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RESEARCH ARTICLE

Stream biodiversity and monitoring in North Central, Nigeria: the use of macroinvertebrate indicator species as surrogates

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Abstract

Indicator species (IS) have been employed in modern aquatic research for monitoring of environmental changes and evaluating the efficiency of environmental management procedures. In this study, we evaluated the possibility of developing surrogate indicator groups as tools for the conservation and management of the biodiversity of Northern Nigeria streams by surveying 15 streams in Niger state for benthic macroinvertebrates and environmental variables as data sets, over a period of 24 months (2016 and 2017). Samples were collected in two locations of reference and impacted sites for each of the streams surveyed. The statistically significant ($P < 0.05$; based on 1000 permutations) indicator species for each of the status classes (reference versus impacted) was identified using the indicator species analysis/indicator value (Indval) method. Canonical correspondence analysis (CCA) was used to evaluate the IS-environment relationships. Indicator value found fifteen species for the reference streams including Ephemeropteran (*Bugilliesia* sp., *Tricorythus* sp., *Thraulus* sp., *Crassabwa* sp.) and the Tricopteran (*Leptonema* sp.). Opposite, the Indval found seven (7) indicator species for the impacted streams, which included the Dipteran (*Pentaneura* sp., *Tabanus* sp.). Multivariate analysis revealed that species assemblage had wide dispersal patterns in relation to the sites for both status classes. CCA revealed that the reference and impacted indicator species responded to entirely different environmental factors, indicating their preference to particular environmental variables along the ecological gradients. While the indicator species of reference sites were associated with environmental predictors of good water quality such as high DO, increased flow, low conductivity, and low BOD, the indicator species of impacted sites were strongly related to environmental predictors of anthropogenic pollution, including low DO, high BOD, and increased nutrients concentrations. This study has provided a reference point and effective tool to monitor environmental changes, community, and ecosystem dynamics across the Northern Nigeria streams.

Keywords Biodiversity · Tolerant species · Surrogates · Conservation · Sensitive species · Reference

Introduction

Following the lack of luxury of requisite resources necessary for biodiversity conservation and surveys, environmental experts and conservationists have made it a duty to develop biological surrogates that would enable biodiversity prediction and mapping (Heino 2010). Similarly, many environmental and ecology experts are thriving to provide measures that would facilitate the mitigation of several environmental challenges currently ravaging the world, including environmental pollution, habitat loss, outbreak of diseases, and climate change. The adoption of monitoring strategies and principles with the capacity to detect such environmental and ecological changes at both stages (early and long term) has been one of the most popular strategies among the various suggested options. Evidences abound on the usefulness of these biological assessment and monitoring strategy in providing robust information, as well as affordable environmental management decisions (Spellerberg 2005; Siddiga et al. 2016). Biodiversity assessment and conservation in a broad-scale pattern have been successful with the utilization of biological surrogates (Caro 2010), and this refers to indicating the biological diversity of a whole metacommunity by using information already established about the biological diversity or taxa richness of a

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few-known taxonomic groups (Angermeier and Winston 1997; Paavola et al. 2003).

Indicator species groups with ability to be employed in predicting various differences in biodiversity of other taxonomic groups are among the most popular surrogates (Heino 2010). The indicator species (IS) are organisms whose presence, absence, or condition gives information about the environmental status or quality of where they are found per time (Bartell 2006; Burger 2006; Siddiga et al. 2016). The principle of the use of indicator species is driven from the idea that the community abundance, diversity, and rates of growth and reproduction among species totally reflect both short- and long-term patterns of change and responses of the organisms to the overall effects of environmental changes (Bartell 2006; Siddiga et al. 2016). The presence or absence of healthy populations of these species indicators gives information about a unique environmental characteristic (Caro 2010). The dearth of understanding of the cumulative synergistic effects of pollution on aquatic ecology, following lack of robust ecological information by the use of environmental variables alone for water quality assessment, has led to the reliance on IS. Though the use of IS as ecological predictors and indicators of environmental and climatic changes has proven to be cost-effective and reliable tool, the major pit-fall and draw-back lie on the rationale and methods of selecting the specific indicators and as well as elucidating the environmental relationships between the specified IS and their various specific applications.

The adoption and use of the indicator species for a broad suite of environmental assessment and ecosystem monitoring has been common in recent publications. For example, a review of the IS use across the world by Caro (2010) and Siddiga et al. (2016) revealed that about 42% (which was the most frequent use) of publications of its use was for ecosystem integrity and health evaluation; about just 4% of the publications was on the use of IS as signals of early warnings of environmental changes; 18% of the publications addressed the use of IS in monitoring changes in the chemical composition of the environment, especially regarding effects of pollution and environmental contamination; and 16% of the publications focused on the use of IS in the evaluation of human-induced disturbances and impact assessment.

While IS has been extensively developed and employed in various environmental assessment and monitoring approaches in developed world (see Caro 2010, Siddiga et al. 2016; Mykrä et al. 2016; Brittain et al. 2020), there is paucity of a robust IS developed for monitoring streams in Nigeria, despite the region being of international ecological significance as a biodiversity hotspot (Luiselli 2009; Tonkin et al. 2016). North Central Nigeria is surrounded by several freshwater bodies that serve as habitat for macroinvertebrates. However, anthropogenic impacts along the banks, most notably in downstream regions, have resulted to river pollution (Keke et al. 2017; Arimoro et al. 2018a; Keke et al. 2020a). Industrial and anthropogenic activities, fishing, quarrying, sprawling urbanization, and water pollution are common issues around these rivers that have threatened the quality of freshwater in the area (Arimoro et al. 2018b; Keke et al. 2020b). Water quality of these rivers decreases as it approaches downstream, affecting macroinvertebrate assemblage structure and composition. In the face of anthropogenic pollution of streams within this region occasioned by rapid industrialization and urbanization, the need to protect aquatic ecosystem against human-induced perturbations has become urgent. We, therefore, aimed to develop an indication surrogate for monitoring environmental health and ecosystem integrity of Northern Nigeria streams, with the ultimate goal of conserving and preserving the biodiversity of the region.

Materials and methods

Study area and sampled rivers

The study area covers the range of 9° N to 10° N and 6° E to 7° E (Fig. 1). Fifteen streams were selected and sampled from Niger State in North Central, Nigeria. The characteristics of the study area are a typical tropical climate of two distinct seasons: the dry season (November–March) and the wet season (April–October). Visible human activities of this study area included forestry and agricultural practices, sand dredging, farming, fishing, gold mining, and indiscriminate defecation. Sampling for both benthic macroinvertebrates and environmental predictors was carried out in 24 months (2016 and 2017). Each of the 15 streams was sampled in two locations of reference and impacted sites. The names of the rivers are Baka-Jeba (BJ), Chanchaga, Chike, Gada, Gbako, Grigada, Gurara, Kaduna, Kataeeregi, Landzun, Musa, Penyan, Samu, Wushishi, and Wuya (see Fig. 1: river names with capital initials denote reference sites, while river names with small initials denote impacted sites).

Water sampling for environmental variables

Water samples were collected monthly over a period of 24 months (2016 and 2017) at each station. On site, during each sampling event, subsurface water temperatures (temperature), dissolved oxygen (DO), temperature-corrected electrical conductivity (EC), total dissolved solids (TDS), pH, depth, and flow velocity were measured. A mercury-in-glass thermometer was used for measuring temperature. A HANNA HI 9828 multi-probe meter manufactured by HANNA instruments was used for measuring values of DO, EC, TDS, and pH. Average mid-channel water velocity was measured in three replicates by timing a float as it moved over a distance of 10 m (Gordon et al. 1994). Depth was measured in the sample area using a

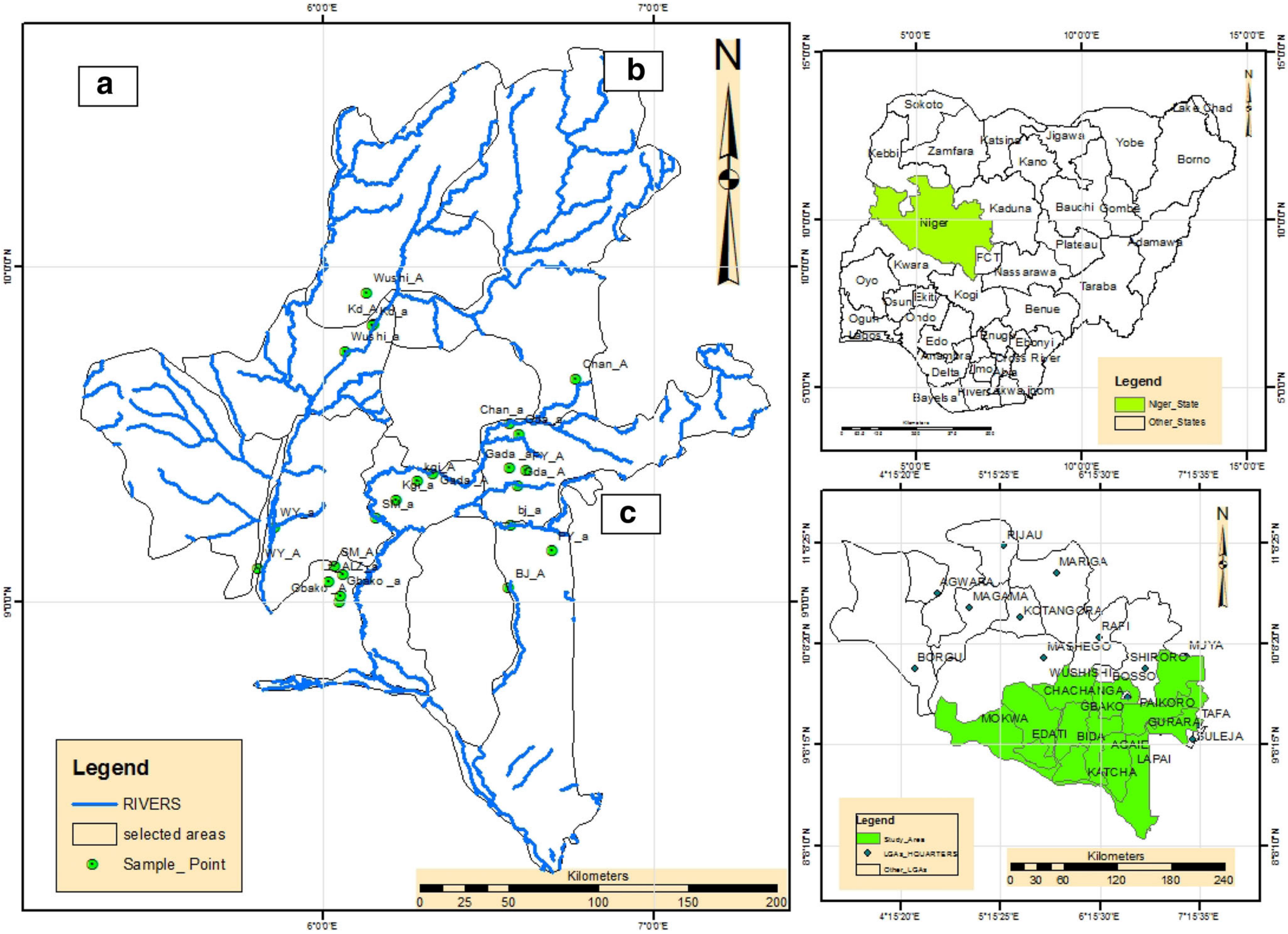

Fig. 1 Map of Nigeria (**b**) showing Niger state (**c**) and the sampling locations (**a**). Source: Department of Federal University of Technology, Minna (2017)

calibrated rod. Water samples were collected in 1-l plastic acid washed bottles and transported to the laboratory in a cooler box containing ice. In the laboratory, water samples were analyzed for nitrate, BOD5, sulfate, phosphate, and sodium according to APHA (1998) methods. Analysis of all samples commenced within 24 h of sampling. Substratum composition in each 25-m sampling reach was estimated visually as percentage of silt, sand, stone, and clay including percentage macrophytes, coarse particulate organic matter (CPOM), and woods/logs (Ward 1992).

Macroinvertebrate sampling and processing

Sampling was conducted four times within a period of one year from each of the sites, representing both seasons (rainy and dry). The process was repeated in the following year. In all cases, environmental predictors' assessment was done simultaneously with benthic macroinvertebrates sampling. To ensure that sets of interacting species were studied, the method used by Leibold et al. (2004) was followed by sampling across the streams within a short period of time. At each station, using a 0.09-m^2 surber sampler with a 250-μm mesh, macroinvertebrates were collected from a 100-m stream reach comprised of three microhabitats, i.e., pools, riffles, and runs, identified according to Jeffries and Mills (1990). To avoid bias due to spatial variations or patchiness, three random samples were collected from each of the three microhabitats by establishing a transect at each sampling reach with five equally spaced points from which a sampling point was selected using random numbers. This procedure was replicated three times for each microhabitat, making nine samples per reach and then the replicates pooled to form one composite sample per station per sampling event. Samples from the three microhabitats per sampling event per site were pooled into one composite sample to avoid artificial effects of pseudo-replication since the reason for the replicate samples from each microhabitat was to ensure that all microhabitats were adequately sampled. The samples were preserved in 10% formaldehyde solution and transported to the laboratory for sorting and identification. In the laboratory, samples were washed through a 250-μm mesh sieve, sorted, and counted using a stereomicroscope. Sorted macroinvertebrates were identified to the lowest taxonomic level possible, mostly genus, according to Merritt and Cummins (1996), Day et al. (2002), and de Moor et al. (2003). Reference was also made to the taxonomic lists of species known to be present in Nigeria (e.g., Arimoro and James 2008; Arimoro et al. 2012).

Data analysis

All analyses were conducted in the R environment (R Core Team 2017).

The statistically significant ($P < 0.05$; based on 1000 permutations) indicator species for each of the status classes (reference versus impacted) were detected using the indicator species analysis/indicator value method (IndVal; Dufrêne and Legendre 1997). The indicator value of a species is the product of its relative abundance and frequency, ranging from 0 (status of no indication) to 100 (status of perfect indication) (Petersen and Keister 2003). A perfect indicator of a group is known to be faithful and exclusive to that particular group, without occurring in other groups (McCune and Grace 2002). For use in this study, any species in a group with indicator value greater than its values in any other group was defined "good indicator species" for that particular group (Mustonen et al. 2016). It identifies indicator taxa that vary more between groups than would be expected by chance, testing their significance through a Monte Carlo randomization procedure (Legendre and Legendre 1998). The indicator value varies between 0 and 100, attaining its maximum value when all individuals of a species occur in a single group of sites, and when the species occurs in all sites of that group. The advantages of using IndVal include the following: IndVal is based only within-species comparisons, regardless of other species occurrence. Furthermore, it is a robust tool in considering differences in group sizes and abundances across species. It is also much more sensitive in detecting indicator species than many other techniques (Dufrêne and Legendre 1997). It is in the light of the above features the IndVal possesses that it is considered superior to other more conventional methods of detecting indicator species (McGeoch and Chown 1998). IndVal was run using the function Indval in the R package labdsv (Roberts 2016).

Cluster analysis is a multivariate method that aims to classify or group samples or sites according to their similarity such that samples, sites, or replicates of a sample with similar biological community composition form distinct clusters from those of other sites or samples. Hierarchical agglomerative clustering was used to group sites for each sampling status class based on macroinvertebrate community structure. Hierarchical agglomerative clustering usually uses a similarity matrix to fuse samples into groups and further fuses the groups into larger clusters, starting with the highest mutual similarities and gradually lowering the similarity level at which groups are formed and resulting in a single cluster containing all samples (Clarke and Warwick 1994). The results of hierarchical clustering are given pictorially in dendrograms, with the x-axis representing the full set of samples and the y-axis the level of similarities of samples.

To visually access the multivariate patterns and structures of the macroinvertebrates indicator species community composition, non-metric multidimensional scaling (NMDS) ordination was performed for each of reference and impacted sites using the metaMDS function in the vegan package (Mustonen et al. 2016). NMDS is an ordination method based on ranked distances, and it is suitable for analyzing ecological data sets for numerous reasons. NMDS performs well with data that are non-normally distributed, are on arbitrary, discontinuous scales, or contain numerous zero values (McCune and Mefford 1999).

Canonical correspondence analysis (CCA) is a multivariate statistical analysis for elucidating the relationships between biological community and their environment (ter Braak and Verdonschot 1995). CCA is a constrained ordination method that concomitantly analyzes both species and environmental data by combining ordination and multiple regression (Ter Braak 1995). CCA is frequently used to determine which environmental variables are important in structuring the biological community. In this study, CCA was applied to elucidate the relationship between the macroinvertebrates community assemblage and the measured physical and chemical water quality variables with a view to determining the important variables responsible for the observed distribution of the macroinvertebrates community in each of the status classes. A Monte Carlo permutation test with 199 random permutations was used to determine the environmental axis that significantly correlated with the biological variables.

Results

Indicator value analysis (Indval) separated the reference streams from the impacted streams. Indval found fifteen species for the reference streams, which are Coleopteran *Hyphydrus* sp., *Dysticus* sp., and *Hydrocanthus*, sp.,; Dipteran *Tanytarsus* sp.; Ephemeropteran *Bugilliesia* sp., *Tricorythus* sp., *Thraulus* sp., *Crassabwa* sp.; the Odonata, *Cordulia* sp., Hemipteran *Naboandelus africanus* and *Ranatra* sp; Tricopteran *Leptonema* sp.; the Decapoda, *Macrobrachium dux*; the Arachnida, *Encentridophorus spinifer*; and the Platyhelminthes, *Dugesia* sp. Opposite, the Indval found seven (7) indicator species for the impacted streams, which include Coleopteran *Hydrophilus* sp.; the Dipteran *Pentaneura* sp., *Tabanus* sp., *Culex pipiens*, *Ablabesmyia* sp.; and the Arachnida, *Arrenurus damkoehlei*. All IS as well as their respective indicator values and P value ($P < 0.05$) are presented in Tables 1 and 2. The overall total indicator abundance for reference stations was 1137 out of the

Table 1 Indicator species (15) of the reference systems identified by Indicator value method (IndVal) at $P < 0.05$ significance level

Order	Species	Indicator value	*P* value
Coleoptera	*Hyphydrus* sp.	0.749	0.001***
Coleoptera	*Dysticus* sp.	0.589	0.002**
Diptera	*Tanytarsus* sp.	0.576	0.002**
Ephemeroptera	*Bugilliesia* sp.	0.559	0.020*
Ephemeroptera	*Tricorythus* sp.	0.550	0.010**
Coleoptera	*Hydrocanthus* sp.	0.548	0.002**
Ephemeroptera	*Thraulus* sp.	0.546	0.010**
Decapoda	*Macrobrachium dux*	0.517	0.004**
Odonata	*Cordulia* sp.	0.496	0.024*
Arachnida	*Encentridophorus spinifer*	0.483	0.010**
Hemiptera	*Naboandelus africanus*	0.483	0.011*
Tricoptera	*Leptonema* sp.	0.476	0.024*
Hemiptera	*Ranatra* sp.	0.458	0.034*
Platyhelminths	*Dugesia* sp.	0.447	0.024*
Ephemeroptera	*Crassabwa* sp.	0.390	0.046*

Table 3 Overall numerical composition of the indicator species across the reference systems

Groups	Species	Composition
Coleoptera	*Hyphydrus* sp.	238
Coleoptera	*Dysticus* sp.	200
Diptera	*Tanytarsus* sp.	60
Ephemeroptera	*Bugilliesia* sp.	83
Ephemeroptera	*Tricorythus* sp.	72
Coleoptera	*Hydrocanthus* sp.	42
Ephemeroptera	*Thraulus* sp.	42
Decapoda	*Macrobrachium dux*	117
Odonata	*Cordulia* sp.	55
Arachnida	*Encentridophorus spinifer z*	28
Hemiptera	*Naboandelus africanus*	40
Tricoptera	*Leptonema* sp.	49
Hemiptera	*Ranatra* sp.	53
Platyhelminths	*Dugesia* sp.	15
Ephemeroptera	*Crassabwa* sp.	43
	Total indicator abundance	1137
	Overall macroinvertebrate abundance	9740

overall abundance of 9740 (Table 3). This constituted for about 12% of the overall abundance of the reference stations (Fig. 1a). Similarly, the overall indicator abundance for the impacted stations was 1016 individuals out of the overall abundance of 13,349 individuals sampled from the impacted sites. This number represented only about 8% of the entire abundance for the impacted stations. The Coleoptera, *Hypydrus* sp. was the best indicator species for reference streams (indicator value = 0.749; $P = 0.001$), jointly followed by the Coleoptera, *Dysticus* sp. (indicator value = 0.589; $P = 0.002$) and the Dipteran *Tanytarsus* sp. (indicator value = 0.576; $P = 0.002$). For the impacted streams, the best two indicators were the Coleopteran *Hydrophilus sp.* (indicator value = 0.715; $P = 0.01$) and the Dipteran *Pentanuera* sp. (indicator value = 0.639; $P = 0.09$) (Table 4).

Hyphydrus sp. was the indicator species that was characteristic of, and dominant, across all reference sites (ubiquitous species). Similarly, *Hydrophilus* sp. was the indicator species that was characteristic of, and dominant across all impacted sites (tolerant species). Site linkages of indicator species occurrence showed clear connections in indicator species across streams in both status classes (Fig. 2). NMDS showed that these species assemblage had wide dispersal patterns in relation to the sites in both status classes (Fig. 3). Both cluster dendrogram and NMDS plots visually showed the general pattern of continuous variation of community structure, although the NMDS showed more discrete variation in community structure.

The eigenvalues of the first three CCA axes for the reference streams were 0.384, 0.268, and 0.207, accounting for 38%, 26%, and 21% of variation, respectively, in the reference indicator species data (Tables 5 and 6; Fig. 4) Likewise, the eigenvalues of the first three CCA axes for the impacted streams were 0.382, 0.371, and 0.223, accounting for 29%,

Table 2 Indicator species (7) of the impacted systems identified by indicator value method (IndVal) at $P < 0.05$ significance level

Order	Species	Indicator value	*P* value
Coleoptera	*Hydrophilus* sp.	0.715	0.001***
Diptera	*Pentaneura* sp.	0.639	0.009**
Oligochaeta	*Stylaria lacustris*	0.628	0.026*
Diptera	*Tabanus* sp.	0.516	0.008**
Diptera	*Culex pipiens*	0.483	0.015*
Diptera	*Ablabesmyia* sp.	0.482	0.023*
Arachnida	*Arrenurus damkoehlei*	0.460	0.030*

Table 4 Overall numerical composition of the indicator species across the impacted systems

Groups	Species	Composition
Coleoptera	*Hydrophilus* sp.	239
Diptera	*Pentaneura* sp.	174
Oligochaeta	*Stylaria lacustris*	289
Diptera	*Tabanus* sp.	116
Diptera	*Culex pipiens*	112
Diptera	*Ablabesmyia* sp.	57
Arachnida	*Arrenurus damkoehlei*	29
	Total indicator abundance	1016
	Overall macroinvertebrate abundance	13,349

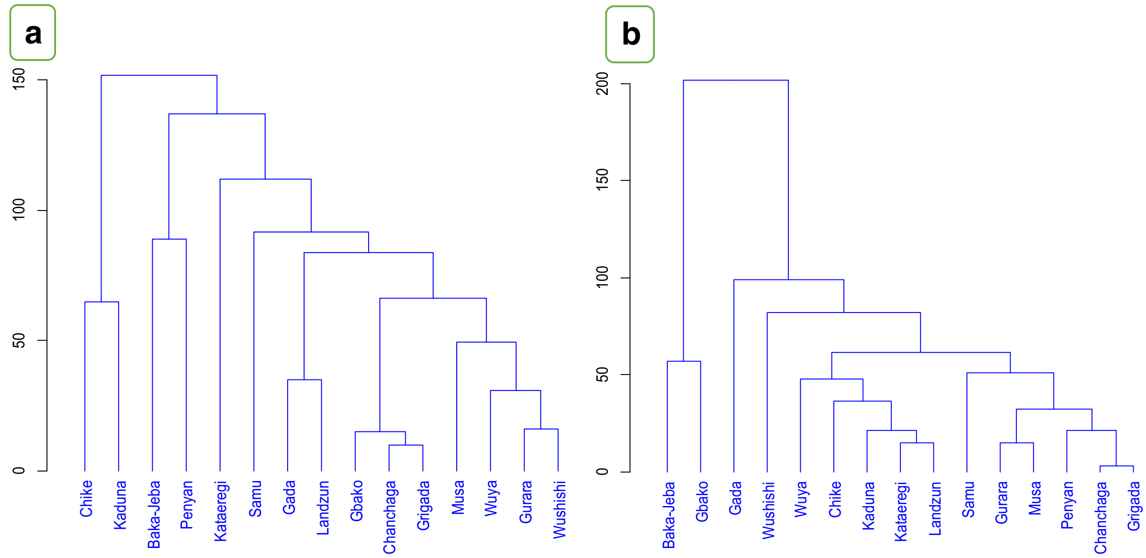

Fig. 2 Cluster dendrogram showing site linkages of indicator species occurrence in reference sites (**a**) and impacted sites (**b**)

28%, and 16% of variation, respectively, in the impacted indicator species data. All CCA analysis showed significant relationships ($P < 0.05$ in Monte Carlo permutations) between the species data and explanatory variables. Significant explanatory variables that were important in structuring macroinvertebrates species indicator assemblage structure of the reference sites included the flow velocities, dissolved oxygen, conductivity, and pH while significant explanatory variables that had influence in indicator speaks assemblage of disturbed/impacted stations were dissolved oxygen, BOD, nutrients (nitrates and phosphates), and temperatures (also see the Appendix).

Discussions

The main patterns produced by the clustering method and NMDS were similar, hence indicating an extensive overlap among the community types in ordination space—and this clearly showed that there are no discrete community types in these systems. This continuous nature of community variation across these streams is plausibly linked to the independent responses of macroinvertebrate species to environmental gradients—since different species have highly different environmental niches (Heino et al. 2014). Similarly, the observed absence of discrete community types across sites has been

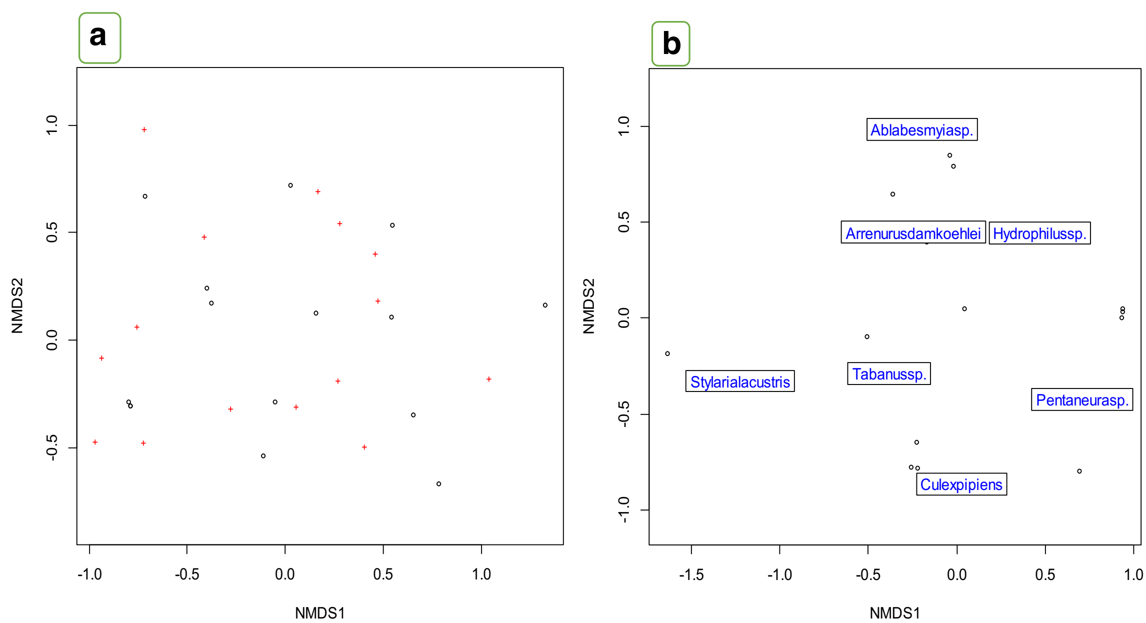

Fig. 3 Non-metric multidimensional scaling (NMDS) of sites and indicator species relationships of the reference sites (**a**; stress = 0.1619457) and impacted sites (**b**; stress = 0.06520508). Open circles, site scores; crosses, indicator species scores

Table 5 Summary of canonical (constraint) correspondence analysis (CCA) of indicator species assemblage structure and environmental predictors correlations for reference sites

	Axis 1	Axis 2	Axis 3
Eigen value	0.38390	0.26759	0.20672
Proportion explained (%)	38	26	21
Temperature	0.01161	−0.26648	**0.41863**
Depth	−0.28741	−0.26648	**0.41863**
Flow velocity	**0.72543**	0.20982	0.07259
Conductivity	**0.52034**	**−0.43843**	0.03310
Dissolved oxygen	**−0.32803**	0.23218	−0.11230
BOD	0.20303	0.00811	−0.09570
pH	−0.07239	**−0.46746**	**−0.86744**
Nitrates	−0.31844	−0.04299	−0.09500
Phosphate	0.07107	−0.16742	0.10501

All canonical axes were significant. Values in bold indicate significant difference at $P < 0.05$

reported by earlier findings from strongly anthropogenically altered streams, where community variation was continuous despite discrete changes in environmental conditions (Merovich and Petty 2010; Heino et al. 2014). Furthermore, different environmental niches of species and the observed overlap among the community clusters may also have been responsible for the variation in community structure across the sites. Nonetheless, it was observed that even in the more homogeneous community clusters, variations in community structures among sites were evidenced. It is suggested here that variation in the size of streams among the sites comprising the particular community cluster may have been responsible

Table 6 Summary of canonical (constraint) correspondence analysis (CCA) of indicator species assemblage structure and environmental predictors correlations for impacted sites

	Axis 1	Axis 2	Axis 3
Eigen value	0.38198	0.37084	0.22347
Proportion explained (%)	29	28	16
Temperature	**0.49950**	0.24369	−0.07160
Depth	0.14050	−0.28520	**−0.60610**
Flow velocity	−0.11650	0.08752	−0.16480
Conductivity	0.17580	0.28524	−0.24470
Dissolved oxygen	−0.10020	**−0.64070**	**0.47250**
BOD	0.07530	**0.62474**	−0.18530
pH	0.20260	0.07529	−0.11930
Nitrates	**0.54130**	−0.10776	−0.37790
Phosphate	**0.68510**	−0.19440	−0.08680

All canonical axes were significant. Values in bold indicate significant difference at $P < 0.05$

for such variations in community structures that showed evidence of more homogeneous community clusters.

Indicator species have been adopted for a wide range of ecological and environmental applications (Borrett et al. 2014; Siddiga et al. 2016). Assessment of the environment and conservation of biodiversity are usually based on the reliance on indicator species groups (Caro 2010). Ephemeroptera (mayflies), Plecoptera (stoneflies), and Tricoptera (caddisflies) have been employed as sensitive indicators of environmental degradation and ecological integrity loss in lotic waters (Rosenberg and Resh 1993). Similarly, dragonflies have been considered as a typical indicator group of the overall biodiversity especially in running waters in the tropics (Simaika and Samways 2011). In congruence to this research, the indicator species found by the Indval in our case for the reference stations were all sensitive indicators and as such proposed here as ideal indicators of environmental degradation and ecological changes in Northern Nigeria streams. Most of the statistically significant indicator taxa were strong indicators of the community clusters (indicator value > 0.5), and are also common species that occur across environmental gradients in both northern and southern Nigeria (Arimoro and Keke 2017; Arimoro et al. 2012). In contrast, *Cordulia* sp., *Encentridophorus spinifer*, *Naboandelus africanus*, *Leptonema* sp., *Ranatra* sp., *Dugesia* sp., and *Crassabwa* sp. were rather weak indicators of the reference community since their indicator values were slightly less than 0.5. Similarly, *Culex pipiens*, *Ablabesmyia* sp., and *Arrenurus damkoehlei* were weak indicators of the impacted communities having earned indicator values less than 0.5. However, these species appeared as significant indicators of the community clusters because their abundance varied among the clusters (i.e., high “specificity”) (Heino et al. 2014). The weak indicator status of most other species also suggests that individual species are distributed individually along the environmental gradients, and this distribution may assume an intermittent or spasmodic pattern following regular disturbances that are evidenced in streams (Heino and Mykrä 2008; Brown et al. 2011) as well as subsequent extinction-colonization mechanisms (Heino and Mykrä 2008; Brown et al. 2011; Swan and Brown 2011; Heino et al. 2014).

The most important pollution-sensitive taxa of macroinvertebrates include the Ephemeroptera (the mayflies), Plecoptera (stoneflies), Tricoptera (caddishflies), and Decapoda (crayfish) (Sharpe et al. 2015), and their mere presence in a stream is indicative of high environmental quality. Ephemeroptera, Tricoptera, and Decapoda were very abundant in the reference stations. The high population of these pollution sensitive taxa in the reference stations was suggestive of the fact that the reference stations had very low levels of pollution, and this was further supported by the results of the environmental variables of the stations that portrayed good environmental quality. However, Plecoptera (the stonefly)

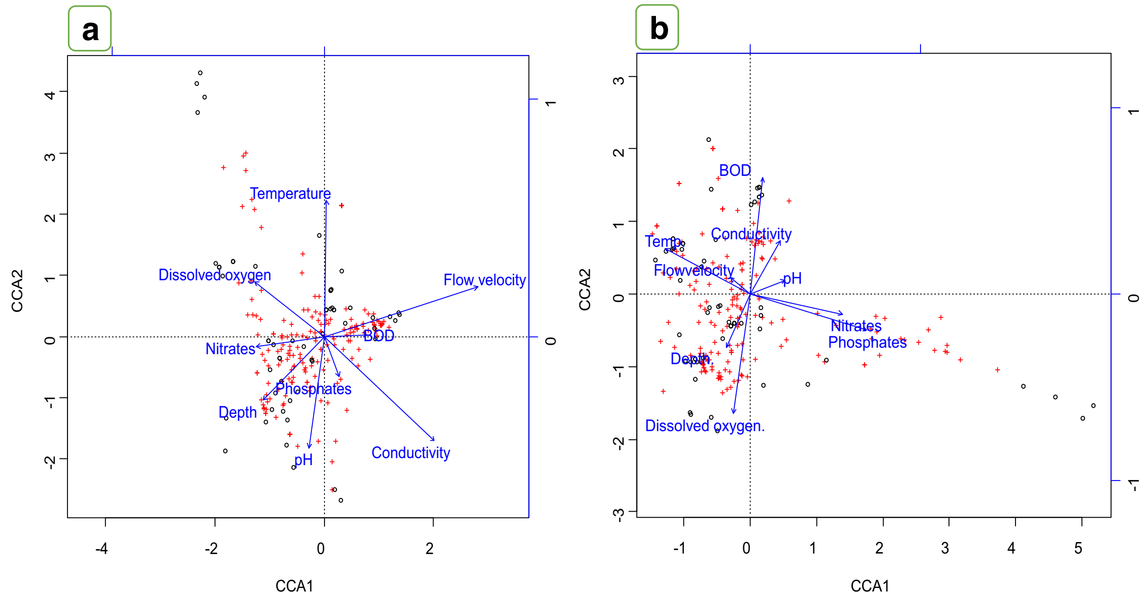

Fig. 4 CCA showing the relationships between the macroinvertebrates indicator species of the reference (**a**) and impacted (**b**) stations and the environmental variables prevailing at the stations. Open circles, site scores; crosses, species scores; based on symmetric scaling

was not found by the Indval model. This could be rightly so because Indval model is the product of its relative abundance and frequency, ranging from 0 (status of no indication) to 100 (status of perfect indication) (Petersen and Keister 2003). IndVal is a method that combines a species mean abundance and frequency of occurrence in each group. A high indicator value results when a species is both abundant ("specificity") and occurs in most sites ("fidelity"), belonging to a group (Dufrêne and Legendre 1997; Heino et al. 2014). It was observed from this study that both the relative abundance and frequency of Plecoptera was very poor in all cases. Dobson et al. (2002) had earlier reported the paucity of stonefly nymphs in tropical African streams, so the paucity of Plecoptera species in this study is neither a new finding nor a limitation. The findings of Odume et al. (2012), Arimoro et al. (2012), and Arimoro and Keke (2017) corroborate this claim on Plecoptera paucity in tropical Nigerian streams.

The constraint ordination using CCA revealed that the macroinvertebrates species indicators for the reference stations preferred high flow velocity, high dissolved oxygen, and low conductivity, and these variables are regarded as ideal indicators of good water quality (Arimoro et al. 2018b). The variables selected by the ordination method have been identified as important correlates of variations in macroinvertebrate communities in reference streams (Arimoro and Keke 2017; Su et al. 2019; Tripathi and Singal 2019). High dissolved oxygen is associated with fast-flowing waters in the headwater/reference stations and these are indicators of good environmental quality (Maagad 2012). The association and preference of the species indicators of the reference sites to high dissolved oxygen and increased flow indicated their sensitivity to pollution as they were abundant in streams with high dissolved oxygen and flow velocity. High levels of conductivity are attributable to so many sources so the actual effects contributing to conductivity are difficult to predict since the specific ions implicated in conductivity are not individually considered when measuring conductivity.

On the other hand, the macroinvertebrates found for the impacted stations by the Indval were taxa that have been widely employed as surrogates for organically polluted areas in Nigeria and elsewhere (Sharma and Chowdhary 2011; Andem et al. 2014; Sharpe et al. 2015; Siddiga et al. 2016). In congruence, the constraint ordination using CCA revealed that these IS of the impacted stations had affinity with and preference mostly for high BOD, low dissolved oxygen, and high nutrients (nitrates and phosphates). High BOD, increased concentrations of nitrates, and phosphates are indicators of gross pollution and organic loads and as such favored taxa such that were found by the Indval for the impacted sites. These organisms are common sights in polluted environments that are rich in nutrients (nitrates and phosphates) and poor in dissolved oxygen with high BOD (Cai et al. 2017; Su et al. 2019), and such was the case of our findings in this study. The cluster nature of indicator species of the impacted sites corroborated with the earlier findings that communities at disturbed sites contain closely related disturbance-adapted species (Helmus et al. 2010; Brunbjerg et al. 2012; Mykrä et al. 2016). The lack of concordance in environmental variables-requirements of the reference species versus the impacted indicator species showed that the two IS groups responded to entirely different environmental factors. This was illustrated by the lack of pronounced environmental variables shared between the two status classes.

Freshwater conservation strategies and monitoring programs usually rely so much on benthic macroinvertebrates as species indicators of ecological integrity. Therefore, this study has provided a reference point and effective tool to monitor environmental changes, community, and ecosystem dynamics in Northern Nigeria streams with the ultimate goal of preserving and conserving the stream biodiversity. However, the potential and veritable usefulness of this tool in generating very useful predictions of other aquatic biodata may be limited. It is therefore advised that components of freshwater biota be tested for possible use as surrogates in freshwater biodiversity research of these streams.

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Data Availability The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Declarations

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Consent to publish Not applicable.

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