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Preliminary survey of harmful algal species in the Bonny Estuary, Niger delta, Nigeria

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Abstract

A preliminary survey of harmful algal species in the Bonny Estuary was conducted in the Dry Season (October to December) 2017, to enhance ecosystem-based management strategies for harmful algal blooms; through HAB detection**.** The experimental approach includes: the deployment of an ACRC GIS tool to select nine geo-reference stations; the collection of plankton samples with the plankton net to provide a qualitative account of harmful algae and a horiba water checker to investigate the physico-chemical characteristics of the Estuary. The result obtained, revealed some level of variability between the physico-chemical parameters and the stations. However, the values of the physicochemical parameters recorded ranged from 29.53 ºC to 32.30 ºC; 7.66 mg/l to 12.73mg/l; 6.66 to 7.23; 5.53ppm to 14.16ppm and 4.10ppt to 10.20ppt for water temperature, dissolved oxygen, pH, total dissolved solid and salinity respectively in the nine stations. The harmful algae recovered were a total of three classes, representing twelve genera and 12 species. Bacillariophyceae had the highest number of species (10) while Chlorophyceae and Cyanophyceae recorded the lowest number of species (1). This study therefore, provided evidence of the presence of harmful algae in the Bonny Estuary. However, the potential of these algae to cause harm either through the production of toxins or excessive accumulations of biomass is triggered by the type of strain, physico-chemical variables, and biogeography of the area. Thus, the need to plan adequate monitoring programs to develop early warning systems and models for short term forecast of Harmful Algal Blooms is highly recommended.

Keywords: Harmful algae; Bonny Estuary; Physico-chemical parameters.

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1. Introduction

Harmful Algal Blooms (HABs) are increasingly spreading to all the oceans of the world; Coastal seas; estuaries and lagoons. In addition to this biogeographic status, HABs also exhibit an increase in frequency and magnitude (Taylor *et al.,* 1995; Boesch *et al.,* 1997; Anderson *et al.,* 2001) which is enhanced by a variety of human activities. A limited number of microalgae; about 60-80 species or 2% of the world flora (Sournia, 1995), may be considered harmful, as they are capable of producing toxins and some other harmful effects, which may result in human and/or marine faunal intoxication (Hansen *et al*., 2001). Although the number of harmful species is low, their impact on the marine environment may be very significant or even catastrophic, leading to marine mortality including maricultured species during events of mass development (bloom) of the harmful algal species.

Evidence from research in most countries of the world has shown that Harmful Algal Blooms (HABs) can exhibit acute and chronic toxicity to man and animals through contact with infested water. Despite available records from other countries in the world (Carmichael *et al.,* 1988; Falconer, 1993; Wayne *et al.,* 2001), including South Africa (Fawcett *et al.,* 2006; Scott, 1991), there is scanty information on the occurrence of HABs, their toxins and effects on seafood, man and other animals in Nigeria (Chai *et al.,* 2009).

When favorable environments coincide to induce (HABs) they produce toxins around stages of food chain which are successively used up by humans resulting to death. Different environmental factors are accountable for HAB. They include increase in temperature, rainfall, and discharge of nutrients in water. Toxins are released when the cell tissue splits causing the blow-out of toxins in water strata. (Epa, 2012). Over past decades, there has been an immense increase of diatoms and dinoflagellate blooms in Oman and Arabian Sea (Al-Azri *et al*., 2007; Gomes *et al*., 2008). Diatoms blooms, dominated by *Pseudo-nitzschia*, with low concentrations (Al-Hashmi *et al*., 2012).

In Nigeria, previous studies on HABs did not capture the Bonny Estuary which is known for its great economic importance; a site for multidisciplinary research; and the indigenous populaces depend solely on it for living and non-living resources. This study was therefore imperative to enhance ecosystem-based management strategies for harmful algal blooms (aimed at preventing HABs before they occur; mitigating their effects and controlling them if they occur) through the rapid detection of harmful algal species.

2. Materials and methods

2.1. Study area

2.1.1 Description of study area

The Bonny Estuary is one of the numerous low land coastal waters 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 River State, Nigeria (Figure 1). Like most other rivers in this region, it is short, extending to approximately 180km from its mouth. It is mainly brackish with very little freshwater discharge, mostly from the New Calabar river system, and consists of a main river channel and a large number of associated creeks and cree-lets. The Bonny Estuarine system (maximum width of 2 km and maximum depth of approximately 15 m near the mouth) has the largest tidal volume of all river system in the Niger Delta and it is mostly affected by tidal movement. The climate of the study area, located in the Bonny Estuary, is tropical and marked by two distinct seasons, the dry season (November-March), and the wet season (April-October). Annual rainfall in the area is about 2405.20mm Annual mean air temperature is 29.7 ˚C with the highest monthly mean temperature at 31.3 ˚C (in August), and the lowest monthly mean temperature at 27.5˚C (in January). The surface seawater temperature varies between 25.9 ˚C and 30.6 ˚C, and the salinity of the surface water varies between 8‰ and 20‰ (Hart and Chindah, 1988). The sampling stations are shown in Figure 1. A total of nine stations were sited at 1000 m interval along the Bonny Estuary.

2.1.2 Sample Collection, Preparation, and Analyses

Samples were collected from nine geo-reference stations using the ACRC GIS tool. Surface water hauls was taken for plankton samples at the various sampling stations using a 20µm-mesh phytoplankton net (Hansen *et al*., 2001) and stored in a 15cm Nalgene bottles. About 50% of the samples were preserved immediately using 2% formaldehyde as described by the IOC manual while the other 50% (live samples) were stored in an insulated box to prevent rapid temperature change. Physico-chemical parameters such as: Temperature (Temp.), Salinity, pH, Dissolved Oxygen (DO) and Total Dissolved Solids (TDS) was measured in-situ using a water checker Model: Extech D0700 at each sampling location. All samples were transported to the laboratory for preparation and analyses.

Microphotographs of Harmful algae of interest were taken by employing a camera fixed at the top of the microscope. Various soft copy reference materials were used to identify the harmful algae; Steidinger *et al*. (1967); Dodge (1982); Taylor (1987); Hallegraeff (1995), and Tomas (1997).

Statistical analysis was done, using Statistical Package for Social Science (SPSS) 16.0 windows for One-way analysis of variance (ANOVA) while the means were separated using

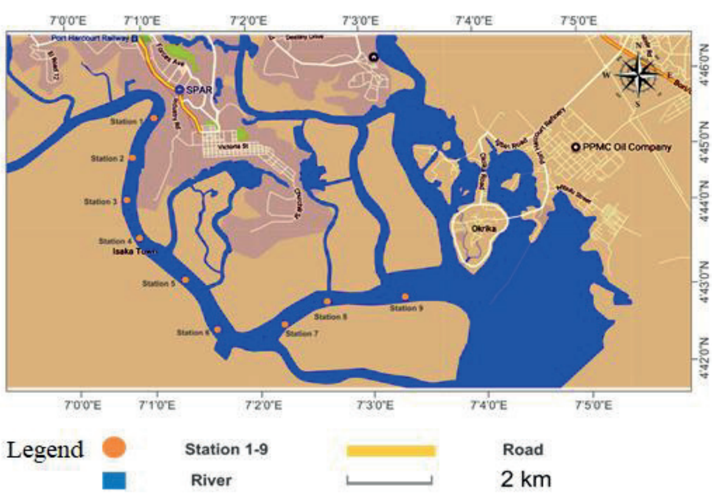


Figure 1. Map of the study area showing the sampling stations (Field Survey, 2017)

Duncan multiple range test for interpretation of data obtained from the study.

3. Results

The Physico-chemical parameters, Table 1 below showed that the highest temperature value was recorded in Station 1 (32.30 ºC) and the lowest in Station 9 (29.53 ºC) while highest Dissolved Oxygen was recorded in Station 3 (12.30mg/l) and lowest in Station 1 (7.66mg/l). The lowest pH value was recorded at Station 1 (6.66) while the highest value was recorded at Station 2 (7.23). The highest Total Dissolved solid values were recorded in Station 1(14.16mg/l) and lowest in Station 9

Table 1. Physico-chemical parameters of the Bonny Estuary

Station	Temp.(ºC)	DO (mg/l)	pH	TDS (mg/l)	Salinity (ppt)
1	32.30 ± 0.00^{a}	7.66 ± 0.03^{e}	6.66 ± 0.03^{d}	14.16 ± 0.03^{a}	10.20 ± 0.05^{a}
2	31.73 ± 0.03^{b}	8.60 ± 0.05^{d}	7.23 ± 0.08^{a}	6.53 ± 0.18^{d}	5.13 ± 0.14^{d}
3	30.33 ± 0.08^{de}	10.70 ± 0.05^{b}	7.20 ± 0.10^{ab}	7.56 ± 0.54^{c}	6.40 ± 0.05^{c}
4	30.16 ± 0.08^{e}	12.30 ± 0.30^{a}	7.13 ± 0.03^{ab}	5.73 ± 0.06^{f}	5.06 ± 0.08^{d}
5	30.80 ± 0.05^{c}	10.06 ± 0.26^{c}	7.13 ± 0.03^{ab}	5.73 ± 0.03^{f}	6.40 ± 0.05^{c}
6	30.36 ± 0.06^{d}	12.73 ± 0.21^{a}	7.16 ± 0.03^{ab}	6.46 ± 0.03^{de}	4.66 ± 0.06^{e}
7	30.16 ± 0.03^{e}	10.53 ± 0.20^{bc}	7.16 ± 0.06^{ab}	12.33 ± 0.17^{b}	9.30 ± 0.05^{b}
8	29.76 ± 0.03^{f}	10.36 ± 0.13^{bc}	7.03 ± 0.03^{bc}	5.80 ± 0.30^{ef}	4.10 ± 0.00^{g}
9	29.53 ± 0.06^{g}	10.46 ± 0.08^{bc}	6.90 ± 0.05^{c}	5.53 ± 0.06^{f}	4.33 ± 0.03^{f}

*Superscripts of the same alphabet are not significantly different (P<0.05)
**Superscripts of different alphabets are significantly different (P<0.05)

Table 2. Harmful algal species in Bonny Estuary

	Class	Family	Genus
1	Bacillariophyceae	Cymbellaceae	*Cymbella*
2	Cyanophyceae	*Microcoleaceae*	*Trichodesmium*
3	Bacillariophyceae	*Pinnulariaceae*	*Pinnularia*
4	Bacillariophyceae	*Naviculaceae*	*Navicula Spp*
5	Bacillariophyceae	*Catenulaceae*	*Amphora*
6	Bacillariophyceae	*Pleurosigmataceae*	*Gyrosigma*
7	Bacillariophyceae	*Stephanodiscaceae*	*Cyclotella*
8	Bacillariophyceae	*Bacillariaceae*	*Nitzchia*
9	Bacillariophyceae	*Pleurosigmataceae*	*Pleurosigma*
10	Chlorophyceae	*Clorococcaceae*	*Tretraedron*
11	Bacillariophyceae	*Coscinodiscaceae*	*Coscinodicus*
12	Bacillariophyceae	*Bacillariaceae*	*Pseudo-nitzschia*

(5.53mg/l). Salinity values in the study area in Station 1 (10.20ppt) recorded the highest value and Station 8 (4.10ppt) with the lowest value.

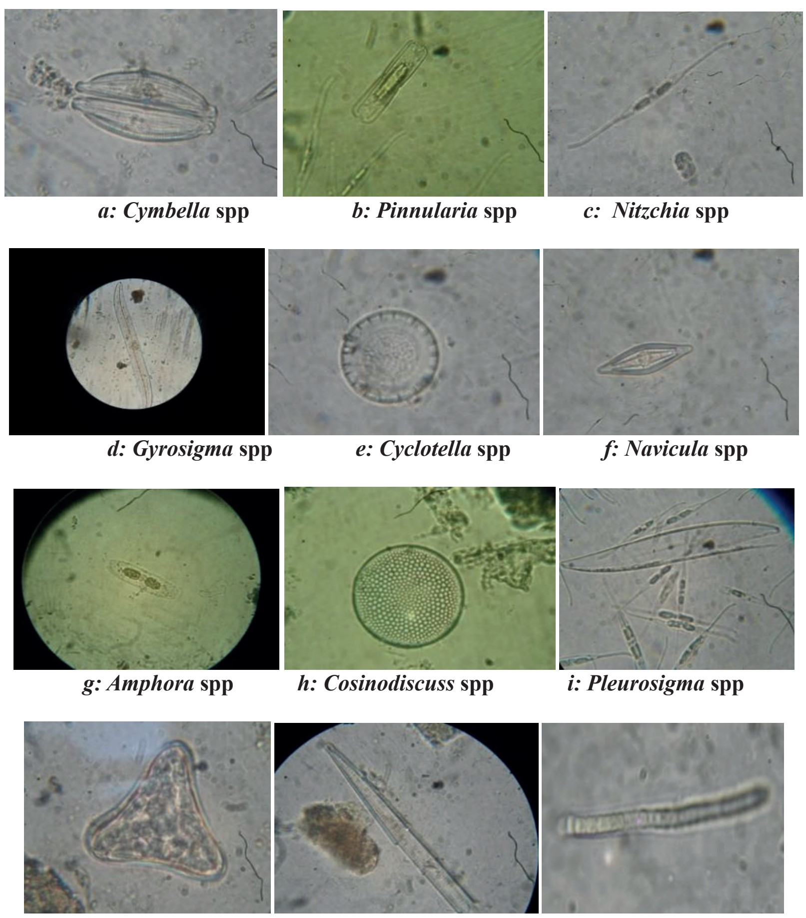
The samples of harmful algal species recovered in the sampling stations of the Bonny Estuary were classified as shown in Table 2 (Figure 1). Three classes of major harmful algal groups were represented in the sampled area of the study; these were Bacillariophyceae, Chlorophyceae and Cyanophyceae which represents twelve genera and thirteen species. Bacillariophyceae had the highest number of species (10) while Chlorophyceae and Cyanophyceae recorded one species.

Cymbella

Cymbella **is** the most diverse genus within the Cymbellaceae family in terms of number of species. These taxa also possess a ventral pyrenoid and ventral deflection of the distal raphe ends. Dorsal and ventral being determined by the curvature of the valve outline). In other taxa stigmata are ventral, the nucleus is ventral, the pyrenoid is dorsal, and the external distal raphe ends are deflected dorsally (Tsarenko, 2011).

Trichodesmium Species

The genus *Trichodesmium* comprises about 10 species.Straight *trichomes* forming assemblages with radially arranged fascicles



***a: Cymbella* spp** ***b: Pinnularia* spp** ***c: Nitzchia* spp**

***d: Gyrosigma* spp** ***e: Cyclotella* spp** ***f: Navicula* spp**

***g: Amphora* spp** ***h: Cosinodiscuss* spp** ***i: Pleurosigma* spp**

***j: Tretraedron* spp** ***k: Pseudo-nitzschia* spp** ***l: Trichodesmium* spp**

Figure1. Harmful algal species in Bonny Estuary

joined by mucilage. Most cells are shorter, wide, red, or brown in color.These are marine pelagic cyanobacteria belonging to the order Oscillatoriales. They are filamentous, non-heterocystous cyanobacteria, known for their ability to fix atmospheric dinitrogen (Capone *et al.*, 1997). They are characterized by *trichomes* (linear arrangements of about 100–200 cells) that form colonies and occur in extensive floating blooms also called sea sawdust by the sailors. *Trichodesmium* blooms are widely distributed in oligotrophic regions of the oceans throughout the tropics and subtropics (Carpenter *et al*., 2004). Despite a number of surveys dedicated to the ecological aspects of *Trichodesmium spp*. their toxicity remains sparsely documented. The stochastic nature of the blooms has greatly hampered toxicological studies (Bell *et al.*, 2005). To date, two species have been reported to be toxigenic, *T. erythraeum* and *T. thiebautii.* Strains can produce neurotoxins and hepetotoxins (Cronberg and Annadotter, 2006).

Pinnularia Species

A unicellular diatom, bilaterally symmetric, with relatively pronounced “costae” (thickened silica rows) between striations bearing two or three rows of punctae. The genus *Pinnularia* occurs most often in fresh waters and rarely in salty waters as epipelic algae. They prefer oligo- and dystrophic waters with low electrolyte content (Round *et al.*, 1990).

Navicula Species

Naviculaceae are typically composed of lineate areolae, one of the many forms of areolae. Some of the other areolae are punctate (*Gomphoneis)* and loculate *(Diploneis)*. These can be found among other families of diatoms including Thalassiosiraceae. The areolae found in Naviculaceae tend to be uniseriate. Some Naviculaceae tend to have a pseudoseptum which is a silica plate extending internally from the apical portion of the valve. Axial area very broad, widening to produce a lanceolate area with either straight margins that are curved to follow those of the valves; striae in the form of sub-marginal band occupying about half area between the raphe and the valve margin (Hendey, 1964).

Amphora Species

This is a major genus of the marine and freshwater diatoms with over 1000 species; it is one of the largest genera of diatoms Parnell and Trevor (2007). These diatoms are recognized by their strongly dorsi ventral frustules, which means that their ridges lie close to the ventral margin of the valve, and their girdle is much wider on the dorsal side. Valves are lunate, but entire cells are bi-convex due to mantle on dorsal margin being much deeper than that on ventral margin. Raphe is usually towards ventral margin and the dorsal margin sometimes is with hyaline areas. A strain of the species *Amphora coffeaeformis* (from Canada) was found to produce Domoic acid.

Gyrosigma Species

Gyrosigma Cells are solitary or can occasionally be enclosed in a mucilage tube with other cells and generally lies in valve view. It has two large plastids per cell, one against each side of the girdle. In valve view the cells are in valve view the cells are linear and curve to a rounded point at each end opposite of each other. The raphe is generally in the middle of the cell with a central nodule. Found attached to fine sand or mud (epepelic), in brackish waters extending into marine habitats. Some species are also common in freshwater (Round *et al.*, 1990).

Cyclotella Species

The species is a small, centric diatom with cells only 3-5 μm in diameter. The valves are short and drum-shaped. *Cyclotella* is common in the plankton of freshwater lakes and rivers throughout the world, and is sometimes found in saline lakes and shallow coastal marine environments. The genus is known to inhabit the deep part of oligotrophic lakes known as the chlorophyll maximum. It is very important environmentally, but needs further research to sort out its confusing taxonomy. Species are known to thrive in environments ranging from oligotrophic to highly eutrophic. The valve morphology is highly variable and appears to respond to subtle micro-environmental changes. The circular valve face has rows of areolae radiating from a distinct central area that is sometimes covered by warts, spines, or granules. The cells sometimes have long chitinous bristles that likely help to increase buoyancy or protect the cells from being consumed by herbivores. Each cell has numerous discoid plastids, there are about 100 species (Hendey, 1964).

Nitzschia Species

This species is a common genus of diatoms in both freshwater and marine ecosystems. There are some 423 valid species in this large genus. Species of *Nitzschia* have not been responsible for any toxic blooms until 2000, when the first toxic *Nitzschia, N. navis-varingica* was reported to be responsible for a toxic bloom incident in Vietnam (Lundholm and Moestrup, 2000). The toxin was confirmed as domoic acid (DA) which causes amnesic shellfish poisoning (ASP) (Smida *et al*., 2014). Domoic acid, a neurotoxin produced by various species of *Nitzschia*, was identified as responsible for causing an outbreak of Amnesic Shellfish Poisoning in humans (involving 107 illnesses and three deaths) after the consumption of blue mussels from Prince Edward Island (Canada) in 1987 Since then, blooms of these pennate diatoms have resulted in a range of, often large-scale, shellfish toxicity events, affecting humans and other large vertebrates.

Pleurosigma Species

The genus Pleurosigma is a diatom and was first described by Smith (1852) as organisms with shape of an elongated diamond, with regular pulsating inner organelles and characterized by having valves convex, sigmoid, and striated, with striae visible as dots. Smith (1852) established two sections in the genus, one characterized by transverse and oblique striae and the other with trans-verse and longitudinal striae. Pleurosigma appear all over the world, regardless of location. The genus is one of the larger groups of diatoms, containing hundreds of different species A pelagic, or ocean-floating, genus, Pleurosigma organisms generally either float on the tides, sink to lower levels on top of the salt layer or attach to marine organisms.

Tretraedron Species

Tetraedron is the coccal unicellular green algal genus which can be easily identified by its typical polygonal shape. It is a common member of freshwater planktonic algae frequently observed in temperate and tropical waters (Stoyneva *et al*., 2012). Cells of the *Tetraedron* are solitary and unattached of various shapes, triangular and flat, pyramidal, polyhedric; the angles entire, with or without spines, or variously lobed to form dichotomous or trichotomous spine-tipped processes (Prescott, 1951). The spines have an inflated base and are longer than the diameter of the cell. The cells have one parietal chloroplast and one pyrenoid (Jadhavar and Papdiwal, 2016).

Coscinodiscus Species

Coscinodiscus is a species of diatom

which belongs to a group of ocean algae—phytoplankton. *Coscinodiscus* is cylindrical in shape. The internal organelles, including chloroplasts can be seen with a microscope. Chromatophores are numerous, small with resting spores known in several species, resembling biconvex lenses, formed in regular cells. Mucilaginous threads help adapt it for floating (Cupp, 1943). They seem to resemble bike tires with its spokes or a circular honey comb pattern. They are also drifters so they have no control over their movement and always move with the tides. *Coscinodisucs* is photosynthetic using light to produce organic matter. They are very small, measuring around 150um in length and many can be found within a single drop of water. In fact, hundreds of individual *Coscinodiscus* were observed in a drop of water. At times they can grow into large mats and then these microorganisms can become visible to the naked eye. Coscinodiscus range of existence extends from the warm tropic waters up until the cold Arctic ecotone waters. They are widespread and good indicator of rising warming waters.

Pseudo-nitzschia Species

Species of *Pseudo-nitzschia* are marine, planktonic, pennate diatoms with a worldwide distribution. This species is a cosmopolitan genus of diatoms, consisting of 45 valid species, of which 16 are toxic. Recently, *P. kodamae* was shown to be the first toxic Pseudo-nitzschia species in Southeast Asia (Teng *et al*., 2014). This species is believed to be associated with domoic acid occurrences in the spiny oyster Spondylus versicolor in Vietnam (Ha *et al*., 2014). Diatoms in the genus *Pseudo-nitzschia* produce a neurotoxin, domoic acid. It is the cause of Amnesic Shellfish Poisoning, ASP, which can be life-threatening. In severe cases, neurological symptoms occur within 48 hours of eating toxic shellfish. Most *Pseudo-nitzschia* blooms have not been linked to nutrient pollution but instead to natural events including spring and summer changes in currents, temperature, and salinity (Yap-Dejeto *et al*., 2010).

4. Discussion

The pH values recorded in this study area were well within the preferred pH of 6.5 to 9.0 recommended for optimal fish and aquatic life (Boyd and Lichktopller, 1979). The variation of pH values observed in this study is in agreement with results of previous studies conducted by Dublin-green (1990) in Bonny River, where the highest pH values were recorded in the dry season month. Similar trend was reported by Ekeh and Sikoki (2003) in the New Calabar River and also by Ansa (2005) in Andoni flats of Niger Delta area. The mean temperature values in the study area ranging from 29.53°C to 32.30°C across the Stations were observed normal with the reference to the location in Niger Delta region. Alabaster and Lloyd (1980) reported that temperature on natural inland waters in the tropics usually varies between 25°C and 35°C; values recorded also agrees with earlier works in the Niger Delta water by Abowei (2010) who reported temperature range between 27°C - 31°C. Chinda *et al.* (1998) also stated temperature range between 26 °C and 30.5 °C, Zabbey (2002) recorded between 26.3 °C and 30.4 °C, the values by Ansa (2005) were between 25.9 ºC and 32.4 ºC, Hart and Zabbey (2005) reported range between 25.8 ºC and 30.4 ºC, Sikoki and Zabbey (2006) recorded values between 26.0ºC and 27.8 ºC, Omokheyeke (2014) and Jamabo (2008) reported a temperature range between 27 ºC and 30 ºC in the upper Bonny River of Niger Delta. According to Okayi (2003) temperature ranges of 24.5-29.5 ºC for tropical water are normal and optimal for growth of aquatic organisms. Adebisi (1981), stated that most tropical fresh water have stable temperature regime with seasonal variations between 20 and 30 ºC.

Dissolved Oxygen values recorded was within the range of 7.66 to 12.73(mg/l), which is in agreement with Abowei (2010) with a higher mean value of Dissolved Oxygen in the dry season. He attributed it to the effect of lower temperature and other industrial activities. Ajuzie and Houvenaghel (2009) reported that the low salinity values recorded for the various stations in November 1999 was abnormal. This is because November is normally within the dry season period in Nigeria, and the coastal waters are less diluted by fresh water input; which is in agreement with the range of salinity recorded in this study. Suspended solids and colour are factors that determine the transparency of any water body (Parson and Kessler, 1987). The TDS values recorded were generally lower than 41.0mg/lin the study area. This was possibly because of colloids, drainage channels, sand mining, dredging, logging of timber and discharge of effluents and sewage

A preliminary survey of the potentially harmful dinoflagellates in Nigerian Coastal waters carried out by Ajuzie and Houvenaghel (2009) recorded a total of 18 dinoflagellates which include 9 toxic and 9 bloom forming dinoflagellates, while Abowei *et al.* (2012) represented major families of phytoplankton namely; Baccillariophyceae, Dinophyceae, Chlorophyceae and Cyanophyceae in the coastal waters of Koluoma in Bayelsa. Baccillariophyceae were the dominant family which constitute 60% of the total number of algae. This is in agreement with the findings of this study, which was also dominated by the family Baccillariophyceae Babu *et al.* (2013) stated the total number of 101phytoplankton in the east-west coast of India. Among them, 76 species were diatoms (Bacillariophyceae), 17 species were dinoflagellates (Dinophyceae), 5 species were blue greens (Cyanophyceae), 2 species were green algae (Chlorophyceae) and 1 specie was silicoflagellates (Chrysophyceae). Onyema (2008) reported seven major algal groups in the mico-flora in Iyagbe lagoon. These were Bacillariophycea, Cyanophyceae, Euglenophycea, Chlorophycea and Dinophyceae, Chlorophyceae and Raodophyceae. A total of 129 species from 64 genera were recorded. Diatoms were the most abundant group making up 90 species from 39 genera; Cyanobacteria recorded 19 species from nine genera, green algae with 10 species from eight genera Eugleniods with four species from three genera.

Nwankwo (1998) explained that phytoplankton production in the Lagos lagoon was high and principally dominated by diatoms. Similar dominance of diatoms among phytoplankton assemblage has been reported by other ecologist in the coastal waters of Nigeria (Imevbore, 1965, Kadiri, 1999, Nwankwo, 1988, Nwankwo and Onyema, 2004). However, 14 phytoplankton species within the Lagos lagoon were reported to be potentially harmful species. Nwankwo *et al. (*2003) also focused on the toxic potential danger and harmful effects of some of these species in south-western Nigeria, especially for the Lagos lagoon. The dominance of Bacillariophyceae in this study is not an unusual occurrence. Many phytoplankton studies have reported the dominance of Bacillariophyceae in rivers and creeks of the Niger Delta and Nigeria. Such reports include Ogamba *et al*. (2004), Emmanuel and Onyema (2008), Abowei *et al*. (2008), Zabbey *et al*. (2008), Davies *et al.* (2009), and Nkwoji *et al*. (2010). Margalef (1968) found that species with the highest self-sustaining natural mechanisms of natural increase usually become dominant. This may account for the widespread dominance of Bacillariophyceae in both fresh and brackish waters.

Conclusion

The preliminary study revealed the presence of some harmful algal species which has therefore provided evidence of the presence of harmful algae in the Bonny Estuary. The potential of these algae to cause harm either through the production of toxins or excessive accumulations of biomass (bloom) is triggered by the type of strain, physico-chemical variables, and biogeography of the area. Thus, there is a real danger for future algal toxic event outbreaks in the Nigerian waters leading to future economic loss to the Nigerian fishery in addition to human health impacts that which cannot be underestimated. Therefore, there is need for adequate monitoring program to prevent the formation of harmful algal blooms in addition to effective education, dissemination, and communication of the available information to necessitate easy regulation, harvesting, and use of the fishery resource.

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