ORIGINAL RESEARCH

Diversity of bloom forming harmful algal species in the central Bonny estuary, Niger delta, Nigeria

Henry E. Dienye[1, *], Francis D. Sikoki[2], Geoffrey N. Woke[2] and Olaniyi A. Olopade[1]

[1]Department of Fisheries, Faculty of Agriculture, University of Port Harcourt, East/West Road, PMB 5323 - Choba, Nigeria. [2]Department of Animal and Environmental Biology, University of Port Harcourt East/West Road, PMB 5323 - Choba, Nigeria.
ORCID *Henry E. Dienye* https://orcid.org/0000-0001-6254-9179

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ABSTRACT. This study was carried out from December 2018 to November 2019 to examine the distribution and abundance of harmful algal species (HAS) in the central Bonny estuary. Seven sampling stations were established with ArcGIS tool. Microalgae species were sampled with 20 µm mesh plankton net. Nutrients were analyzed in the laboratory using the APHA 4500 Method, while physicochemical characteristics were determined *in situ*. Results revealed that environmental gradients were adequate to support life in that part of the estuary except for phosphate (2.90 ± 0.22-9.48 ± 1.06 mg l^{-1}). A total of 31 HASs categorized into 17 genera and three classes were determined: Bacillariophyceae (29 species), Chlorophyceae and Cyanophyceae (one species each). *Navicula amphibola* had the highest density (4.713 × 10^3 cells l^{-1}) while *Pinnularia divergens* recorded the lowest density (0.00049 × 10^3 cells l^{-1}). Total density values decreased across seasons with 9.157 × 10^3 cells l^{-1} in dry season and 8.907 × 10^3 cells l^{-1} in wet season. Checklist of species across stations showed that five species were distributed across the seven stations, while two were found only in Station 2 and 7. Diversity indices revealed Shannon's index ranged between 3.17 and 3.25 and species evenness ranged between 0.78 and 0.88, while Margalef range value (3.09-3.31) was considered moderately stable. Therefore, there is a need for proper management practices which could help to reduce the level of nutrient discharge into the central Bonny estuary.

Key words: Distribution, season, abundance, HAS, environmental gradients.

*Correspondence:
henry.dienye@uniport.edu.ng

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Diversidad de floraciones de especies de algas nocivas en el área central del estuario del Río Bonny, delta del Níger, Nigeria

RESUMEN. Este estudio se llevó a cabo entre diciembre de 2018 y noviembre de 2019 para examinar la distribución y abundancia de especies de algas nocivas (HAS, por sus siglas en inglés) en el área central del estuario del Río Bonny. Se establecieron siete estaciones de muestreo con la herramienta ArcGIS. Las especies de microalgas se muestrearon con una red de plancton de 20 µm de malla. Los nutrientes se analizaron en laboratorio mediante el Método APHA 4500, mientras que las características fisicoquímicas se determinaron *in situ*. Los resultados revelaron que los gradientes ambientales fueron adecuados para sustentar la vida en esa parte del estuario, excepto por el fosfato (2,90 ± 0,22-9,48 ± 1.06 mg l^{-1}). Se determinaron un total de 31 HAS categorizadas en 17 géneros y tres clases: Bacillariophyceae (29 especies), Chlorophyceae y Cyanophyceae (una especie cada una). *Navicula amphibola* tuvo la mayor densidad (4,713 × 10^3 células l^{-1}) mientras que *Pinnularia divergens* registró la menor densidad (0,00049 × 10^3 células l^{-1}). Los valores de densidad total disminuyeron a través de las estaciones con 9,157 × 10^3 células l^{-1} en la estación seca y 8,907 × 10^3 células l^{-1} en la estación húmeda. La lista de especies en las estaciones mostró que cinco especies se distribuyeron en las siete estaciones, mientras que dos se encontraron solo

en las estaciones 2 y 7. Los índices de diversidad revelaron que el índice de Shannon osciló entre 3,17 y 3,25 y la uniformidad de las especies osciló entre 0,78 y 0,88, mientras que el valor del rango de Margalef (3,09-3,31) se consideró moderadamente estable. Por lo tanto, existe la necesidad de prácticas de gestión adecuadas que podrían ayudar a reducir el nivel de descarga de nutrientes en el área central del estuario del Bonny.

Palabras clave: Distribución, estación, abundancia, HAS, gradientes ambientales.

INTRODUCTION

The estuarine ecosystem is an ecotype affected by sea inflow and neighboring freshwater, which results in high levels of nutrients in the water body (Jha et al. 2014). According to Kress et al. (2002), estuaries are places for human settlements and activities (shipping, urban and industrial waste) making them vulnerable to changes caused by pollution, climate change and overfishing, which in turn alter the water body's productivity. Dynamics in biological populations, especially planktonic communities, represent variations in physical and chemical processes in estuaries (Marques et. al. 2007).

Harmful algal blooms (HABs) have become the preferred scientific term instead of red tides because these outbreaks have no connection to the tides and may or may not color the water red (Sverdrup et al. 2003). Additionally, some algae species may bloom and color water, which is not harmful. HABs are thus defined as high propagation of algae, ensuing transformation. Such algae have the probability of producing toxins (Boesch et al. 1997).

Approximately 300 algal species are said to cause these blooms. It is understood that almost one-fourth produce toxins (IOC 2015). A very small number remains potentially harmful, which can pollute aquatic organisms through contaminants resulting in health problems in human beings, as well as multiplying and changing habitats in ways that may be considered unfavorable to them (Brand et al. 2012). Under the right conditions, these groups of algal species form an algal bloom provided that sufficient nutrients, water column steadiness, enough light and ideal temperatures are present (Hall et al. 2013). Nutrient enrichment is the key mechanism through which fertilizer or nutrient loads of nitrates and phosphates are discharged into a waterbody, such as livestock farming waste (Larsson et al. 1985) and industrial or municipal waste (Larsson et al. 1985; Gilbert et al. 2005). Runoffs transport these nutrients through river systems and eventually to marine or freshwater systems. Many algal blooms can damage aquatic species, and adverse blooms are the result of an occasional accumulation of toxic algae which can create hypoxic conditions, producing damaging effects on aquatic ecosystems (Gilbert et al. 2005).

Several new bloom species are assumed to follow the discovery of concealed flora communities (Smayda 1998) that had been there for years in these lakes, but were not identified as detrimental until more subtle toxin-revealing techniques or an increase in the measurement and teaching of observers were employed (Anderson et al. 1994). The coastline is vulnerable to HABs, particularly enclosed embayments, due to urbanization, tourism, and industrial waste (Anderson et al. 2002; Sellner et al. 2003). Furthermore, the flow of water, relaxation, and development of cysts are factors in the creation of blooms (Sellner et al. 2003). There are several environmental factors (both physical and chemical), including nutrient availability and temperature changes, which are being described as important drivers to harmful algal species diversity (Giannuzzi et al. 2012). The aim of this study was to assess the diversity of bloom forming harmful algal species in the central Bonny estuary of the Niger delta.

MATERIALS AND METHODS

Study area

The Bonny estuary is among the numerous low-land coastlines of the Niger delta complex. It is located between 4° 25′ and 4° 50′ N latitude and 7° 0′ and 7° 15′ E longitude in Rivers State of Nigeria (Figure 1). It extends in length to about 180 km from its mouth to the upper limits of saline influence. It is mainly brackish and consists of a main river channel and creek. The Bonny estuarine channel has the highest tidal flow of all river systems, which is influenced mostly by tidal movements. The Bonny estuary extends from the mouth of the estuary (lowest reach) close to the Atlantic Ocean, where salinity is > 30 in dry season and about 28 in rainy season, to the uppermost reaches of the Iwofe area, where salinity is < 5 and < 3, respectively (Dangana 1985).

Sampling stations

Seven geo-referenced stations were set up along the estuary course using the ArcGIS tool, through a reconnaissance preliminary survey: Station 1 (Nembe waterside), Station 2 (Ebetu), Station 3 (Isaka open river), Station 4 (Isaka main town), Station 5 (Back of Ibeto cement), Station 6 (Macoba), Station 7 (NPA dockyard) (Figure 1).

Sample collection, preparation and analyses

Samplings were carried out at low tide in seven geo-referenced stations previously described. Surface water hauls, collected in triplicate at various sampling stations by filtering 100 l of surface water over a 20 µm phytoplankton net. For analysis and identification (Hansen 2002), they were kept in 15 cm Nalgene storage bottles. Fifty percent were preserved immediately using 2% formaldehyde while the other 50% (live samples) were stored in an insulated box to prevent rapid

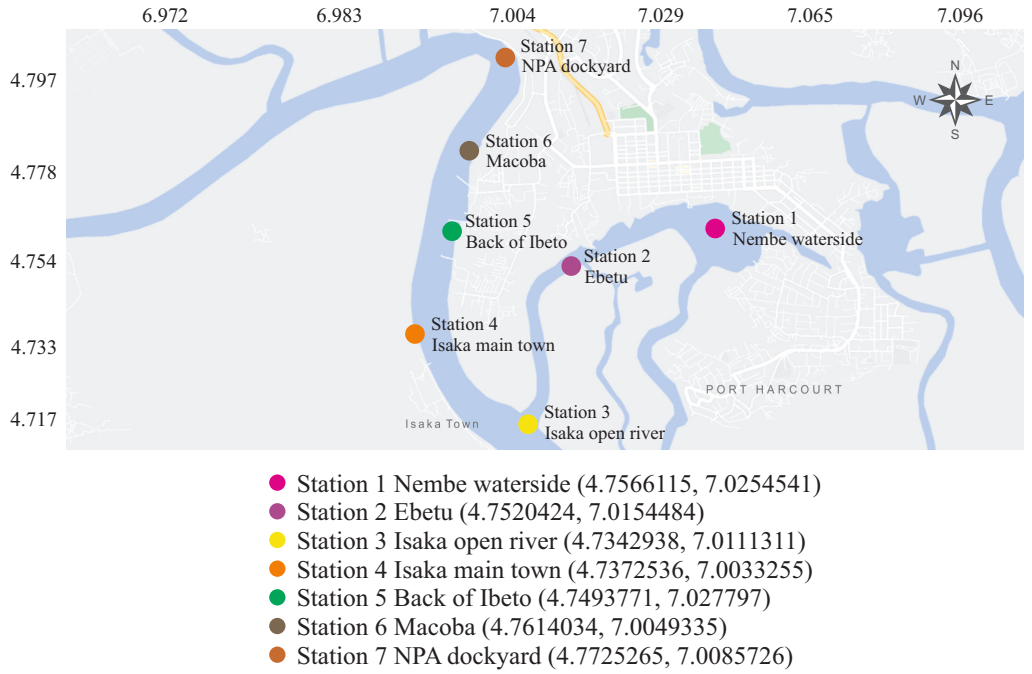

Figure 1. Study area indicating sampling stations in central Bonny estuary, Niger delta.

temperature change (IOC 2015). Temperature, salinity, Total Dissolved Solids (TDS), pH and DO were measured *in situ* with a Horiba water checker (Model Extech D0700) at each sampling location. Triplicate surface water samples for nutrients (phosphate PO_4, nitrate NO_3, nitrite NO_2, and sulphate SO_4) were collected at neap tide at a depth of 5 cm with pre-cleaned plastic container, kept in ice-chest box and taken to the laboratory for further nutrient analysis. Laboratory determination of nutrients followed the standard procedures of water and wastewater analysis of the American Public Health Association for PO_4, NO_3, NO_2 and SO_4 (APHA 2012).

Enumeration of harmful algal species

Microalgae were counted using the Lackey Drop Micro-transect Counting Method (APHA 1998). The sample was mixed well before subsampling a drip of 0.05 ml onto a glass-slide in triplicate with cover-slip. The processed volume and the number of observed microalgae were known in a given volume; their abundance was counted with a low power objective with an inverted microscope (Leica DMIL). Microphotographs of harmful algae were taken by employing a camera fixed to the microscope. Identification of algae was done by following references of Taylor (1987), Hallegraeff et al. (1995), and Tomas (1997). Density was calculated as:

$$\text{Number (No) individuals ml}^{-1} = \frac{C \times TA}{A \times S \times V}$$

where, C = number of organisms counted; TA = area of the cover slip, mm^2 ; A = area of one strip, mm^2; S = number of strips counted; and V = volume of sample under the cover slip, ml.

Data analysis

Physicochemical and nutrient parameters of samples were analyzed using one-way analysis of variance of SPSS version 20. Fixed effect ANOVAs were done in replicates. Tukey HSD was used to separate the mean differences at a 95% confidence interval ($p < 0.05$). Spatial variation of the various environmental parameters and harmful algal species across the season was done using the T-test. The diversity of HAS in the estuary was calculated with harmful algal species abundance, using the PRIMER software version 6.1.6 (Clarke and Gorley 2006).

Simpson's diversity indices

The term Simpson's diversity index is any of three (3) closely related indices (Simpsons 1949).

- Simpson's Diversity Index (D): it measures the possibility of randomly picked individuals from a sample:

$$D = \sum (n/N)^2$$

$$D = \frac{\sum n(n-1)}{N\,(N-1)}$$

- Simpson's Diversity Index 1-D: here, the index denotes possibility of entities randomly picked in a sample.
- Simpson's Reciprocal Index 1/D: it represents a community of one species and a higher value.
- Shannon-Weiner Diversity Index (H'): the level of uncertainty of forecasting a random sample is associated to a community. Community with one species (low diversity) (Shannon and Wienner 1963):

$$H' = -\sum p_i \, \text{In}P_i$$

where p_i is the proportion of individuals of the *i* species.

Species richness (S) is a total number of dissimilar species in an area. It is intensely hooked

on sample size and strength (Begon et al. 1990):

- Margalef's Diversity Index:

$$Dmg = \frac{S\text{-}1}{InN}$$

- Menhinick's Diversity Index:

$$DMn = \frac{S}{\sqrt{N}}$$

RESULTS

Results from physicochemical parameters and seasonal variation of the surface water from the sampled sites in the central Bonny estuary revealed that there was a significant a difference in pH, DO and turbidity ($p < 0.05$), while temperature, salinity, BOD, conductivity and TDS showed no significant difference ($p > 0.05$) across stations. Mean values of pH, DO, salinity, BOD, conductivity, and TDS decreased across the season (dry to wet), while temperature and turbidity values increased across the season (dry to wet) (Table 1).

Nutrient composition of sampled sites from the central Bonny estuary indicated that there was a significant difference across stations ($p < 0.05$). PO_4 and NO_3 decreased across seasons (dry to wet), while NO_2 and SO_4 increased from dry to wet season. Nitrate and sulphate showed significant differences ($p < 0.01$ and $p < 0.05$, respectively) across seasons (Table 2).

Three classes of major groups were represented in the samples: Bacillariophyceae, Chlorophyceae and Cyanophyceae, with 15 genera and 31 species (Table 3). Families Pinnulariaceae and Stephanodiscaceae recorded two species each; Pleurosigmataceae and Coscinodiscaceae recorded three

Table 1. Physicochemical parameters at different stations and seasons in the central Bonny estuary. T: temperature, DO: dissolved oxygen, BOD: biological oxygen demand, COND: conductivity, TDS: total dissolved solids.

Station	pH	T (°C)	DO (mg l^{-1})	Salinity	BOD (mg l^{-1})	COND (µS cm^{-1})	Turbidity (NTU)	TDS (mg l^{-1})
1	6.85 ± 0.09^{a}	29.97 ± 0.71^{a}	4.97 ± 0.37^{b}	15.09 ± 1.41^{a}	2.36 ± 0.09^{a}	21.39 ± 2.39^{a}	7.17 ± 1.02^{a}	19.57 ± 9.30^{a}
2	7.11 ± 0.07^{b}	29.48 ± 0.82^{a}	4.64 ± 0.36^{ab}	16.20 ± 0.98^{a}	2.12 ± 0.19^{a}	20.82 ± 2.32^{a}	7.31 ± 0.57^{a}	17.44 ± 2.33^{a}
3	7.26 ± 0.05^{ab}	28.97 ± 0.56^{a}	4.46 ± 0.28^{ab}	19.40 ± 2.40^{a}	2.49 ± 0.18^{a}	25.19 ± 3.51^{a}	9.90 ± 1.07^{b}	18.34 ± 2.24^{a}
4	7.26 ± 0.05^{ab}	28.95 ± 0.58^{a}	4.39 ± 0.35^{ab}	19.47 ± 2.29^{a}	2.30 ± 0.21^{a}	25.24 ± 3.46^{a}	10.45 ± 1.02^{b}	18.33 ± 2.31^{a}
5	7.32 ± 0.20^{c}	28.96 ± 0.50^{a}	3.89 ± 0.16^{a}	18.24 ± 2.22^{a}	2.42 ± 0.21^{a}	24.21 ± 3.04^{a}	6.06 ± 0.65^{a}	17.16 ± 2.44^{a}
6	7.34 ± 0.05^{c}	29.07 ± 0.53^{a}	3.97 ± 0.17^{a}	18.88 ± 2.04^{a}	2.42 ± 0.13^{a}	24.27 ± 3.11^{a}	5.20 ± 0.63^{a}	18.67 ± 2.24^{a}
7	7.35 ± 0.05^{c}	28.96 ± 0.54^{a}	4.32 ± 0.20^{ab}	17.81 ± 1.59^{a}	2.34 ± 0.13^{a}	22.84 ± 2.67^{a}	7.20 ± 0.35^{a}	16.87 ± 2.21^{a}
Season								
Dry	7.39 ± 0.03	28.32 ± 0.39	5.10 ± 0.20	24.10 ± 1.24	3.00 ± 0.08	29.91 ± 1.10	5.42 ± 0.29	19.20 ± 1.60
Wet	7.08 ± 0.03	29.85 ± 0.25	3.97 ± 0.77	13.20 ± 0.33	1.83 ± 0.06	14.84 ± 1.0	19.26 ± 0.50	17.20 ± 0.85
t value	6.94	3.481	6.762	9.55	11.97	13.32	6.094	1.178
p value	0.62	0.00*	0.00*	0.00*	0.00*	0.22	0.13	0.00*

Superscripts of the same alphabet are not significantly different across the column ($p > 0.05$). Superscripts of different alphabets are significantly different ($p < 0.05$).

Table 2. Nutrients (phosphate PO_4, nitrate NO_3, nitrite NO_2, and sulphate SO_4) across stations and seasons in the central Bonny estuary.

Station	PO_4 (mg l^{-1})	NO_3 (mg l^{-1})	NO_2 (mg l^{-1})	SO_4 (mg l^{-1})
1	3.14 ± 0.2^{a}	0.72 ± 0.07^{a}	0.0034 ± 0.0004^{a}	$1{,}010.43 \pm 9.02^{c}$
2	2.90 ± 0.22^{a}	2.62 ± 0.92^{b}	0.0039 ± 0.0007^{a}	$1{,}026.14 \pm 6.32^{c}$
3	3.70 ± 0.25^{a}	0.53 ± 0.04^{a}	0.0046 ± 0.0007^{a}	967.90 ± 9.20^{a}
4	6.71 ± 0.53^{b}	0.66 ± 0.06^{a}	0.0048 ± 0.0003^{a}	978.81 ± 6.76^{ab}
5	9.48 ± 1.06^{c}	0.71 ± 0.06^{a}	0.0067 ± 0.0003^{b}	$1{,}004.10 \pm 14.03^{bc}$
6	3.73 ± 0.24^{a}	0.54 ± 0.04^{a}	0.0043 ± 0.0002^{a}	$1{,}029.62 \pm 10.19^{c}$
7	5.40 ± 0.67^{b}	0.49 ± 0.08^{a}	0.0043 ± 0.0006^{a}	962.381 ± 6.43^{a}
Season				
Dry	4.68 ± 0.548	1.12 ± 0.33	0.0044 ± 0.0003	974.06 ± 6.03
Wet	5.26 ± 0.32	0.73 ± 0.03	0.0047 ± 0.0002	$1{,}014.30 \pm 4.54$
t value	1.059	1.371	0.601	5.439
p value	0.11	0.00**	0.13	0.02*

Superscripts of the same alphabet are not significantly different ($p > 0.05$). Superscripts of different alphabets are significantly different ($p < 0.05$).

*Significant at $p < 0.05$

**Significant at $p < 0.01$

species each; Naviculaceae recorded six species; Triceratiaceae recorded five species; and Bacillariaceae recorded four species, while other families recorded one species each. Class Bacillariophyceae had 29 species, while Chlorophyceae and Cyanophyceae recorded one species each.

The Family Naviculaceae had the highest density followed by Bacillariacea, while the Family Microcoleaceae recorded the least density (Figure 2). *Navicula* spp. recorded the highest percentage (19%) followed by *Nitzschia* spp. (12%), while the lowest (1%) was recorded for *Thalassiosira eccentrica* (Figure 3). Mean cell density plotted against species in the study area indicated that *N. amphibola* recorded the highest mean abundance (4,714.38 cells l^{-1}), followed by *N. dicephala* (4,603 cells l^{-1}), while *Pinnularia divergens* (4.9 cells l^{-1}) recorded the lowest abundance (Figure 4). Abundance across seasons indicated that 17 species decreased with season (dry to wet), while 11 species increased across seasons (dry to wet). Two species (*Gyrosigma stigma* and *P. divergens*) recorded mean value only during the dry season, while only one species (*N. hybrida*) recorded mean values in the wet season (Figure 5). Total density values increased across season with 9,157 cells l^{-1} and 8,907 cells l^{-1} in dry and wet seasons, respectively. The Class Bacillariophyceae recorded the highest percentage composition of harmful algal taxa (75%), followed by the Class Chlorophyceae (15%), and the Class Cyanophyceae (10%).

Cyclotella meneghiniana, *Cymbella turgidula*, *Diploneis finnica*, *N. amphibola* and *Tretraedron tumidulum* were fairly distributed across the seven sampling stations, while two species, *P. divergens*, *N. hybrida* were the least distributed harmful algal species in stations 2 and 7, respectively (Table 4). Diversity indices showed that the highest taxa value (31) was recorded in Station 4 and the least taxa value (29) was recorded in Sta-

Table 3. Harmful algal species (HAS) composition in the Central Bonny estuary.

Class	Family	Species
	Cymbellaceae	*Cymbella turgidula* (Grunow, 1875)
	Pinnulariaceae	*Pinnularia undulata* (Sensu Cleve, 1891)
		Pinnularia divergens (W. Smith, 1853)
Bacillariophyceae	Naviculaceae	*Navicula amphibola* (Cleve, 1891)
		Navicula dicephala (Ehrenberg, 1838)
		Navicula oblonga (Kützing, 1844)
		Gyrosigma fasciola (Griffith and Henfrey, 1856)
		Gyrosigma stigma (Hassall, 1845)
		Gyrosigma acuminatum (Rabenhorst, 1853)
	Catenulaceae	*Amphora holsatica* (Hustedt, 1925)
	Tabellariaceae	*Asterionella japonica* (Cleve and Möller, 1882)
	Diploneidineae	*Diploneis finnica* (Cleve, 1891)
	Stephanodiscaceae	*Cyclotella antigua* (Smith, 1853)
		Cyclotella meneghiniana (Kützing, 1844)
	Bacillariaceae	*Nitzchia hybrida* (Cleve and Grunow, 1880)
		Nitzchia sigma (Smith, 1853)
		Nitzchia vermicularis (Hantzsch, 1860)
		Bacillaria paxillifera (Muller and Hendy, 1951)
	Surirellaceae	*Surirella robusta* (Ehrenberg, 1841)
	Pleurosigmataceae	*Pleurosigma elongatum* (Smith, 1852)
	Coscinodiscaceae	*Coscinodiscus concinnus* (Smith, 1856)
		Coscinodiscuss granni (Gough, 1905)
		Coscinodiscuss radiatus (Ehrenberg, 1840)
	Triceratiaceae	*Odontella aurita* (Agardh, 1832)
		Odontella longicruris (Hoban, 1983)
		Odontella mobiliensis (Grunow, 1884)
		Odontella sinensis (Grunow, 1884)
		Triceratium favus (Ehrenberg, 1839)
	Thalassiosiraceae	*Thalassiosira eccentrica* (Cleve, 1904)
Chlorophyceae	Clorococcaceae	*Tretraedron tumidulum* (Hansgirg, 1889)
Cyanophyceae	Microcoleaceae	*Microcystis aeruginosa* (Kützing, 1846)

tion 2, while taxa values of 30 were recorded in Stations 1, 3, 5, 6, and 7 (Table 4). The number of individuals with the highest value (9,625) was observed in Station 7, while the lowest value (8,496) was reported in Station 2. The highest value of dominance D (0.049) was reported in Station 4, followed by 0.048 in Station 2, while the lowest value (0.043) was reported in Stations 2 and 7. The Shannon index with the highest value (3.25) was reported in Station 7, followed by Stations 2 and 6 (3.23), while the lowest value (3.17) was reported in Station 3. The highest

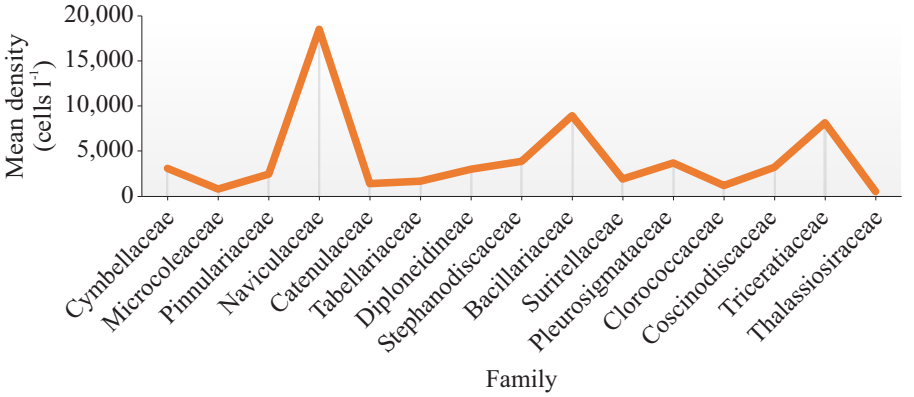

Figure 2. Mean density of harmful algal family in the central Bonny estuary.

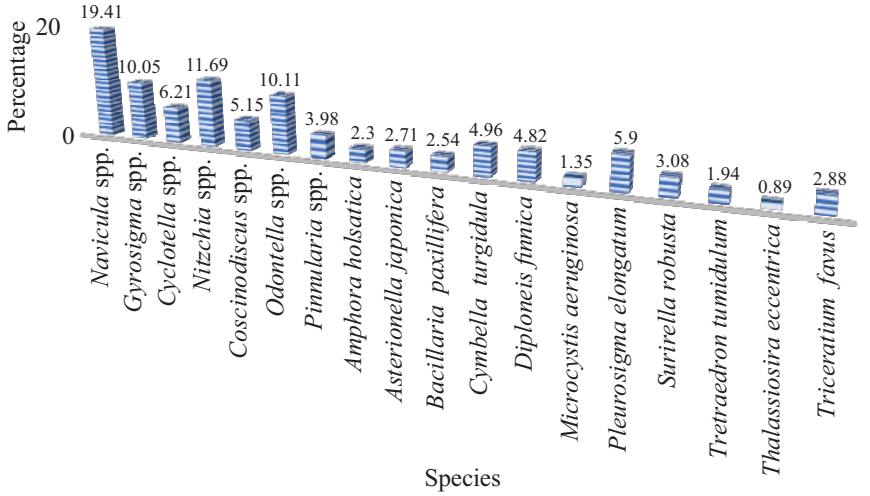

Figure 3. Percentage composition of harmful algal species (HAS) in the central Bonny estuary.

value of evenness (0.88) was registered in Station 2, followed by 0.86 in Station 7, while the least value (0.78) was reported in Station 4. The highest Margalef value (3.31) was reported in Station 4, followed by 3.19 in Station 5, while the least value of 3.09 was reported in Station 2 (Table 4).

DISCUSSION

The pH reported in the central Bonny estuary was well within the preferred pH range limits of 6.5 to 9.0 for optimal fish and aquatic life (Boyd and Lichktopller 1979) recommended by the World Health Organization (WHO 2008). Vincent-Akpu and Nwachukwu (2016) reported a pH value of 7.7 ± 0.1 in Bonny. Valsaraj et al. (1995) reported increased pH on days of extreme photosynthetic activity. The seasonal difference in pH values recorded was in line with results of earlier studies conducted by Dublin-Green (1990) in the Bonny estuary, where lower values of pH were recorded in the rainy season. However, studies by Nweke (2000), Ebere (2002), and Clarke (2005) registered higher pH in the dry season than in the wet season.

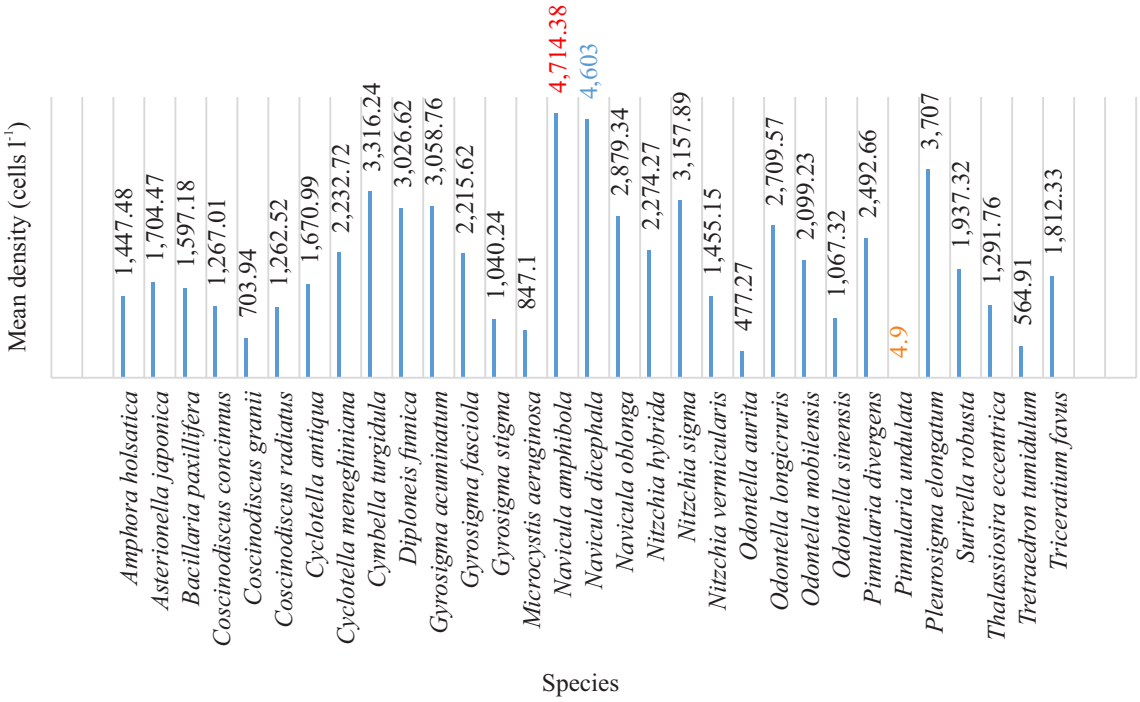

Figure 4. Abundance of harmful algal species (HAS) in the central Bonny estuary.

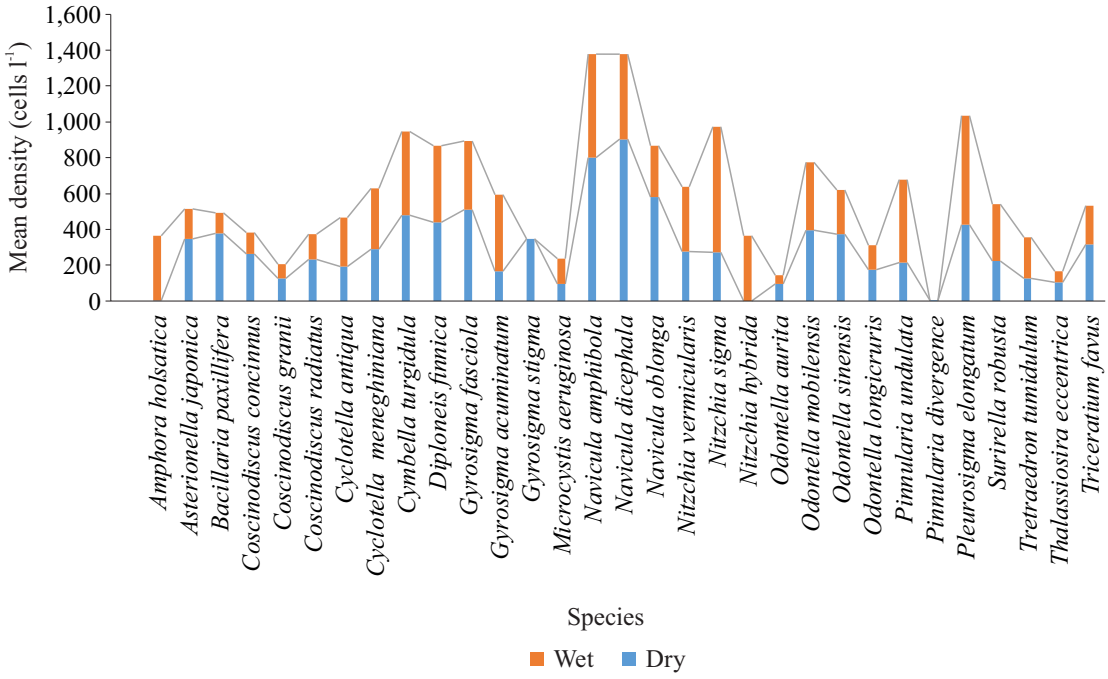

Figure 5. Mean density of harmful algal species (HAS) across seasons in central Bonny estuary.

Table 4. Checklist and diversity of harmful algal species (HAS) in the central Bonny estuary.

	Station						
Species	1	2	3	4	5	6	7
Bacillariophyceae							
Amphora holsatica	-	+	-	+	+	+	+
Asterionella japonica	+	-	+	+	-	+	-
Bacillaria paxillifera	+	+	+	+	-	-	+
Coscinodiscus concinnus	+	+	+	+	+	-	+
Coscinodiscus granii	+	+	-	-	+	-	+
Coscinodiscus radiatus	+	+	+	+	+	-	+
Cyclotella antiqua	+	+	+	+	+	+	-
Cyclotella meneghiniana	+	+	+	+	+	+	+
Cymbella turgidula	+	+	+	+	+	+	+
Diploneis finnica	+	+	+	+	+	+	+
Gyrosigma fasciola	-	+	+	+	+	-	-
Gyrosigma acuminatum	+	-	-	-	+	-	+
Gyrosigma stigma	+	+	-	-	-	-	-
Navicula amphibola	+	+	+	+	+	+	+
Navicula dicephala	+	+	+	+	-	+	-
Navicula oblonga	+	-	+	+	+	-	+
Nitzchia vermicularis	+	-	+	+	+	+	+
Nitzchia sigma	-	+	+	+	+	+	-
Nitzchia hybrida	-	-	-	-	-	-	+
Odontella aurita	+	-	-	-	-	-	+
Odontella mobilensis	+	-	+	+	-	+	+
Odontella sinensis	+	-	+	-	+	+	-
Odontella longicruris	-	+	-	-	-	+	-
Pinnularia undulata	+	-	+	+	+	+	+
Pinnularia divergens	-	+	-	-	-	-	-
Pleurosigma elongatum	+	-	+	+	+	+	+
Surirella robusta	+	+	-	-	+	+	+
Thalassiosira eccentrica	+	-	+	+	+	+	+
Triceratium favus	+	-	+	+	+	+	-
Chlorophyceae							
Tretraedron tumidulum	+	+	+	+	+	+	+
Cyanophyceae							
Microcystis aeruginosa	-	-	+	+	+	-	-

Table 4. Continued.

	Station						
	1	2	3	4	5	6	7
Taxa_S	30	29	30	31	30	30	30
Individuals	9,282	8,496	8,832	8,628	8,903	9,237	9,625
Dominance_D	0.046	0.043	0.048	0.049	0.045	0.044	0.043
Shannon_H	3.21	3.23	3.17	3.19	3.22	3.23	3.25
Evenness_e^H/S	0.83	0.88	0.79	0.78	0.83	0.84	0.86
Margalef	3.17	3.09	3.19	3.31	3.19	3.18	3.16

Temperatures across stations and seasons were normal with reference to their location in the Niger delta. Ansa (2005) stated between 25.9 °C and 32.4 °C. Uedema-Naa et al. (2011) reported a range between 28.94 °C and 29.72 °C. Vincent-Akpu and Nwachukwu (2016) measured temperatures of 28.0 ± 0.5 °C in Bonny. Onwugbuta-Enyi et al. (2008) reported DO values ranged from 4.6 to 11.8 mg l^{-1}. These findings are in contrast with the results of this study, which may be due to seasons. Davies et al. (2008) also stated reduced DO in the wet season as compared to the dry season and attributed it to a decrease in photosynthetic events of algae, which agrees with the result of this study. The reason for the reduced mean DO values was attributed to the turbidity of the water due to influxes from run-offs and degeneration of waste in the water. Water with DO above 6 mg l^{-1} will sustain fish and desirable forms of aquatic biota, whereas water with 2 mg l^{-1} DO will support mainly decomposers.

The present salinity and conductivity records showed a similar trend within the acceptable range for coastal waters. Chindah and Nduaguibe (2003) obtained salinity values from 11.5 ± 1.8 to 20.3 ± 3.0 in the lower Bonny. Clarke (2005) registered higher salinities in the dry season than in the wet season, which is in line with the results of this study. Dibia (2006) described conductivity values increasing during the dry season due to absorption of ions. Values of BOD recorded in the study are within the tolerable range for aquatic environments (WHO 2008). Vincent-Akpu and Nwachukwu (2016) reported a lower value of 2.80 mg l^{-1} in Nembe and 2.50 mg l^{-1} in Bonny estuary. Also, the observation of Braide et al. (2004) on water quality in the Eastern Niger delta showed that the BOD load in this study did not pose a hazard to the aquatic environment. Boyd (1981) reported that turbidities in natural waters rarely go beyond 20,000 mg l^{-1} and even muddy waters frequently have less than 2,000 mg l^{-1}. Also, the observed turbidity level in this study corroborates the range of 2 NTU to 47 NTU stated by Asonye et al. (2007). Turbidity from plankton is not harmful to fish when it is at a mild level. Fish harvesting is made easier as they are less suspicious (Swann 2006). Roelke et al. (2007) reported that stability of light energy is expected to regulate algae ecosystem structure. Vincent-Akpu and Nwachukwu (2016) reported TDS values of 13.1 mg l^{-1} in Nembe and 14.9 mg l^{-1} in Bonny estuary. The higher total dissolved organic solid concentration observed in this study may be ascribed to high surface runoff, overland flow, as well as higher release of organic wastes into the river.

Higher phosphate values were recorded in the wet season than in the dry season, which is in contrast with the findings of Chinda and Braide (2001), who reported higher phosphate in the dry season. This may be ascribed to the higher biomass of phytoplankton and epiphyton in the wet season. Natural inputs from decay of organic matter might be a contributor to the high phosphate levels in this estuary. Davies et al. (2009) and Davies (2013) recorded a higher nitrate value in the dry season than in the wet season, which is in line with the finding of this study and might be ascribed to high anthropogenic inputs. Nitrate does not pose a health threat, but it is readily reduced to nitrite by the enzyme nitrate reductase, which is widely distributed and abundant in both plants and microorganisms (Glidewell 1990).

Abowei et al. (2012) reported algae families including Baccillariophyceae, Dinophyceae, Chlorophyceae, and Cyanophyceae along the shor eline of Koluoma Creek in Bayelsa. Baccillariophyceae were the dominant and constituted 60% of the phytoplankton biomass. Babu et al. (2013) recorded 101 phytoplankton species on India's East-west coast, in which 76 species corresponded to Bacillariophyceae, 17 to Dinophyceae, 5 to Cyanophyceae, 2 to Chlorophyceae), and 1 to Chrysophyceae.

According to Elliot (2010) the distribution pattern of phytoplankton of Black Volta waters in Ghana showed that all species, except two species of *Euglena* sp. and *Phacu spyrum* (Euglenophyceae), were fairly distributed in the four hydrological seasons. He further stated that the impoundment of Black Volta might, however, be the main factor responsible for the discontinuous seasonal distribution of *Euglena* sp. and *P. spyrum* observed in the study. The result was similar to other research indicating that Bacillariophyceae were the dominant genera in water samples (Badsi et al. 2012). Abubakar (2009) stated that in tropical regions, dry and rainy seasons showed distinct fluctuations with an abundance of algae. Swann (2006) reported that algae was among the reasons for turbidity, as high turbidity during the rainy season was probably attributed to runoff. Iqbal et al. (1990) reported that monthly variability in algal population resulted in major seasonal disparity in the physicochemical parameters in Hub Lake. The higher abundance during the wet season was due to nutrients and the water level at the time. This finding is in contradiction to the results of this study. Total density values decreased across seasons, with 9.157×10^3 cells l^{-1} and 8.907×10^3 cells l^{-1} recorded in the dry and the wet season, respectively. Seasonal differences in algal abundance in the dry season have also been reported by Erondu and Chinda (1991) and Ogamba et al. (2004) in the Niger delta. Indabawa and Abdullahi (2004) also recorded higher algal cells in the dry season than in the rainy season.

Diversity is dependent on key ecological practices such as competition, predation and succession, therefore, changes in these processes can alter the species diversity index through modifications in evenness (Stirling and Wilsey 2001). According to the classification of the Shannon-Wiener index, if the diversity index is lower than 1, then biota communities would be regarded as unstable, whereas a diversity index of 1-3 would be considered moderately stable, and a value higher than three would signify a stable or prime condition (Mokoginta 2016). Shannon-Wiener indices above three recorded in most of sampled stations confirmed that these stations were moderately stable and not under pollution stress, suggesting that central Bonny estuary is relatively vulnerable to environmental changes. Ofonmbuk and Lawrence (2015) reported low Margalelf's diversity values from 2.871 to 3.513 in the Qua Iboe estuary. This was similar to 2.93 reported by Ogbuagu and Ayoade (2012), which is in agreement with the findings of this study. This indicated that the harmful algal community was stable among seasons in the study area. Minimal variations in the density of harmful algal species as reflected by Shannon-Wiener, Pielous evenness, and Margalef species richness, may be ascribed

to uniform physical and chemical conditions (Ogamba et al. 2004). The high diversity of values could be attributed to the influence of bunkering activities, which are highly likely in the estuary, as also reported by Adesalu and Nwankwo (2008).

CONCLUSIONS

This study provides clear information regarding the level of diversity and environmental gradients in relation to species abundance and distribution in the central Bonny estuary. Observed cell densities serve as an early warning for future bloom occurrences of potential impacts if the density increases significantly beyond a determined threshold. In addition to effective education, dissemination, and communication of the available information, there is a need for an adequate monitoring program warning on the formation of harmful algal blooms which requires easy regulation of the aquatic resource in the central Bonny estuary.

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Declaration of interest

The authors declare that there is no conflict of interest.

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