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Identifying and classifying macroinvertebrate indicator signature traits and ecological preferences along urban pollution gradient in the Niger Delta☆

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ABSTRACT

Urbanisation of riverine landscape is an increasing threat to the functionality of river ecosystems. In this study, we identify and classify macroinvertebrates indicator signature traits and ecological preferences.We hypothesised that urban pollution would differentially influence the distribution of macroinvertebrate traits and ecological preferences along a gradient of water quality deterioration. Hence, we identified and classified potential biological indicators traits and ecological preferences that were deemed tolerant of or sensitive to urban pollution gradient in the Niger Delta region of Nigeria. Physico-chemical variables (water temperature, depth, flow velocity, dissolved oxygen, biochemical oxygen demand, electrical conductivity (EC), nitrate, phosphate), and macroinvertebrates were collected from 2008 to 2012 seasonally during the wet and dry seasons once in a month in 11 stations in eight river systems. The results based on RLQ, fourth-corner and Kruskal-Wallis analyses indicate that traits/ecological preferences such as tegumental/cutaneous respiration, cased/tubed body armouring, a preference for silty water, bivoltinism, burrowing and a high tolerance for oxygen depletion, were statistically significantly associated with the heavily impacted stations. These traits were positively correlated with physico-chemical variables such as EC, nitrate and phosphate indicative of urban pollution. On the other hand, traits/ecological preferences such as permanent attachment, crawling, swimming, univoltinism and a moderate sensitivity to oxygen depletion were associated with the least impacted stations and were negatively correlated with physico-chemical variables indicative of urban pollution. Overall, the observed differential responses of traits and ecological preferences to urban pollution along a gradient of water quality impairment suggest that traits and ecological preferences can serve as useful biological indicators and thus supports the growing evidence of the utility of the trait-based approach.

1. Introduction

Urban development in riverine landscapes represent one of the biggest threat to ecological integrity of river ecosystems (Desrosiers et al., 2019; Edegbene et al., 2019a). Rivers in urban landscapes have been observed to consistently display impaired water quality conditions, depleting biota, modified channels, and alteration of micro-habitat complexity and heterogeneity (Olden et al., 2004; Kuzmanovic et al., 2017; Desrosiers et al., 2019). In Africa, where urbanisation and associated rural-urban migration is on the rise, there is a significant risk that rivers in urban landscapes would be seriously impaired, particularly because of poor planning and poor environmental safeguards. Traditionally, effects of urbanisation on riverine systems, particularly in Africa, have been monitored through the analysis of physico-chemical variables, combined with structural assessments of resident biota such as vegetation, macroinvertebrates and fish (Edegbene and Arimoro 2012; Arimoro et al., 2014; Moges et al., 2016).

Macroinvertebrates are among the widely used biota for assessing ecological status of riverine systems (Mereta et al., 2013;

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Fierro et al., 2017). Studies focusing on taxonomic assessment of macroinvertebrate structure have shown that urban pollution impact on the diversity, richness, composition and abundance of macroinvertebrates (Lakew and Moog 2015; Edegbene et al., 2019a, b). Through the so called effects of urban stream syndrome, including depleting dissolved oxygen, increases in metal, solids, and nutrient concentrations, certain macroinvertebrates taxa such as chironomids dominate polluted sites. However, despite the growing recognition of the complementarity of traits with taxonomic analysis, very few studies in Africa have explored the utility of the trait-based approach (e.g. Akamagwuna et al., 2019; Edegbene et al., 2020). An investigation of the responses of macroinvertebrate traits to urban pollution is particularly useful because traits enable organisms to adapt to prevailing environmental alteration (Edegbene et al., 2020). While a number of studies have used the traits and ecological preferences to assess the effect of different stressors such as metals, cargo ship, sedimentation and organic waste (Pallottini et al., 2017; Akamugwuna et al., 2019; Desrosiers et al., 2019), not much has been done in terms of how urban pollution influence the distribution pattern of macroinvertebrates traits and ecological preferences, particularly in Africa. The increasing recognition accorded to the TBA could be attributed to empirical evidence suggesting that i) it is less spatially constraint compared to the taxonomic approach, ii) has more direct link to ecosystem function iii) has potential for impact diagnosis (Ding et al., 2017; Milosevic et al., 2018; Desrosiers et al., 2019). Given the growing recognition of the trait-based approach (Poff et al., 2006; Liess et al., 2008; Stazner and Beche 2010; Ding et al., 2017; Pallottini et al., 2017); it was asked whether traits and ecological preferences would respond differentially to a gradient of urban pollution in the Niger Delta region of Nigeria? Odume et al. (2018a) and Edegbene (2020) distinguished between traits and ecological preferences. While traits refers to any morphological, physiological or behaviour feature of an organism, ecological products of the interactions between the organism and its external environments are referred to as ecological preferences (Odume et al., 2018a; Edegbene 2020). In this study, signature traits and ecological preferences are characteristics possessed by macroinvertebrate taxa which make them to be either resilience of or vulnerable to deteriorating water quality. Traits and ecological preferences can be used in measuring ecological integrity of riverine systems, as specific macroinvertebrate taxa possesses traits and ecological preferences that enable them to respond differentially to pollution (Edegbene et al., 2020). The Niger Delta region of Nigeria is subject to urban pollution, particularly because of growing urban developments. The growing urban developments such as housing, road constructions and industrialisation are impacting on rivers and wetlands within the region. Given the prevailing urban pollution of riverine systems within the region, it was hypothesised that urban pollution would differentially influence traits and ecological preferences of macroinvertebrates so that a pattern attributable to urban pollution effect is discernible. For instance traits such as small body size and very small body size would dominate heavily impacted stations, while traits such as large body size and very large body size would dominate least impacted stations. Thus, this study explores the distribution and patterns of macroinvertebrate signature traits and ecological preferences to a gradient of pollution in rivers within urban catchments in the Niger Delta region of Nigeria.

2. Materials and methods

2.1. Description of the study area

The Niger Delta region in Nigeria harbours a diverse body of wetlands, rivers/streams and vegetation. It is situated at the interception of latitude 4°50'00"N and longitude 6°00'00"E, and characterised by two distinct wet and dry seasons. The wet season spans from April to September, and the dry season usually starts in October and ends in March. The average annual temperature is usually about 28 °C (Tonkin et al., 2016). Major land use types in the region include urban development, farming, fishery and forestry. Urban development in the region is accelerating with increasing rural-urban migration.

2.2. Study rivers and stations – physico-chemical sampling

Samples were collected from 11 stations distributed among eight urban rivers. The rivers are located within the administrative boundaries of Delta and Edo States within the Niger Delta region of Nigeria. These rivers include Adofi, Anwai, Ethiope, Obosh, Ogba, Oleri, Orgodo and Warri Rivers (Fig. 1). The samples were collected once every month covering both dry and wet seasons from 2008 to 2012. The measured physico-chemical variables included depth, dissolved oxygen (DO), water temperature, five-day biochemical oxygen demand (BOD_5), flow velocity, electrical conductivity (EC), phosphate, pH, and nitrate. A calibrated rod was used to measure depth in meter. Gordon et al. (1994) method was used to measure flow velocity. Dissolved oxygen was measured using the YSI 55 DO meter. pH and EC were measured using the portable multi-parameter water analyser HANNA HI 9913001/1. For the analyses of nitrate, phosphate and BOD_5 separate water sample were collected on each sampling occasion in a sterile bottle of 500 ml and thereafter analysed in the laboratory within 24 h of collection using standard method by American Public Health Association (APHA, 1995).

2.3. Macroinvertebrates sampling

Macroinvertebrates were collected using a D-frame kick-net of mesh size 500 μm. During each sampling visit macroinvertebrates samples were taken from all available representative biotopes. To standardize the collection process, four sub-samples were collected per biotope, with 4 min spent per sub-sample collection. Samples were stored in 70% alcohol and then transported to the laboratory for sorting, identification and abundance counting. Macroinvertebrates samples were identified to families using taxonomic keys by Merritt and Cummins (1996); Day et al. (2003) and De Moor et al. (2003).

2.4. Traits and ecological preferences analysed for the study

A stressor-based approach was followed in selecting appropriate traits and ecological preferences. First, we use the literature to identify stressors linked to urbanisation (urban pollution), and the main reported stressors include suspended sediment/storm water return flow (Roy et al., 2005; Walsh et al., 2005; Jones et al., 2012; Odume et al., 2018a; Edegbene et al., 2020); organic pollution (Lee and Bang 2000; Hatt et al., 2004, Walsh et al., 2005; Heino 2013; Krynak and Yates 2018); and potential metals pollution (Doledec and Stazner 2008; Kuzmanovic et al., 2017) – all of which were evident in the selected rivers of the present study area. Secondly, traits and ecological preferences potentially mechanistically linked to the stressors modes of urban stress were then selected, thus, 11 traits and ecological preferences including respiration, body armouring, a preference for turbid water, voltinism, attachment mechanism, mobility, body shape, food preference, sensitivity to organic pollution, body size and aquatic stages, were deemed mechanistically linked to urban pollution (Table 1). Forty seven (47) attributes belonging to the 11 traits and ecological preferences

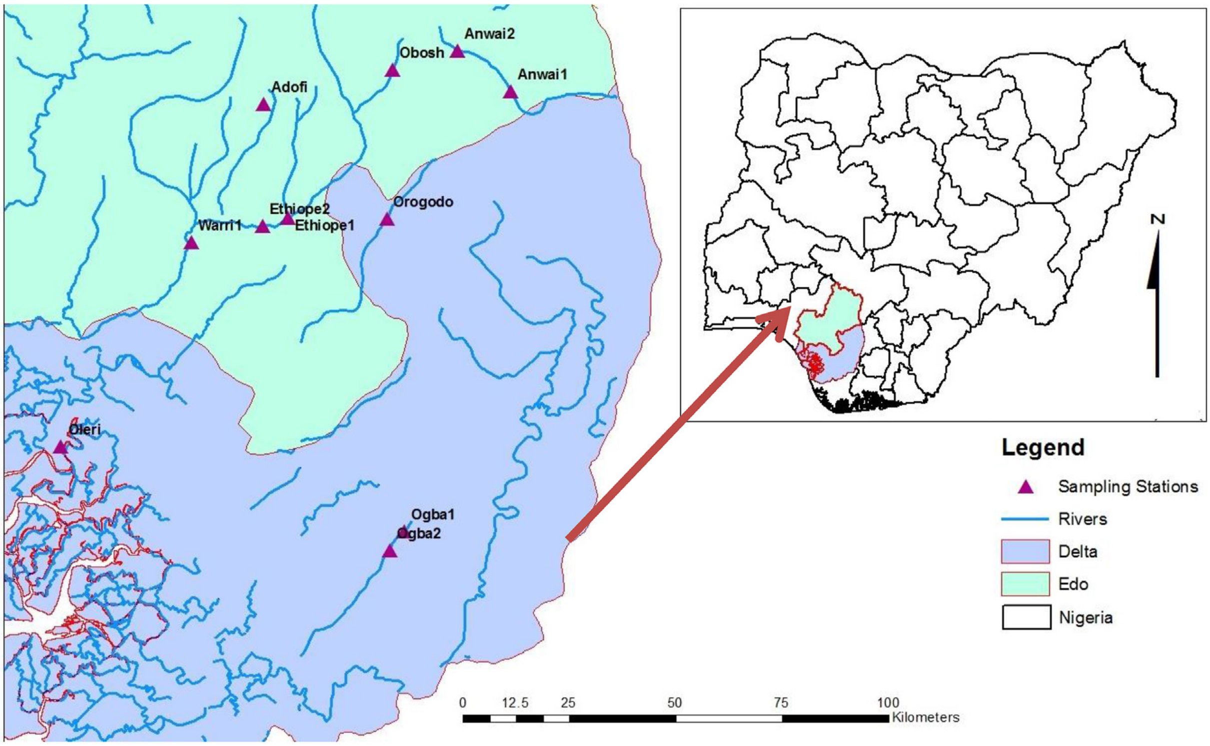


Fig. 1. Study area map showing samplings stations/rivers within Delta and Edo States in the Niger Delta region of Nigeria (This map had earlier be published by Edegbene et al., 2019b).

were used in this study. Information on traits and ecological preferences identified were obtained mainly from Odume et al. (2018b) traits database, and supplemented with traits information earlier used by Edegbene et al. (2020). Trait information was retrieved at the family level because species level information is very sparse in Afrotropical region, Nigeria where this study was carried out no exception. In awarding affinity scores to macroinvertebrate taxa, Fuzzy coding system of 0, 1, 2, and 3 were employed (Chevenet et al., 1994). The score 0 indicates no affinity for a given trait or ecological preference, 1 indicates low affinity while 2 and 3 indicates moderate and high affinity respectively (Chevenet et al., 1994; Edegbene et al., 2020). Each trait and ecological preference score was multiplied by logarithm transformed relative abundance of the macroinvertebrate taxa (Doledec et al., 1996; Dray and Dufour 2007) to avoid skewness of macroinvertebrate taxa with high affinity to a particular trait or ecological preference (Edegbene, 2020). Fuzzy coding was employed because it takes into account the variability and plasticity in life history of macroinvertebrate that may occur within species in a given genus or family (Chevenet et al., 1994; Edegbene et al., 2020).

2.5. Statistical analysis for the study

2.6. Categorising river stations into gradients of urban pollution

In order to analyse the spatial distribution of traits and ecological preferences, we use the classification of the stations into three impact categories by Edegbene et al. (2019b). Principal Component Analysis (PCA) was used in categorising the river stations into impact categories, and this was computed by correlating selected physico-chemical variables with the sampled stations (see Fig. 1A in Edegbene et al., 2019b). The sites coordinate values on the first axis of the PCA ordination was extracted for computation of the characterisation of the stations into impact categories (Edegbene et al., 2019b). A similar approach was earlier employed by Murphy et al. (2013) by using (CCA) in calculating species distances along a CCA first axis. Based on the PCA results, and further analysis as described by Edegbene et al. (2019b), the stations were classified as least impacted (LIS), moderately impacted (MIS) and heavily impacted stations (HIS) (Appendix 1).The three impact categories delineated by the PCA would later be used in comparing traits and ecological preferences that would be identified and classified into urban pollution gradients in this study. For detailed description of the classification process, see Edegbene et al. (2019b). Station classifications into impact categories are provided in Appendix 1.

2.7. Identifying, classifying and exploring the distribution and patterns of selected traits and ecological preferences in relation to urban pollution gradient

In exploring the distribution and patterns of trait attributes and ecological preferences in relation to urban pollution gradient, a multivariate analysis RLQ was performed following Doledec et al. (1996) method. RLQ analysis performs an ordination tests on three datasets; physico-chemical variables (R), taxonomic abundance (L) and traits/ecological preferences (Q). This present study used RLQ ordination to explore physico-chemical variables (R), macroinvertebrates taxonomic abundance (L) and traits/ecological preferences (Q) relationship with urban pollution impact categories depicted by the sampled stations. Correspondence ordination analysis (dudi.COA) was applied to the macroinvertebrate taxa table (Dray and Dufour 2007) and a PCA (dudi. PCA) was applied to traits and ecological preferences table, while the Hill-smith (dudi.Hillsmith) function was applied to the environmental variables (physico-chemical variables) matrix (Dray and Dufour 2007). On the RLQ ordination planes, trait attributes and ecological

Table 1
Selected traits and ecological preferences categories and attributes mechanistically linked with urban pollution in this study.

Categories of traits and ecological preferences	Attributes of traits and ecological preferences	Representing codes
Respiration	Respiration by gills	A1
	Respiration by tegument/cutaneous	A2
	Respiration by aerial: spiracle	A3
	Respiration by aerial/vegetation: breathing tube, strap/other apparatus	A4
Body armouring	Hardshell body armouring	B1
	Completely sclerotized body armouring	B2
	Partly sclerotized body armouring	B3
	Soft and exposed body armouring	B4
	Cased/tubed body armouring	B5
Preference for turbid water	preferences for clear and transparent water	C1
	preferences for silty water	C2
	preferences for opaque water	C3
	Low preference for turbid water	C4
No. of generation per year (Voltinism)	Univoltinism- 1 year	D1
	Bivoltinism-2 years	D2
	Multivoltinism- > 2years	D3
	Semivoltinism- longer than one year	D4
Attaching mechanism	Free-living mechanism	E1
	Temporary mechanism for attachment	E2
	Permanent mechanism for attachment	E3
Mobility mode	Climbing mobility preference	F1
	Crawling mobility preference	F2
	Sprawling mobility preference	F3
	Swimming mobility preference	F4
	Skating mobility preference	F5
	Burrowing mobility preference	F6
Shape of body	Streamlined body shape	G1
	Flattened body shape	G2
	Spherical body shape	G3
	Cylindrical/tubular body shape	G4
preference for food/feeding mode	Detrital feeding mode (FPOM)	H1
	Detrital feeding mode (CPOM)	H2
	Macrophytes/algae feeders	H3
	Animal materials feeders	H4
Oxygen depletion response	High sensitivity to oxygen depletion	I1
	Moderate sensitivity to oxygen depletion	I2
	Moderate tolerance of oxygen depletion	I3
	A preference for depleted dissolved oxygen	I4
Size of body	Very small body size (<5 mm)	J1
	Small body size (>5–10 mm)	J2
	Medium body size (>10–20 mm)	J3
	Large body size (>20–40 mm)	J4
	Very large body size (>40–80 mm)	J5
Aquatic life stages	Egg as an aquatic life stage	K1
	Larva as an aquatic life stage	K2
	Nymph as an aquatic life stage	K3
	Pupa as an aquatic life stage	K4

preferences associated with stations categorised as heavily impacted were deemed tolerant of urban pollution while traits and ecological preferences associated with the least impacted stations, were deemed sensitive to urban pollution. The first two RLQ axes were statistically tested for significance at 999 permutations argument at $P = 0.05$ using Monte Carlo test.

A multivariate analysis fourth-corner test that elucidates a global picture of traits-environment relationship was computed to further confirm the sensitivity to and tolerance of traits and ecological preferences to urban pollution gradient. It reveals the traits attributes that either negatively or positively relates to a given physico-chemical variable. The relationship of traits and ecological preferences and physico-chemical variables was revealed in this study using the fourth-corner test. For instance, a trait or ecological preference which associated with the least impacted stations, and also either associated positively to increasing DO or negatively associated with any two pollution indicator physico-chemical variables (e.g. BOD_5, EC and nutrients) were deemed signature traits and ecological preferences sensitive to urban pollution, while traits and ecological preferences associated with heavily impacted stations and also either positively associated with two pollution indicator physico-chemical variables (e.g. BOD_5, EC and nutrients) or associated negatively with increasing DO were deemed signature traits and ecological preferences tolerant of urban pollution. Visualisation of sensitive and tolerant signature traits and ecological preferences for each urban pollution impact categories were done using box plots. Version 2.5.4 of the ade4 package within the R programming statistic environment was used to compute RLQ and the fourth-corner analyses (Dray and Dufour 2007 on R core team, 2019- Oksanen et al., 2019) while Statistica version 13.4.0.14 was used to compute box plots.

To assess whether the identified sensitive and tolerant signature traits and ecological preferences differed statistically among the three classified urban pollution impact categories (i.e. LIS, MIS and HIS) Kruskal-Wallis test was used to further test the statistical significance between LIS, MIS and HIS in terms of the identified and classified signature traits and ecological preferences. Finally, Turkey Honestly Significant Difference (HSD) was used to identify stations impact categories that differ when a global significant difference was indicated by Kruskal-Wallis test. Statistica version 13.4.0.14

was used to compute Kruskal-Wallis and HSD tests.

3. Results

3.1. Distribution and patterns of identified signature traits and ecological preferences

The least impacted stations (Anwai River station 1 and Warri River) and moderately impacted stations (Rivers Adofi, Oleri, Anwai station 1 and Ethiope station 1) were associated with Axis 1 while most of the stations categorised as heavily impacted were associated with Axis 2 on the RLQ ordination plane (Fig. 2c). Stations categorised as LIS and MIS were positively correlated with DO and depth on the RLQ Axis 1 (Fig. 2a). The LIS, MIS and HIS are depicted as A, B and C respectively on the RLQ ordination (Fig. 2a). The following traits/ecological preferences namely possession of hard-shell, swimming, a moderate sensitivity to oxygen depletion, a high sensitivity to oxygen depletion, flattened body shape, a preference for opaque water, very large body size individuals (>20–40 mm), preference for temporary attachment, crawling, aerial/vegetation respiratory apparatus: breathing tube, strap/other apparatus, and streamlined body, were associated with the LIS. Most of the heavily impacted stations (Ethiope River station 2, Ogba River station 2 and Orogodo River) were positioned on the second axis of the RLQ biplot (Fig. 2c). Physico-chemical variables such as EC, nitrate, phosphate and BOD_5 were correlated with pupa aquatic stage, a low preference for turbid water, large body size, larva aquatic stage, free-living, skating, soft and exposed, cased/tubed, sprawling, >2 years (bivoltine) and burrowing in the HIS on the RLQ biplot (Fig. 2a and b).

The Eigen values of the first two RLQ axes were 6.57 and 0.36, respectively (Supplementary material 1) while the RLQ Axes 1 and 2 explained 91.17% and 5.02%. For physico-chemical variables, the variance for Axes 1 and 2 were 3.83 and 6.17 respectively while the traits and ecological preferences variance for Axis 2 was 18.45 and Axis 1 was 11.18. Axes 1 and 2 of the RLQ ordination plane were statistically significant in terms of the relationship between traits/ecological preferences and physico-chemical variables analysed ($P < 0.05$) as revealed by Monte-carlo test at 999 permutation argument.

Following the RLQ analysis and to further explore the correlation between physico-chemical variables and traits/ecological preferences a fourth-corner test was performed. Univoltinism, permanent attachment, crawling, swimming and a moderate sensitivity to oxygen depletion were positively correlated with increasing DO (Fig. 3). These traits/ecological preferences were identified and classified as sensitive signature traits/ecological preferences. Further, traits/ecological preferences that were positively associated with HIS on the RLQ planes, which were also either significantly positively associated with any two of the urban pollution indicator physico-chemical variables (i.e. EC, nutrients and BOD_5) or negatively associated with increasing DO were identified and classified as signature traits and ecological preferences tolerant of urban pollution. These traits and ecological preferences include tegumental/cutaneous respiration, cased/tubed protection, a preference for silty waters, bivoltinism, burrowing and a preference for depleted dissolved oxygen. Supplementary material 2 shows a summary of the signature traits and ecological preferences identified and classified to be sensitive to and tolerant of urban pollution in this study.

Of the five signature traits and ecological preferences identified and classified as sensitive to urban pollution, the medians

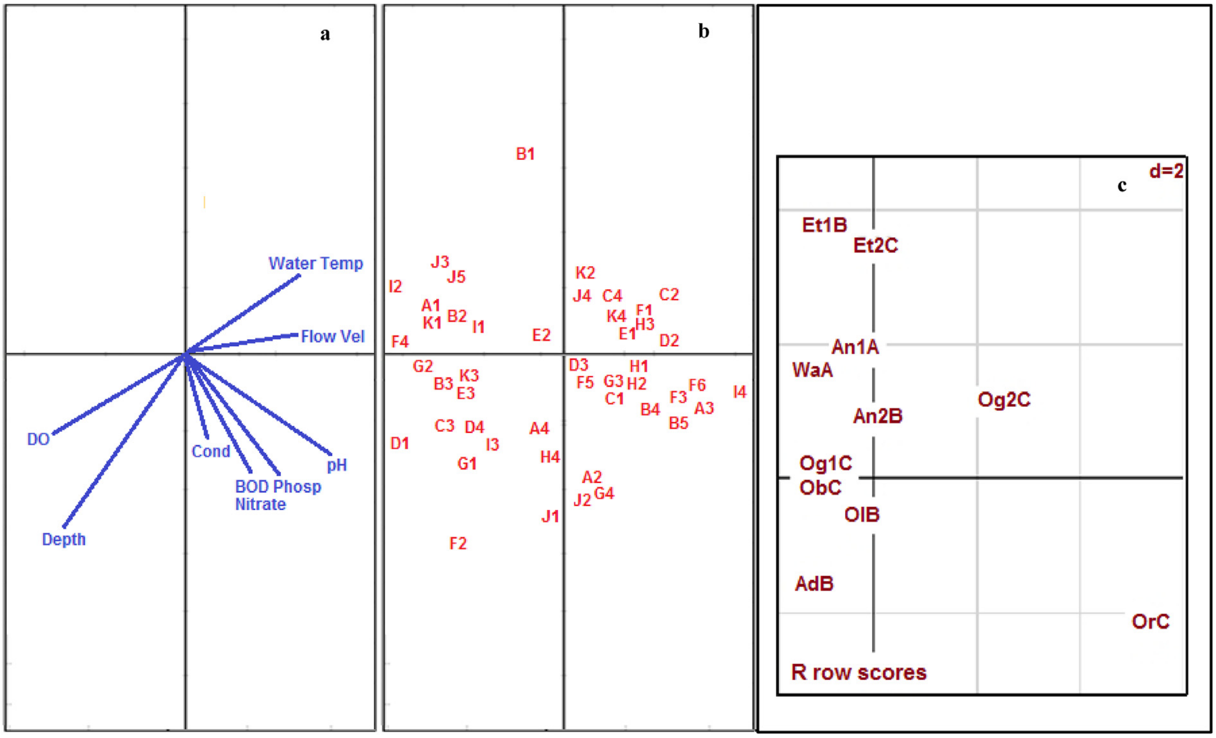
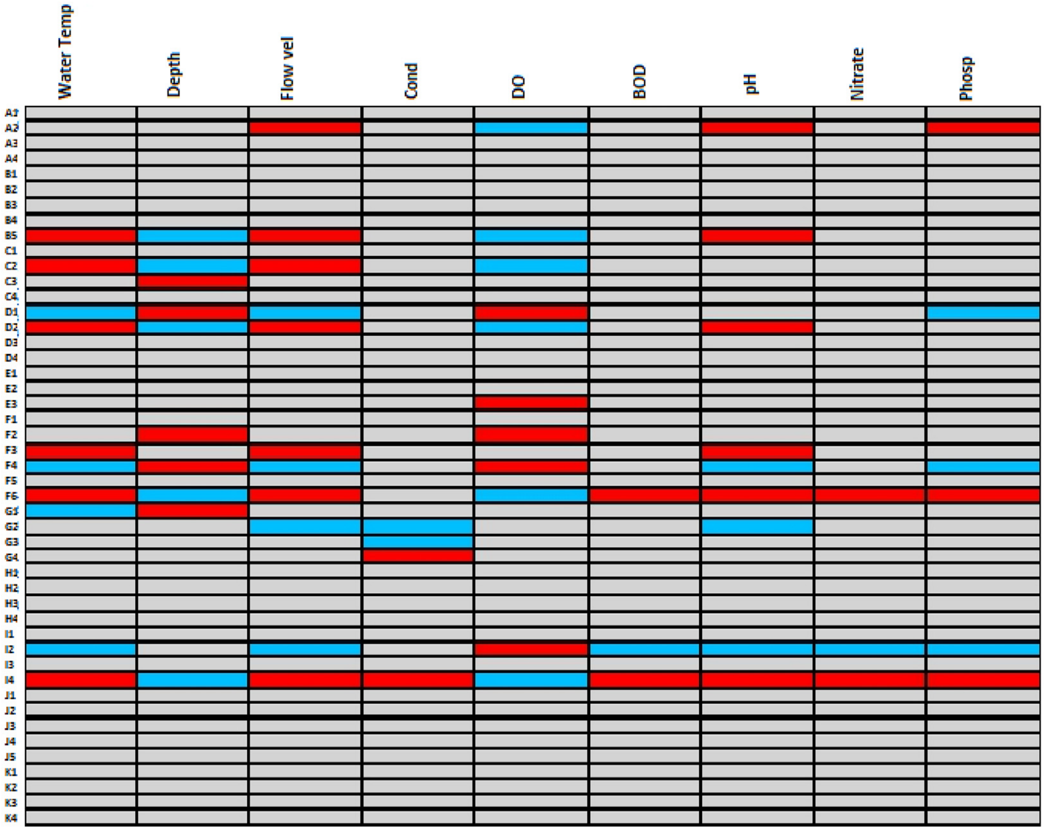


Fig. 2. (a): Physico-chemical variables along the first two axes of the RLQ, (b): traits and ecological preferences (Codes of traits/ecological preferences are shown in Table 1), and (c) Co-variation of the 11 river stations. **Stations abbreviations:** An1A (Anwai River station 1), (WaA (Warri River), An2B (Anwai River station 2), AdB (Adofi River), OlB (Oleri River), Et1 (Ethiope River station 1), Et2C (Ethiope River station 2), OrC (Orogodo River), ObC (Obosh River), Og1C (Ogba River station 1) and Og2C (Ogba River station 2). **Letters attached to Stations:** A = least impacted stations (LIS), B = moderately impacted stations (MIS), C = heavily impacted stations (HIS). **Physico-chemical variables:** Cond = Electrical conductivity, Flow Vel = Flow velocity, Water Temp = Water temperature, DO = Dissolved oxygen, BOD= Five day biochemical oxygen demand, Phosp = Phosphate. Codes names of selected traits and ecological preferences code names are shown in Table 1.



	Water Temp	Depth	Flow vel	Cond	DO	BOD	pH	Nitrate	Phosp
A1	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
A2	⬜	⬜	🟥	⬜	🟦	⬜	🟥	⬜	🟥
A3	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
A4	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
B1	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
B2	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
B3	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
B4	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
B5	🟥	🟦	🟥	⬜	🟦	⬜	🟥	⬜	⬜
C1	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
C2	🟥	🟦	🟥	⬜	🟦	⬜	⬜	⬜	⬜
C3	⬜	🟥	⬜	⬜	⬜	⬜	⬜	⬜	⬜
C4	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
D1	🟦	🟥	🟦	⬜	🟥	⬜	⬜	⬜	🟦
D2	🟥	🟦	🟥	⬜	🟦	⬜	🟥	⬜	⬜
D3	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
D4	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
E1	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
E2	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
E3	⬜	⬜	⬜	⬜	🟥	⬜	⬜	⬜	⬜
F1	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
F2	⬜	🟥	⬜	⬜	🟥	⬜	⬜	⬜	⬜
F3	🟥	⬜	🟥	⬜	⬜	⬜	🟥	⬜	⬜
F4	🟦	🟥	🟦	⬜	🟥	⬜	🟦	⬜	🟦
F5	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
F6	🟥	🟦	🟥	⬜	🟦	🟥	🟥	🟥	🟥
G1	🟦	🟥	⬜	⬜	⬜	⬜	⬜	⬜	⬜
G2	⬜	⬜	🟦	🟦	⬜	⬜	🟦	⬜	⬜
G3	⬜	⬜	⬜	🟦	⬜	⬜	⬜	⬜	⬜
G4	⬜	⬜	⬜	🟥	⬜	⬜	⬜	⬜	⬜
H1	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
H2	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
H3	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
H4	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
I1	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
I2	🟦	⬜	🟦	⬜	🟥	🟦	🟦	🟦	🟦
I3	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
I4	🟥	🟦	🟥	🟥	🟦	🟥	🟥	🟥	🟥
J1	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
J2	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
J3	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
J4	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
J5	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
K1	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
K2	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
K3	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜
K4	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜	⬜

Fig. 3. Fourth-corner test summary for macroinvertebrates traits/ecological preferences and physico-chemical variables in the selected stations/rivers. Red coloured cells indicate significant positive relationships, and blue coloured cells indicate significant negative correlations. No significance relationships are indicated by grey coloured cells. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

distributions of univoltinism and a preference for permanent attachment were highest at the LIS. Kruskal-Wallis and post hoc (Honestly significant difference, HSD) tests revealed univoltinism to be significantly different among the three stations impact categories (LIS, MIS and HIS—$P<0.05$), with the median distribution at LIS being significantly higher compared with that of MIS and HIS (Fig. 4) ($P < 0.05$).

Tegumental/cutaneous respiration, a preference for silty water, burrowing and bivoltinism median distributions were significantly highest at the HIS (Fig. 5). Kruskal-Wallis and HSD tests revealed that these signature traits/ecological preferences were significantly lowest at LIS and MIS compared to HIS ($P < 0.05$) except for tegumental/cutaneous respiration and bivoltinism which showed no significant differences among the LIS, MIS and HIS ($P > 0.05$).

4. Discussion

This study identified and classified traits and ecological preferences sensitive to and tolerant of urban pollution gradient. It also explores the distribution and patterns of traits and ecological preferences between urban pollution impact categories. The results indicate traits/ecological preferences to be differentially influenced by urban pollution. Traits/ecological preferences such as univoltinism, a preference for permanent attachment, crawling, swimming and a moderate sensitivity to oxygen depletion, which were associated with the LIS and also positively correlated with increasing DO, were deemed sensitive. In the present study, traits such cased/tubed amouring, burrowing and a high tolerance of oxygen depletion were deemed pollution tolerant. These traits/ecological preferences were significantly higher at the HIS compared with the LIS. The differential responses of traits/ecological preferences to urban pollution suggest that they may be suitable as indicators of urban pollution. The present study thus adds to the already existing studies indicating the importance of the trait-based approach for monitoring freshwater ecosystems health (Liess et al., 2008; Ding et al., 2017; Pallottini et al., 2017; Desrosiers et al., 2019).

A preference for permanent attachment, univoltinism, crawling, swimming and a moderate sensitivity to oxygen depletion were depicted as sensitive to urban pollution. For instance, macroinvertebrates that swim quickly relocate in a perturbed environment (Buendia et al., 2013) while the reverse is the case for macroinvertebrates that crawls. The classification of crawling as an ecological preference sensitive to urban pollution in this study favourably agrees with similar studies (Mather et al., 2017; Murphy et al., 2017) which depict crawling as an ecological preference sensitive to disturbances. However, it has also been argued by Wilkes et al. (2017) that crawlers are relatively sedentary; hence they may not be able to escape an area with increased sediment inflow occasioned by erosional processes in an urban river system, hence crawling as an ecological preference is tolerant of pollution while the classification of swimming as an ecological preference as classified in this study is in line with Wilkes et al. (2017) assertion who claimed that macroinvertebrates that can swim are able to escape from impeding pollution, hence they are sensitive to pollution (Wilkes et al., 2017).

In this present study, crawling and swimming as ecological preferences were classified as been sensitive to urban pollution. The inconsistent responses of traits/ecological preferences to urban pollution gradients as observed in the present study may not be

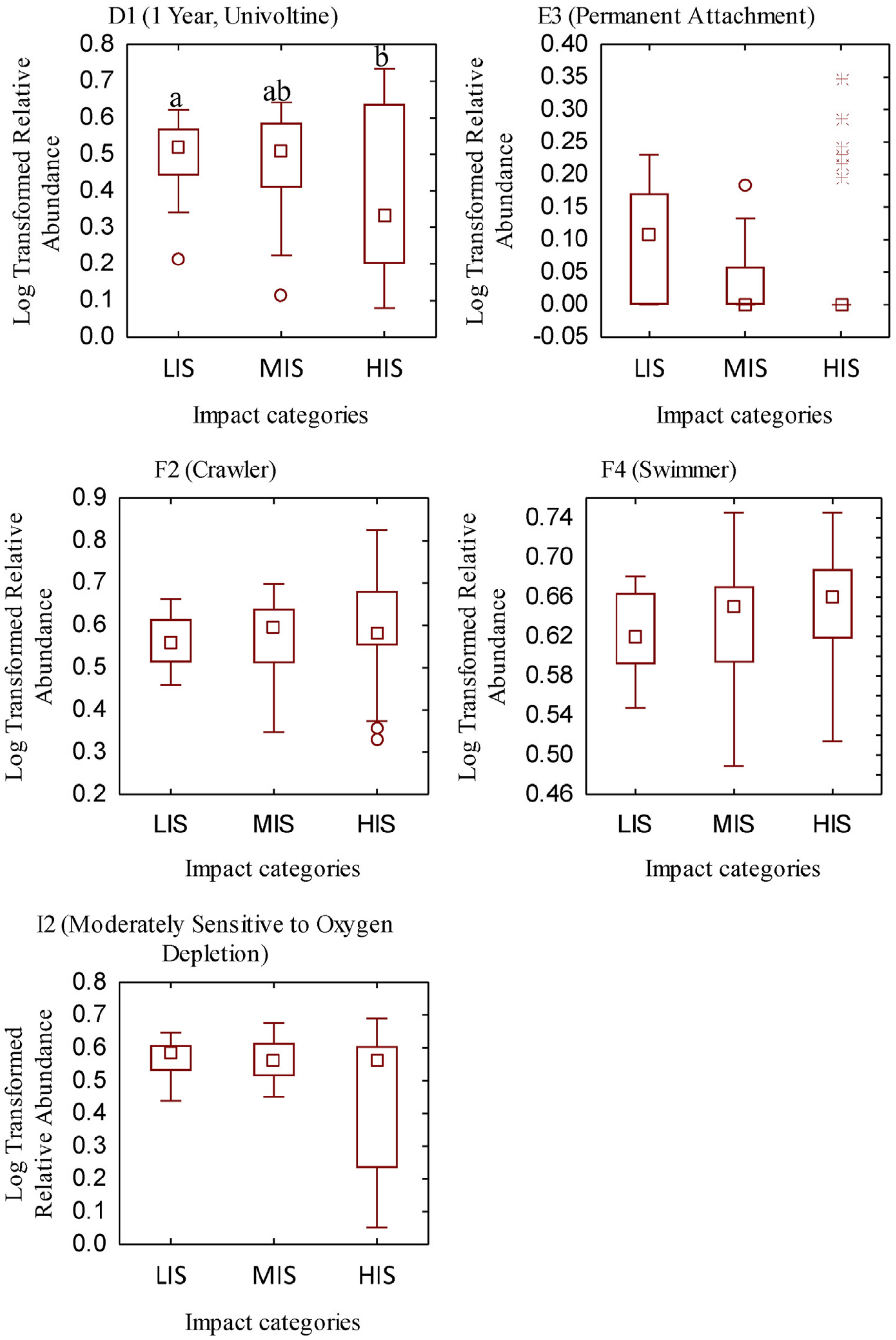


Fig. 4. Distribution and patterns of sensitive signature traits and ecological preferences between LIS, MIS and HIS. Graphs with different alphabets showed significant differences between the stations impact categories while graphs without letters showed no significant differences between the stations impact categories as revealed by Turkey Honestly Significant Difference (HSD). **Stations impacts categories:** HIS = heavily impacted stations, MIS = moderately impacted stations and LIS = least impacted stations.

unconnected to the concept of “trait syndromes” (Berger et al., 2018). Phylogenetic constraints have also been attributed to observed inconsistent responses of traits to stressors in freshwater ecosystem(Piliere et al., 2016).

Cased/tubed armouring, burrowing and a high tolerance for oxygen depletion were associated with the HIS. These signature traits and ecological preferences confer resilience and resistance on macroinvertebrates in the face of environmental disturbances, indicating why they were statistically significantly higher at the HIS (Tomanova et al., 2008). Our observation is consistent with earlier results reported by Pallottini et al. (2017) and Desrosiers et al. (2019), who indicated that cased/tubed possessing taxa were found to be associated with increased nutrient enrichment and electrical conductivity. Further, burrowing, which was found to be associated with the HIS in the present study, have also been reported to be associated with increasing sedimentation (Tomanova and Usseglio-Polatera 2007).

Voltinism is an important reproductive trait that reflects the number of life cycle an organism under goes in a year. It has been hypothesised that organisms exhibiting life cycle that is more than

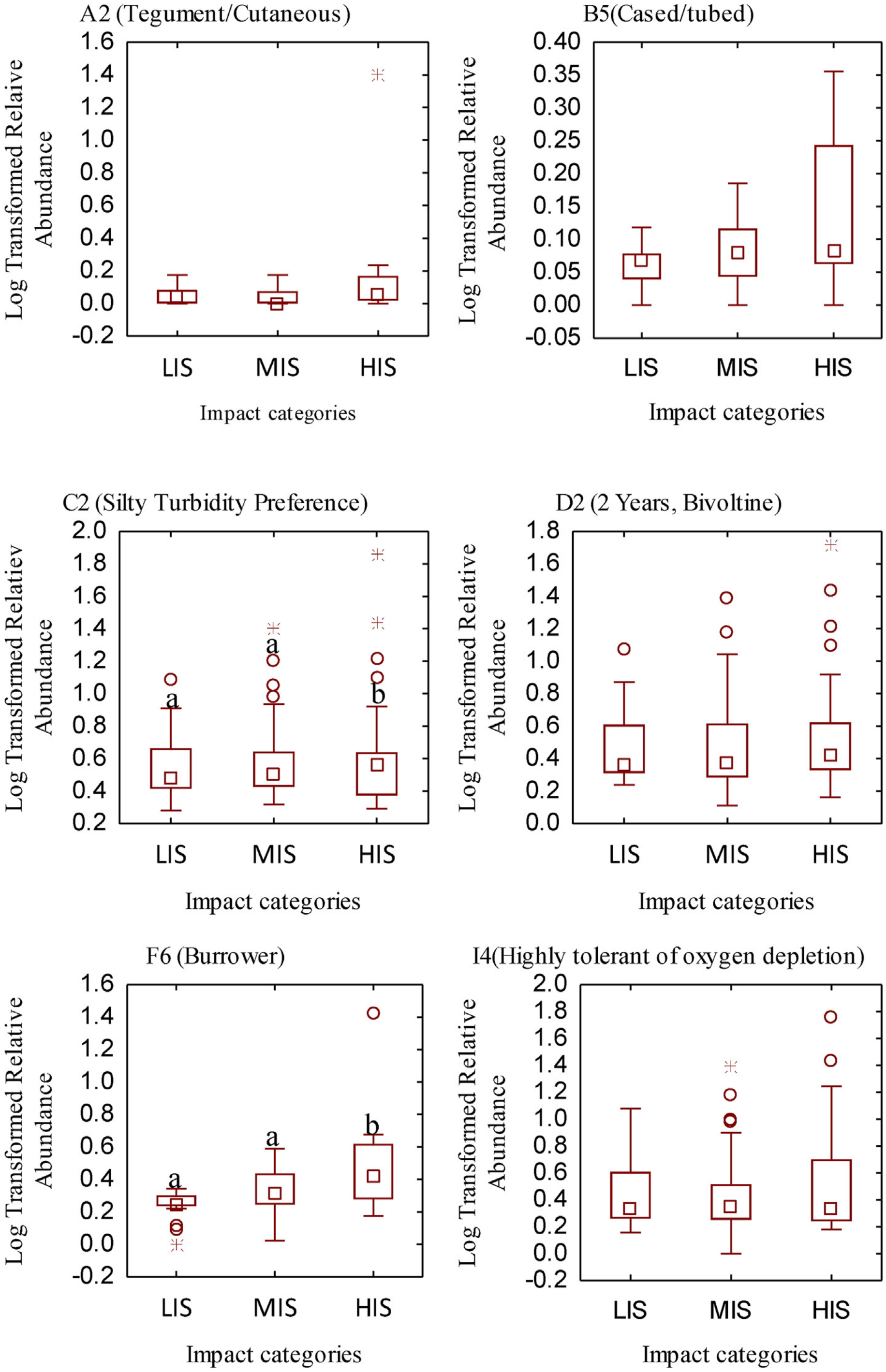


Fig. 5. Distribution and patterns of tolerant signature traits and ecological preferences between LIS, MIS and HIS. Graphs with different alphabets showed significant differences between the stations impact categories while graphs without letters showed no significant differences between the stations impact categories as revealed by Turkey Honestly Significant Difference (HSD). **Stations impacts categories:** HIS = heavily impacted stations, MIS = moderately impacted stations and LIS = least impacted stations.

one in a year e.g. bivoltinism and mutivoltinism are likely to be more tolerant of pollution compared with those exhibiting one or less life cycle per year such as univoltinism (Dolédec et al., 2006; Tomanova et al., 2008; Kuzmanovic et al., 2017). Kuzmanovic et al. (2017) had earlier reported the presence of organisms that exhibits bivoltinism to pesticide laden sites in some polluted Iberian rivers.

Furthermore, organisms that have more generations in their life time have been reported to adapt to water condition that is seriously deteriorating (Mondy et al., 2012; Kuzmanovic et al., 2017; Berger et al., 2018). This assertion was attributed to ecological theory which states that polyvoltinism exhibits high recolonization potential after perturbation as an adaptations for resilience (Mondy et al., 2012; Berger et al., 2018). Univoltine taxa were found to be more associated with the LIS compared with the HIS in this study, and taxa exhibiting life cycle that is more than one in a year (bivoltines and multivoltines) were found to be more associated with the HIS. Similarly, it has been reported that organisms with one life cycle per year (univoltines) were positively correlated with increased DO (Kuzmanovic et al., 2017). This implies that univoltine taxa seemed to be less resilient to pollution because of the long-time taken during the reproductive cycle.

Pollution tolerant signature traits such as tegumental/cutaneous respiration was more pronounced in the HIS. Tegumental respiration has been reported to be positively associated with heavily polluted sites in similar studies conducted elsewhere (Tomanova et al., 2008; Ding et al., 2017; Desrosiers et al., 2019). Organisms that respires tegumentally or cutaneously are able to cope with reduced DO concentrations (Chapman et al., 2004; Tomanova et al., 2008).

5. Conclusions

The present study identifies and classifies potential urban pollution sensitive and tolerant indicator traits and ecological preferences. Traits and ecological preferences such as univoltinism, crawling, swimming as well as preferences for permanent attachment and moderate sensitivity to oxygen depletion were identified and classified as sensitive to urban pollution. Traits and ecological preferences such burrowing, bivoltinism, a preference for silty waters, cased/tubed armouring were identified and classified as tolerant of urban pollution. The present study is a novel attempt at identifying and classifying macroinvertebrates traits and ecological preferences, which can be use as potential urban pollution indicators, where taxonomic knowledge may be sparse.

Authors' contributions

Edegbene, A.O. and Odume, O.N.: Conceptualization; Edegbene, A.O. and Arimoro, F.O.: Study design and structuring of manuscript; Edegbene, A.O. and Arimoro, F.O.: Data collection; Edegbene, A.O.: Data/statistical analyses; Edegbene, A.O.: Funding acquisition; Edegbene, A.O., Odume, O.N and Arimoro, F.O.: Methodology; Edegbene, A.O.: Original manuscript draft; Edegbene, A.O. and Odume, O.N.: Writing; Edegbene, A.O., Odume, O.N., Arimoro, F.O. and Keke, U.N.: Review and editing; Edegbene, A.O.: Manuscript finalization.

Declaration of competing interest

We declared that there is no conflict of interest in this study.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envpol.2021.117076.

References

Akamagwuna, F.C., Mensah, P.K., Nnadozie, C.F., Oghenekaro, O.N., 2019. Traits-based Responses of Ephemeroptera, Plecoptera and Trichoptera to Sediment Stress in the Tsitsa River and its Tributaries, Eastern Cape, South Africa. River Research and Applications. https://doi.org/10.1002/rra.3458.

APHA, 1995. Standard Methods for the Examination of Water and Wastewater. American Public Health Association, Washington, DC.

Arimoro, F.O., Ikomi, R.B., Nwadukwe, F.O., Eruotor, O.D., Edegbene, A.O., 2014. Fluctuating salinity levels and increasing pollution gradient on fish community structure and trophic levels in a small creek in the Niger Delta, Nigeria. Int. Aquat. Res. 6 (4), 187–202.

Berger, E., Haase, P., Schafer, R.B., Sundermann, A., 2018. Towards stressor-specific macroinvertebrate indices: which traits and taxonomic groups are associated with vulnerable and tolerant taxa? Sci. Total Environ. 619, 144–154.

Buendia, C., Gibbins, C.N., Vericat, D., Batalla, R.J., Douglas, A., 2013. Detecting the structural and functional impacts of fine sediment on stream invertebrates. Ecol. Indicat. 38, 351–367.

Chapman, L.J., Schneider, K.R., Apodaca, C., Chapman, C.A., 2004. Respiratory ecology of macroinvertebrates in a swamp-river system of East Africa. Biotropica 36,, 572-523.

Chevenet, F., Dolédec, S., Chessel, D., 1994. A fuzzy coding approach for analysis of longterm ecological data. Freshw. Biol. 31, 295–309.

Day, J.A., Harrison, A.D., De Moor, I.J., 2003. Guides to the Freshwater Invertebrates of Southern Africa: Diptera. Water Research Commission, Pretoria.

De Moor, I.J., Day, J.A., de Moor, F.C., 2003. Guides to the freshwater invertebrates of southern Africa. In: Insecta I. Ephemeroptera, Odonata and Plecoptera. Water Research Commission, Report No. TT207/03, vol. 7.

Desrosiers, M., Usseglio-Polatera, P., Archaimbault, V., Larras, F., Methot, G., Pinel-Alloul, B., 2019. Assessing anthropogenic pressure in the St. Lawrence River using traits of benthic macroinvertebrates. Sci. Total Environ. 649, 233–246.

Ding, N., Yang, W., Zhou, Y., Gonzalez-Bergonzoni, I., Zhang, J., Chen, K., Vidal, N., Jeppesen, E., Liu, Z., Wang, B., 2017. Different responses of functional traits and diversity of stream macroinvertebrates to environmental and spatial factors in the Xishuangbanna watershed of the upper Mekong River Basin, China. Sci. Total Environ. 574, 288–299.

Dolédec, S., Phillips, N., Scarsbrook, M., Riley, R.H., Townsend, C.R., 2006. Comparison of structural and functional approaches to determining land use effects on grassland stream invertebrate communities. J. N. Am. Benthol. Soc. 25 (1), 44–60.

Dolédec, S., Statzner, B., 2008. Invertebrate traits for the biomonitoring of large European rivers: an assessment of specific types of human impact. Freshw. Biol. 53, 617–634.

Dolédec, S., Chessel, D., ter Braak, C.J.F., Champely, S., 1996. Matching species traits to environmental variables: a new three-table ordination method. Environ. Ecol. Stat. 3 (2), 143–166.

Dray, S., Dufour, A.B., 2007. The ade4 package: implementing the duality diagram for ecologists. J. Stat. Software 22, 1–20.

Edegbene, A.O., 2020. Developing macroinvertebrate trait-and taxonomically-based approaches for biomonitoring wadeable riverine systems in the Niger Delta, Nigeria.. Ph.D. thesis Rhodes University, Grahamstown, South Africa, doi: 10.21504/10962/140660.

Edegbene, A.O., Arimoro, F.O., 2012. Ecological status of owan river, southern Nigeria using aquatic insects as bioindicators. J. Aquat. Sci. 27, 99–111.

Edegbene, A.O., Arimoro, F.O., Odume, O.N., 2020. Exploring the distribution patterns of macroinvertebrate signature traits and ecological preferences and their responses to urban and agricultural pollution in selected rivers in the Niger Delta ecoregion, Nigeria. Aquat. Ecol. 54 (2), 553–573. https://doi.org/10.1007/s10452-020-09759-9.

Edegbene, A.O., Arimoro, F.O., Odume, O.N., 2019b. Developing and applying a macroinvertebrate-based multimetric index for urban rivers in the Niger Delta, Nigeria. Ecology and Evolution 9, 12869–12885. https://doi.org/10.1002/ece3.5769.

Edegbene, A.O., Elakhame, L.A., Arimoro, F.O., Osimen, E.C., Odume, O.N., 2019a. Development of macroinvertebrates multimetric index for ecological evaluation of a River in north central Nigeria. Environ. Monit. Assess. 2019 (191), 274. https://doi.org/10.1007/s10661-019-7438-8.

Fierro, P., Bertran, C., Hauenstein, E., Pena-Cortes, F., Vergara, C., Cerna, C., Vargas-Chaoff, I., 2017. Effects of local land-use on riparian vegetation, water quality and the functional organisation of macroinvertebrate assemblages. Sci. Total Environ. 609, 724–734.

Gordon, N.D., McMahon, T.A., Finlayson, B.L., 1994. Stream Hydrology, an Introduction for Ecologists. John Wiley & Sons Ltd, New York.

Hatt, B.E., Flecther, T.D., Walsh, C.J., Taylor, S.L., 2004. The influence of urban density and drainage infrastructure on the concentrations and loads of pollutants in small streams. Environ. Manag. 34, 112–124.

Heino, J., 2013. The importance of metacommunity ecology for environmental assessment research in the freshwater realm. Biol. Rev. 88, 166–178.

Jones, J.I., Murphy, J.F., Collins, A.L., Sear, D.A., Naden, P.S., Armitage, P.D., 2012. The impact of fine sediment on macroinvertebrates. River Res. Appl. 28 (8), 1055–1071.

Krynak, E.M., Yates, A.G., 2018. Benthic invertebrates taxonomic and trait associations with land use intensively managed watershed: implications for indicator identification. Ecol. Indicat. 93, 1050–1059.

Kuzmanovic, M., Doledec, S., deCatro-Catala, N., Ginebreda, A., Sabater, S., Munoz, I., Barcelo, D., 2017. Environmental stressors as driver of the trait composition of benthic macroinvertebrates assemblages in polluted Iberian rivers. Environ. Res. 156, 485–493.

Lakew, A., Moog, O., 2015. A multimetric index based on benthic macroinvertebrates for assessing the ecological status of streams and rivers in central and southeast highlands of Ethiopia. Hydrobiologia 751, 229–242.

Lee, J.H., Bang, K.W., 2000. Characterization of urban stormwater runoff. Water Res. 34, 1773–1780.

Liess, M., Schafer, R.B., Schriever, C.A., 2008. The footprint of pesticide stress in a communities-species traits reveal community effects of toxicants. Sci. Total Environ. 406, 484–490.

Mathers, K.L., Rice, S.P., Wood, P.J., 2017. Temporal effects of enhanced fine sediment loading on macroinvertebrate community structure and functional traits. Sci. Total Environ. 599, 513–522. https://doi.org/10.10016/j.scitotenv.2017.04.096.

Mereta, S.T., Boets, P., De Meester, L., Goethals, P.L.M.C., 2013. Development of multimetric index based on benthic macroinvertebrates for the assessment of natural wetlands in southwest Ethiopia. Ecol. Indicat. 29, 510–521.

Merritt, R.W., Cummins, K.W., 1996. An Introduction to the Aquatic Insects of North America. Kendall Hunt, St. Louis.

Milosevic, D., Stojanovic, K., Djurdevic, A., Zoran, M., Piperac, S.M., Zivic, M., Zivic, I., 2018. The response of chironomid taxonomy-and functional trait-based metrics to fish farm effluent pollution in lotic systems. Environ. Pollut. 242, 1058–1066.

Moges, A., Beyene, A., Kelbessa, E., Mereta, S.T., Ambelu, A., 2016. Development of a multimetric plant-based index of biotic integrity for assessing the ecological state of forested, urban and agricultural natural wetlands of Jimma Highlands, Ethiopia. Ecol. Indicat. 71, 208–217. http://dx.org/10.1016/j.ecolind.2016.06.057.

Mondy, C.P., Villeneuve, B., Archaimbault, V., Usseglio-Polatera, P., 2012. A new macroinvertebrate-based multimetric index (I_2M_2) to evaluate ecological quality of French wadeable streams fulfilling the WFD demands: a taxonomical and trait approach. Ecol. Indicat. 18, 452–467.

Murphy, J.F., Jones, J.I., Arnold, A., Duerdoth, C.P., Pretty, J.L., Naden, P.S., Sear, D.A., Collins, A.L., 2017. Can macroinvertebrate biological traits indicate fine-grained sediment conditions in streams? River Res. Appl. 33, 1606–1617. https://doi.org/10.1002/rra.3194.

Murphy, J.F., Davy-Bowker, J., McFarland, B., Ormerod, S.J., 2013. A diagnostic biotic index for assessing acidity in sensitive streams in Britain. Ecol. Indicat. 24, 562–572.

Odume, O.N., Ntloko, P., Akamagwuna, F.C., Dallas, H.M., Barber-James, H., 2018b. A trait database for South African macroinvertebrates. WRC Report No.K1/7157.

Odume, O.N., Ntloko, P., Akamagwuna, F.C., Dallas, H.M., Barber-James, H., 2018a. Development of macroinvertebrate trait-based approach for assessing and managing ecosystem health in South African Rivers- incorporating a case study of the Tsitsa River and its triturates. WRC, Eastern Cape. No.: K1/7157.

Oksanen, J., Blanchet, D., Minchin, PR., O'Hara, RB., Simpson, G.L., Solymos, P., Steven, MHM., Szoecs, E., Wagner, H., 2019. R Development Core Team. Vegan, Community Ecology Package. Retrieved 11/02/2019. https://cran.r-project.org. https://github.com/veganders/vegan. Published 04-02-2019, 11:50:04 UT.

Olden, J.D., Poff, N.L., Douglas, M.E., Fausch, K.D., 2004. Ecological and evolutionary consequences of biotic homogenization. Trends Ecol. Evol. 19, 18–24.

Pallottini, M., Cappelletti, D., Fabrizi, A., Gaino, E., Goretti, E., Selvaggi, R., Cereghino, R., 2017. Macroinvertebrate functional trait responses to chemical pollution in agricultural landscapes. River Res. Appl. 33, 505–513. https://doi.org/10.1002/rra.3101.

Pilière, A.F.H., Verberk, W.C.E.P., Gräwe, M., Breure, A.M., Dyer, S.D., Posthuma, L., de Zwart, D., Huijbregts, M.A.J., Schipper, A.M., 2016. On the importance of trait interrelationships for understanding environmental responses of stream macroinvertebrates. Freshw. Biol. 61, 181–194. https://doi.org/10.1111/fwb.12690.

Poff, N.L., Olden, J.D., Vieira, N.K.M., Finn, D.S., Simmons, M.P., Konddratieff, B.C., 2006. Functional trait niches of North American lotic insects: traits-based ecological applications in light of phylogenetic relationships. J. North Am. Benthol. Soc. 25, 730–755.

Roy, A.H., Freeman, M.C., Freeman, B.J., Wenger, S.J., Ensign, W.E., Meyer, J.L., 2005. Investigating hydrological alteration as a mechanism of fish assemblage shifts in urbanizing streams. J. North Am. Benthol. Soc. 24, 656–678.

Statzner, B., Beche, L., 2010. Can biological invertebrate traits resolve effects of multiple stressors on running water ecosystems? Freshw. Biol. 55, 80–199.

Tomanova, S., Usseglio-Polatera, P., 2007. Patterns of benthic community traits in neotropical streams: relationship to mesoscale spatial variability. Fund. Appl. Limnol. 170, 243–255.

Tomanova, S., Moya, N., Oberdorff, T., 2008. Using macroinvertebrate biological traits for assessing biotic integrity of neotropical streams. River Res. Appl. 24 (9), 1230–1239.

Tonkin, J.D., Arimoro, F.O., Haase, P., 2016. Exploring stream communities in a tropical biodiversity hotspot: biodiversity, regional occupancy, niche characteristics and environmental correlates. Biodivers. Conserv. 25, 975–993.

Walsh, C.J., Jack, W.F., Cottingham, P.D., Groffman, P.M., Morgan, R.P., 2005. The urban syndrome: current knowledge and the search for a cure. J. North Am. Benthol. Soc. 24 (3), 706–723.

Wilkes, M.A., Mckenzie, M., Murphy, J.F., Chadd, R.P., 2017. Assessing the mechanistic basis for fine sediment biomonitoring: inconsistencies among the literature, traits and indices. River Res. Appl. https://doi.org/10.1002/rra.3139.