A first record of extant silicoflagellates in coastal waters of Nigeria

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Abstract: Silicoflagellates are photosynthetic microalgae with a multi-stage life-cycle. They live in the upper part of the water column and are adapted for life in both warm and cold waters. They have been associated with fish kills in many places, e.g. Europe and Australia. To the best of our knowledge, there is no report in the literature on the occurrence of extant silicoflagellates in the coastal waters of Nigeria. Water samples were collected at Bar Beach (a marine habitat) and in the Lagos Lagoon, all in Lagos State, Nigeria in December 1999 and analyzed for the presence of extant silicoflagellates. Four species of silicoflagellates were recorded for the first time in these coastal waters. The species included *Dictyocha crux*, *Dictyocha fibula*, *Distephanus octonarius* var. *polyactis* and *Octactis octonaria* var. *pulchra*. Salinity, and not temperature, was a major environmental variable that influenced the distribution of the silicoflagellates in Nigeria's coastal waters.

[Ajuzie CC, Houvenaghel GT. **A first record of extant silicoflagellates in coastal waters of Nigeria.** *Nat Sci* 2015;13(3):74-79]. (ISSN: 1545-0740). http://www.sciencepub.net/nature. 13

Keywords: silicoflagellates, Nigeria, salinity, Bar Beach, Lagos Lagoon

1. Introduction

Silicoflagellates are photosynthetic microalgae with a multi-stage life-cycle. They live in the upper part of the water column and are adapted for life in both warm and cold waters. They exhibit two forms, which are classed as stages: the skeleton-bearing stage and the naked stage (e.g. Henriksen et al., 1993). However, the feature which conspicuously distinguishes silicoflagellates from other phytoflagellates is the skeleton, which is composed of hollow beams of opaline silica. These are of various shapes and are variously ornamented with spines or other processes (Parkinson, 2002). The shape of the skeleton is related to the physical and, perhaps, the chemical nature of the environment in which they live, assisting with resistance to sinking, orientation, and locomotion in the water of widely differing temperature, chemical conditions and illumination. The skeleton also functions as a scaffold, supporting pseudopodia and cytoplasmic strands during the photosynthetic, motile and vegetatively reproducing phase of the life history (Parkinson, 2002). Like diatoms, silicoflagellates are most productive where near-surface waters have high levels of silica and nutrients (Lipps, 1970), and the occurrence of the siliceous plankton is associated with areas of high biological productivity such as coastal and equatorial upwelling regions and sub-polar seas (Lisitzin, 1972; Schrader and Schuette, 1981).

Silicoflagellates are known to have caused red tides in many parts of the world. For example, they caused red tides in the Bay of Kiel, Germany in 1983 and 1986 (Nöthig, 1984; Neuer, 1986; Jochem, 1987). Blooms of silicoflagellates have also been associated with fish-kills in European waters (Lassus, 1988). In Ireland, a bloom of silicoflagellates killed salmons in huge numbers in 1983, and in Scotland similar events were recorded in 1979 and 1982 (Doyle et al., 1984; Gowen, 1984; Lassus, 1988). Silicoflagellates also caused fish mortalities in Kattegat, Denmark (Aertebjerg and Borum, 1984) and in a salmon fish farm in the Bay of Douarnenez in France in 1987 (Lassus, 1988). In Australia, *Dictyocha actonaria* (= *Octactis octonaria* var. *pulchra*) caused a massive fish kill in the coastal waters off Newcastle in 1993 (Ajani et al., 2001).

Silicoflagellates may kill fish by physically clogging and abrading fish gills (causing gill damage), which leads to asphyxiation and consequent death of the affected fish (Bruslé, 1995). Certain silicoflagellates may produce substances that are toxic to fish (i.e. ichthyotoxins). For example, *Distephanus speculum* (= *Dictyocha speculum*) causes oedema and hyperplasia in fish gills, as well as liver degeneration, which lead to nuclear pyknosis of fish that come in contact with the species (Erard-Le Den and Ryckaert, 1990). Similar histopathologic conditions were observed when juveniles of the European sea bass *Dicentrarchus labrax* were exposed to cultures of toxic *Prorocentrum lima* (Ajuzie and Houvenaghel, 2003; Ajuzie, 2008). However, Henriksen et al. (1993) performed different toxicological tests on fish with cultures of the naked stage of *D. speculum* and found the species to be non-toxic.

It has been postulated that the taxonomic composition of living silicoflagellate populations is controlled to some extent by temperature (e.g. Gemeinhardt, 1934; Mandra, 1969). But other coastal environmental factors, apart from temperature, may contribute to the development of different populations of silicoflagellates (see Glezer, 1966; Huang, 1979). To our knowledge, silicoflagellates have, hitherto, not been reported in Nigeria's coastal waters. It may have escaped the attention of researchers. Huang (1979) noted that silicoflagellates are widely distributed in the world, but have low population density in comparison with other planktonic algae, and that (except for a few extant species) most of them appear in fossil state. Huang (1979) then concluded that, because of their negligible cell number and production in the sea, silicoflagellates are not so well known to many marine biologists. We report here a first incidence of occurrence of four silicoflagellate species in the coastal waters of Nigeria, so as to contribute to the knowledge of their biogeography, as well as stimulate research interest on these microphytoflagellates among marine biologists working in Nigeria. The potential dangers silicoflagellates pose to fisheries and coastal aquaculture are also discussed. The work reported here was designed for a qualitative description of the silicoflagellates (see Smayda, 1995).

2. Material and Methods

2.1. Sample collection

Near-surface hauls of water samples were taken in two different water bodies in Lagos State, Nigeria in December 1999, using a 20µm-mesh phytoplankton net tied to a recipient. The sampling locations included a station at Bar Beach (a marine water) and four other stations (Tarkwa Bay, Ijora, Lekki and Majidun) in the estuarine Lagos Lagoon (Figures 1 and 2). The water samples were fixed in borax-buffered formaldehyde and flown to Belgium, and analysis carried out in Laboratoire d'Océanographie Biologique et Aquacultures, Université Libre de Bruxelles.

Water temperature and salinity were determined on the spot using a mercury thermometer and a refractometer, respectively. Nitrogen to phosphorus (N:P) ratios were determined from data on dissolved inorganic nitrogen (NO_3^- + NO_2^- + NH_4^+) and inorganic phosphate (PO_4^{3-}), which were also measured on the spot using JBL TESTSET^{TM} reagents for ammonium, nitrate, nitrite and phosphates.

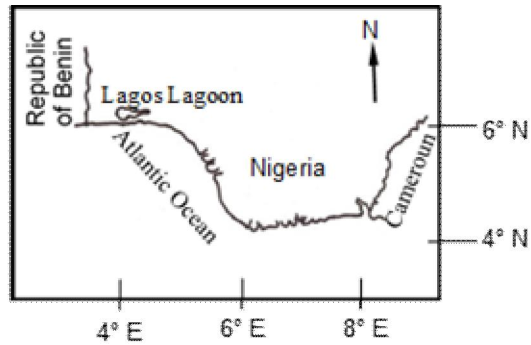

Figure 1. Coastal area of Nigeria showing Lagos Lagoon

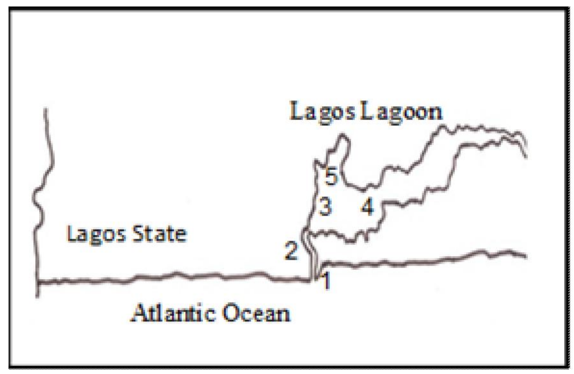

Fig. 2. Map showing the sampling sites (1 = Bar Beach; 2 = Tarkwa Bay; 3 = Ijora; 4 = Lekki; 5 = Majidun

2.2. Laboratory studies

Samples were examined for the presence of silicoflagellates under the light microscope. Microphotographs of identified silicoflagellates were taken using a camera that was attached to the top of the microscope. The silicoflagellates reported here were identified to the species level and each species was determined according to the siliceous skeleton they possess, and as described in the literature, e.g. Bukry and Foster (1973) and Throndsen (1997).

3. Results

3.1. Observed physico-chemical parameters

Water temperature was the same for all the sampling stations. The sea water at Bar Beach had the highest salt concentration (34‰). In the Lagos Lagoon, salinity decreased upstream. Thus, salinity was 31‰ at Tarkwa Bay, 10‰ at Ijora and 2‰ at both Lekki and Majidun (see Figure 2, Table. 1). The N:P ratio was high in these waters, ranging from 12.0 at Ijora to 32.3 at Bar Beach. Apparently, these waters are rich in nitrogen. This could imply that phosphorus is the limiting nutrient for silicoflagellates in the study area (also see Henriksen et al., 1993).

Table 1. Observed physical and chemical properties at the sampling stations

Stations / Parameters:	Water t °C	Salinity ‰	N:P ratio
Bar Beach	30	34	32.3
Tarkwa Bay	30	31	31.0
Ijora	30	10	12.0
Lekki	30	2	14.3
Majidun	30	2	16.0

3.2. Observed silicoflagellate species

Four species of extant silicoflagellates, belonging to three different genera, were recorded in this study. The species included *Dictyocha crux* Ehrenberg, *Dictyocha fibula* Ehrenberg, *Distephanus octonarius* var. *polyactis* (Ehrenberg) Glezer and *Octactis octonaria* var. *pulchra* (in Throndsen, 1997). These species are shown in Figs. 3A-J and a summary of their taxonomy is presented in Table 2. *Dictyocha crux* and *Octatis octonaria* var. *pulchra* were recorded in samples collected at Bar Beach. *Distephanus octonarius* var. *polyactis* was recorded at Tarkwa Bay, and *Dictyocha fibula* at Ijora. No silicoflagelate was observed in samples collected at Majidun and Lekki sampling stations (Table 3).

Table 2. Taxonomy of the silicoflagellates

Phylum: Ochrophyta **Cavalier-Smith**
- **Class:** Dictyochophyceae **Silva**
  - **Order:** Dictyochales **Haeckel**
    - **Family:** Dictyochaceae **Lemmermann**
      - **Genus:** *Dictyocha* **Ehrenberg**
        - **Species:** *Dictyocha fibula* **Ehrenberg**
        - **Species:** *Dictyocha crux* **(Ehr.) Haeckle**
      - **Genus:** *Distephanus* **Haeckel**
        - **Species:** *Distephanus octonarius* var. *polyactis* (**Ehr.**) **Glezer**
      - **Genus:** *Octactis* **Schiller**
        - **Species:** *Octactis octonaria* var. *pulchra* (in **Throndsen, 1997**)

4. Discussion

4.1. Occurrence of the species in relation to physico-chemical characteristics of the study sites

Although Glezer (1966) reported that the morphology and quantitative distribution of silicoflagellates are greatly influenced by temperature and salinity of water, temperature was not the main factor influencing the occurrence of silicoflagellates in Nigeria's coastal waters. Temperature was exactly the same in all the sampling locations. In contrast, salinity differed among the sampling stations, and the species were observed only in samples collected from the marine water at Bar Beach and at stations (Ijora and Tarkwa Bay) with comparatively higher salinity values in the Lagos Lagoon. Therefore, in these waters, salinity could be a major environmental variable that predicts the occurrence of silicoflagellates.

Many workers have described silicoflagellates as marine organisms (e.g. Bukry and Foster, 1973; Perch-Nielsen, 1976; Henriksen et al., 1993). From the present study, it is understood that these organisms also occur in estuarine ecosystems, like the Lagos Lagoon in Nigeria. Experimental studies by Henriksen et al. (1993) support this field observation. The workers (Henriksen et al., 1993) observed that the naked stage of *Dictyocha speculum* was able to grow in the salinity range of 10-35‰. Moreover, Throndsen (1997) reported that silicoflagellates are found in coastal and oceanic areas but mostly confined to inshore waters, including brackish ecosystems. It should, however, be noted that Pérez et al. (2009) recorded both *Dictyocha crux* and *Dictyocha fibula* in the Ebro River Estuary, Spain where surface salinity varied between 2.3‰ and 5.1‰.

4.2. Description of the silicoflagellates and their hitherto biogeography

Dictyocha crux has a skeleton with four protruding spines and five windows. The skeleton size ranges from 20-40 µm (Throndsen, 1997). This name is of an entity that is currently accepted taxonomically (Guiry and Guiry, 2014). The species is present in the Atlantic and Pacific Oceans, as well as the Mediterranean Sea (Throndsen, 1997), the Black Sea (BSPC Editorial Board, 2014), and in the coastal waters of France (Guilloux et al., 2013) and Spain (Pérez et al., 2009).

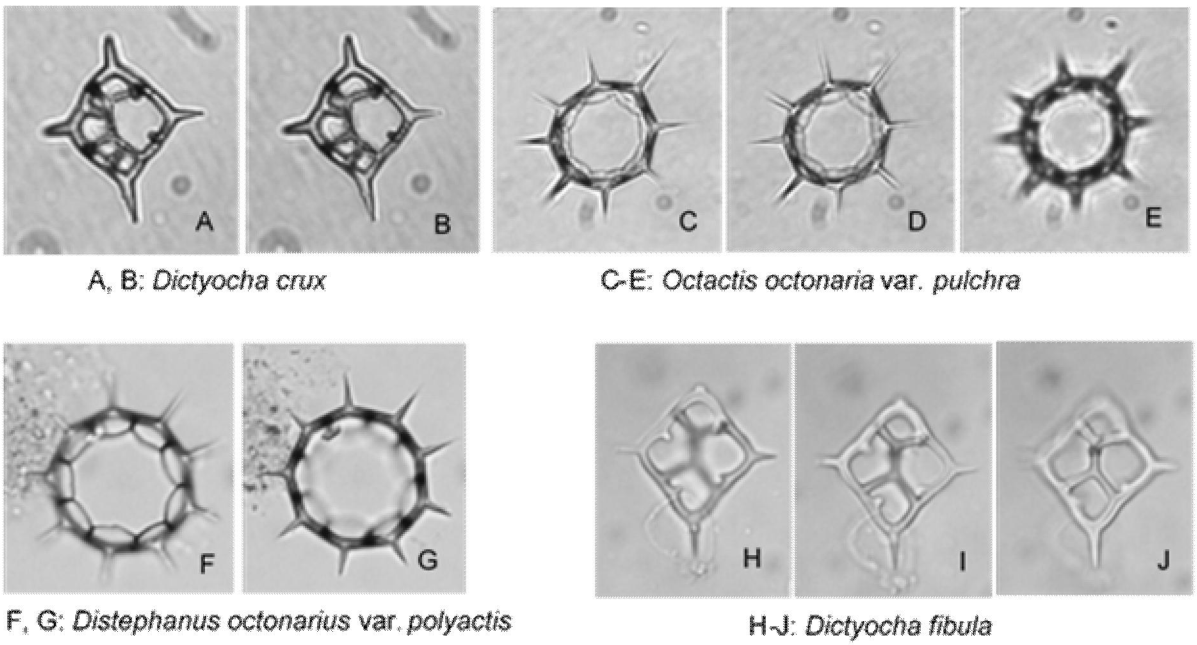

Figure 3. The Silicofalgellates

Table 3. Salinity vs. silicoflagellate occurrence in the study area

Station	Salinity ‰	Silicoflagellate species
Bar Beach	34	*Dictyocha crux* and *Octactis octonaria* var. *pulchra*
Tarkwa Bay	31	*Distephanus octonarius* var. *polyactis*
Ijora	10	*Dictyocha fibula*
Lekki	2	none observed
Majidun	2	none observed

Dictyocha fibula is a name of an entity that is currently accepted taxonomically (Guiry and Guiry, 2014). According to Throndsen (1997), *D. fibula* is characterized by a skeleton with four protruding spines and four windows. The basal ring is quandrangular, with four almost equal length of radial spines developed at the corners. Supporting spines of basal rods attach on the sides of lateral rods. Apical rod is longer than the lateral rods, and the skeleton is tubular in structure. Apical ring is absent and the skeleton is 10-45 µm long (see Huang, 1979; Throndsen, 1997). It is reported to be an oceanic (Throndsen, 1997) and a marine species (Guiry and Guiry, 2014). It is present in: Adriatic Sea (e.g. Vilicic et al., 2002), Baltic Sea (e.g. Hällfors, 2004), Black Sea (BSPC Editorial Board, 2014), British waters (Parke and Dixon, 1976), French waters (Nival, 1965; Guilloux et al., 2013), Spanish waters (Pérez et al., 2009), North American waters (e.g. Van Valkenburg and Norris, 1970), Argentinan waters (Frenguelli, 1935), Chinese and Taiwan waters (e.g. (Huang, 1979; Lui, 2008), Japanese waters (Sekiguchi et al., 2003), New Zealand waters (Harper et al., 2012), as well as in Antarctica and the Subantarctic Islands (Hallegraeff, 2005).

Distephanus octonarius var. *polyactis* has a skeleton with nine radial spines and a nine-side, wide basal ring, which is about 30 µm in diameter (see

Bukry and Foster, 1973; Huang, 1979). Supporting spines are also present. Apical ring has a diameter about 21 µm (Huang, 1979). It is present in USSR waters (Glezer, 1966) and in the coastal waters of Taiwan (Huang, 1979). According to Guiry and Guiry (2014) the taxonomic (and perhaps the nomenclatural) status of this entity requires further investigation.

Octactis octonaria var. *pulchra*. This name is of an entity that is currently accepted taxonomically (Guiry and Guiry, 2014). The basal ring is wide and with eight spines. Two spines, which are opposite to each other, are comparatively longer than the rest and the diameter of the octogonal basal ring is about 26-38 µm (see Huang, 1979; Throndsen, 1997). It is oceanic and Mediterranean (Throndsen, 1997). It has been documented in different geographical locations including Australia (Ajani et al., 2001), Taiwan (Huang, 1979) and Mexico (Martinez-Lopez et al., 2012).

4.3. Potential harmful effects of the silicoflagellates

Based on the conflicting reports in the literature, it could be argued that the capacity of silicoflagellates to produce potent phycotoxins is debatable. But the point that a bloom of silicoflagellates could result in fish kills is not in doubt. The spines of silicoflagellates make them a dangerous group of microalgae to fisheries and aquaculture. For example, the skeleton-bearing stage of *D. speculum* was associated with a fish-kill in France in 1987 (Erard-Le Denn and Ryckaert, 1990), and mucus secretion from the gills due to irritation from the siliceous skeletons was thought to have lowered gill exchange potential and caused the mortalities (Henriksen et al., 1993). Apart from the physical damages to fish organs, silicoflagellates, also cause damages to fisheries and aquaculture via depletion of dissolved oxygen. Henriksen et al. (1993) argued that oxygen depletion during the night from respiration of the large population of naked *D. speculum* remains one of the most likely explanations for the fish-kill in Denmark that occurred in 1983.

Acknowledgements

C.C. Ajuzie received financial support for this work from Harmful Algal Bloom Programme of IOC/UNESCO (contract nr. SC/RP 207.600.9).

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