more precise measures could give more reliable hidden information by use of lower level identification perhaps based on DNA-based identification of taxa such as meta-barcoding.

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No potential conflict of interest was reported by the authors.

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