Journal of Limnology and Freshwater Fisheries Research
http://www.limnofish.org

Benthic Macro-invertebrate Community Diversity of Orhuwhorun River in Udu Wetlands

Gloria Akohame OSUINDE [1*], **John Ovie OLOMUKORO** [1]

[1] Department of Animal and Environmental Biology, Faculty of Life Science, University of Benin, Benin City, PMB 1154, Nigeria

ABSTRACT

Benthic macro-invertebrate studies were done on Orhuwhorun River in Udu wetlands in Delta State, Southern Nigeria from March to December, 2011 in three selected stations. Sampling was done using a hand modified Eckman grab for sand and silt, the kick sampling technique and floatation method. They were sorted and identified using identification keys. A total of 2466 individuals were recorded in 66 taxa species belonging to thirteen (13) groups. Crustacean was the dominant group (36.29%) closely followed by gastropoda (35.60%) and diptera (21.04%). Significant similarity in fauna composition was observed. Station 3 had the highest population density with a relative abundance of 58.19% followed by station 2 (32.03%) and station 1 (9.77%). Diptera had the highest species diversity while nematode and lepidoptera had the least amongst the groups. Station 1 had the highest species richness (d) followed by station 3 and least in station 2. Species diversity showed no significant difference between the stations. Values for pollution tolerance index ranged between 13 and 15 at the stations. The highest value for pollution tolerance (PTI) was recorded in station 2 and the least in station 1. Positive significant correlations existed between most benthic organisms. The water quality is described as "fair".

Keywords: Benthic macro-invertebrates, Orhuwhorun River, Diversity, Pollution Tolerance Index (PTI).

ARTICLE INFO

RESEARCH ARTICLE

Received : 29.04.2023
Revised : 06.07.2023
Accepted : 10.07.2023
Published : 25.08.2023

DOI:10.17216/LimnoFish.1110878

*** CORRESPONDING AUTHOR**

gloriaonde@gmail.com
Phone : +234 703 817 29 68

How to Cite
Osuinde GA, Olomukoro JO. 2023. Benthic Macro-invertebrate Community Diversity of Orhuwhorun River in Udu Wetlands. LimnoFish. 9(2): 53-62. doi: 10.17216/LimnoFish.1110878

Introduction

Nigeria has a coastline of about 853 km inundated with different types of aquatic systems which are majorly estuarine in nature (Uwadiae 2013). One of them is wetlands. Wetlands are transitional lands between terrestrial and deep water habitats where the water table is usually at or near the land surface and usually flooded (Egborge et al. 2003). They include "areas of marsh, fen, peat-land or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water, the depth of which at low tide does not exceed 6 m" (Ramsar Convention Secretariat 2007). Wetlands contribute significantly to world biodiversity (Keddy 2010). They are one of the most important ecosystems in the world performing essential ecosystem services including preservation of biodiversity and providing habitat for many endangered species amongst others (Asibor 2009; Hu et al. 2017; Ogbeigbu and Ohiorobo 2020).

The Udu wetlands cover part of an area that harbours the oil and gas industries and its allied industries and is usually susceptible to degradation and fauna loss in the water bodies due to water pollution either directly or indirectly. The loss of biodiversity and its effect seems to be greater for aquatic ecosystems than for terrestrial ecosystens because of its sensitive chemical nature.

The benthic macro-invertebrate community occupies an important trophic level in wetland ecosystems and can also be found in a variety of habitats (Stenert and Maltchik 2007). They mix up of soils by their activities which include burrowing, ingestion and defecation of sediment grains (Aller and Cochran 2019). Nutrient transport across sediment is a major role played by these bottom dwelling organisms. They also serve as a food source for other aquatic organism in the food chain (Silva et al. 2006) which when stressed such other organisms on the food chain is affected. Diaz et al. (2004) described benthic infauna as opportunistic species that can adapt to any habitat circumstance of possible benefits such as a dynamic salinity regime and variable physical conditions. Their composition, abundance, biomass and distribution patterns are to a large extent determined by a number of interacting variables of physical and chemical parameters like temperatue, dissolved oxygen concentrarion, salinity and biochemical oxygen demand (Ikomi et al. 2005; Hepp et al. 2013).

Benthic invertebrates are useful as bioindicators of environmental degradation in the aquatic ecosystems, ecological monitoring and assessing pollution status (Olomukoro and Osuinde 2015; Arimoro et al. 2015; Anyanwu et al. 2019). Biological monitoring is the systematic use of living organisms (benthic invertebrates) and their responses to their environment in the determination of water quality (Barbour and Paul 2010; Muralidharan 2010).

Aquatic insects give a more accurate interpretation of changing aquatic conditions (Ikomi et al. 2005; Xu et al. 2014) and a more reliable assessment of pollution status in a waterway than other organisms like fish, due to the greater variety of insect species present in a water body representing an entire range of water quality tolerance. Some insects are only found in clean waters while some are facultative that is show no preference for either polluted or clean waters. The poorer the quality of the water body, the fewer the number and types of organisms that can live in it. Some species are more sensitive to chemical and physical changes than other species. If sensitive species are more available then the waterway is described as clean and of good quality. The objective of this paper is to determine the composition and diversity of benthic fauna in Orhuwhorun River and to determine the water quality of the river using the PTI key.

Materials and Methods

Study Area

Orhuwhorun River in Udu wetlands is located between latitude 05°47’-05°52’E and longitude 05°28’-05°33’N (Figure 1). It is a tributary flowing into Warri River and tidal influenced with a 12 hourly cycle. The river is about 7 m above sea level and 10 km long with a sloppy and undulating terrain. The catchment’s area is surrounded by homesteads, houses, fish ponds, and shopping complexes. The bottom is more than 50% clay and the depth of the river is about 2.5 m. The study area consists primarily of freshwater swamp, mangrove swamp and tropical rainforest characterized by dense vegetation. It is dark and turbid flanked by red mangrove (*Rhizophora racemosa*), oil palm trees (*Elaeis guinensis*), mahogamy trees, raffia palm, *Hevea brasilensis*, *Rahia hookeria, Alstonia sp., Ficus sp, Kigelia africana, Aestotrophyllum secundifloum, Clamitus sp., Lemna sp.* and water hyacinth (*Eichhornia crassipes*). The shrubs around the water body include *Alchoma laxiflora, Nephrolepsis biseraa, Amarathus sp* and *Anacandium occidentale* etc. Farming, fishing and felling of trees are the major human activities alongside domestic activities such as bathing, laundry and defecation. The rainy season lasts from March to early November, while the dry season spans from November to February of the following year.

Sampling Stations

Station I

Station I (N 05° 30’ 42.6”, E 05° 50’ 4.5”) is located in Orhuwhorun village, 5 m above sea level. It is about 2.8 km upstream of station II; the water is dark and turbid. The water drains primarily through a thick freshwater swamp forest with an average velocity of 0.02 m/s.

Station II

Station II (N 05° 30’ 49”, E 05° 49’ 0.30”) is located 2.5 km upstream from station III and is at the center of Igbogidi village axis, 2 m above sea level. The substratum is mainly sand and silt. Human activities are fishing, bathing and washing. The flow rate was faster than station I with an average current velocity was 0.05 m/s.

Station III

Station III (N 05° 30’ 52.5”, E 05° 48’ 18.0”) is located at Ekete waterside, 7 m above sea level. The substratum is sandy silt (laterite). Human activities include timber felling, fishing, shrimping and laundry. The water is fast flowing with an average velocity of 0.18 m/s.

Sampling of Macro-benthic Invertebrates

Benthic macro-invertebrates were sampled randomly every two weeks using three methods. First, a 6-inch metal container (modified grab) was used to sample the substratum of the river. It was operated by hand in the shallow waters forced to a depth of 15-20 cm. The contents were sieved and put in sampling containers holding 10% formalin solution. Secondly is the kick sampling method (Victor and Ogbeibu 1985). Here, the water close to the bankroots and macrophytes is kicked with the leg to disturb the organisms and divert the flow of water to another direction where the sieve is placed to collect the detached and floating invertebrates and placed in sampling containers holding 10% formalin solution. Thirdly, floating aquatic plants-water hyacinth (*Eicchornia crassipes*) was collected midstream and put in plastic buckets containing 10% formalin and left for 3-5 minutes. Then it is shaken vigorously within the bucket and transferred to another bucket of water. It is dusted again to shake off completely any organism still attached to its root (Olomukoro and Osuinde 2015). Then the contents of the buckets are filtered through a set of sieves. All samples were preserved in sampling containers holding 10% buffered formalin solution.

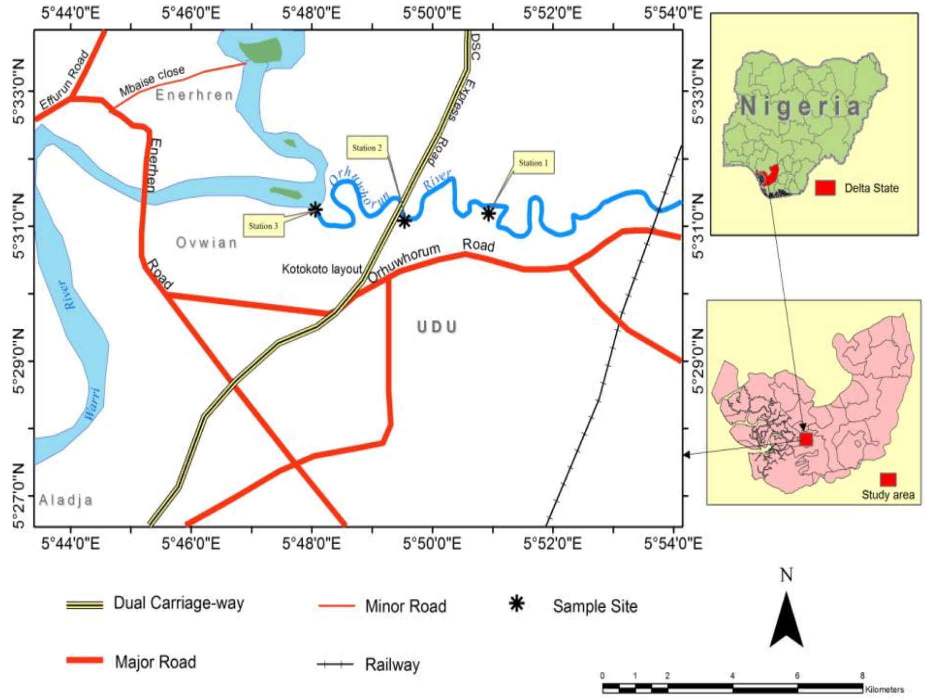

Figure 1. Map of study area showing sampled locations

Sorting, Identification and Counting

Sorting was done using an American optical dissecting microscope; model 570 with a magnification of 25- 40x, preserved in 4% formalin and stored in labeled specimen bottles. Identification and counting was done using a binocular Olympus microscope; model WF 10x. The methods of Olomukoro (1996) and Olomukoro and Ezemonye (2007) were employed for the identification of macroinvertebrate organisms and further confirmed with keys by Needham and Needham (1962), Mellanby (1963), Pennak (1978) and Olomukoro (1983). Some organisms were identified to generic level due to the poor knowledge of taxonomy in Nigerian fresh and brackish water.

Statistical Analysis

Statistical analysis was computed using the SPSS statistical package and micro-soft excel. Biotic indices to ascertain the diversity such as Margalef's index (d), Shanon-Weinner index (H), Evenness index (S) and Dominance index (C) were analyzed using computer software known as PAST (Paleontological Statistics) (Hammer et al. 2001). Comparism between the stations was done using the single analysis of variance (ANOVA) and the significant difference pointed out using the Duncan multiple range tests, (DMR). Correlation between the macro invertebrates were analyzed to show the relationship between the parameters across the stations.

Pollution Tolerance Index

The health status of the water body was assessed using the method described by Klemm et al. (1990) under three groups. The first-pollution sensitive group of Epemeroptera, Trichoptera, and Coleoptera was multiplied by 3. The second-somewhat sensitive group of Decapoda, Zygoptera, Anisoptera and Diptera was multiplied by 2 and the third –pollution tolerant group of Oligochaetes, and gastropods was multiplied by 1. The total was summed up to get a value which was compared with PTI index categories in Table 1 for each station.

Table 1: Pollution tolerance index categories and its description

PTI index	Description
23 and above	Excellent
17-22	Good
11-16	Fair
10 or less	Poor

Results

A total of 2466 individuals belonging to 66 taxa were collected in this study. Station 1 recorded 37 taxa species, station 2 recorded 45 taxa species and station 3 recorded 40 taxa species respectively while the number of individuals in each station were 241, 790 and 1435 respectively (Table 2). Throughout the study period, among the dominant groups, dipteran population occurred more in the rainy season in station 1 except in May than in other stations. While station 3 recorded low numbers of dipteran population throughout the study period (Figure 3).

Table 2. General composition and diversity and abundance in the study stations

Stations Taxa	1	2	3
Nematoda			
Diplogaster sp.	1	-	-
Annelida (Oligochaete)			
Nais simplex	-	-	1
Nais osborni	-	1	-
Nais sp.	1	-	-
Lumbricus sp.	12	1	-
Polychaeta			
Lycastoides alticola	-	-	1
Lycastopsi sp	-	-	1
Namanereis hawaiiensis	2	-	2
Crustacean			
Caridina gabonensis	-	-	1
Potamalpheops monody	-	280	614
Arachnida			
Sesarma alberti	-	-	28
Agyronecta aquatic	-	4	1
Megapus sp	-	1	-
Ephemeroptera			
Baetis bicaudatus	3	-	-
Ephemerella ignita	-	1	-
Cleon simplex	3	1	-
Cleon bellum	8	9	2
Centroptilum sp.	1	4	-
Unidentified ephemeroptera	-	-	1
Odonata (Anisoptera)			
Libellula sp.	1	4	1
Orthemis sp	-	-	1
Gomphid sp	2	-	-
Zygoptera			
Hesperagrion heterodoxum	-	3	-
Enallagma sp	1	2	-
Coenagrion scitulum	-	1	1
Lestes sp.	-	1	-
Hemiptera			
Pelocoris femoratus	1	-	2
Unidentified hemiptera	-	-	1
Lepidoptera			
Lepidoptera larva	6	4	7
Coleoptera			
Berosus sp.	-	1	-
Hydrophilus sp.	1	8	9
Hydroptillid larva	-	3	5
Hydroporus larva	-	-	1
Dysticus marginalis	-	7	1
Phylidrous larva	4	1	-
Unidentified dysticus larva	1	1	2
Unidentified coleopteran	-	1	-
Diptera			
Stilobezzia antenalis	1	-	-
Probezzia sp.	1	-	-
Palpomyia sp.	44	2	1
Forcipomyia sp.	27	1	1
Allaudomyia needhami	5	5	1
Pentaneura sp.	10	40	26
Polypedilum sp.	12	45	62
Tanytarsus sp.	3	15	16

Table 2. Continued

Stations Taxa	1	2	3
Diptera			
Chironomus fractilobus	15	14	17
Chironomus travailensis	7	1	-
Chironomid sp.	5	-	-
Procladius sp.	6	22	6
Unidentified dipteran larva	-	1	-
Unidentified diptera pupa	-	1	-
Cricotopus sp.	2	44	15
Pseudochironomus sp.	3	6	1
Culex sp.	7	6	4
Tanypus sp.	10	6	2
Gastropoda			
Neritina glabrata	-	109	288
Nerita senegalensis	-	33	60
Hydrobia sp.	4	7	4
Hydrobia guyenoti	1	24	70
Potamopyrgus sp.	-	10	21
Potamopyrgus ciliates	-	54	110
T. fuscatus radula	-	3	-
T. fuscatus fuscatus	-	-	48
Planorbis complanatus	1	-	-
Limnea glabra	13	1	-
Limnea auricularia	16	1	-
Total	**241**	**790**	**1435**

The benthic fauna was dominated by Crustaceans (36.29%) closely followed by Gastropods (35.60%) and Diptera (21.04%) (Figure 2). The others fell into the category of rare groups having a population density <5% (Slack et al. 1977). They include Coleoptera (1.82%), Ephemeroptera (1.37%), Arachnida (1.37%), Lepidoptera(0.68%), Oligochaete (0.65%), Anisoptera (0.36%), Zygoptera (0.36%), Polychaeta (0.24%), Hemiptera (0.16%), and Nematoda (0.04%).

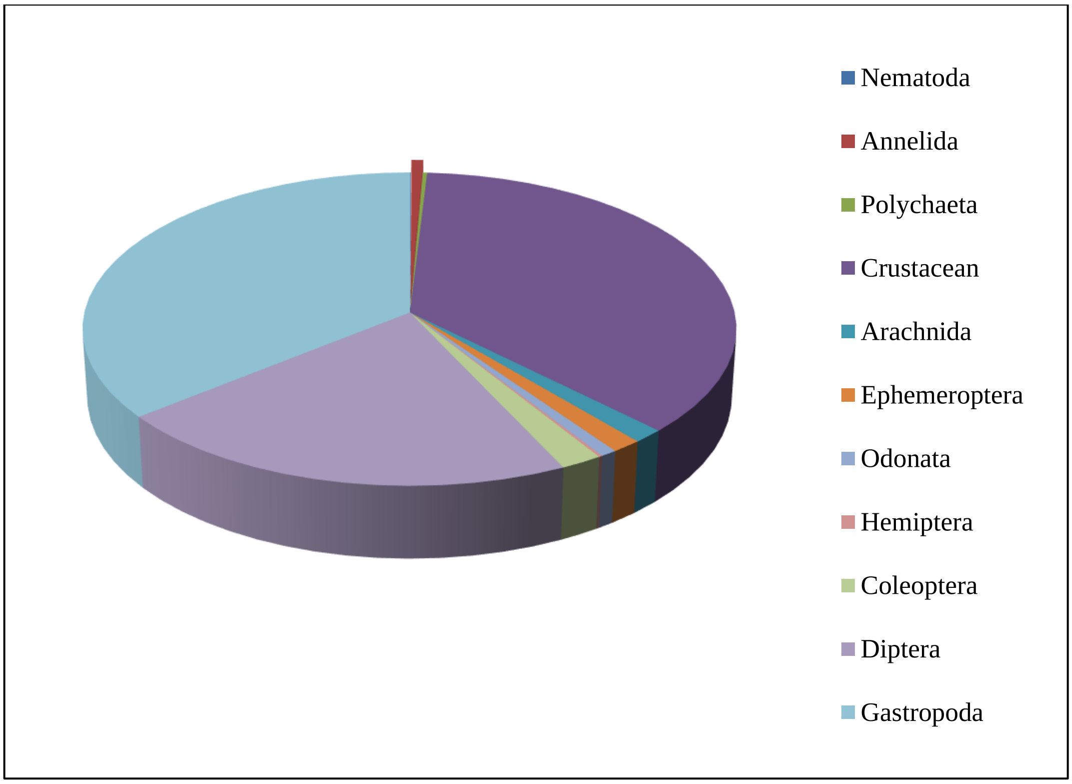

Figure 2: Overall composition of benthic macrofauna in the stations

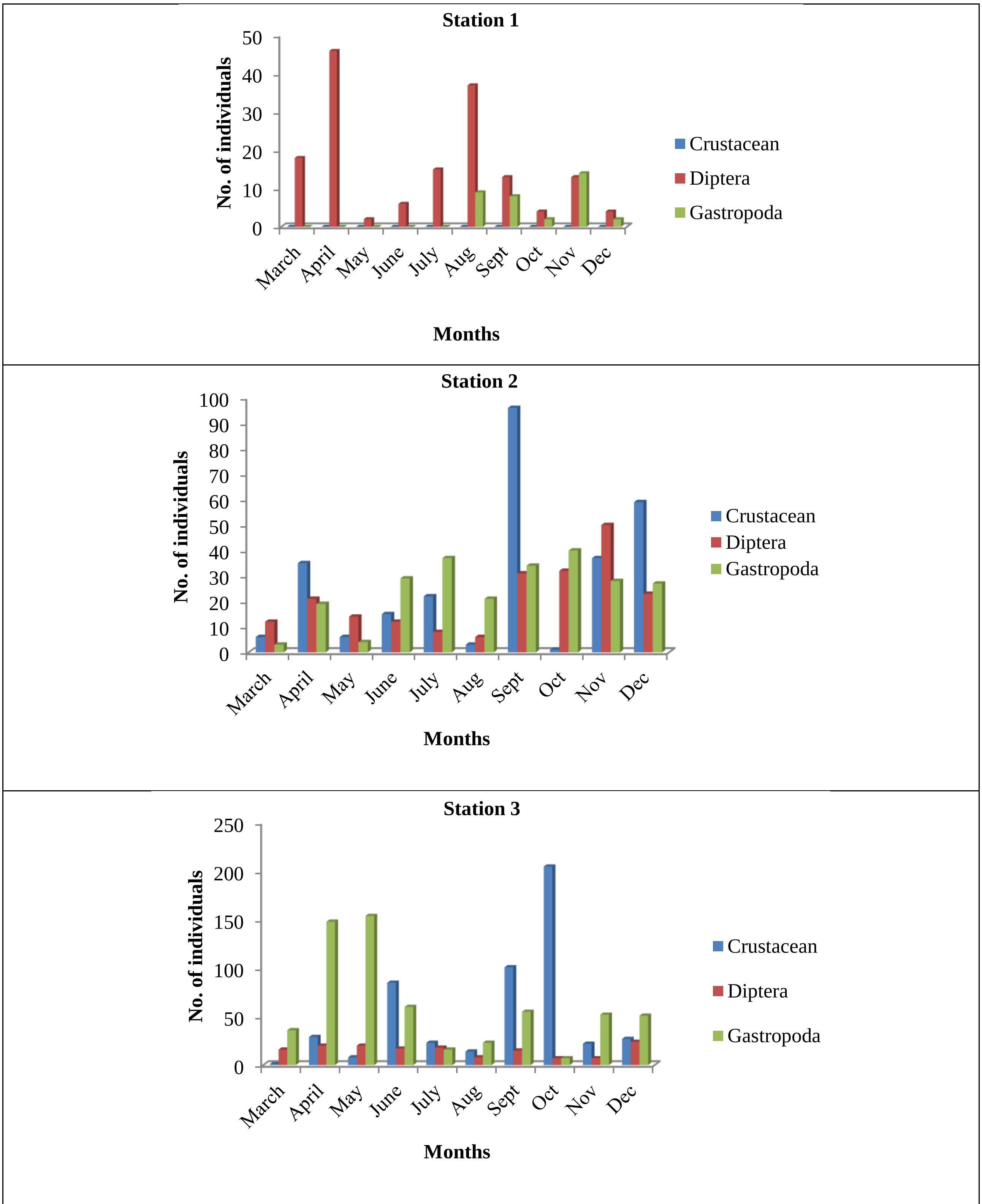

Figure 3: Seasonal variation of the dominant macrobenthic fauna in the three stations

The community structure include Nematode (1 species), Oligochaete (4 species), Polychaete (3 species), Crustaean (2 species), Arachnida (3 species), Ephemeroptera (6 species), Odonata (7 species), Hemiptera (2 species), Lepidoptera (1 species), Coleoptera (8 species), Diptera (18 species) and Gastropods (11 species) (table 2).

Species evenness (E) was highest in station 2 and lowest in station 3. Taxa richness (d) was highest in station 1 and lowest in station 2. Station 2 was highest for general diversity (D) while station 3 had the lowest diversity (table 3). There exist no significant differences in diversity between the stations. Comparism between stations using Sorenson's quotient showed strong similarity in species composition between the stations. Similarity was highest between stations 2 and 3 (62.7) and least between stations 1 and 3 (54.5).

Table 3: Diversity indices of macrobenthic fauna of the study stations in Orhuwhorun River

INDICES	STN 1	STN 2	STN 3
No. of taxa	37	45	40
Percentage taxa (%)	56.06	68.18	60.60
Number of individuals	241	790	1435
Relative abundance (%)	9.77	32.03	58.19
Margalef's index (d)	1.823	1.349	1.513
Shanon-Weinner's index (H)	1.234	1.398	1.183
Dominance index (D)	0.4592	0.2908	0.3709
Simpson's index (1-D)	0.5408	0.7092	0.6291
Evenness index (S)	0.3122	0.4048	0.2719
Menhinick' s index	0.7086	0.3558	0.3168
PIE	0.5523	0.8237	0.6308

On the pollution tolerance index scale, it gave close values of 13, 15 and 14 at stations 1, 2 and 3 respectively. Across the sampling months, it was highest in September and December (14) and lowest in April (3) (Figure 4).

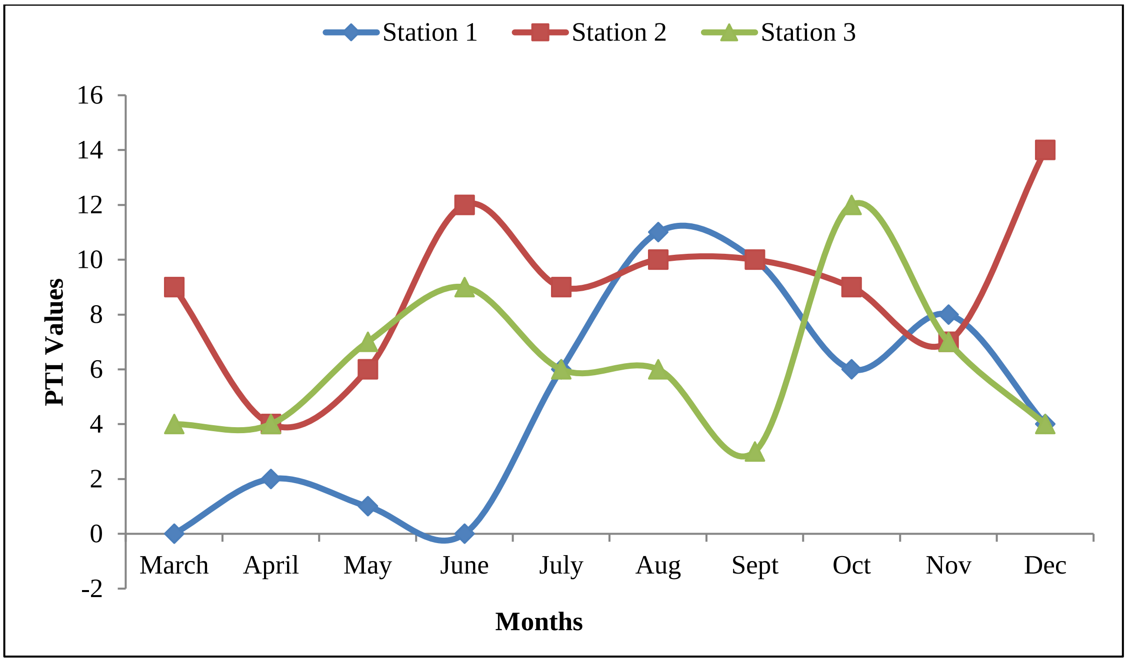

Figure 4. Spatial and temporal variation in pollution levels in the stations

Discussion

It is known that tropical streams record higher numbers of benthic fauna than temperate waters (Bishop 1973). This study recorded 66 taxa in the study period. The high taxa number recorded corroborates Olomukoro (1996) and Ajao and Fagade (2002). Previous works on Udu-ghievwen wetlands recorded 40 taxa (Olomukoro and Dirisu, 2014). Also, Agbede wetlands recorded 42 taxa (Olomukoro et al. 2013) despite its disturbance with lindane. However, It is important to note that the numbers was quite low when compared with other tropical water bodies such as Olomokoro and Egborge (2003) (138 taxa species), Olomukoro (2007) (112 taxa species). Such differences may be as a result of variation in sampling methods, pollution and increased environmental and anthropogenic activities.

The overall diversity of a water body is a product of all dynamic spatial and temporal changes affecting the communities and a reflection of the extent to which a biotope is disturbed by human activity (May 1981). According to the intermediate disturbance hypothesis of diversity, disturbance either by predation or by physical process prevents species from reaching densities where competition begins and thus allows more species to co-exist than where there is no distubance (Gray 1985). This was observed in station 2 where species diversity is high (1.4) that is having more species co-existing together and at the same time having reduced taxa richness

(1.35). While in station 1 where there was relative calmness and much reduced disturbance by physical processes, the species diversity was low (1.23) and the taxa richness high (1.82). Olomukoro et al. (2013) was also of the view that human activities can significantly alter the eco-balance of any aquatic system.

Also observed in this study is that a high abundance of benthic invertebrates in aquatic ecosystem does not simultaneously mean greater species diversity in the system as seen in the upstream and midstream stations. This is seen in station 3 having the highest abundance of benthic invertebrates (58.19%) and the least in species diversity (1.18) while station 2 which had a reduced abundance of species (32.03%) recorded the highest diversity (1.4).

The nature of the substratum or particle size distribution was a vital factor that influenced the occurrence and distribution of the benthic fauna. The dominant fauna were Diptera, Gastropoda and Crustaceans (P>15%). The dominance of diptera in tropic freshwater bodies has been acknowledged (Ogbeibu 2001; Olomukoro and Ezemonye 2007). The clayey sediment at the river bottom may also have supported the ubiquitous dipteran and gastropod population during exposure periods due to its ability to retain much water as the organisms burrow into the soil to find shelter. Other factors which support dipteral population include current (velocity, temperature, season, total suspended solids and vegetation).

An important factor in shell formation is bicarbonate and acidity. These major factors affect gastropod distribution Thus they survive well in nuetral to slightly alkaline waters which favors the toughness and rigidity of their shells (Olomukoro and Azubuike 2009). This was the prevailing condition in this study. A study conducted by Spyra (2017) showed that a more diverse gastropod fauna was found in neutral ponds, whereas the lowest degree of diversity was found in ponds with the lowest pH. Gastropods were more downstream due to favorable conditions such as the presence of leaf litter which serve as food for them and extensive canopy cover provided by the trees and mangrove vegetation against predators (Lajtner et al. 2022). Economically important gastropod species such as *Tympanotonus sp.* and crustaceans are eaten by the locals in the area and by fish. Thus they play a vital role in the aquatic food web. They are detritus feeders and largely influenced by desiccation (Stickle et al. 2017).

Eutrophication was an observed phenomenon in station 1 as a result of increased nutrients from flood, sewage discharge and runoff from dumpsites into the river at this point. Also, some portions of the river bank are used as a dumpsite releasing nutrient leak into the watercourse. Similar observation by Mandal et al. (2012) reported nutrient (phosphate) contamination from sewage discharge, use of detergents in water and runoffs laden with fertilizers. Eutrophication alters habitat structure for benthic organisms, reduces water clarity and affects oxygen levels in the water and increased heat. This may have affected the crustacean population as they were very much reduced at station 1 when compared to the other two stations. Studies have shown that crustaceans are susceptible to oxygen depletion and increased heat (Verberk et al. 2018). Generally, demand for oxygen in aquatic organisms increases abnormally with every 10°C increase in temperature which directly affects their physiological activities (Halim et al. 2018).

A wide variety of benthic organisms usually indicate clean water conditions. This is drawn from the fact that high quality water provides an optimum environment for the existence of a large number of species. Polluted water on the other hand imposes one or more limiting factors on the benthic community and restricts the variety of species that can survive in such conditions. Sensitive species of Ephemeroptera, Odonata, and Coleoptera occurred in low numbers at all three stations. They are usually abundant in waters unpolluted with organic waste and lots of dissolved oxygen (Ezemonye et al. 2004). A low number of these sensitive species clearly indicates a compromised state in the water body. The close values of 13, 15 and 14 at stations 1, 2 and 3 (Figure 4) respectively from the PTI scale fell in category of 11-16 which describes the water quality as “fair” (Klemm et al. 1990). Olomukoro et al 2015 also reported PTI values in this category in Ekpan creek. Unlike the report given by Olomukoro and Dirisu (2013) who recorded water quality with values less than 10 in most stations. Olomukoro and Anani (2019) reported fair in some rivers, poor in others and excellent in a few rivers.

The water quality status of the study area depicts susceptibility to pollution and contamination as anthropogenic activities increases along the river course. A strategic management plan is thereby recommended to preserve its diversity and maintain natural conditions in the wetland area.

Acknowledgments

The authors wish to acknowledge the assistance of Robert Nsisong in collection of samples and Dr. Dirisu A-R for technical advice

References

Ajao EA, Fagade SO. 2002. The benthic macrofauna of Lagos lagoon. The Zoologist 1(2):1–15.

Aller RC, Cochran JK. 2019. The Critical Role of Bioturbation for Particle Dynamics, Priming Potential, and Organic C Remineralization in Marine Sediments: Local and Basin Scales. Front. Earth Sci. 7:157. doi: 10.3389/feart.2019.00157

Asibor G. 2009. Wetlands: values, uses and challenges. A Paper presented to the Nigerian Environmental Society at the Petroleum Training Institute, Effurun, 21st November, 2009.

Anyanwu ED, Okorie MC, Odo SN. 2019. Macroinvertebrates as bioindicators of water quality of effluent-receiving Ossah River, Umuahia, Southeast Nigeria. ZANCO J. of Pure and Appl. Sci. 31(5):9-17. doi: 10.21271/zjpas

Arimoro FO, Odume ON, Uhunoma SI, Edegbene AO. 2015. Anthropogenic impact on water chemistry and benthic macroinvertebrate associated changes in a southern Nigeria stream. Environ. Monitor. and Assess. 187:14. doi: 10.1007/s10661-014-4251-2

Barbour MT, Paul MJ. 2010. Adding value to water resource management through biological assessment of river. Hydrobiologia. 651: 17 – 24. doi:10.1007/s10750-010-0287-7

Bishop JE. 1973. Limnology of a small Malayan river, Sungai Gombak. Dr. W. Sunk publishers. The Hague, 485pp. doi:10.1007/978-94-010-2692-5

Diaz RJ, Solan M, Vahente RM. 2004. A review of approaches for classifying benthic habitats and evaluating habitat quality. J Env Manage. 73: 165 – 181. doi:10.1016/j.jenvman.2004.06.004

Egborge ABM, Ezemonye, LIN, Awoze GE. 2003. Macro-invert fauna of Udu-Ughievwen wetlands, Southern Nigeria. J of Aqua Sci. 18(1):1 – 8. doi: 10.4314/jas.v18i1.19937

Ezemonye LIN, Olomukoro JO, Igbinosun E. 2004. Comparative studies of macro-invertebrate community structure in two river-catchment areas (Warri and Forcados) in Delta State, Nigeria. Afr Sci. 5(4):181 – 191.

Gray JS. 1985. Ecological theory and marine pollution monitoring. Mar Poll Bull. 16:224 – 227. doi: 10.1016/0025-326X(85)90504-1

Halim A, Sharmin S, Rahman, H., Haque M, Rahman S, Islam S. 2018. Assessment of water quality parameters in baor environment, Bangladesh: A review. Int. J. of Fisheries and Aqua. Stud. 6(2), 269-263.

Hammer Ø, Harper DAT, Ryan PD. 2001. PAST: Paleontological statistics software package for education and data analysis. Paleontologia Electronica. 4(1):9pp. http://palaeo-electronica.org/2001_1/past/issue1_01.htm.

Hepp LU, Restello RM, Milesi SV. 2013. Distribution of aquatic insects in urban headwater streams. *Acta Limnologica Brasiliensia.* ; 25(1):1–9. doi: 10.1590/S2179-975X2013005000014.

Hu S, Niu Z, Chen Y. 2017 Global wetlands: Potential distribution, wetland loss, and status. Sci. of the Total Environ. 586:319–327. doi: 10.1016/j.scitotenv.2017.02.001

Hynes HBN. 1971. The ecology of running water. Toronto University press. 555pp.

Ikomi RB, Arimoro FO, Odihirin OK. 2005. Composition, distribution and abundance of macroinvertebrates of the upper Reaches of River Ethiopia Delta State, Nigeria. The Zoologist. 3:68-81.

Keddy PA. 2010. Wetland ecology: principles and conservation. Cambridge University Press.

Klemm DJ, Philip AL, Florence Lozoreckak. 1990. Macroinvertebrate field and laboratory method for evaluating the biology integrity of surface water. U.S EPA, EPA/600/4-90.030 xii, 256pp.

Lajtner J, Kozak A, Špoljar M, Kuczyńska-Kippen N, Dražina T, Sertić Perić M, Tkalčec I, Gottstein S, Zrinščak I. 2022. Gastropod Assemblages Associated with Habitat Heterogeneity and Hydrological Shifts in Two Shallow Waterbodies. Water. 14:2290. doi: 10.3390/w14152290.

Mandal SH, Das A, Nanda AK. 2012. Study of some Physicochemical Water Quality Parameters of Karola River, West Bengal- An Attempt to Estimate Pollution Status, International J. of Envir. Protection, 2(8): 16-22.

May RM. 1981. Theoretical ecology, principles and applications, 2nd Ed. Oxford: Blackwell scientific publications, 489pp.

Mellanby H. 1963. Animal life in freshwater. Chapman and Hall, London. 308pp.

Muralidharan M, Selvakumar C, Sundar S, Raja M. 2010. Macro-invertebrate as potential indicators of environmental quality. Inter J of Bio Tech. 1:23-28.

Needham JG, Needham PR. 1962. A Guide to the study of freshwater biology. Holden-Day, San Francisco.108pp.

Ogbeibu AE. 2001. Composition and diversity of Diptera in temporary pond in Southern Nigeria, Trop Ecol 42(2):259 – 268.

Ogbeibu AE, Ehiorobo SI. 2020. Physicochemical Characteristics of the Okomu Wetland, Edo State, Nigeria. Nigerian J. of Envir Sci and Tech. (NIJEST). 4:(2):398 – 410. doi: 10.36263/nijest.2020.02.0225

Olomukoro JO. 1983. Limnological investigations of macrobenthic fauna of Eruvbi stream. A tributary of the river Ikpoba, Benin City, Nigeria. Msc. Thesis, University of Benin, Nigeria.

Olomukoro JO. 1996. Macrobenthic fauna of Warri river in Delta State of Nigeria. Ph.d Thesis, University of Benin, Benin City, Nigeria. 350pp.

Olomukoro JO. 2007. Salinity and the macrobenthic community structure in *Eichhornia crassipes* of Warri River, Nigeria. J of Bio Sci. 7(2):309-314. doi: 10.3923/jbs.2007.309.314

Olomukoro JO. 2008. Factors influencing the benthic macro-fauna of erosional biotope in Warri River, Nigeria. Biosci Res Comm. 20(33):153-165.
Olomukoro JO, Egborge ABM. 2003. Hydrobiological studies on Warri River, Nigeria; Part I: The composition, distribution and diversity of macrobenthic fauna. Bios Res Comm. 15(4):15-22.
Olomukoro JO, Ezemonye LN. 2007. Assessment of the macro-invertebrates fauna of rivers in southern Nigeria, Afr Zoo 42(1): 1 – 11. doi: 10.1080./15627020.2007.11407371
Olomukoro JO Azubuike CN. 2009. Heavy metals and macro-invertebrates communities in bottom sediment of Ekpan creek, Warri, Nigeria. Jordan J of Bio Sci 2(1):1 – 8.
Olomukoro JO, Osuinde GA. 2015. Associations of benthic macroinvertebrate assemblages with environmental variables in a creek flowing through an urban area in southern Nigeria. Eger J Sci and Tech. 15:141-156.
Olomukoro JO, Osamuyiamen IM, Dirisu A-R. 2013. Ecological Survey of Macrobenthic Invertebrates of Selected Ponds in Agbede Flood Plain, Southern Nigeria. J of Bio Agric and Healthcare. 3(10):23-29.
Olomukoro JO, Dirisu AR. 2013. Biodiversity and pollution tolerance index of selected rivers in derived savannah belt in Edo-North, Nigeria. In proceedings of the 4th Annual Biodiversity Conference on "Sustaining the Remaining Tropical Biodiversity." 54-59pp.
Olomukoro JO, Dirisu A-R. 2014. Status and the Diversity of Macrobenthos of Udu – Ghievwen Wetlands in the Niger Delta, Nigeria. J of Nat Sci Res. 4(18): 1-6.
Olomukoro JO, Anani OA. 2019. Evaluation of aquatic macro-invertebrate populations: a model for emergent bio-monitoring guide for quantifying uncleanness of some Rivers in Northern Central Nigeria. NJTR. 14(2): 54-62. doi: 10.4314/njtr.v14i2.7
Pennak RW. 1978. Freshwater invertebrates of the United States. Press 2nd Edn. John and Sons, 18: 803. doi: 10.4319/lo.1980.25.2.0383a
Ramsar Convention Secretariat (RCS) 2007. Wise use of wetlands: a conceptual framework for the wise use of wetlands. Ramsar handbooks for the wise use of wetlands. 3rd edn. Ramsar Convention Secretariat Gland, Switzerland.
Silva G, Costa J, De Almeida T, Costa M. 2006. Structure and dynamics of a benthic invert community in an intertidal area of the Tagus Estuary, Western Portugal: A six year data series. Hydrobiologica 555(1):115 – 128. doi: 10.1007/1-4020-46972-9 10
Slack KV, Nauman JW, Tilley LJ. 1979. Benthic invertebrates in a North flowing stream, Brooks Range, Alaska. Water Res Bull. 15(1):108 – 135. doi:10.1111/j.1752-1688.1979.tb00293.x
Spyra A. 2017. Acidic, neutral and alkaline forest ponds as a landscape element affecting the biodiversity of freshwater snails. Sci Nat. 104:73. doi: 10.1007/s00114-017-1495-z
Stenert C, Maltchik L. 2007. Influence of area, altitude and hydroperiod on macroinvertebrate communities in southern Brazil Wetlands. Marine and Freshwater Res. (58):993-1001. doi: 10.1071/mf07073
Stickle WB, Carrington E, Hayford H. 2017. Seasonal changes in the thermal regime and gastropod tolerance to temperature and desiccation stress in the rocky intertidal zone. J. Exp. Mar. Biol. 488: 83–91. doi: 10.1016/j.jembe/.2016.12.006
Uwadiae RE. 2013. Spatial patterns in diversity and distribution of benthic molluscs in a weak tidal tropical lagoon. Inter. J. of Mar. Sci. 3(14):111-120. doi: 10.5376/ijms.2013.03.0014
Verberk WCEP, Leuven RSEW, Van der Velde G, Gaber F. 2018. Thermal limits in native and alien freshwater precarid Crustacea: the role of habitat use and oxygen limitation. Funct. Zool. 32 (4):926-936. doi:10.1111/1365-2435.13050.
Victor R, Ogbeibu AE. 1985. Macrobenthic invertebrates of a stream flowing through farmlands in southern Nigeria. Env Pollut Series. A, 39:337-349. doi: 10.1016/0143-1471(85)90114-x
Xu M, Wang Z, Duan X, Pan B. 2014. Effects of pollution on macroinvertebrates and water quality bio-assessment. *Hydrobiologia*. 729:247–259. doi: 10.1007/s10750-013-1504-y