Spatial and Seasonal Dynamics of Benthic Microalgae and Phytoplankton in the Upper Bonny Estuary in Relation to Jetty Operations

***[1,2]Erema R. Daka, [1]Calista A. Miebaka, [1]Hason Uyi, & [1]Anwaini Osuampke**
[1]Institute of Pollution Studies,
Rivers State University, Nkpolu-Oroworukwo,
Port Harcourt, Nigeria
[2]Department of Animal and Environmental Biology,
Rivers State University, Nkpolu-Oroworukwo,
Port Harcourt, Nigeria
*daka.erema@ust.edu.ng

Abstract
Epipelic algae and phytoplankton were studied in the upper Bonny estuary to determine the effects of jetty operations on population and community indices. Samples were collected in the wet (September, 2018) and dry (December, 2018) seasons from five stations, four of which are proximal to Jetty operations (Stn 1, Stn 2, Stn 4 & Stn 5) and a Control (Stn 3 remote from jetty operations). Five replicates each of phytoplankton and epipelic algae were collected from each station and processed for identification and enumeration of component algal flora. Community indices such as Margalef richness (d), Shannon-Weiner diversity (H'), Pielou evenness (J') and Simpson dominance (λ) were calculated. Analysis of Variance (ANOVA) was used to test for significant differences between stations and seasons. The diatoms (bacillariophyceae) were the sole algal group recorded. The number of epipelic algae species recorded in the wet season (range 6 species at Stn 1 to 8 at Stns 2, 3 and 4 were significantly higher than those of the dry season (2-3) ($p<0.001$); there was also significant difference between stations ($p=0.023$) with Tukey tests showing Stn 4=Stn 3=Stn 2 (> Stn 1) =Stn 5; Stn =Stn 1. The density of epipelic algae ranged from 2 x 10^2 cells/cm^2 at Stn 1 in the dry season to 59 x 10^2 cells/cm^2 at Stn 4 in the wet season, but there was no significant difference between stations, seasons or stations. There were also no significant spatial differences in the values of Margalef, Shannon-Weiner diversity, Pielou evenness and Simpson dominance indices. The number of phytoplankton species observed ranged from 4 at Stn 4 to 8 at Stn 2, while the density values ranged from 8 x 10^2 cells/L at Stn 2 in the wet season to 71 at Stn 5 in the dry season. Neither of these showed significant differences between stations nor seasons. Similarly, none of the community indices showed had significant differences between stations or seasons. The most abundant species observed in the phytoplankton and epipelic alage species (Navicula spp, Nitzschia spp and Synedra spp) are known to be indicators of pollution. The mean values of epipelic algal and phytoplankton population and community indices at the control station did not stand out significantly for any of the indices. It is concluded that other factors - natural (in terms of upstream-downstream dilution) and anthropogenic inputs contributed more than jetty operations to the communities of epipelic algae and phytoplankton in the upper Bonny Estuary.

Keywords: *Phytoplankton; Epipelic algae; Bonny Estuary. Jetty, Niger Delta*

Introduction

Plankton constitutes the primary producers of the aquatic food chain. Epipelic algae are the major group of photoautotrophic organisms inhabiting intertidal sediments in estuaries and free living on submerged sediment (Underwood *et al.*, 2010); they serve as available food base for many invertebrates (Kara and Sahin, 2000). Any variation in the water quality affects their abundance, species composition and diversity, stability, productivity and physiological condition. The communities of phytoplankton and epipelic algae play important roles as primary producers in aquatic ecosystems. The distributions, abundance, species diversity, species composition of the phytoplankton are used to assess the biological integrity of the water body (Townsend *et al*., 2000; Abowei *et al*., 2012).

The Bonny estuary is a mangrove swamp with similar species to those found in the rest of the estuarine portion of the Niger Delta. It is a busy transport route for vessels and the presence of a number of industries such as petroleum refinery, petrochemical industries, tire industries, bottling companies and other oil and gas companies sited along or close to the banks of the estuary exposes it to a range of pressures, some of which are capable of inducing environmental stress (Ekweozor *et al*., 2004). Previous studies of phytoplankton and epipelic algae include Chindah and Pudo (1991) in Bonny River, Erondu and Chindah (1991) in the New Calabar River, Ogamba *et al*., (2004) in Elechi Creek, Ekeh 2010 in Azuabie Creek, Davies and Ugwumba, (2013) in upper Bonny Estuary covering an area that includes Azuabie Creek and Okpoka Creek, Ejiowhor *et al.* (2018) in Okpoka Creek. None of the above studies focused on the influence of logistics activities at jetties on the populations. Daka *et al.* (2019) have evaluated the effects of jetty operations in the upper Bonny estuary on the water quality variables of surface water and zooplankton. In this paper, we report the spatial and seasonal distribution of phytoplankton and microbenthic (epipelic) algae in the upper Bonny Estuary in relation to jetty operations.

Materials and Methods

Study Sites

Four jetties in the upper Bonny Estuary with different levels of activity, and a control location were selected for this study. The sampling sites were: Stn 1- NNPC Refinery petroleum products loading jetty (N 4.72372°, E 7.08389°); Stn 2 – ATC Okrika passenger Jetty (N 4.74278°, E 7.70372°); Stn 3- Kalio George-Ama axis (presumed Control with no jetty activity)(N 4.75488°, E 7.06971°); Stn 4 – Abuloma passenger jetty and logistics bases for some companies(N 4.77000°, E 7.06002°); Stn 5- Marine Base passenger jetty (N 4.77001°, E 7.03051°) (Fig.1). Details of spatial and seasonal characterization of physicochemical parameters and concentration of nutrients (nitrate) and total hydrocarbon content in these study stations are published elsewhere (Daka *et al*., 2019).

Sample Collection and Analyses

Samples were collected in September 2018 for wet season and December 2018 for dry season. Five replicates of phytoplankton samples were collected using the screen method (APHA. 1999). Composite of 1L water sample were collected and preserved immediately with 5% formaldehyde-brackish water solution. In the laboratory, samples were allowed to stand for a few days for the organisms to settle, following which the supernatant was siphoned off to reduce the samples to volume of 50 ml. After a thorough agitation and homogenization, 1 ml sub-samples were taken using a Pasteur pipette and transferred to a Bogorov counting chamber for observation under a binocular compound microscope. The organisms were simultaneously identified and enumerated with the aid of a binocular microscope using appropriate keys (Newell and Newell, 1977; Durand and Leveque, 1980; Suthers, 2008).

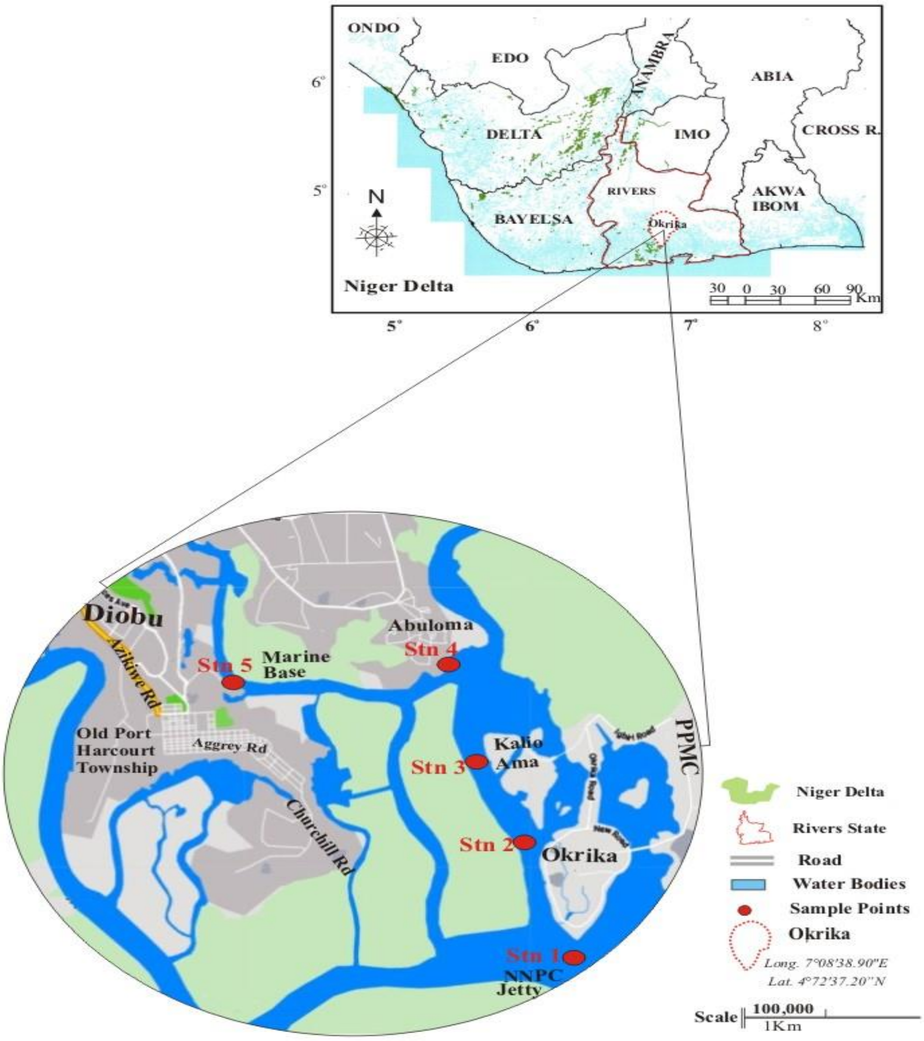

Fig 1: Map of study area showing sampling locations

Data Analysis

A number of statistics were used as measures of the attributes of community structure of the, zooplankton samples. These include measures of species richness (Margalef, d) diversity (Shannon-Weiner H') and equitability (Pielou, J') and dominance (Simpson λ). The formulae for the calculation of the various indices are as follows (Pielou, 1975, Heip *et al*., 1988, Magurran, 1991):

Margalef index: $d = (S-1) / \log N$
Shannon-Weiner Index: $H' = -\Sigma_i p_i \log(p_i)$
Pielou Evenness: $J' = H'/H'_{max} = H' / \log S$
Simpson Index: $\lambda = \Sigma pi^2$

These were computed using the Plymouth Routines of Multivariate Experimental Research (PRIMER) software.

Analysis of Variance (AN1OVA) was used to test for significant spatial and seasonal differences in physicochemical parameters and faunal indices. Tukey tests were applied for pair-wise comparisons between stations, where ANOVA gave a significant difference.

Results and Discussion

A total of eight genera of diatoms (bacillariopyceae) were recorded in the epipelic alge (Table 1). Four of these (*Fragilaria* spp, *Synedra* spp, *Surirella* spp and *Thallasiothrix* spp) were recorded only in the dry seasons; while the others were observed in both wet and dry seasons are presented in Figure 2. The lowest and highest densities of *Navicula* spp were observed at Stn 3 and Stn 5 respectively (Fig. 2A). There were significant spatial and seasonal variations in density of *Navicula* spp as well as significant interaction (Table 2). Tukey tests showed Stn 4 > 2 = 5 = 3 = 1); the interaction was given by a non-significant difference in mean dry season value of Stn 4 and other station/season comparisons. *Nitszchia* spp was recorded at all stations in both seasons with mean densities ranging from 0.8 x 10^2 cells/cm^2 at St 1in the wet season to 19.1 8 x 10^2 cells/cm^2 in the dry season at Stn 4 (Fig 2B). ANOVA showed significant difference between sites with Tukey tests indicating Stn 5=Stn 1=Stn=Stn3, but Stn 5> Stn 4, Stn 2. However, there was no significant difference between seasons (p=0708). *Pleurosigma* spp was recorded in the dry season only at Stn 2 which also had the lowest mean density in the wet season, while the highest mean density was at Stn 5 (Fig. 2C). There was no significant difference between sites (p=0234). The lowest mean value of *Coscinodiscus* spp was recorded at Stn 1 in dry season, while the highest was at Stn 4 in the wet season (Fig 2D). There were significant differences between stations, seasons (wet>dry) and interaction. Tukey tests showed Stn 4 = Stn 5 = Stn 3; Stn 4>Stn 1=Stn 2.

The number of epipelic algae species recorded in the wet season (range 6 species at Stn 1 to 8 at Stns 2, 3 and 4) (Fig. 3A) were significantly higher than those of the dry season (2-3) ($p<0.001$, Table 3); there was also significant difference between stations ($p=0.023$) with Tukey tests showing Stn 4=Stn 3=Stn 2 (> Stn 1) =Stn 5; Stn =Stn 1. The density of epipelic algae ranged from 2 x 10^2 cells/cm^2 at Stn 1 in the dry season to 59 x 10^2 cells/cm^2 at Stn 4 in the wet season (Fig. 3B), but there was no significant difference between stations seasons or stations (Table 3). There were also no significant spatial differences in the values of Margalef (Fig. 3C), Shannon-Weiner diversity (Fig. 3D, Pielou evenness (Fig. 3E) and Simpson dominance (Fig. 3F) indices. There were, however, significant seasonal differences in Shannon-Weiner and Simpson indices (Table 3). The K-dominance curves (Fig. 4) also show the seasonality in the cumulative dominance of species. The correlation coefficients between water quality variables and epipelic population and community indices were only significant ($p<0.05$) between pH: No of species/Shannon-Weiner/Simpson (Table 4). All the indices were had negative correlations with THC but none was significant.

Table 1: Checklist showing spatial and seasonal composition of epipelic algae in the study area

Taxa	St 1		St 2		St 3		St 4		St 5	
	WS	DS	WS	DS	WS	DS	WS	DS	WS	DS
Bacillariophycae										
Navicula spp	+	-	+	+	+	+	+	+	+	-
Nitszchia spp	+	+	+	+	+	+	+	+	+	+
Pleurosigma spp	+	-	+	+	+	-	+	-	+	-
Coscinodiscus spp	+	+	+	-	+	+	+	+	+	+
Fragilaria spp	-		+		+		+		+	-
Synedra spp	+		+		+		+		+	-
Surirella spp	-		+		+		+		-	-
Thallasiothrix spp	+		+		+		+		+	-

WS = Wet Season; DS = Dry Season

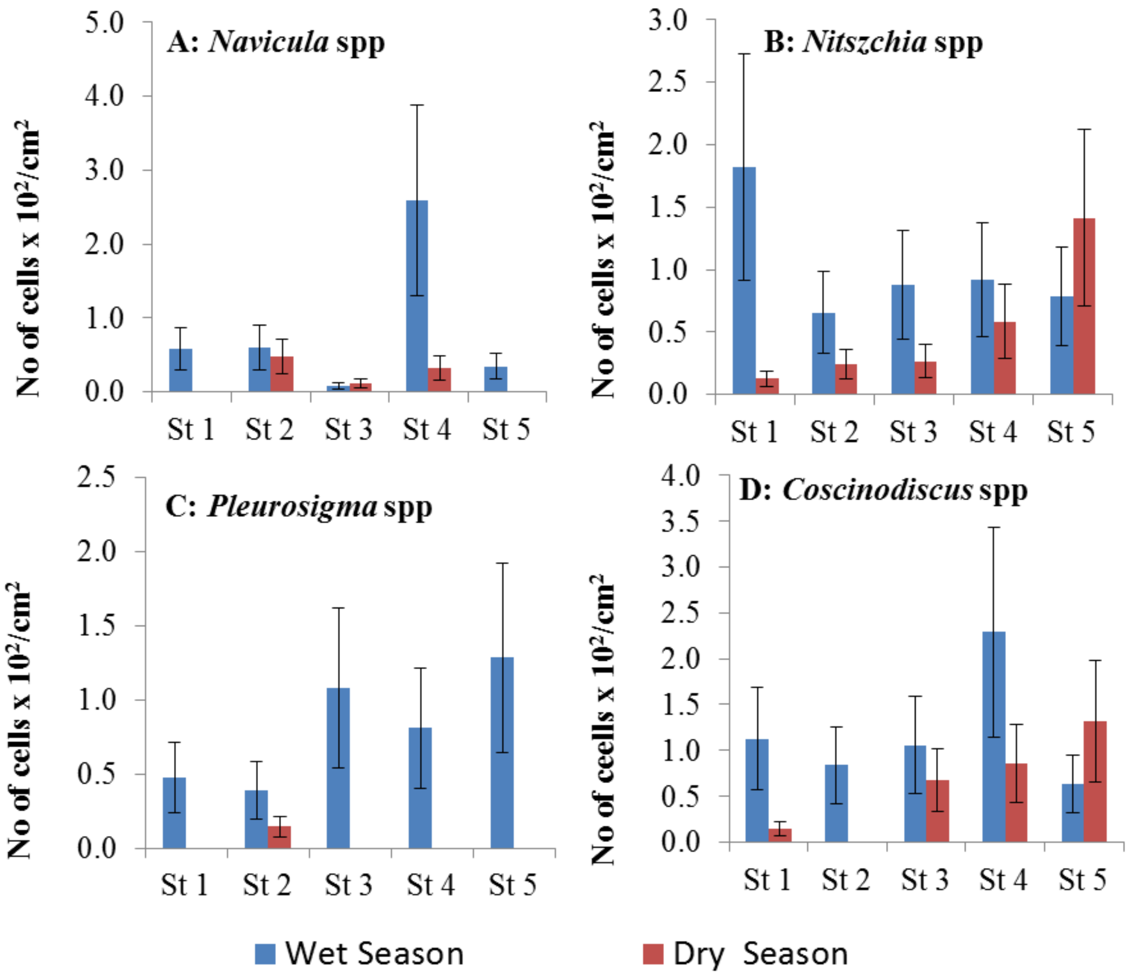

Fig. 2: Spatial and seasonal differences in mean (± SE) densities of epipelic algal taxa in the upper Bonny Estuary

Table 2: Summary of Analysis of Variance for abundance of epipelic algae taxa

Parameter	**Station**		**Season**		**Interaction**	
	F	**p-Value**	**F**	**p-Value**	**F**	**p-Value**
Navicula spp	15.34	<0.001	17.93	<0.001	13.45	<0.001
Nitszchia spp	3.77	0.011	0.14	0.708	18.67	<0.001
Pleurosigma spp	1.43	0.243	34.81	<0.001	2.34	0.072
Coscinodiscus spp	9.53	<0.001	4.41	0.042	5.89	0.001

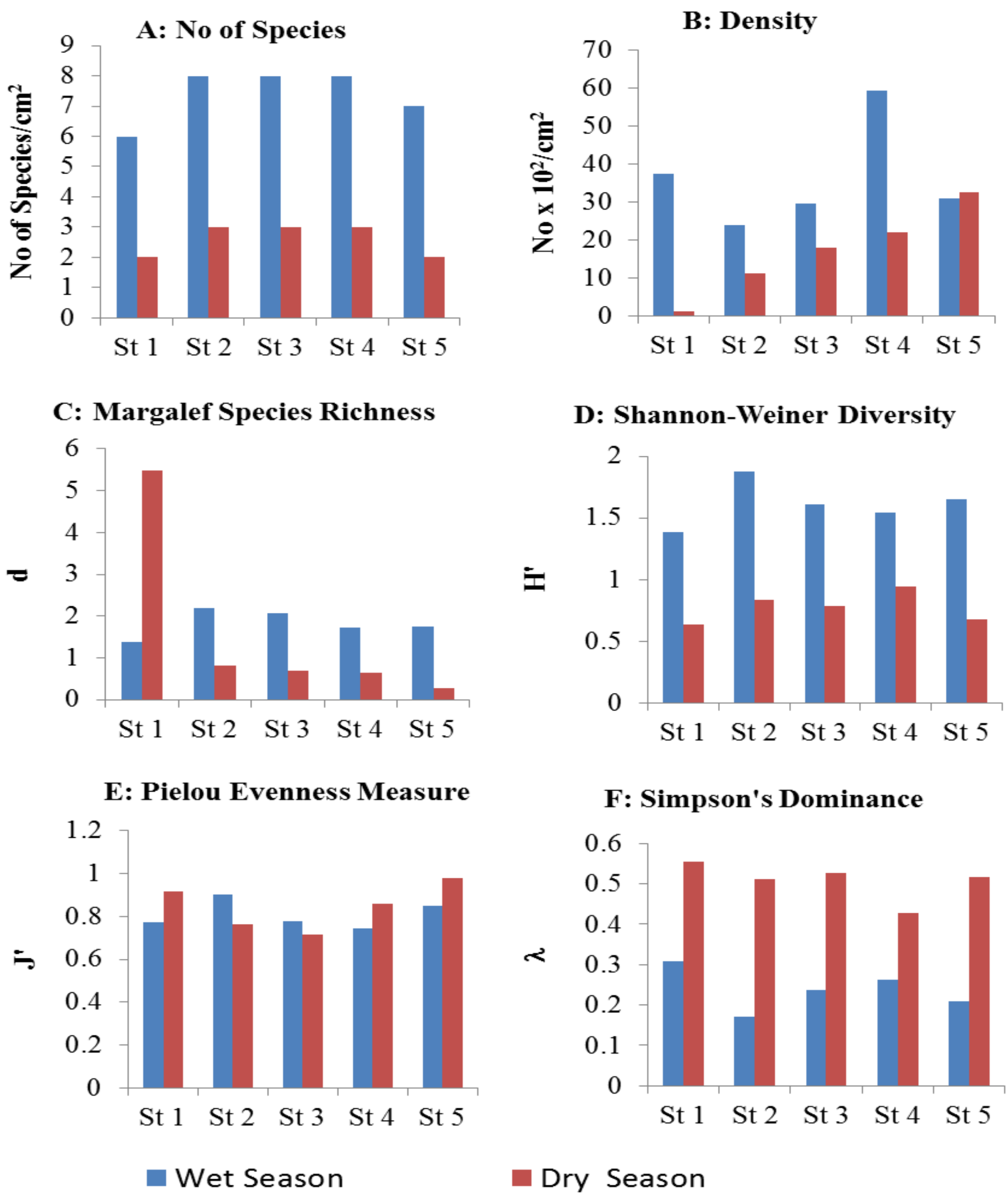

Fig. 3: Community indices of epipelic algae

Table 3: Summary of analysis of variance for epipelic algal population and community indices

Index	Station			Season		
	MS	F	p-Value	MS	F	p-Value
No of species S	1.00	10	0.023	57.6	576	<0.001
Density N	182.0	1.27	0.410	927.4	6.49	0.063
Margalef d	1.935	0.66	0.654	0.138	0.05	0.839
Shannon-Weiner H'	0.0316	2.03	0.255	1.758	112.8	<0.001
Pielou J'	0.0076	0.89	0.542	0.0035	0.40	0.559
Simpson λ	0.002753	1.18	0.438	0.1818	77.88	<0.001

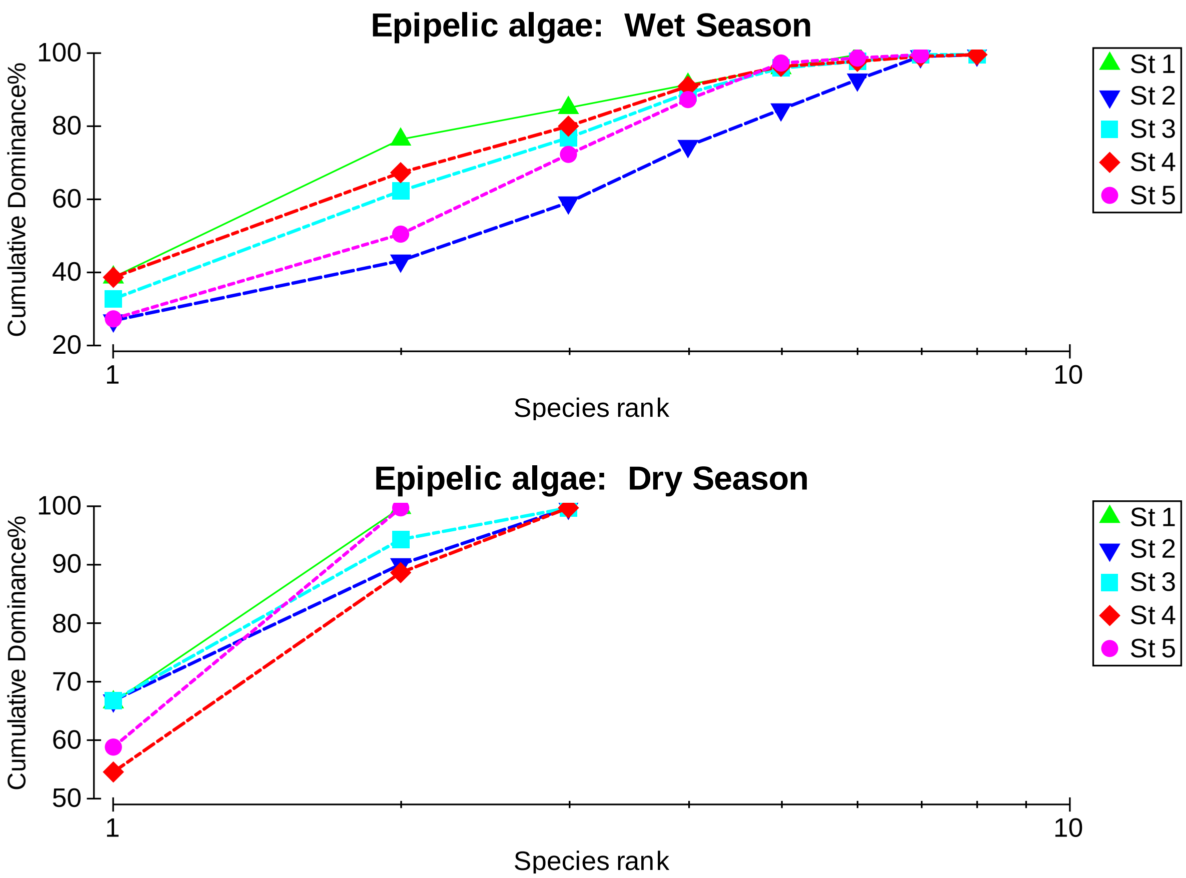

Fig. 4: K dominance curves of epipelic algae

Table 4: Product moment correlation coefficients between water quality variables and epipelic algae community indices

	pH	Temp.	Cond	Salinity	TDS	Turb.	Nitrate	THC
No of species S	-0.696*	-0.506	-0.160	-0.171	-0.160	0.165	0.367	-0.495
Density N	-0.213	-0.390	-0.439	-0.446	-0.439	0.427	0.637*	-0.300
Margalef d	-0.369	-0.308	0.389	0.391	0.389	-0.388	-0.307	-0.241
Pielou J'	0.415	0.300	-0.167	-0.165	-0.167	0.228	0.040	-0.289
Shannon-Weiner H'	-0..686*	-0.452	-0.146	-0.158	-0.146	0.257	0.357	-0.562
Simpson λ	0.632*	0.414	0.188	0.198	0.188	-0.347	-0.420	0.559
Navicula spp	-0.498	-0.526	-0.292	-0.300	-0.292	0.162	0.268	-0.344
Nitszchia spp	0.182	-0.250	0.016	0.012	0.016	0.291	0.358	-0.161
Pleurosigma spp	-0.614	-0.524	-0.315	-0.319	-0.315	0.318	0.612	-0.479
Coscinodiscus spp	-0.038	-0.201	-0.426	-0.432	-0.426	0.327	0.533	-0.147

*p<0.05 Water quality data from Daka *et al*., 2019

The phytoplankton was composed predominantly of by the class bacillariophyceae (diatoms), consisting of ten genera four of which (were recorded only during the dry season (Table 5). The spatial and seasonal differences in the densities of the other six genera are presented in Figure 4. *Nitszchia* spp (Fig. 4B), *Synedra* spp (Fig. 4C) and *Coscinodiscus* spp (Fig. 4E) were the most widely distributed being found at all stations in both seasons, but had variable seasonal profiles. All the three species had significant differences between stations, seasons and interaction p<0.001, Table 6). Tukey tests gave the following inferences: *Nitszchia* spp (Stn 5> Stn 4=Stn 3=Stn 1; Stn 4>Stn 1=Stn 3=Stn 2), *Synedra* spp (Stn 5>Stn 4>Stn 1=Stn 3) and *Coscinodiscus* spp (Stn 4=Stn 5=Stn 1;Stn 4>Stn 3 =Stn 2. : *Nitszchia* spp (Stn and *Synedra* spp were significantly higher in the dry season, while *Coscinodiscus* spp was significantly higher in the wet season. Also, the density of *Pleurosigma* spp (Fig 4D) was significant differences for station (Stn 5>, Stn 4=Stn 1=Stn 2=Stn 3), season (wet>dry) and interaction. *Navicula* spp (Fig. 4A) showed significant difference between stations Stn 5> Stn 1 =St 4 = Stn 2 = Stn 3) but none between season; while the reverse is the case for *Thallasiothrix* spp (Fig 4F).

The number of phytoplankton species observed ranged from 4 at Stn 4 to 8 at Stn 2 (Fig. 5A), while the density values ranged from 8 x 10^2 cells/L at Stn 2 in the wet season to 71 at Stn 5 in the dry season (Fig. 5B). Neither of these showed significant differences between stations or seasons (Table 5). Similarly, none of the community indices (Figs 5 C to 5F) showed had significant differences between stations or seasons, except Pielou evenness which was significantly higher in the wet season (p=0.013). K-dominance curves showed similar cumulative species dominance patterns between seasons (Fig. 6). Significant positive correlations were observed between pH and *Synedra* spp; *Pleurosigma* spp and nitrate (Table 7). *Pleurosigma* spp also had significant negative correlations with temperature and THC, while *Thallasiothrix* spp had significant negative correlation with temperature (Table 8).

Table 5: Checklist showing spatial and seasonal composition of phytoplankton in the study area

Taxa	St 1		St 2		St 3		St 4		St 5	
	WS	**DS**	**WS**	**DS**	**WS**	**DS**	**WS**	**DS**	**WS**	**DS**
Bacillariophyceae										
Navicula spp	+	+	+	+	+	-	+	+	+	+
Nitszchia spp	+	+	+	+	+	+	+	+	+	+
Synedra spp	+	+	+	+	+	+	+	+	+	+
Pleurosigma spp	+	-	+	+	+	-	+	-	+	+
Coscinodiscus spp	+	+	+	+	+	+	+	+	+	+
Thallasiothrix spp	+	-	-	+	+	-	+	-	+	+
Chaetocerus spp	-	-	-	+		-	-	-	-	-
Tabellaria spp	-	-	-	-		+	-	-	-	-
Gyrosigma spp	-	-	-	+		+		-	-	-
Rhizosolaria spp	-	+	-	-		-	-	-	-	-

WS = Wet Season; DS = Dry Season

Table 6: Summary of Analysis of Variance for abundance of phytoplankton taxa

Parameter	Station		Season		Interaction	
	F	**p-Value**	**F**	**p-Value**	**F**	**p-Value**
Navicula spp	27.55	<0.001	0.66	0.421	12.87	<0.001
Nitszchia spp	39.45	<0.001	50.82	<0.001	30.96	<0.001
Synedra spp	71.20	<0.001	201.36	<0.001	62.47	<0.001
Pleurosigma spp	11.27	<0.001	79.88	<0.001	10.12	<0.001
Coscinodiscus spp	9.10	<0.001	4.96	0.032	6.31	<0.001
Thallasiothrix spp	1.44	0.237	13.28	0.001	3.44	0.017

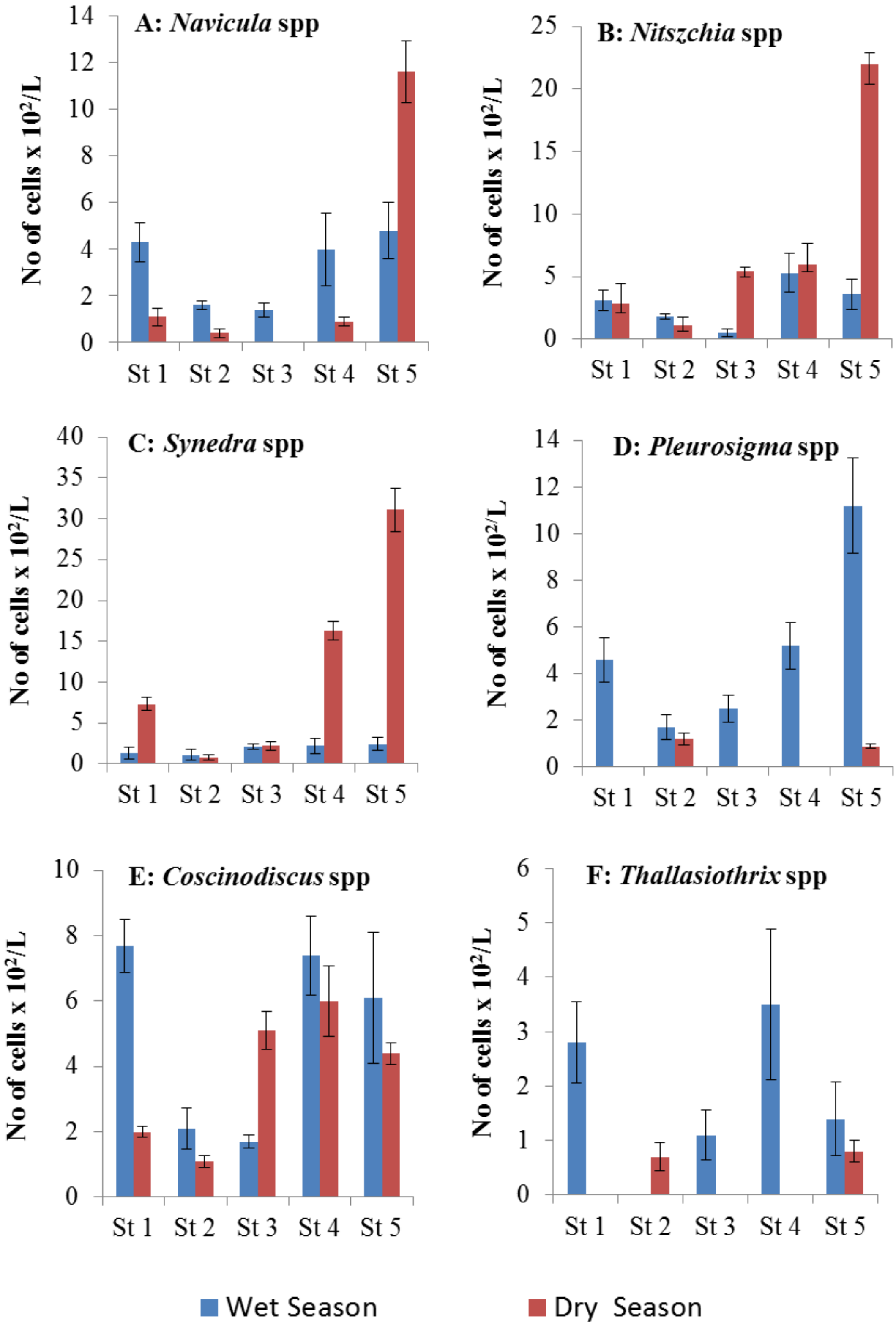

Fig. 5: Spatial and seasonal differences in mean (± SE) densities of phytoplankton taxa in the upper Bonny Estuary

Table 7: Summary of analysis of variance for phytpolankton and community indices

Index	Station			Season		
	MS	F	p-Value	MS	F	p-Value
No of species S	1.750	1.30	0.404	8.100	6.00	0.070
Density N	569.8	2.90	0.164	134.0	0.68	0.456
Margalef d	0.7016	1.59	0.331	0.0012	0.001	0.961
Shannon-Weiner H'	0.052	0.63	0.669	0.178	2.12	0.219
Pielou J'	0.0082	3.45	0.129	0.044	18.36	0.013
Simpson λ	0.0048	0.88	0.548	0.024	4.42	0.103

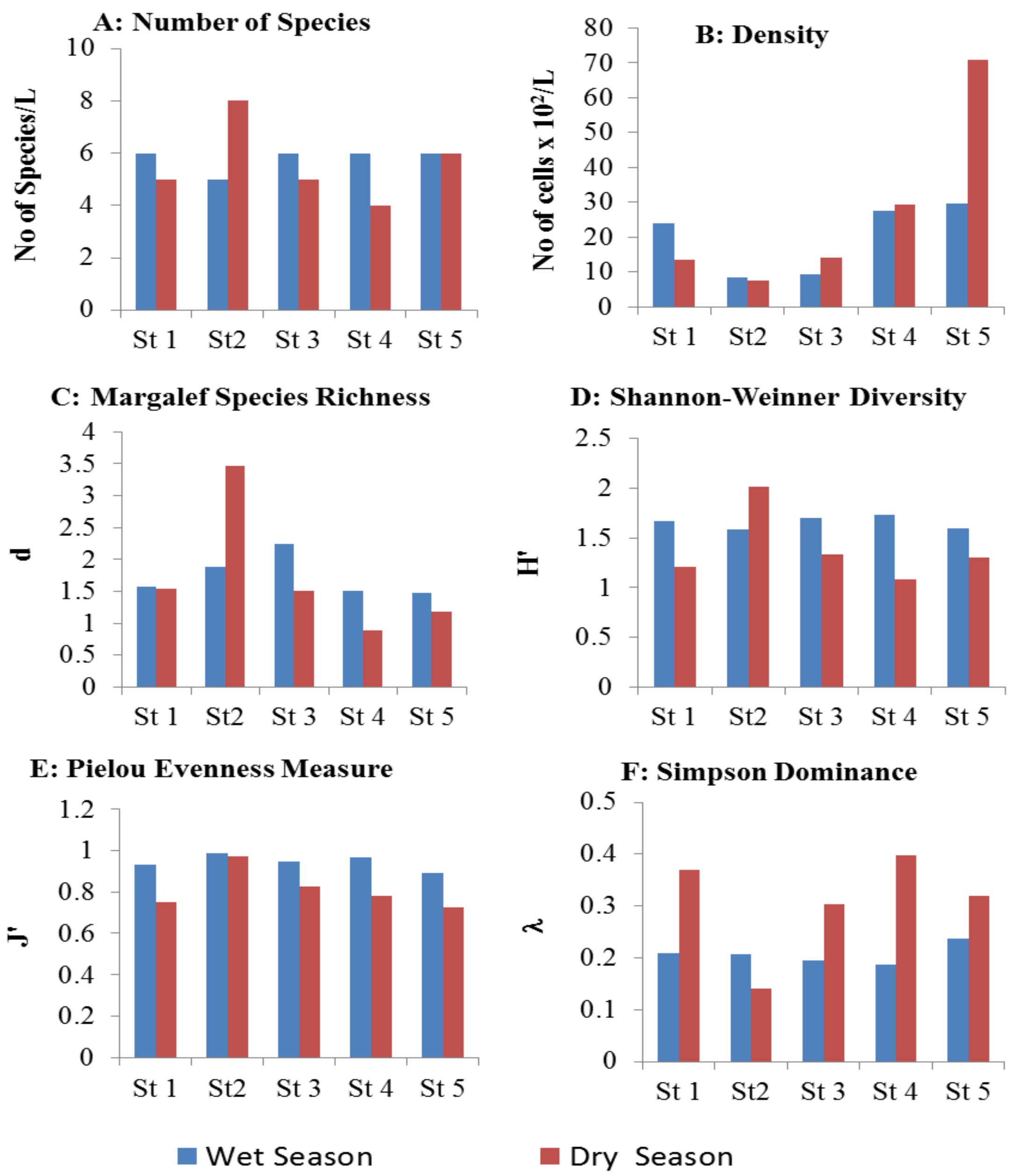

Fig. 6: Community indices of phytoplankton

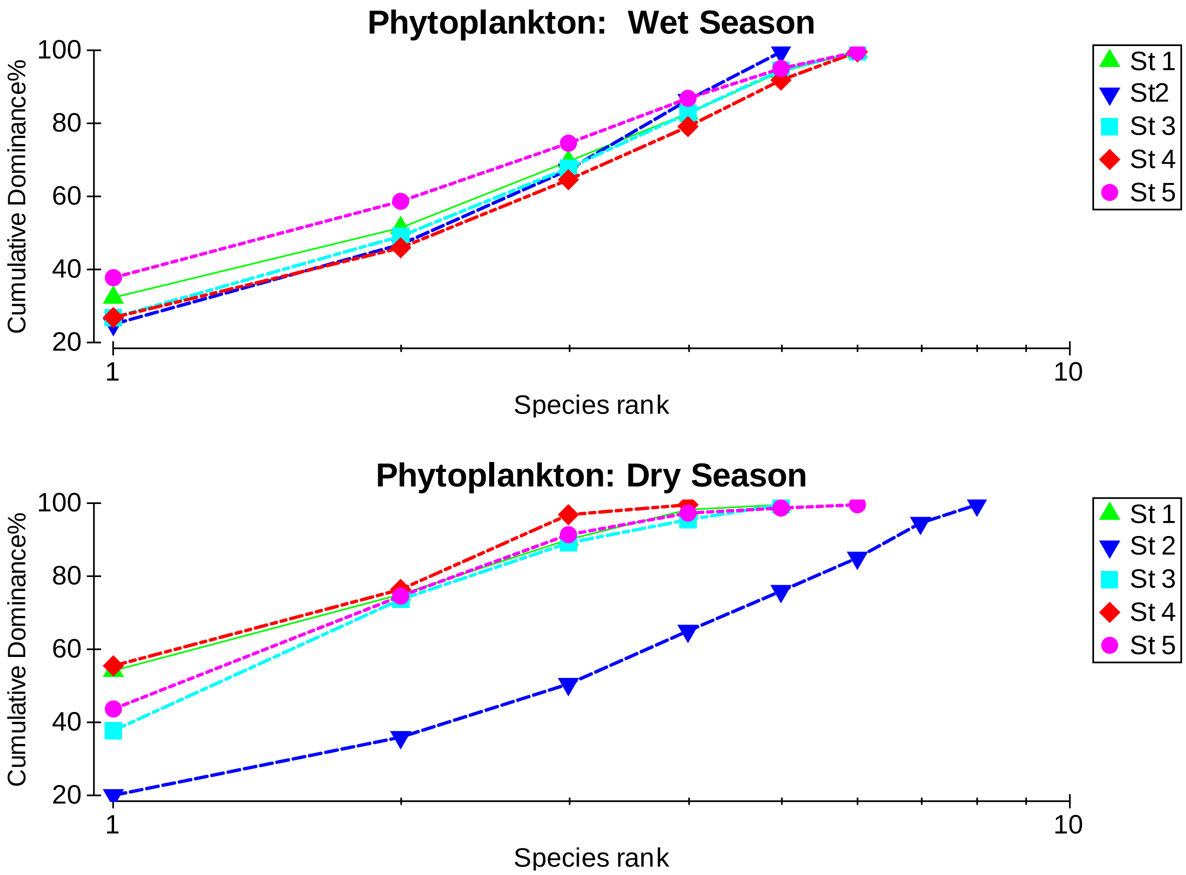

Fig. 7: K dominance curves of phytoplankton

Table 8: Product moment correlation coefficients between water quality variables and phytoplankton community indices

	pH	Temp.	Cond	Salinity	TDS	Turb.	Nitrate	THC
No of species S	-0.507	-0.512	-0.258	-0.269	-0.258	-0.205	0.120	-0.491
Density N	0.622	0.204	-0.518	-0.514	-0.518	0.508	0.543	-0.081
Margalef d	-0.245	-0.231	0.210	0.206	0.210	-0.585	-0.472	0.019
Pielou J'	-0.709*	-0.547	0.084	0.072	0.084	-0.178	-0.062	-0.343
Shannon-Weiner H'	-0.509	-0.608	0.021	0.013	0.021	-0.289	-0.050	-0.307
Simpson λ	0.544	0.615	0.014	0.025	0.014	0.264	-0.015	0.360
Navicula spp	0.428	-0.080	-0.461	-0.461	-0.461	0.368	0.555	-0.323
Nitszchia spp	0.742	0.346	-0.482	-0.479	-0.482	0.289	0.369	0.044
Synedra spp	0.866*	0.594	-0.365	-0.358	-0.365	0.332	0.189	0.222
Pleurosigma spp	-0.610	-0.666*	-0.346	-0.349	-0.346	0.542	0.738*	-0.689*
Coscinodiscus spp	-0.105	-0.272	-0.158	-0.158	-0.158	0.622	0.577	-0.127
Thallasiothrix spp	-0.368	-0.704*	-0.091	-0.096	-0.091	0.173	0.409	-0.304

*p<0.05 Water quality data from Daka *et al.*, 2019

The composition of epipelic algae and phytoplankton taxa observed in this study showed a lower variety than previously reported values by some previous authors (Ekeh 2010, Davies and Ugwumba, 2013). While only one class (bacillariophyceae) was recorded in this study, Ekeh (2010) observed from the Azuabie creek that bacillariophyceae were the most dominant followed by chlorophyceae, cyanophyceae, and protozoa. Davies and Ugwumba (2013) reported seven taxa (bacillariophyceae, chrysophyceae, chlorophyceae, cyanophyceae, pyrrophyceae, euglenophyceae and xanthopyceae) from the upper Bonny Estuary including the Okpoka and Azuabie Creeks recorded However, our findings agree with the Ejiowhor *et al.* (2018) who reported that only bacillariphyceae in plankton and epipelic algae in the Okpoka Creek They observed that eight algae species (*Gyrosigma* spp., *Synedra* spp., *Navicula*, spp., *Nitzschia* spp., *Coscinodicus* spp., *Pleurosigma* spp., *Thalassiothrix* spp., *Fragillaria* spp.,) were common to both phytoplankton and epipelic, whereas two species *Cyclotella* spp. and *Rhizosolema* spp. were only present in the phytoplankton and *Cymbella* spp. and *Cocconeis* spp. were observed only in Epipelic algae.

The most common species (*Navicula* spp, *Nitzschia* spp and *Synedra* spp) recorded in this study are known to be tolerant to pollution and are useful as pollution indicators (Davies and Ugwumba, 2013). The composition of the species is indicative of polluted environments. However, the spatial differences in the densities of the species did not show any significant contrast in the stations associated with the Jetties (Stns 1, 2, 4 and 5) when compared with the control (Stn 3) for any of the variables. Presumably, other anthropogenic influences in the study area overshadowed the operations at the jetty. For example frequent spills of petroleum products from makeshift refineries would affect all the stations in a similar manner. Daka *et al.* (2019) reported that physicochemical parameters of water in stations sampled for this study, showed more of natural upstream-downstream gradients; pollution and nutrient indices such as THC and nitrate did not indicate any influence of jetty operations. The community indices such as Shannon-Weiner, Margalef, Pielou and Simpson did not show spatial distributions that were suggestive of the effects of jetty operations in isolation from other anthropogenic inputs.

Conclusion

The phytoplankton and epipelic algae in the study are was predominantly composed of bacilliriophyceae. Most of the species recorded are known to be pollution indicators, so the area may be regarded as polluted. However, pollution from jetty operations were add-ons to other sources in a manner that could not be significantly inferred.

Acknowledgements

This research was funded by the Years 2011/2012/2014/2016 TETFund Research Projects (RP) Intervention for Rivers State University, Port Harcourt. We are grateful for the assistance of Nathan Nario, Oluka Ifiesimama, Robert Dede and Stanley Kalio (fieldwork), and Uche Anireh (geomatics and mapping).

References

Abowei, J.F.N., Ezekiel, E.N. & Hanson U (2012). Effects of Water Pollution on Phytoplankton Species Composition in Koluama Area, Niger Delta Area, Nigeria. *International Journal of Fisheries and Aquatic Sciences* 1(2): 134-139, 2012.

APHA (1999). Standard Methods for the Examination of Water and Wastewater. APHA, AWWA, WPCF, American Public Health Association Washington. DC.

Chindah, A.C. and Pudo, J. (1991). A preliminary checklist of algae found in plankton of Bonny River in Niger Delta, Nigeria. *Fragmenta Floristica et Geobotanica.*, 36: 112-126

Daka, E.R., Miebaka, C.A., Uyi, H., Ikoro, U & Osuampke, A (2019). Physicochemical variables and zooplankton Populations of the Upper Bonny Estuary in relation to Jetty Operations. *IIARD International Journal of Geography and Environmental Management*, 5 (1): 20-31.

Davies, A.O. & Ugwumba, O.A. (2013). Tidal influence on nutrients status and phytoplankton population of Okpoka Creek, Upper Bonny Estuary, Nigeria. *Journal of Marine Biology*, http://dx.doi.org/10.1155/2013/684739.

Durand, J.R. & Leveque .C. 1980. Flora at farune aquatiques de I' Afrique cah. Off *Rech. Saci-Tech. Outr-Mr.*,1:5 - 546.

Ejiowhor, I., Moslen, M. and Daka, E.R. (2018). Phytoplankton and epipelic algal abundance in relation to bridge construction on Okpoka River in the Upper Bonny Estuary, Nigeria. *Archives of Agriculture and Environmental Science*, 3(4): 337-343.

Ekeh, C.A. (2010). A study of the dynamics of plankton communities in Azuabie Creek, upper Bonny Estuary. Ph.D. Thesis, Rivers State University, Port Harcourt, Nigeria.

Ekweozor, I.K.E, Daka, E.R., Ebere, N., & Bob-Manuel, K.N.O. (2004). An estuary under stress: A case study of eighteen years chronic hydrocarbon pollution of Bonny Estuary. *Journal of Nigeria Environmental Society*, *2*(1) 12-15.

Erondu, E.S. and Chindah, A.C. (1991). Physico-chemical and phytoplankton changes in a tidal freshwater station of the New Calabar River South Eastern Nigeria. *Environmental Ecology*, 9: 561-570.

Heip, C., Herman, P.M.J. & Soetaert, K. (1998). Data processing, evaluation and analysis. In: Higgis, R.P. and Thiel, H. (eds), Introduction to the study of meiofauna. Smithsonian Institution, Washington DC, pp. 197-231.

Kara, H. and Sahin, B. (2000). Epipelic and epilithic algae ofDegirmendere River (Trabzon-Turkey). *Turkish Journal of Botany*, 25: 177-186.

Magurran, A.E. (1991). Ecological diversity and its measurement. Chapman and Hall, London.

Newell, G.E.& Newell, R.C. 1977. *Marine Plankton: a Practical Guide. Revised Edition.* London Hutchinson Publish Limited.

Ogamba, E.N., Chindah, A.C., Ekweozor, I.K.E. & Onwuteaka, J.N. (2004). Water quality and phytoplankton in Elechi creek complex of the Niger Delta. *Journal of Nigeria of Environment Society*, 2(2):121-130.

Pielou, E.C. (1975). Ecological diversity. Wiley, New York

Suthers, I. M. and Rissik, D. (2008). Plankton. A guide to their ecology and monitoring for water quality. Pp 115 – 132.

Townsend, C.R., Harper J.D. & Begon, M. (2000). *Essentials of Ecology*. 3rd Edn., Blackwell Science, London, UK.

Underwood , G., Phillips J. & Saunders, K. (1998). Distribution of estuarine benthic diatom species along salinity and nutrient gradients, *European Journal of Phycology*, 33:2: 173-183, DOI: 10.1080/09670269810001736673