PLANKTON DIVERSITY AND COMMUNITY STRUCTURE OF ASARAMA ESTUARY IN THE NIGER DELTA IN RELATION TO PHYSICO-CHEMISTRY

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Abstract. Biodiversity of Asarama estuary at Andoni flat in the Niger Delta was surveyed in the wet and dry seasons of 2016/17; in order to ascertain the diversity, composition and community structure of plankton. Qualitative plankton samples, were collected from different sources including surface water and analysed in the laboratory. The results for the analyses for water chemistry showed optimal to near high values for the parameters, which were within the normal range of normality in tropical brackish waters. Biodiversity analyses revealed eight divisions of phytoplankton in the given order; (bacillariphyta constituting 84% > cyanophyta 8% > chlorophyta 6%, > euglenophyta 1%, ≥ dinophyta 1%, > ochrophyta < 1%, ≥ charophyta < 1%, ≥ oligohymenophorea < 1%) and three groups of zooplankton which were cyclopoida (composed of 98% of the species), harpaticoida and rotifera (which had 1% of the constituent species each). Species diversity and composition were low for zooplankton and very high for phytoplankton. Meanwhile, unregulated boat traffic and illegal pollution with crude oil products pose major challenges to the biotic communities. Nutrient enrichment may perhaps become an issue in the near future if no monitoring efforts backed with legislature are imposed on the maricultural practices of bivalves at the upstream.
Keywords: *Andoni, inter-tidal, phytoplankton, salinity, zooplankton*

Introduction

Estuaries are shallow open systems that are strongly influenced by river inflows, mixing with the coastal ocean and exchanging sediment including the cleaning of the atmosphere and the water interfaces. They usually have distinct salinity gradients in their lower part and a tidal influence in their upper freshwater part providing specific hydrological properties when compared to rivers. Importantly, estuaries form transition zones between freshwater and marine environments, and are thus characterised by a large variability in their biophysical and chemical properties under both the influence of climate change and intense anthropogenic activities (Pearle et al., 2010; Lancelot and Muylaert, 2011; Yang et al., 2014). Asarama estuary is one of the most important navigable waterways in the far reaches within Andoni land and it connects several communities therein. Besides, it is exposed to both the natural factors and human exploitation activities daily (Ansa and Francis, 2007).

The estuarine environment represents an ecotone between freshwater and marine ecosystems and is influenced by both, but is in many ways more complex than either of

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them (Cearreta et al., 2000; Elliott and De Jonge, 2002; Elliott and McLusky, 2002; Yang et al., 2014). Both river flow and tidal motions drive the riverine and marine communities towards estuaries (Waniek et al., 2005) and hence shape the diversity and abundance of estuarine communities (Elliott and McLusky, 2002; Waniek, 2003; Froneman, 2004; Cloern et al., 2014). Despite the well-documented role of zooplankton in the transfer of carbon and energy, and in ichthyofaunal abundance, relatively few studies have dealt with the determinants of zooplankton assemblages in estuarine ecosystems (Carlsson et al., 1995; Dalal and Goswami, 2001; Tan et al., 2004; Thor et al., 2005; Hwang et al., 2010).

The productivity of any water body is determined by the amount of plankton therein as they are the major primary and secondary producers. Plankton communities serve as a base for the food chain that supports the commercial fisheries (Townsend et al., 2000; Godhantaraman et al., 2003; Conde et al., 2007; Davies et al., 2009; Ogbuagu et al., 2011). They are essential tools for biomonitoring programme (Davies et al., 2009) and as such their relative high abundance and diversity is crucial.

Some available studies in the Niger Delta brackish waters dealing with phytoplankton and zooplankton include Opute (1990) on the phytoplankton of Warri/Focados estuary in Delta State; Kadiri (2006) on the survey of phytoplankton on the western Niger Delta; Davies et al. (2009) on the phytoplankton of Elechi creek, and Ogbuagu et al. (2011) on the myco-plankton of Imo River in the Niger Delta).

There is a huge dearth of knowledge on the plankton communities of Asarama estuary regarding its checklist, diversity and community structure; as no such known study was documented prior to this work upon search. Hence, this study was timely and addresses the influence of environmental activities upon the composition, diversity and community structure of the plankton of Asarama estuary at Andoni flat in the Niger Delta. Therefore, the aim and objectives of this study were to document the diversity, community composition and the physicochemical environment associated with the plankton of Asarama estuary. We used Multivariate approach such as canonical correspondence (CC) analysis to test for the associations between plankton communities and the physicochemical environment in the study area.

Materials and methods

Study area

Asarama estuary at Adoni land in Rivers State is located within the coordinates (04°30’37”N, 007°27’05”E and 04°31’35”N, 007°28’44”E). It is a semi-diurnal tidal estuary system with a bridge across to other communities near shore (*Fig. 1*). The sampling stations (which are designated as points 1 to 5, in yellow ink along the water course on the map) were fixed by using a hand held Global Positioning System (GPS) and were maintained throughout the study period.

Sampling stations

The ecosystem is characterised by rich flora communities of white and red mangroves, Nipa palm forests and other halophytes. At station 1, is located a forest of mangroves named; Aso mangrove forest which is over 200 years old (personal communication, 2016). The forest is a host to several species of birds, monkeys, reptiles, bees and insects as observed during field studies. Stations 2 is rich in

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mangroves as well. Decapods and bivalves were commonly seen on mangrove branches here. Stations 3 is characterised by an admixture of white mangrove and nipa palms. The sediment was mostly silty and contained a lot of dead decaying organic matter like dead woods, dead leaves and dead shells of molluscs. Station 4 is located far downstream after the bridge by the fishing wooden traps. The substratum was a mixture of sandy-muddy bed. A film of soot from an illegal petroleum local refinery was observed on the water surface throughout the study. Station 5 is equally located downstream of station 4. A lot of nipa palms were found here with so much decomposition activities of the palm fronds and their seeds. The substratum was mostly muddy at the upper most reaches.

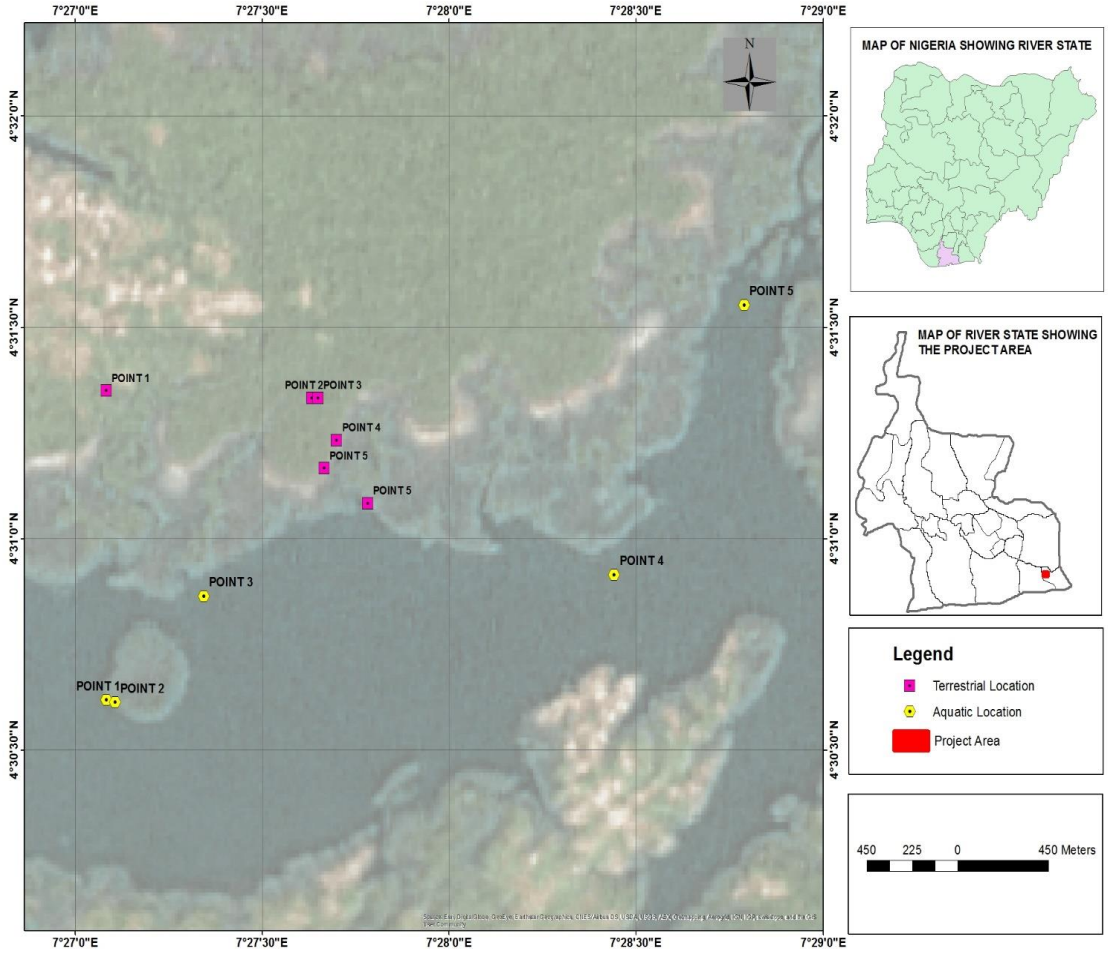

Figure 1. *Map of the study area*

Human activities and land used pattern

The major human activities in the locality include land and water transportations using cars, motor-bikes and boats, fishing with fish nets, gears and fish traps. Mariculture of Oysters (*Castrostrea* sp) and Periwinkles (*Tympanotonus fuscatus* Var. *Radular*) were predominant. At low tides particularly between 08:30 and 10:00 some of the locals were engaged in harvesting periwinkles indiscriminately without regulations.

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Illegal local refinery of petroleum products was observed far upstream off the estuary at the north-western bank which was emitting soot into the atmosphere.

Surface water sampling and analyses

Surface water samples were collected, preserved where applicable and analysed either in the field or laboratory according the methods of Eaton et al. (2005). A HANNAH field pH meter was used for the determination of pH in-situ. Turbidity was determined in the laboratory by using a HACH DR - 2000 spectrophotometer (Hach instrument). Salinity was determined in the laboratory by using HACHCO150 Model for Total Dissolved Solid/Conductivity/Salinity. This was determined using a HACHCO150 TDS/Conductivity/Salinity meter. Azide modification of Winkler's method was used to determine dissolved oxygen content of the water samples. Also, the Azide modification of Winkler's method was used to determine BOD content of the water samples. Nitrate was determined using HACH ER 2000 spectrophotometer. Determination of sulphate was done using a HACH DR 2000 spectrophotometer.

Plankton sampling and laboratory analyses

We used qualitative method to collect both phyto and zooplankton communities from the subsurface water in August 2016, the peak of wet season in the Niger Delta and March 2017 (driest month in the dry season) across five sampling stations (designated as points 1 to 5 on the map) by towing a 55 micron plankton net tied to a 25 HP engine-powered boat cruising at a speed of about 5 km h^{-1} for not more than 3 minutes in all. Plankton samples were then preserved with few drops of 10% buffered formaldehyde solution in 250 ml plastic bottles (polypropylene bottles) (Davies et al., 2009; Imoobe and Adeyinka, 2009). Samples were observed in the postgraduate laboratory of the Department of Animal and Environmental biology, University of Benin, Benin, Nigeria; using the Olympus binoculars microscope (CH). Identification and classification to species level where possible, was carried out with the appropriate literatures (Newell and Newell, 1966; Prescott, 1975; Needham and Needham, 1978 and Van De Velde, 1984; Jeje and Fernando, 1986).

Data analyses

Physicochemical data were subjected to the Analysis of Variance (One-way ANOVA) using SPSS (version 16.0). Plankton results were tested for biological diversity indices such as species richness, Shannon diversity index and species evenness with the aid of Palaeontological Statistics software (PAST 1.99 version) and canonical correspondence analysis (CCA) was also performed to test for any existing association between environmental condition and the biota (Hammer et al., 2001; Uwagbae et al., 2017). Plankton data were equally analysed by using basic tools for the measurement of central tendency such as graphics and percentage distribution.

Results

Physico-chemical environment of Asarama estuary

The physical and chemical condition of Asarama estuary surface water is presented in *Tables 1* and *2*, respectively.

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Table 1. *Summary of the seasonal mean and standard deviation of the physicochemical condition in surface water of Asarama estuary (between August, 2016 and March, 2017)*

Parameters	Station 1 Mean±SD	Station 2 Mean±SD	Station 3 Mean±SD	Station 4 Mean±SD	Station 5 Mean±SD	Significant values
Air temperature (°C)	30.00±2.83	30.00±4.24	30.00±4.24	30.50±3.54	31.00±4.24	0.998
Water temperature (°C)	28.00±2.83	27.75±1.77	28.00±2.83	29.00±4.24	28.50±3.54	0.996
pH	7.20±0.14	7.30±0.14	7.30±0.14	7.15±0.21	7.00±0.28	0.554
Turbidity (NTU)	9.00±1.41	19.00±8.49	10.00±4.24	11.00±1.41	14.00±1.41	0.259
EC ($mSCm^{-1}$)	8.35^{a}±0.28	9.37^{a}±0.08	7.82^{a}±0.71	7.05^{a}±0.15	5.22^{b}±1.27	0.022
TDS (mgL^{-1})	5.12^{a}±1.38	5.53^{a}±5.30	4.95^{a}±3.75	4.94^{a}±7.01	3.04^{b}±389	0.010
DO (mgL^{-1})	7.21±0.72	7.32±0.28	7.74±0.59	7.45±0.42	7.88±0.40	0.669
BOD (mgL^{-1})	0.98^{c}±0.01	0.99^{c}±0.01	1.89^{a}±0.16	1.18^{bc}±0.03	1.49^{ab}±0.38	0.014
Salinity (‰)	4.95±0.49	5.25±0.07	4.55±0.78	4.25±0.64	3.20±1.27	0.234
Total hardness ($CaCO_3$) (mgL^{-1})	1160.00±70.71	1430.00±14.14	1075.00±91.92	1075.00±162.63	1210.00±424.26	0.545
Nitrate (mgL^{-1})	0.13±0.03	0.10±0.01	0.14±0.03	0.12±0.04	0.09±0.01	0.378
Phosphate (mgL^{-1})	0.30^{c}±0.03	0.34^{bc}±0.04	0.42^{ab}±0.04	0.44^{ab}±0.04	0.46^{a}±0.04	0.033
Sulphate (mgL^{-1})	358.50±44.55	455.00±91.92	350.00±42.43	311.00±26.87	254.00±79.20	0.157

Significant < 0.05: significant difference. Superscript denotes the source of significant variation

Table 2. *Mean values of the investigated parameters in surface water across wet and dry seasonal during the study*

Parameters	Wet season Mean±SD	Dry season Mean±SD	Significant
Air temperature (°C)	27.60±0.55	33.00±0.71	0.000
Water temperature (°C)	26.10±0.22	30.40±1.14	0.000
pH	7.06±0.17	7.32±0.08	0.015
Turbidity (NTU)	15.00±5.87	10.20±2.77	0.107
EC ($mSCm^{-1}$)	7.21±1.85	7.91±1.29	0.480
TDS (mgL^{-1})	4.61±1.19	4.84±0.86	0.700
DO (mgL^{-1})	7.86±0.29	7.18±0.33	0.008
BOD (mgL^{-1})	1.38±0.47	1.23±0.33	0.599
Salinity (‰)	3.98±1.09	4.90±0.51	0.139
Total hardness ($CaCO_3$) (mgL^{-1})	1108.00±199.67	1272.00±202.53	0.223
Nitrate (mgL^{-1})	0.13±0.03	0.10±0.02	0.038
Phosphate (mgL^{-1})	0.42±0.07	0.36±0.07	0.252
Sulphate (mgL^{-1})	386.00±82.04	305.40±69.91	0.132

Significant < 0.05: significant difference

Air and water temperatures closely followed each other. The differences between air and water temperatures was not more than 4 °C. Mean air temperature ranged between 30 and 31 °C across the stations. Likewise water temperature varied from 27.75 °C at station 2 to 29 °C at station 4. There was however no significant differences between the two parameters ($P > 0.05$).

The mean spatial and temporal concentrations of hydrogen ion concentration (pH) values showed an alkaline condition ranging between 7.00 at station 5 and 7.30 at stations 2 and 3 respectively. The mean values across stations 1 to 5 in wet and dry seasons were between 7.06 and 7.32. Turbidity mean wet and dry season values ranged from 10.20 to 15.00 NTU. Turbidity mean concentration values were between 900 NTU at station 1 and 19.00 NTU at station 2. Electrical conductivity (EC) mean seasonal concentrations were between 5.22 $mScm^{-1}$ at station 5 and 9.37 $mScm^{-1}$ at station 2.

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Total hardness and nutrients (phosphate, sulphate and nitrate) exhibited condition tenable in the marine environment. Mean values of total hardness varied from 1075.00 mgL^{-1} at station 3 and 4 respectively to 1430.00 mgL^{-1} at station 2. Its mean concentration value in the water was between 1108.00 mgL^{-1} in the wet season and 1272.00 mgL^{-1} in the dry season. Nitrate and phosphates both had low range of values. The mean temporal and spatial concentration values were less than 0.5 mgL^{-1}. However, sulphate recorded very high values of between 386.00 mgL^{-1} during the wet season and 305.40 mgL^{-1} during the dry season. Sulphate mean concentration were between 254.00 mgL^{-1} at station 5 and 455.00 mgL^{-1} at station 2. The seasonal values of dissolved oxygen (DO) ranged between 7.18 mgL^{-1} in the dry season and 7.86 mgL^{-1} in the wet season. Mean values across the stations ranged from 7.21 mgL^{-1} at station 1 to 788 mgL^{-1} at station 5. Biological oxygen demand (BOD_5) seasonal values ranged from 1.23 mgL^{-1} in the dry season to 1.38 mgL^{-1} in the wet season. And mean values showed variations from 0.98 mgL^{-1} at station 1 to 1.89 mgL^{-1} at station 3.

Salinity mean concentrations varied from 3.20 ppm at station 5 to 4.95 ppm at station 1. Seasonal concentrations varied between 3.98 ppm in wet season and 4.90 ppm in the dry season.

Plankton studies

Both phyto- and zooplankton were characterised and presented in this section.

Phytoplankton

Phytoplankton analysis revealed a total of eight divisions dominated by the Bacillariphyta constituting about 84%. Others were in the order Cyanophyta (8%) > Chlorophyta (6%), > Eglenophyta (1%), ≥ Dinophyta (1%), > Ochrophyta (< 1%), ≥ Charophyta (< 1%), ≥ Oligohymenophorea (< 1%) (*Figs. 2* and *3*). The total number of individuals is represented by 9,276 individuals per meter squared, amongst 57 taxa. Phytoplankton taxa had higher percentage composition and distribution across the study stations except at station 5 and were significantly higher during the dry season of the study in 2017 (*Table 3*).

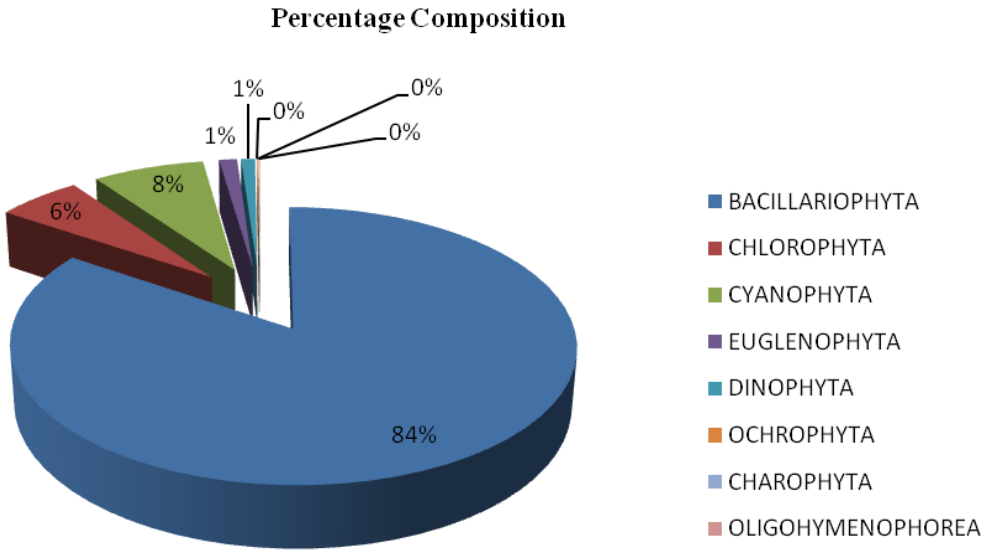

Figure 2. *Percentage composition of phytoplankton divisions*

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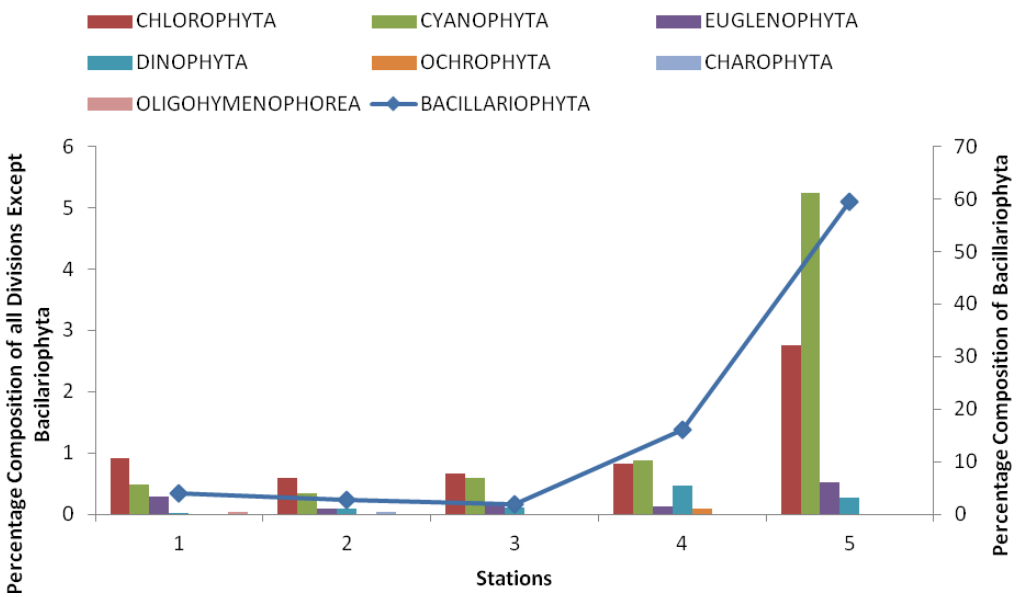

Figure 3. *Percentage composition and distribution of phytoplankton groups across the study stations*

Table 3. *Summary of the composition and distribution of phytoplankton species across the study stations*

Phytoplankton species	Stations					
	1	**2**	**3**	**4**	**5**	**Total**
DIVISION: BACILLARIOPHYTA						
Actinoptychus splendens	0	2	0	0	0	2
Amphiprora alata	0	3	0	0	0	3
Bacillaria paradoxa	10	18	32	244	1446	1750
Bacillaria sp.	0	0	0	0	48	48
Biidulphia regia	0	6	0	0	0	6
Chaetoreros sp.	4	0	0	0	0	4
Coscinodiscus cencinnus	1	0	0	0	0	1
Eunotia flexuosa	4	0	0	0	0	4
Flagillaria javanica	0	0	0	0	1200	1200
Flagillaria sp.	79	31	96	1216	2664	4086
Melosira granulata	4	0	0	0	0	4
Pinnularia cardinaliculus	4	0	0	0	0	4
Pinnularia sp.	0	0	6	12	24	42
Surirella robusta	1	0	0	0	0	1
Surirella sp.	3	0	0	0	60	63
Synedra acus	152	76	24	0	0	252
S. ulna	112	80	20	0	0	212
Tabellaria floculosa	0	40	0	0	0	40
TOTAL BACILLARIOPHYTA	374	256	178	1472	5442	7722
DIVISION: CHLOROPHYTA						
Clostrerium gracile	4	4	0	0	0	8
Cosmarium bretum	0	0	0	0	48	48
Cosmarium connatum	4	0	0	0	0	4

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Cosmarium pseudoconnatum	4	0	0	0	0	4
Cosmarium resiforme	0	0	4	0	0	4
Eudorina elegans	0	11	0	0	0	11
Mougeotia sp.	4	0	0	0	0	4
Pandorina morum	18	0	0	0	0	18
Pandorina sp.	18	8	40	0	0	66
Pediastrum gracillinum	0	0	0	0	72	72
Pleodorina illinosensis	0	1	0	0	0	1
Scenedesemus dimorphus	0	0	0	8	0	8
Scenedesemus opollensis	0	0	0	8	0	8
Sirogonium melanosporum	26	8	8	8	48	98
Spirogyra karnalae	0	0	0	0	24	24
Spirogyra sp.	4	0	0	0	0	4
Volvox africana	2	10	0	32	36	80
Volvox aureus	0	12	8	20	24	64
TOTAL CHLOROPHYTA	84	54	60	76	252	526
DIVISION: CYANOPHYTA						
Aphanothecae sp.	0	0	16	0	0	16
Coelosphaerium sp.	24	8	32	32	168	264
Coelosphaerium pallidum	0	0	0	48	288	336
Microcystis aeruginosa	3	0	0	0	0	3
Microcystis flos-aquae	0	0	0	0	24	24
Oscillatoria bornettia	11	0	0	0	0	11
Oscillatoria sp.	0	24	0	0	0	24
Plectonema sp.	6	0	0	0	0	6
Lyngba aestuarri	0	0	6	0	0	6
TOTAL CYANOPHYTA	44	32	54	80	480	690
DIVISION: EUGLENOPHYTA						
Euglena sp.	18	0	0	8	48	74
Euglena spirogyra	0	8	16	0	0	24
Euglena viridia	5	0	0	0	0	5
Phacus tontus	1	0	0	0	0	1
Trachelomonas eurysloma	3	0	0	0	0	3
Trachelomonas oblonga	0	0	0	4	0	4
TOTAL EUGLENOPHYTA	27	8	16	12	48	111
DINOPHYTA						
Gymnodinium fuscum	1	9	10	42	24	86
TOTAL DINOPHYTA						
OCHROPHYTA						
Gonyostomum semen	0	0	0	8	0	8
TOTAL OCHROPHYTA	0	0	0	8	0	8
CHAROPHYTA						
Actinotaenium cucurbitinum	12	0	28	32	0	72
Euastrum elegans	0	0	0	24	24	48
Nitella gracilis	6	0	0	0	0	6
Straurodesmus leptodermus	0	3	0	0	0	3
TOTAL CHAROPHYTA	0	3	0	0	0	3
OLIGOHYMENOPHOREA						
Epistylis plicatilis	4	0	0	0	0	4
TOTAL OLIGOHYMENOPHOREA	4	0	0	0	0	4

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Zooplankton

The zooplankton taxa were poorly represented and distributed in three groups; Cyclopoida, Harpaticoida and Rotifera of the phylum Arthropoda and sub-phylum Crustacea. A total of 1,299 individuals per unit area represented in 15 taxa were recorded in this aspect of the study. The group Cyclopoida constituted 98% of species while Harpaticoida and Rotifera had 1% each. Taxa composition and distribution varied irregularly across the sampled stations (*Figs. 4* and *5*). Meanwhile, Rotifera was highest at station 5. There was no zooplankton recorded at station 4 throughout the study (*Table 4*).

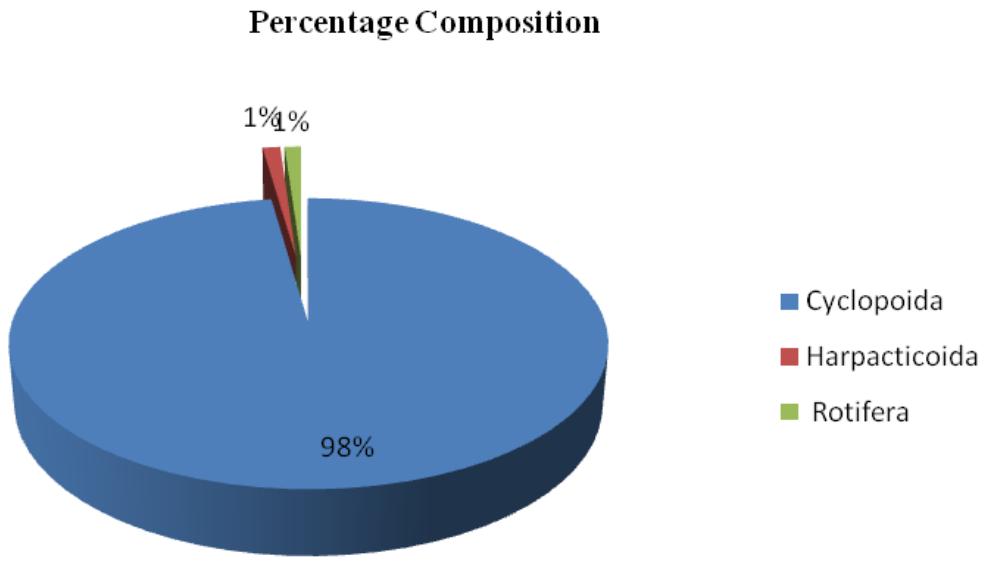

Figure 4. *Percentage composition of zooplankton taxa in study area*

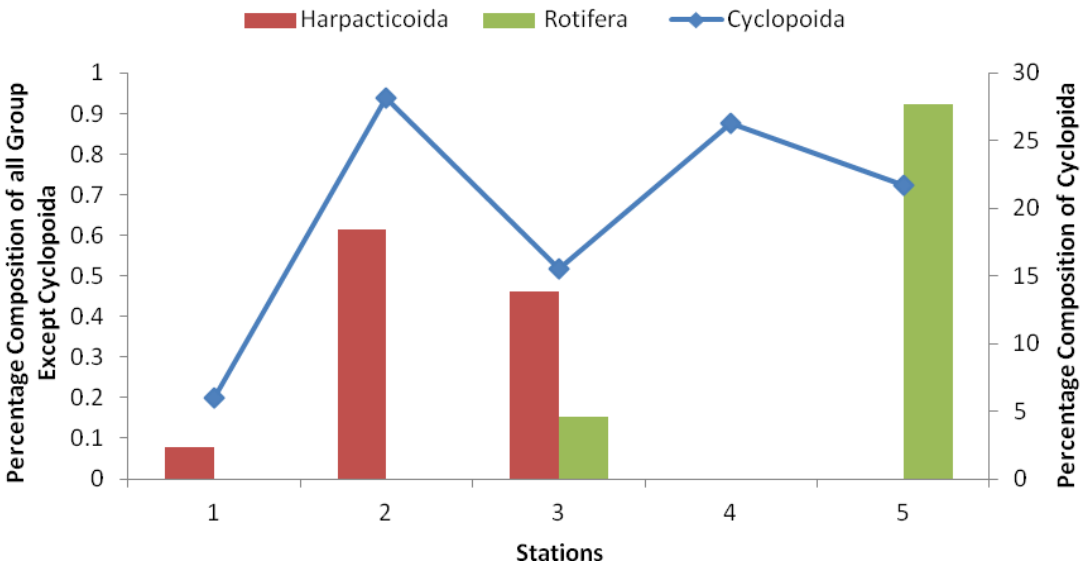

Figure 5. *Percentage composition and distribution of zooplankton species across the sampled stations*

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Table 4. *Summary of the composition and distribution of zooplankton taxa across the study stations*

Zooplankton species	Stations					
	1	**2**	**3**	**4**	**5**	**Total**
Phylum: Arthropoda						
Subphylum: Crustacea						
Subclass: Copepoda						
Cyclopoida						
Thermocyclops neglectus	26	46	100	38	90	300
Mesocyclops bodanicola	32	256	84	272	120	764
Metacyclops minutus	4	0	0	0	0	4
Microcyclops javanus	0	0	2	0	24	26
Acanthocyclops sp.	6	48	8	0	48	110
Eucyclops macruroides	10	0	8	32	0	50
Achidius (Neotachidius) triangular	0	16	0	0	0	16
Harpacticoida						
Shizopera neglecta	1	8	6	0	0	15
TOTAL COPEPODA	79	374	208	342	282	1285
Rotifera						
Keratella hiemalis	0	0	0	0	12	12
Rotaria neptunia	0	0	2	0	0	2
TOTAL ROTIFERA	0	0	2	0	12	14

Diversity indices for plankton

Biological diversity index for phytoplankton with respect to species richness was highest at station 1 and least at station 2. Species were only evenly distributed at stations 2 and 3. Meanwhile species dominance was highest at station 4 and Shannon diversity was least at stations 4 and 5 respectively (*Table 5*).

Table 5. *Phytoplankton diversity index*

Description	STN 1	STN 2	STN 3	STN 4	STN 5	Total
Taxa_S	32	20	15	16	18	**101**
Individuals	552	362	346	1746	6270	**9276**
Dominance_D	0.1469	0.1253	0.1291	0.5074	0.2737	
Shannon_H	2.455	2.434	2.352	1.217	1.659	
Simpson_1-D	0.8531	0.8747	0.8709	0.4926	0.7263	
Evenness_e^H/S	0.364	0.57	0.7004	0.2111	0.292	
Menhinick	1.362	1.051	0.8064	0.3829	0.2273	
Margalef	4.91	3.225	2.395	2.009	1.944	
Equitability_J	0.7084	0.8123	0.8685	0.4389	0.5741	
Fisher_alpha	7.398	4.559	3.196	2.433	2.272	
Berger-Parker	0.2754	0.221	0.2775	0.6964	0.4249	

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DOI: http://dx.doi.org/10.15666/aeer/1705_1027710292

For the zooplankton, species richness was observed at stations 1 and 3 only, and evenness was least at stations 3. Dominance of species occurred at station 4 and fairly at station 4 (*Table 6*).

Table 6. *Zooplankton diversity index*

Description	STN 1	STN2	STN 3	STN 4	STN 5	Total
Taxa_S	6	5	7	3	5	**26**
Individuals	79	374	210	342	294	**1299**
Dominance_D	0.2969	0.5024	0.3907	0.6536	0.2953	
Shannon_H	1.396	0.9978	1.159	0.6479	1.359	
Simpson_1-D	0.7031	0.4976	0.6093	0.3464	0.7047	
Evenness_e^H/S	0.6729	0.5425	0.4553	0.6372	0.7786	
Margalef	1.144	0.6752	1.122	0.3428	0.7038	
Equitability_J	0.7789	0.62	0.5956	0.5898	0.8445	

Application of canonical correspondence analysis (CCA) on the biota

We used Canonical correspondence analyses to characterise the relationships between the abiotic and biotic components of Asarama estuary.

For phytoplankton several associations were found at axis 2 of the CCA (*Fig. 6*). There was a positive association between phosphorus, sulphur and Ochrophyta species at plot 4. At plot 1, there was a positive association between pH and Charophyta. Meanwhile, Cyanophyta and Euglenophyta showed some positive correlations with nitrate respectively.

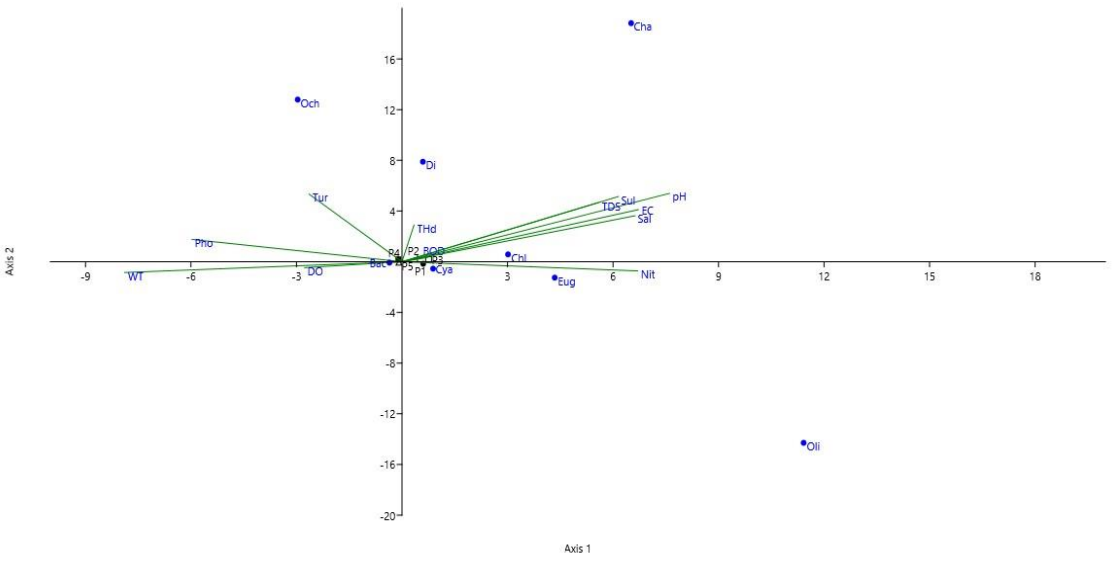

Figure 6. *Canonical corresponded analysis (CCA) for phytoplankton community*

However, for the zooplankton taxa (*Fig. 7*) there was a strong negative correlation between cyclopoida taxa and water temperature at axis 1. Also at axis 1, positive

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association between biological oxygen demand (BOD), dissolve oxygen (DO) and rotifers was observed. Importantly, pH, EC, salinity, turbidity, sulphate and nitrate showed strong negative association with harpacticoida taxa during the study.

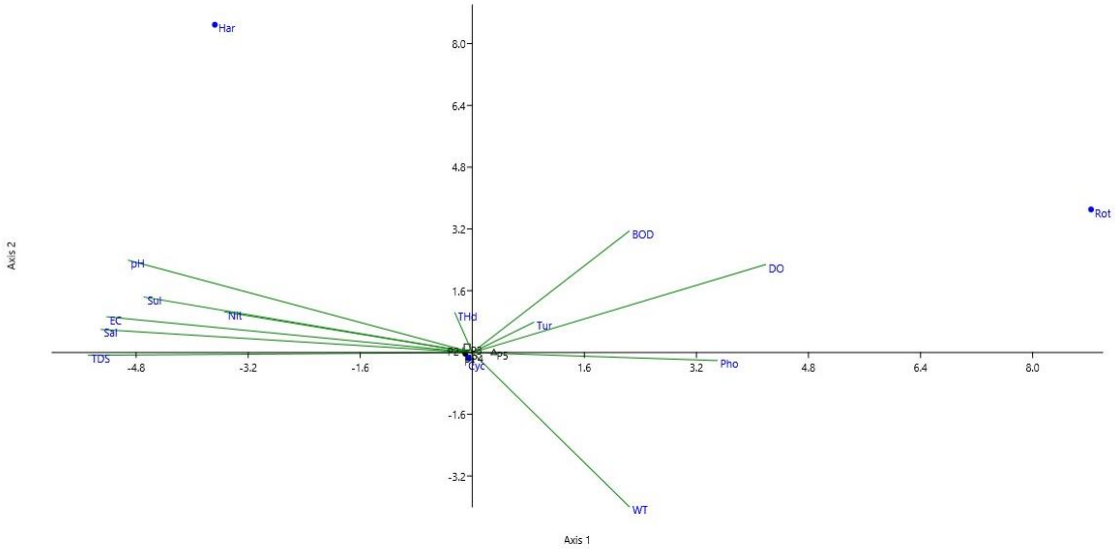

Figure 7. *Canonical corresponded analysis (CCA) for zooplankton community*

Discussion

The result of phytoplankton showed high species diversity, abundance and a robust community structure. In a given healthy aquatic environment, phytoplankton high population density is expected particularly in the shallow water depth rich in nutrient materials (Castro and Huber, 1997; Kadiri, 2006; Davies, 2009; Cloern et al., 2014; Dalu et al., 2016) except otherwise in contaminated or polluted waters. The dominance of Bacillariophyta division amongst the eight divisions recorded in this study corroborate the study by Kadiri (2006) and Egborge et al. (2001) in the western Niger Delta explaining that most inter-tidal waters in the zone are likely to be in this nature. Davies (2009) demonstrated that day light event (sun shine rays) play very important role in the production activities of both the primary and secondary producers as the latter is dependent on the former. The taxa among the division Bacillariophyta which were well represented across the study irrespective of the prevailing season were; *Bacillaria paradoxa*, *Flagillaria sp* and *Synedra acus* and were occasionally sampled at stations 1, 2, 3 and 5 respectively. The reason why the divisions Dinophyta, Ochrophyta and Oligohymenophorea recorded one species each throughout this study could not be well ascertained. However, the pattern of phytoplankton diversity is similar to what was reported (Kadiri, 2006) across waterways in the western Niger Delta of Nigeria. The pattern of diversity and species abundance observed in this study whereby some stations did not record any individual was affirmed by the output of the performance of diversity indices such as species richness and Shannon wiener diversity, and was earlier acclaimed (Kadiri, 2006 in the Niger Delta; and Lancelot and Muylaert, 2011). Environmental conditions such as temperature, pH, DO, BOD, salinity and EC in the surface water of Asarama estuary greatly influenced the production (particularly of phytoplankton), distribution and stability of the biotic community (typical for the zooplankton).

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The zooplankton of Asarama estuary were in conformity to what have been documented for some coastal or brackish waters in the Niger Delta of Nigeria (Davies, 2009; Ogbuagu et al., 2011). Though, the zooplankton community structure had more taxa of the sub-class copepod which consist of the order cyclopoida and harpaticoida, and the class rotifer respectively. The dominance of copepods in this study as a finding is in consistency with some earlier studies (Kolo et al., 2001; Davies, 2009) in Nigerian coastal environments and Hwang et al. (2010) for a study in Taiwan. Zooplankton-cyclopoida was represented by seven species of which; *Thermocyclops neglectus and Mesocyclops bodanicola* were the most dominant and abundant species recorded across the five sampled stations. *Shizopera neglecta* (Harpacticoida) and the two species of Rotifers only (*Keratella hiemalis and Rotaria neptunia*) were recorded at station 4. We strongly attribute this phenomena to the presence of soot and oil film on the surface water which could perhaps inhibit the activities of primary producers. The restriction of the occurrence of Rotifers species to stations 3 and 5 only could not be fully ascertained in this study. Importantly, the dominance of copepods in a given aquatic environment as in this study, is an indication of a perturbed or stressed environment (Davies, 2009). Imoobe and Adeyinka (2009) reported a high species diversity for rotifers and copepods for an inland stream in Benin, Nigeria, which proved contrary to our findings for the same group of zooplankton. Environmental perturbation was found to be associated with Asarama estuary resulting from intense human activities such as transportation/navigation and over harvesting of periwinkle (*T. fuscatus)*. Despite the diversity of phytoplankton, the zooplankton diversity was low however, a situation that was least expected since Asarama estuary is typically a shallow inter-tidal ecosystem rich in nutrient resulting in high productivity in the littoral zone. However, we believe that the effect of vertical migration in zooplankton and the choice of sampling the subsurface water using qualitative method only could have accounted for the low zooplankton species abundance and species composition.

The application of canonical correspondence analysis in data analysis (*Fig. 7*) has been used as clarification method to establish any relationships or associations between biota and environmental variables in recent ecological studies (Lengendr and Lengendr, 1998; Yang et al., 2014 and Uwagbae et al., 2017). The positive association between BOD, DO and members of the rotifer group suggests that they have affinity for environment rich in dissolved oxygen as well as requiring low biological oxygen demand for decomposition activity. This finding was not farfetched from the observation in the Asarama estuary as there were a lot of decomposing woods and leaf litter, and dead mollusc shells in the river bed. The positive relationship that was observed between DO, BOD and rotifers was truly reflected at station 5 of *Tables 1* and *2* in which case, DO and BOD had higher mean concentrations. In addition, environmental perturbation was lesser at station 5 except for dead nipa palm trees remains. Meanwhile, the negative association or correlation between harpacticoida species with several environmental factors such as salinity, EC, nutrient and pH; foretell that they may be more tolerant to waters of very low salinity and electrical conductivity with moderate nutrient such as in inland waters. Conversely, it also suggested that total hydrocarbon content affected abundance of the already mentioned taxa. This is evident and further explains the phenomenon of the low species abundance at station 4 in particular. The same negative correlated relationship was observed for pH and rotifers, implying that they perhaps prefer habitats with non-acidic pH condition (i.e. between 6.8 and 8.2) which is contrary to our finding. Equally, at station 4, CCA proved that

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cyclopoida-zooplankton were negatively influenced by water temperature, which is attributed to the total effect of direct sun heating of the littoral zone and the due to the absence of floral community that plays temperature regulation role by providing canopy effect as well as due to the presence of soot and petroleum slick on the water surface. The combination of these environmental factors can greatly influence the abundance, diversity and community structure of biota in any give aquatic ecosystem. The work by Lancelot and Muylaert (2011) satisfactorily explains the relationships between light, temperature and turbidity in shallow estuaries which supports our finding on the negative correlation between zooplankton and water temperature in the study area. However, it could also be attributed to the phenomena of tidal action still in shallow estuaries.

Conclusion

We conclude that the species diversity and composition for zooplankton was very low when compared with the result of the phytoplankton diversity in this study. The low zooplankton composition and diversity may be attributed to the phenomenon of vertical migration in shallow water coupled with the choice of sampling which was strictly restricted to the subsurface water considering the effect of sun rays on the shallow water in terms of increasing productivity.

However, the abundance of phytoplankton and diversity is attributed to the high effect of sun light and nutrient enrichment of the shallow estuary. Nevertheless, the indiscriminate human activities such as the unregulated transportation of goods and services, shipment of petroleum fractions from an illegal local refinery at upstream (though, they have relocated their activities as at early 2017) via wooden boats including bivalve mariculture, tend to pose danger to the biodiversity sustainability, and the environmental quality. Though this study is preliminary, we advocate that a major funded survey on the biodiversity of Asarama estuary should be carried out particularly on the influence of environmental factors on the fauna and flora organisms with a broadened scope. Besides, a comprehensive study on the physicochemical oceanography of Asarama estuary is of paramount importance amidst the rapid developments in the Niger Delta of Nigeria.

It is also very important to have a formal environmental legislature in place that seeks to protect the estuary and its kinds in the region, which allows its sustainable use of the resources amongst the locals. This way, the indiscriminate human impact on the environment would be greatly reduced sustainably.

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