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Multivariate assessment of a creek subjected to ecological disturbances: impact of sand dredging on zooplankton

Abstract

In the present study, water samples were collected across the three observation stations (Stations 1, 2 and 3) while plankton samples were extracted from the water surface at the stations using net plankton. Identification and enumeration were carried out under a binocular compound microscope with model XSZ-701A(N). Statistical multivariate techniques were employed to assess the effect of sand dredging on the marine ecosystem. The study revealed a significant difference between the minimum and maximum values for total dissolved solids (TDS), temperature, dissolved oxygen (DO) and water conductivity. Although, zooplankton abundance showed inverse relationship with water salinity (r=-0.090), TDS (r=-0.108), and pH (r=-0.162) which is poorly negatively correlated while transparency (r=-0.497) is moderately negatively correlated. However, zooplankton showed direct relationship with water temperature (r=0.012), DO (r = 0.075), BOD (r=0.110), flowrate (r=0.450) and conductivity (r=0.484). Similarly, station 2 showed inverse and significant relationship with TDS (r= -0.821), salinity (r=-0.669) pH (r=-0.659). Meanwhile, the water physicochemical parameters like Conductivity (r=0.484) and flow rate (r=0.450) are moderately and positively correlated. Additionally, a significant impact was observed at station 3, which caused a temporal effect on station 2 from January to April because the river flows from station 3 through station 2 to station 1. Thus, the deleterious effects on the creek as a result of dredged-material deposition need to be reduced to meet the recommended environmental guidelines, and consequently avert heavy remedial costs.

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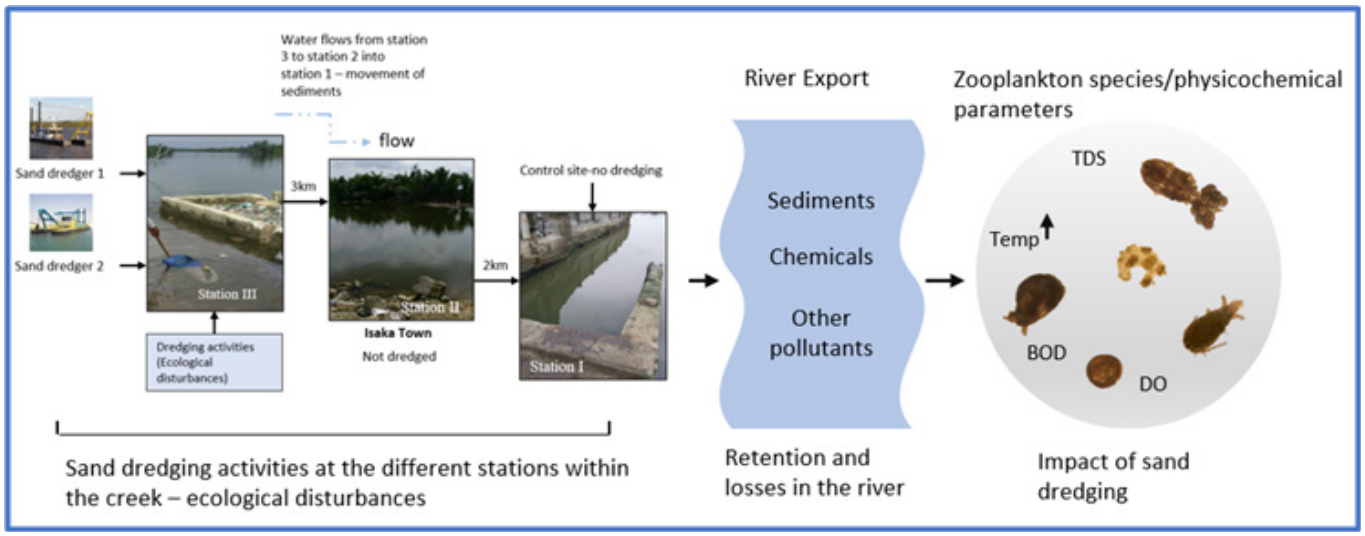
Graphical abstract



Keywords multivariate technique, zooplankton, surface water characteristics, creek, ecological disturbances

Introduction

Frequent ecological disturbances from expanding anthropogenic activities such as sand dredging have made the marine ecosystems among the most endangered habitats globally. Ecological impacts stemming from the dredging of susceptible environments cause injuries to flora and fauna, topographic and hydrological modifications combined with damage of quality of surrounding water. Zooplankton, phytoplankton, benthic invertebrates and vegetation are other elements of the aquatic environment disturbed by dredging activities. Zooplanktons are biological pointers which help to ascertain water quality status and extent of contamination, because they are influenced by environmental alterations and respond swiftly to modifications in locality quality (Gannon and Stemberger,

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1978). According to Gannon and Stemberger (1978), rotifers serve as water quality indicators, because they exhibit higher sensitivity to environmental changes relative to other zooplankton groups. When compared to other zooplankton groups, they are plentiful and usually abound in eutrophic freshwater habitat (Herzig, 1987). Reports from several authors revealed the importance of zooplankton in the efficacy of self-cleaning processes (Deksne, 2011). Sharma et al. (2010) stated that, zooplanktons are essential link in the conversion of energy from producers to consumers. They play a vital role as efficient filter feeders as a source of food for other invertebrates, fish larvae and fish (Deksne, 2011). However, the mechanism underlying variability in species composition and geographical distributions of zooplankton biodiversity are complex in water bodies. Some research findings indicate that the dispersal capacity of organisms define local community structure, while others demonstrated that local environmental factors, such as water temperature, pH, salinity, trophic state or combinations of these factors were responsible for establishing species sorting. Additionally, environmental factors are imperative for shaping community structure when dispersal rates are at the basic level. Similarly, the socio-economic functions of coastal environments are also often hampered by dredging operations as well thus creating ecosystem imbalance.

Therefore, examining the dynamics concerning the impacts of dredging is essential as well as to project its long-term physical and chemical stability. This could be realized by considering the results of the surface water quality parameters gathered in pre-dredging and dredging phases. However, a more inclusive phase should be a post-dredging phase, to ascertain the recuperative capability of aquatic environments and surrounding coastal regions to their natural state after dredging activities.

The incessant sand dredging operations along the waterways of Nigeria's Niger-Delta region has resulted in pollution of the surface water, causing a reduction in the yield of several kinds of seafood like fishes and other aquatic organisms.[1] The Isaka Creek is one of the vital coastal areas around the Isaka waterfront characterized by several years of sand wining using mechanical dredging operations. However, over the years dredging of the Creek has been a profit-oriented activity with a detrimental consequence on the environment. Impacts are the destruction of wetlands and mangrove swamps, incessant water turbidity, the departure of certain phytoplankton and zooplankton, including several species of macro-benthos which ultimately affect aquatic life.[2]

Therefore, this study seeks to evaluate the characteristics of a creek subjected to ecological disturbances to ascertain the impact of dredging on Zooplankton using multivariate techniques.

Material and experimental procedure

Study area and sampling sites

The present study was carried out around the Isaka creek which lies between N 4°45'12.039" and N 7°0'29.952" off the bonny River channel. It is an industrial area that is surrounded by four communities. The creek channel serves as a means for transportation, discharge of industrial wastes and artisanal fishing and fishing communities. The creek is characterized by swamps and marshes, it is a water lodged environment which is gradually being reclaimed as a result of dredging, and the vegetation present in the area is the white mangrove *Lagunculariaracemosa* and red mangrove *Rhizophora mangle*. The direction of the surface water along the creek flows from station 3 to station 2 and finally to station 1 (no dredging activities). Station 1 is used as the control. Station 2 is like a tunnel that water flows into coming out at the other end of the road, so the river is still interconnected, it's close to residential area and there's no presence of mangrove plants.

Sampling and measurement procedure

Surface water sampling

The water samples were collected from each station both surface and sub-surface water, in a labeled sampling bottle using the plankton net at about 10–15cm below the surface against the water current. Collected samples were preserved in 2% formalin solution and taken to the laboratory for analysis. Sampling was done for 6 months to determine season variations. Measurements of water variables were carried out by handheld Multi-Parameter Water Quality Checker (WQC)-24. In-situ, measurements of physicochemical variables were carried out, such as temperature (T,°C), salinity (s, psu), pH, dissolved oxygen (DO, mgL^{-1}), total dissolved solids (TDS, mgL^{-1}) and conductivity (µS/cm) at each site and on each sampling trial. Transparency (I,m) was measured using a 20cm diameter Secchi disc and flow would be obtained from existing data (Wilson, 1999). Sampling was carried out in a month between January and June 2019. This would be carried out during the first week of each sampling month.

Zooplankton sampling

The zooplankton samples were collected at the surface layer of the three stations using net plankton. Before the sampling date, a survey of the stretch of the Isaka-creek was carried out, during which stations 1, 2 and 3 were selected to capture all the activities and environmental actions on all sites along the waterway to ascertain the condition of the river. Standard methods were adapted for the sampling of all variables throughout the study period from January to June 2019. A plankton net of mesh size 22m was used and the towing technique was adopted for zooplankton collection. A locally constructed plankton net with a long wooden handle and plastic collection bottle was used (Figure 3). The sample was collected with plastic 500mL bottles, 3 each for the different selected sampling stations and appropriately labeled. The samples were immediately preserved with drops of 10% formalin and transported to the Animal and Environmental Biology Department laboratory, University of Port Harcourt for analysis. The preserved samples were shaken well. This routine is useful and one of the simplest and cost-effective methods of preserving organisms.

The sample was allowed to settle on the laboratory workbench for about 10–15 minutes and subsequently filtered and the supernatant was agitated and collected with a plastic 2ml pipette for microscopy. The preserved samples were shaken well and examined under the light microscope to determine the general community composition of zooplankton, Identification was carried out based on the following levels the different families, species and genus. A clean grease-free glass slide and macro -plastic pipette of 2mL were used, about 0.8 ml of the water sample was placed on the microscope slide using the pipette and examined with the magnification of the microscope×10 and×40. Identification and enumeration were carried out under a binocular compound microscope with model XSZ-701A(N). The identification and characterization of the zooplankton's species were based on the descriptive keys and illustration of the authors. The zooplanktons were identified based on the careful observation of their size, shape,

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morphological feature both internal and external and platonic thing of interest. Information on the genus was made concerning the fuller description given and the photographs plus line drawings provided in the keys (Edward et al., 2010, and Taylor et al., 2007).

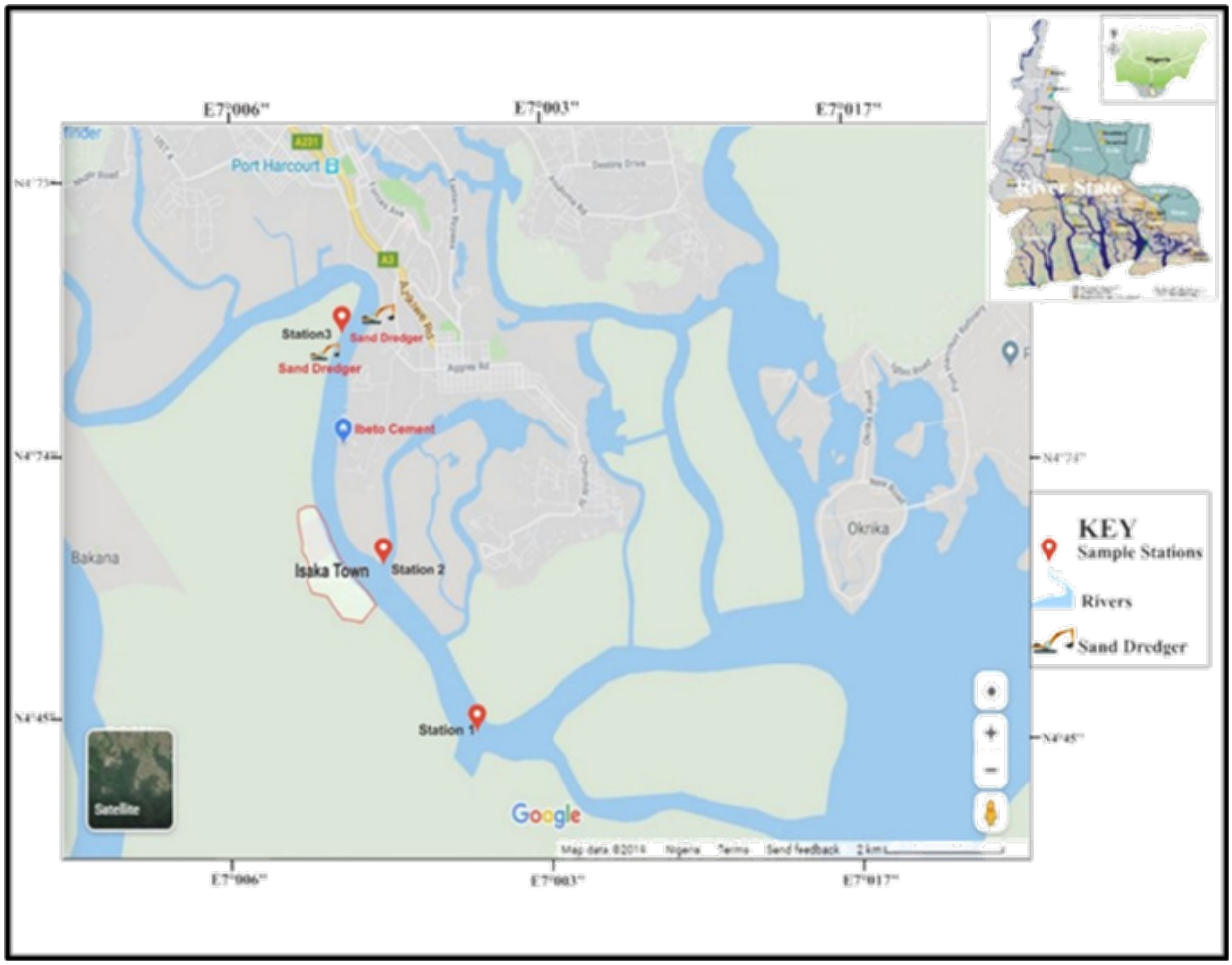

Figure 1 Map of the study area.

Multivariate techniques

Principal component analysis (PCA)

PCA as a powerful pattern recognition technique was used to identify the major possible sources of disturbances in the creek. It was employed to transform originally observed variables to new orthogonal, uncorrelated variables known as principal components (PCs) which is preserved as a linear combination of the original variables.[3] PCA reduces the dimensionality of large data sets without loss of the original variables.[4]

Cluster analysis (CA)

Similar to PCA, CA is an unsupervised pattern recognition technique used to aggregate a similar group of entities that portrays a strong internal (within-class) homogeneity and strong external (between classes) heterogeneity.[5] These spatial classes of water quality sampling sites can be illustrated using a dendrogram that measures the level of risk homogeneity through Ward's method and Euclidean distance.[6] CA is used to extract the pattern of surface water quality that can be used as a guide for future sampling.[7]

The multivariate analysis was performed in SAS JMP Pro 14, using the experimental data as input. Multivariate method was used for the PCA while clustering was applied for CA using wards linkage method in a two way-hierarchical cluster.

Zooplankton diversity index

Species diversity is the number of different species that are represented in a given community showing a dataset which includes species richness, taxonomic diversity, and/or species evenness. Taxonomic diversity is the genetic relationship between different groups of species and species evenness estimates how equal the abundances of the species are within a particular ecosystem.[8] In this study, Margalef's Diversity Index (MDI) was used to measure the diversity index. According to Uttah et al.[9] the formula for Margalef's index is given as:

$$MDI= (n-1)/\ln N \quad (1)$$

where n is the number of species, and N is the Total Abundance.

Citation: Horsfall IT, Olatunji OM, Ekiyor TH, et al. Multivariate assessment of a creek subjected to ecological disturbances: impact of sand dredging on zooplankton. *J Aquac Mar Biol.* 2020;9(5):177–189. DOI: 10.15406/jamb.2020.09.00294

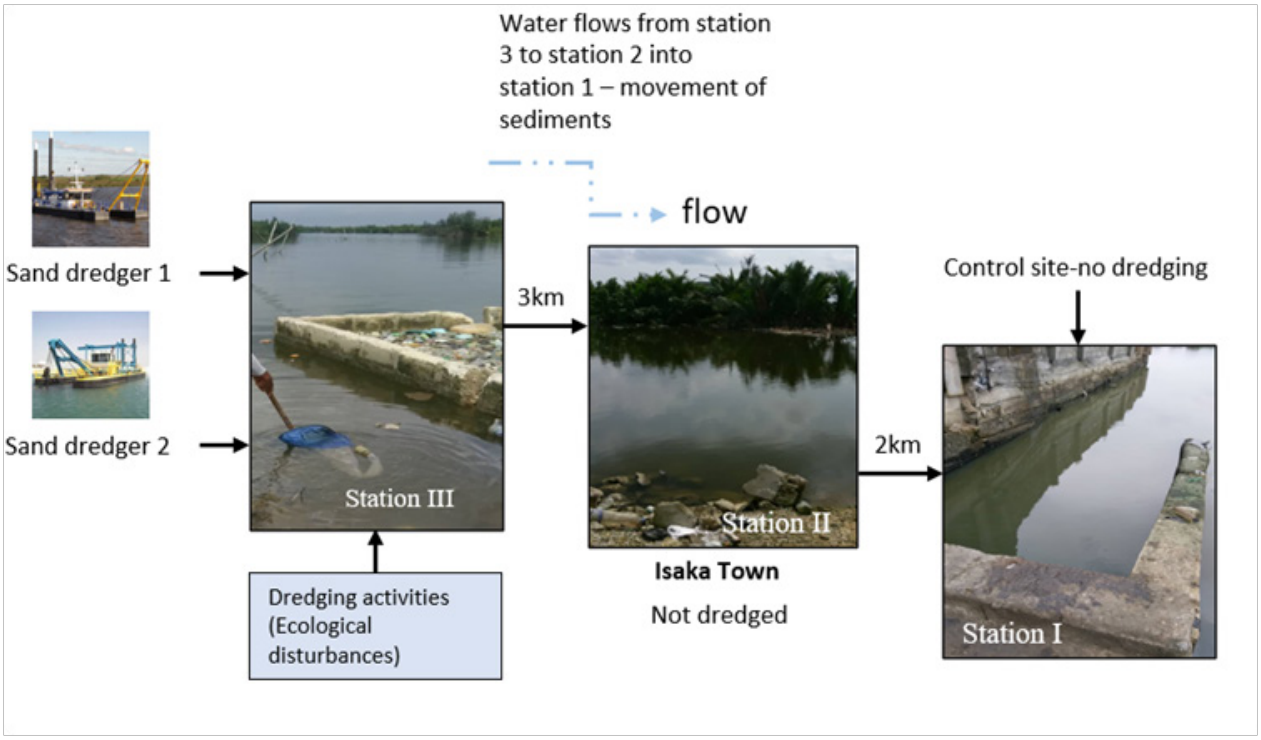

Figure 2 Showing the sampling sites; station1 (lat. 24536406.68m, long. 4524664.52m), station 2 (lat. 24535443.79m, long. 4516904.50m) the distance between station 1 and 2 is approximately 2km and 3km to station 3 (lat. 24538783.46, long. 4501248.22m).

(A) (B)

Figure 3 Showing (A) plankton net with wooden handle (B) plastic collection bottle used to contain zooplankton

Result and discussion

a. Physicochemical variables of the creek

The physicochemical variable values of the entire data sets of the creek have been summarized using descriptive statistics (Table 1).

Table 1 shows that there is significant difference between minimum and maximum values for TDS, temperature, DO and Conductivity, this indicates the difference in physico-chemical variables across the sampling periods from January to June especially for the parameters mentioned above. On other hand, no significant difference of physico-chemical parameters was observed across the sampling locations. Therefore, the changes in the water quality was observed during the different sampling period. This might be due to

ecological disturbances from sand dredging activities, or changes in rainfall patterns for temperature, TDS and pH. The variation in physico-chemical characteristics of the creek is shown in Figure 4. Station 3 showed very high BOD during the month of June, station 2 recorded significant amount of TDS in march compared to other stations, all stations showed high temperature in the month of June. These variations could be as a result of the ecological impact from the dredging activities.

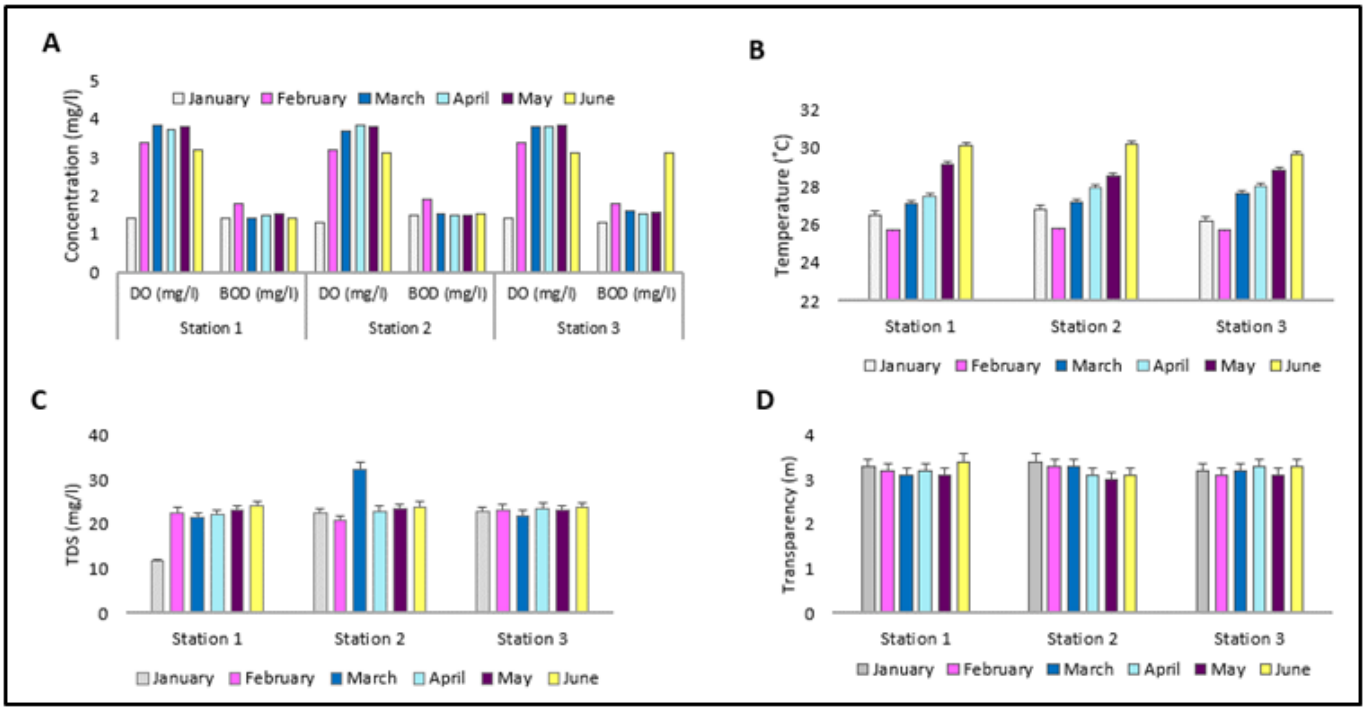

Figure 4 Variation in physicochemical characteristics of the creek among sampling stations throughout the study period

Table 1 Summary statistics of the observed water quality parameters from January – June 2019.

Parameters	Stations	Minimum	Maximum	Mean ±	SD
DO (mg/L)	1	1.40	3.82	3.23 ±	0.93
	2	1.30	3.82	3.16 ±	0.96
	3	1.40	3.82	3.23 ±	0.94
BOD (mg/L)	1	1.40	1.80	1.51 ±	0.15
	2	1.50	1.90	1.58 ±	0.16
	3	1.30	3.12	1.82 ±	0.66
Conductivity (µS/cm)	1	30.80	32.40	31.65 ±	0.62
	2	30.80	32.80	32.00 ±	0.73
	3	30.20	32.50	31.70 ±	0.86
Temperature (°C)	1	25.70	30.10	27.67 ±	1.65
	2	25.80	30.20	27.73 ±	1.52
	3	25.70	29.70	27.67 ±	1.52
TDS (mg/L)	1	11.60	24.00	20.82 ±	4.60
	2	20.9	32.30	24.32 ±	4.04
	3	21.9	23.70	23.02 ±	0.66

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Table Continued

Parameters	Stations	Minimum	Maximum	Mean ±	SD
	1	3.10	3.40	3.22 ±	0.12
Transparency (m)	2	3.00	3.40	3.20 ±	0.15
	3	3.10	3.30	3.20 ±	0.09
	1	21.0	22.9	21.90 ±	0.65
Salinity (psu)	2	20.9	22.6	21.80 ±	0.57
	3	4.90	22.4	18.82 ±	6.88
	1	6.01	7.20	6.75 ±	0.40
pH	2	6.21	7.10	6.79 ±	0.36
	3	6.22	7.20	6.79 ±	0.32

b. Zooplankton assemblages and temporal distribution patterns

In January, it was observed that station 3 showed similar bio-characteristics with station 1, while station 2 was significantly different. Again, station 1 and station 2 had similar characteristics while station 3 is slightly different in February. Again, in March and April, station 1 had a significant difference in variation of zooplankton distribution pattern when compared to station 2 and 3. However, during April, station 2 and station 3 became very alike having no significant difference in the distribution pattern of zooplankton, while in May and June it was observed that there is no significant difference between all three stations (Figure 5). This is an indication that there was no significant impact of the dredging activities between May and June. Nevertheless, the change in the Zooplankton-characteristics during the different sampling periods could be as a result of the frequency of the sand dredging as well volume of sand collected or dumping which would have led to the ecological disturbances within the creek.

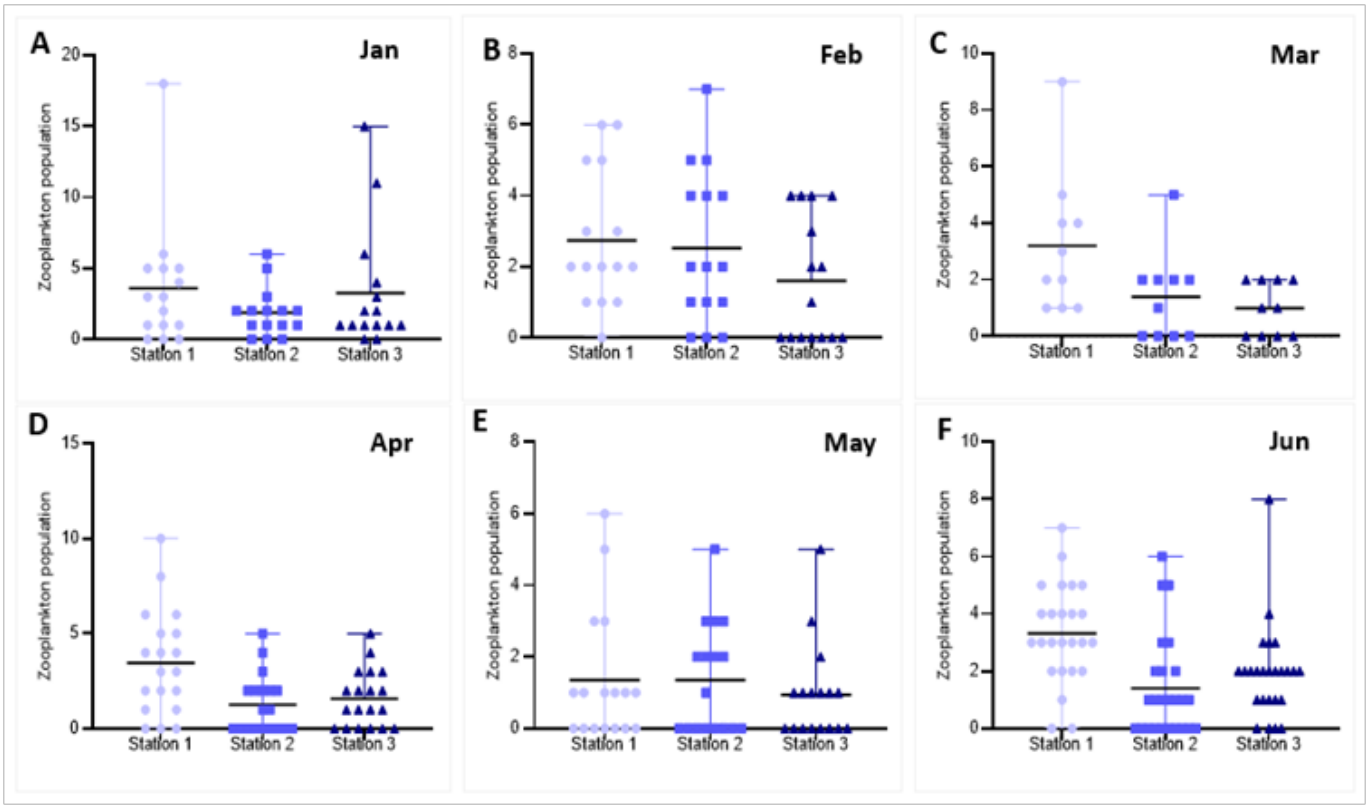


Figure 5 Zooplankton population distribution pattern during the study period

The findings in this study is similar to the report of Fan et al.[10] who applied multivariate techniques to assess river water quality.

c. **Statistical multivariate analysis**

Principal component analysis (PCA)

PCA was used to show the correlation between sampling stations and zooplankton distribution patterns, and to obtain non-correlated factors which are linear combination of the sampling stations. In Figure 6, the correlation biplots which represents the distribution of zooplankton species across the sampling stations showed positive and significant correlation between station 2 and station 3 in January (Figure 6A). Although, station 1 is positive but not significantly correlated. Since, station 1 is the control where dredging activities did not take place, there is an indication of significant impact. In February, all three stations were found to be in positive axis of the biplot (Figure 6B). However, station 1 have significant correlation, meaning there was impact in station 3 but station 2 was free from the ecological disturbances (Figure 6B). Similarly, in March, it showed positive correlation for all stations as shown in Figure 6C. This is an indication of significant impact which may be further interpreted as increased frequency of dredging activities. In April, station 1 and 2 showed slightly significant but negative correlation while station 3 is in no significant correlation with station1 or station 2 (Figure 6D). It shows that station 2 is more correlated to station 1 while station 3 has less correlation. This means that station 3 is more impacted by the sand dredging activities because it is the starting point of the dredging. Again, during May and June of the study period, a slightly significant but negative correlation was observed between station 1 and 2 and station 1 and 3 (Figure 6E). It shows that during this period no significant impact of dredging on the creek which confirms the output of the graphical analysis in Figure 5. In June stations 1 and 2 are positively correlated while station 3 is in the negative axis.

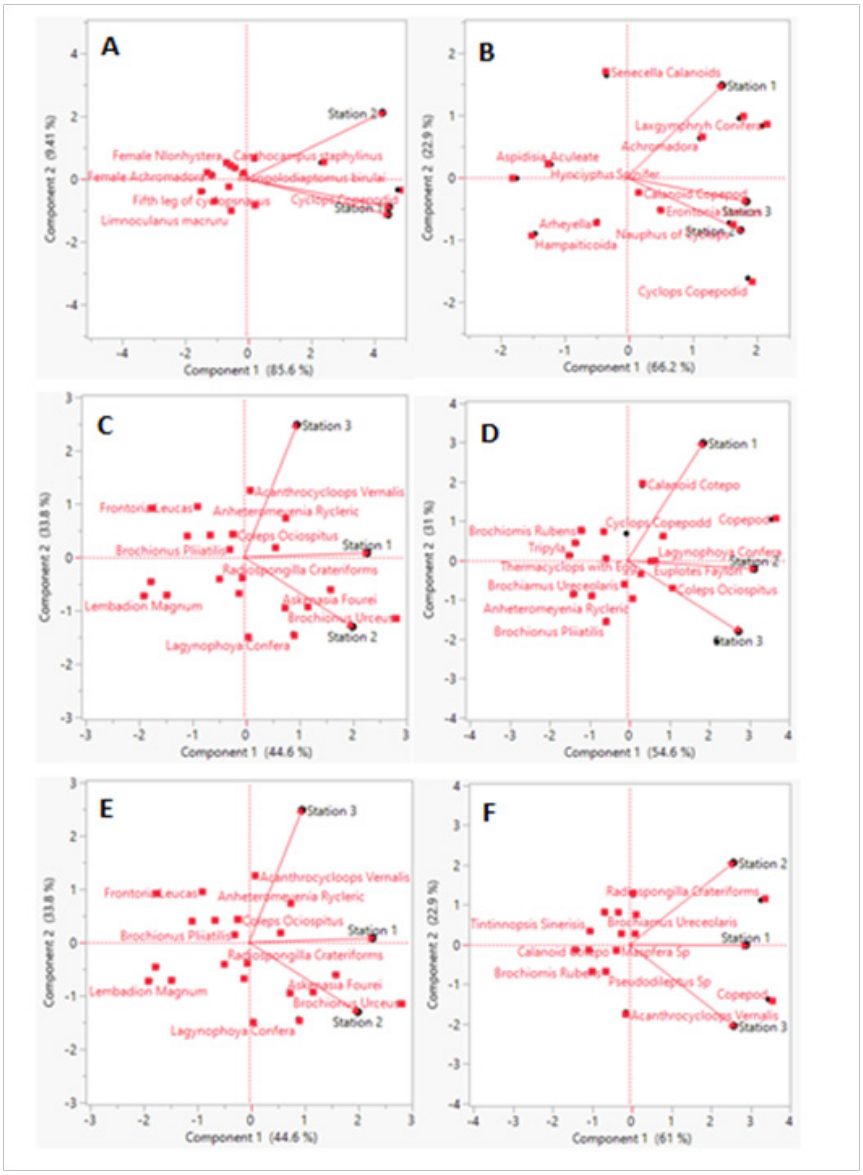
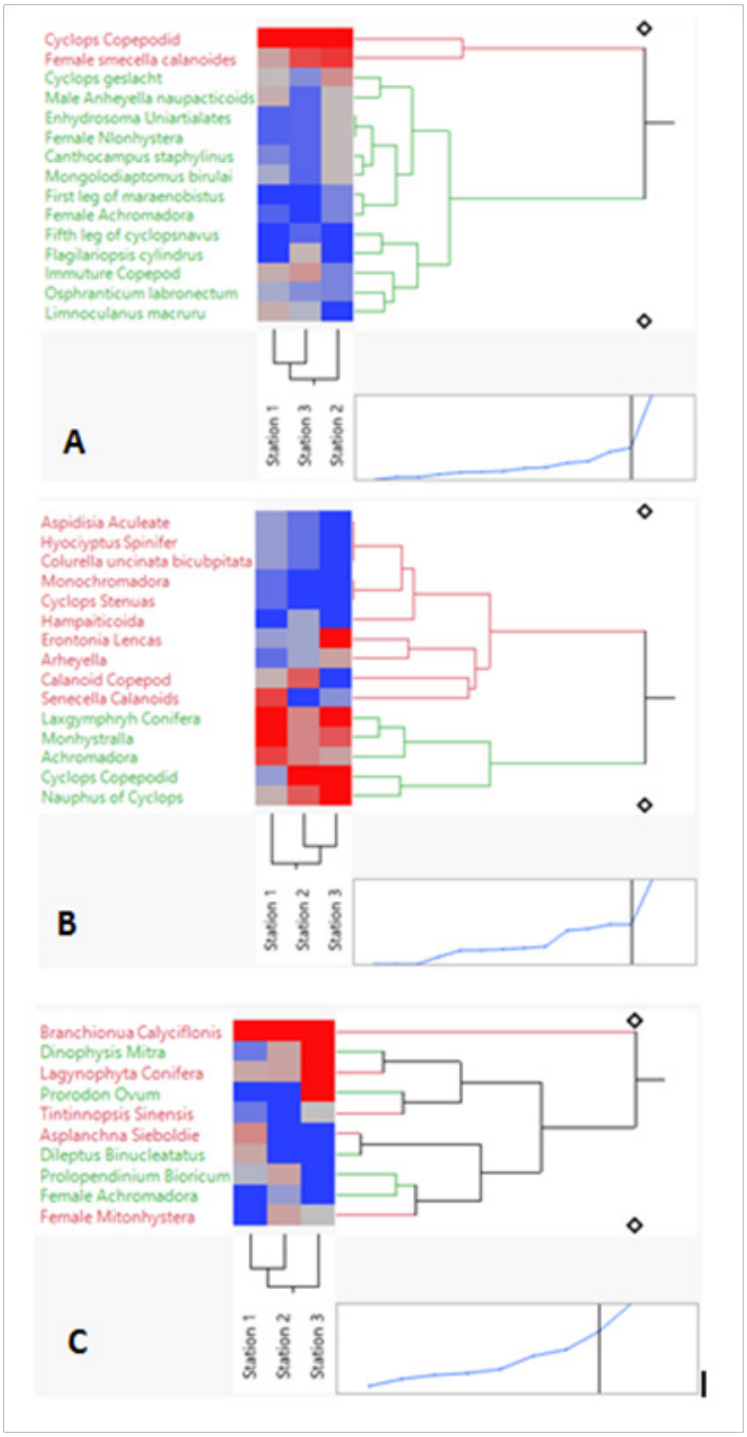


Figure 6 Biplot of principal components (A) January, (B) February, (C) March, (D): April (E) May and (F) June.

Cluster analysis (CA)

The output of the cluster analysis is given in Figures 7A – F. In the month of January, station 1 was found to be in cluster 1, while station 2 and 3 are in cluster 2 (Figure 7A). Since, station 1 is the control point, it reveals significant impact in the creek due to the deviation from the non-dredged site. Meanwhile station 2 is in same cluster with the dredged station 3 as shown in Figure 7A. Similar results were obtained in February and April (Figures 7B and D). Although, the result changed in month of March leaving station 3 in cluster 1 while station 2 and 1 are in cluster 2 (same cluster) (Figure 7C). This is an indication of very low impact in station 2 since it has same characteristics with the control station, it remained the same during May (Figure 7E). Again, in June, station 2 appeared in cluster 1 while station 1 and 3 are in cluster 2 (Figure 7F). It was observed that station 3 has low or no impact since it is in same cluster with the control station. This confirms the PCA results as shown in the biplots of Figure 6.



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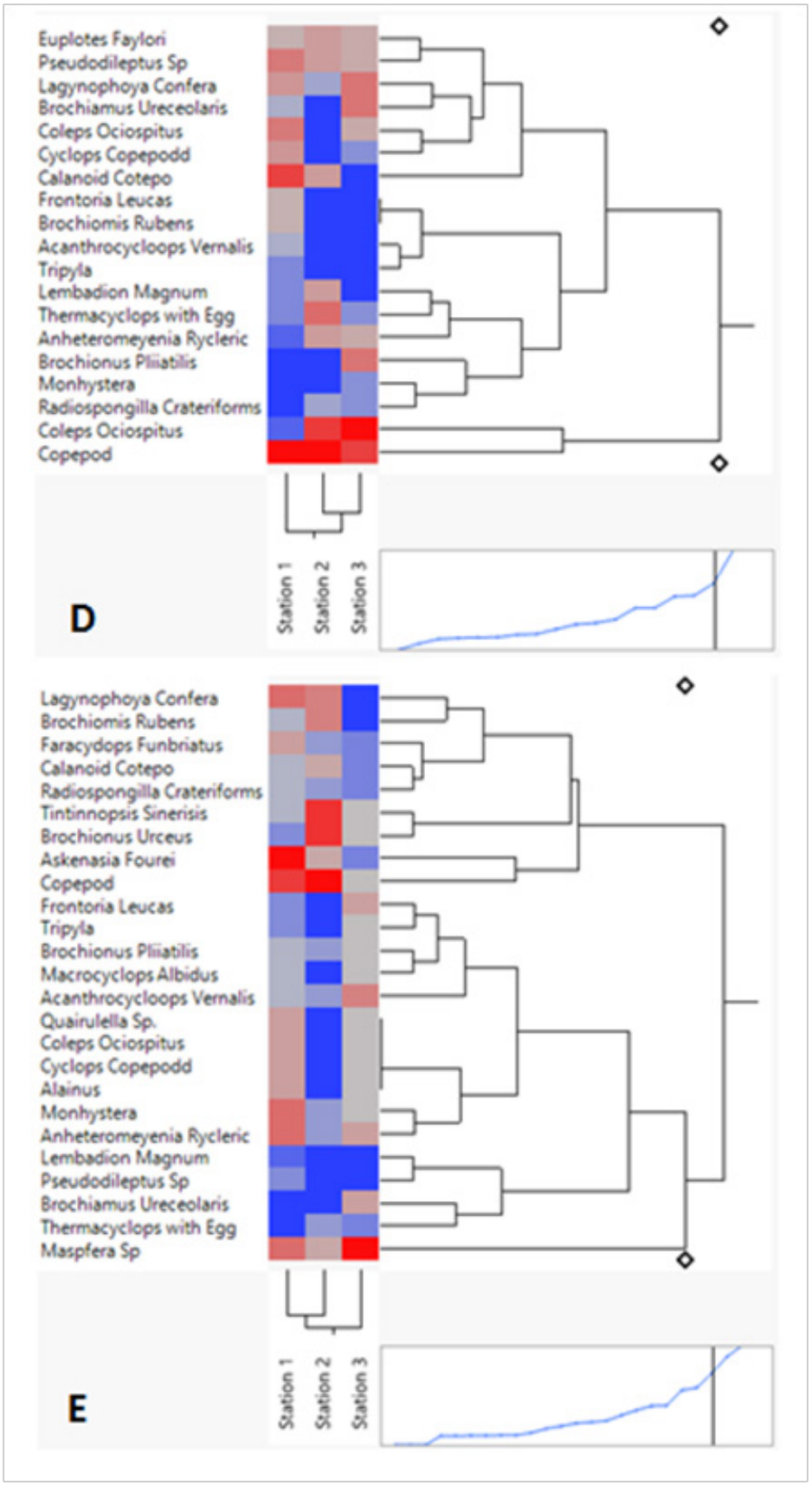

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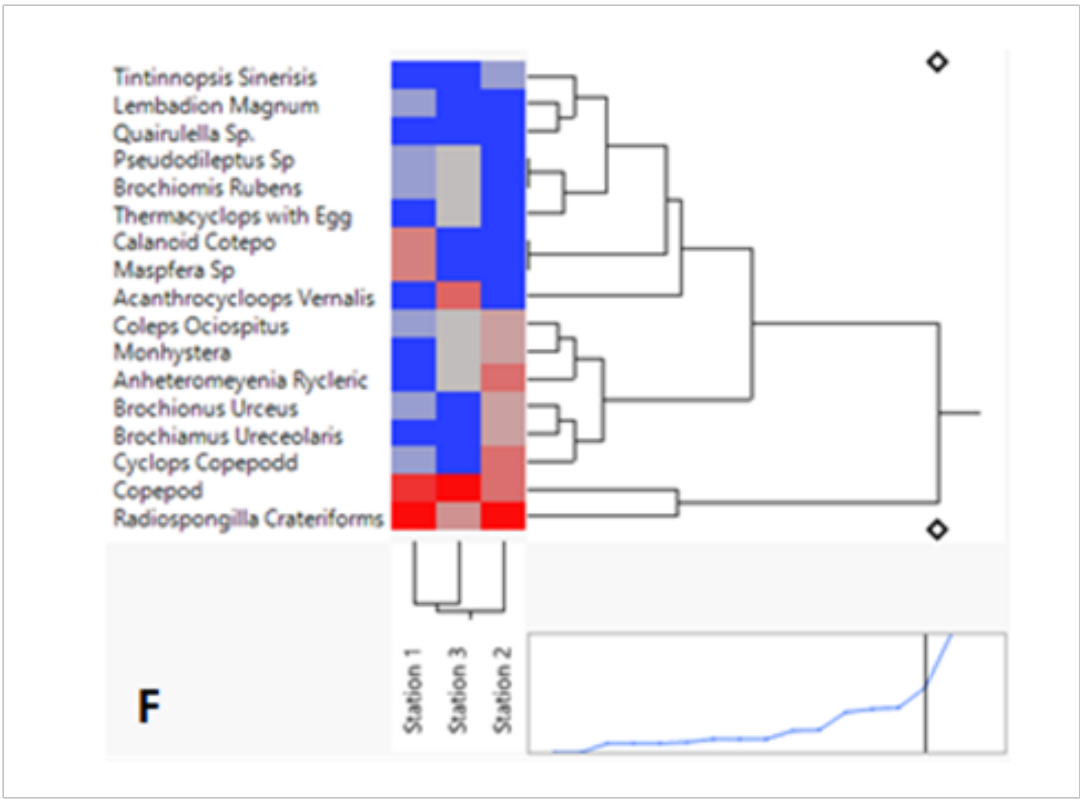

Figure 7 Showing the clusters of zooplankton components of the creek at various stations (A)January, (B) February, (C)March, (D)April (E) May and (F)June.

The findings in this study is similar to the report of Fan et al.[10] who applied multivariate techniques to assess river water quality.

c. Relationships between surface water quality parameters and zooplankton assemblages

In station 1, Zooplankton abundance showed poorly negatively correlated inverse relationship with water salinity (r=-0.090), TDS (r=-0.108) and pH (r=-0.162) while transparency (r=-0.497) was moderately negatively correlated (Table 2). This finding corroborates with the Alam and Kabir (2003) study. Again, zooplankton showed direct relationship with water temperature (r=0.012), DO (r=0.075), BOD (r=0.110), flowrate (r=0.450) and conductivity (r=0.484). Similarly, in station 2, zooplankton showed inverse and significant relationship with TDS (r=-0.821), salinity (r=-0.669) pH (r=-0.659), while temperature (r -0.294) has no significant relationship or poorly and negatively correlated (Table 3). Additionally, zooplankton population showed direct relationship with water BOD in station 2. In station 3, zooplankton abundance showed an inverse relationship with water flow rate pH (r=-0.162), TDS (r=-0.108), and salinity (r=-0.09) which is poorly and negatively correlated while transparency is moderately and negatively correlated (r=-0.497). Meanwhile, the water physicochemical parameters like conductivity (r=0.484) and flow rate (r=0.450) are moderately and positively correlated (Table 4).

In Figure 8, station 3 showed high diversity index during April and May, followed by station 1 and then station 2. However, the highest diversity index was found in station 3 during May. This indicates that station 3 has more species in May followed by station 1 and then station 2. The species decreased as the river flows from station 3 down through station 2 to station 1. The number species across stations decreased significantly in March and increased in May, this might be due to the frequency of the dredging activities showing the standard error bar (Figure 8). However, station 2 showed the lowest number of species throughout the sampling period.

Zooplankton indicators showed negative associations with some surface water parameters, for which the values decreased with increasing water quality and vice versa. Thus, at the level of the observation point, all bioindicators form the various stations yielded consistent results on water quality. All three stations showed a consistent assessment of water quality at the level of observation point also regarding variation, although not with 95% statistical support for all pairs of bioindicators as in the correlation analysis (Tables 3–4). Hence, our results showed differing patterns of covariation among the bioindicators (zooplanktons) depending on the sampling period and station. This finding is consistent with the report of Havel and Shurin[11] on species diversity.

It is well-known that, bioindicators like zooplankton respond to multiple pressures ranging from local point source impacts to larger-scale regional effects, revealing the environmental conditions they are exposed to.[12] However, this study did not consider species sorting or grouping in terms of classification of zooplanktons.[13–21]

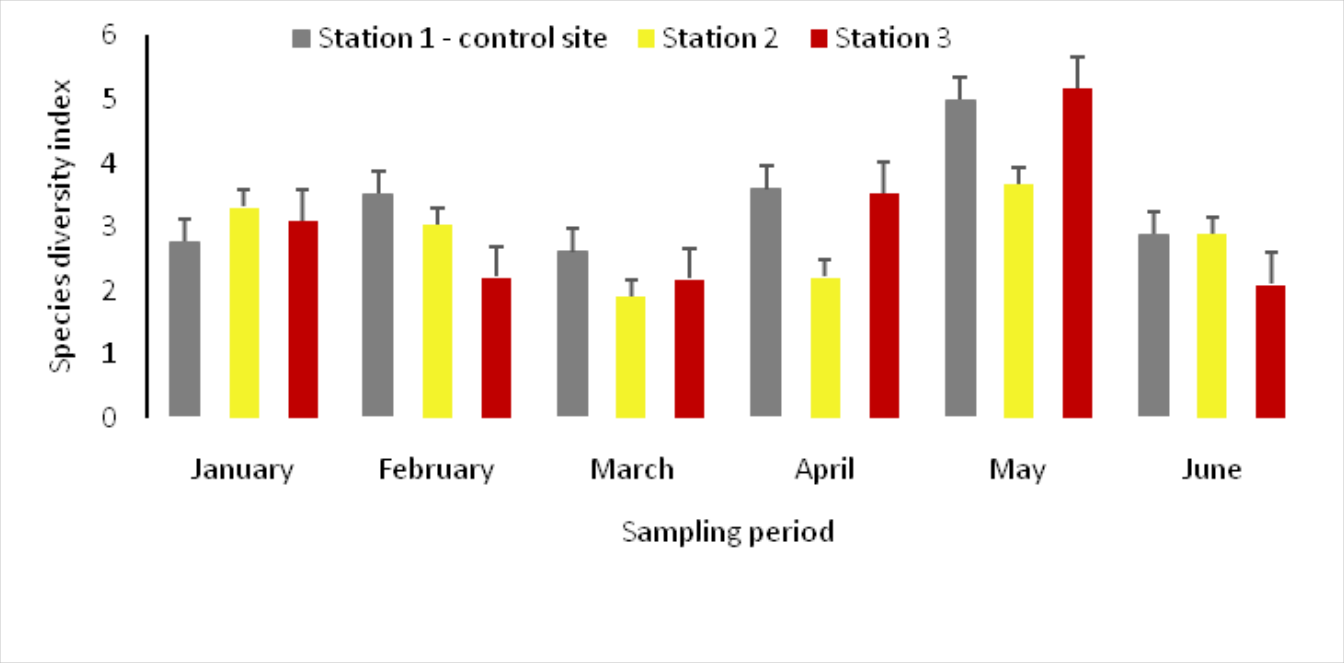

Figure 8 Showing the species diversity across sampling locations and period.

Table 2 Correlation matrix of zooplankton component (zooplankton) on physicochemical characteristics of the creek at station 1 during the study period

STATION 1	Net Zooplankton Abundance	pH	Temperature (˚C)	DO (mg/L)	BOD (mg/L)	Conductivity (µ/cm)	Salinity (ppm)	Transparency (m)	Flow rate (m/s^3)
pH	-0.162	1.00							
Temperature (˚C)	0.012	0.702	1.00						
DO (mg/L)	0.075	-0.050	0.282	1.00					
BOD (mg/L)	0.110	-0.931	-0.503	0.273	1.00				
Conductivity (µ/cm)	0.484	-0.442	-0.150	0.736	0.617	1.00			
Salinity (ppm)	-0.090	0.658	0.063	-0.717	-0.795	-0.683	1.00		
Transparency (m)	-0.497	0.363	0.294	-0.559	-0.261	-0.591	0.497	1.00	
Flow rate (m/s^3)	0.450	0.409	0.757	0.425	-0.141	0.406	-0.106	0.102	1.00
TDS (mg/L)	-0.108	-0.018	0.467	0.913	0.318	0.598	-0.736	-0.217	0.530

Table 3 Correlation matrix of zooplankton component (zooplankton) on physicochemical characteristics of the creek at station 2 during the study period

STATION 2	Net Zooplankton Abundance	pH	Temperature (˚C)	DO (mg/L)	BOD (mg/L)	Conductivity (µ/cm)	Salinity (ppm)	Transparency (m)	Flow rate (m/s^3)
pH	-0.659	1.00							
Temperature (˚C)	-0.294	0.423	1.00						
DO (mg/L)	-0.120	-0.335	0.254	1.00					
BOD (mg/L)	0.574	-0.774	-0.563	0.026	1.00				
Conductivity (µ/cm)	-0.154	-0.303	-0.153	0.857	0.250	1.00			
Salinity (ppm)	-0.669	0.652	0.390	-0.239	-0.188	-0.141	1.00		
Transparency (m)	-0.133	0.043	-0.721	-0.679	0.314	-0.301	0.228	1.00	
Flow rate (m/s^3)	0.009	0.249	0.904	0.383	-0.348	0.036	0.206	-0.870	1.00
TDS (mg/L)	-0.821	0.180	0.067	0.311	-0.373	0.267	0.244	0.147	-0.259

Table 4 Correlation matrix of zooplankton component (zooplankton) on physicochemical characteristics of the creek at station 3 during the study period

STATION 3	Net Zooplankton Abundance	pH	Temperature (˚C)	DO (mg/L)	BOD (mg/L)	Conductivity (µ/cm)	Salinity (ppm)	Transparency (m)	Flow rate (m/s^3)
pH	-0.162	1.00							
Temperature (˚C)	0.012	0.702	1.00						
DO (mg/L)	0.075	-0.050	0.282	1.00					
BOD (mg/L)	0.110	-0.931	-0.503	0.273	1.00				
Conductivity (µ/cm)	0.484	-0.442	-0.150	0.736	0.617	1.00			
Salinity (ppm)	-0.090	0.658	0.063	-0.717	-0.795	-0.683	1.00		
Transparency (m)	-0.497	0.363	0.294	-0.559	-0.261	-0.591	0.497	1.00	
Flow rate (m/s^3)	0.450	0.409	0.757	0.425	-0.141	0.406	-0.106	0.102	1.00
TDS (mg/L)	-0.108	-0.018	0.467	0.913	0.318	0.598	-0.736	-0.217	0.530

Conclusion

To determine the impact of sand dredging in a creek, we studied zooplankton dispersal as well as the water characteristics, their correlation and identified factors influencing zooplankton composition and abundance under a unique in situ environment with water flowing from station 3 (dredging site) through station 2 to station 1 (control site). The study reveals that zooplankton abundance and community composition are substantially different among the three connected stations. Since most studies on dispersal and influence of local factors on zooplankton in new environments have been done largely in temporary ponds, the findings provide unique insights on how zooplankton communities are jointly regulated by their species dispersal origins and local environmental factors in creeks. A significant change in the distribution of zooplankton population was observed in station 3 in February, March, April and slightly significant in station 2 in January, April and June. This may be attributed to sand dredging activities since station 3 is the dredged site and other factors such as seasonal variation, discharge of industrial waste etc. Although, zooplankton characteristic within stations did not show any significant difference in May and June (i.e. comparing the control site – station 1 with 2 and 3). Consequently, some effects resulting from this sand dredging operation include the destruction of wetlands and mangrove swamps, continual turbid appearance of water-body, disappearance of certain zooplankton which ultimately affects other aquatic life.

Hence, we suggest that future dredging activities, regarding the frequency and volume of sand should keep the coverage of zooplanktons as far as possible within the tolerable limits of the natural processes of sediment movements.

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Conflict of interest

None.

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