# Preliminary survey of potentially harmful dinoflagellates in Nigeria's coastal waters

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**Abstract:** In many coastal states the presence and impacts of harmful dinoflagellates have been investigated and documented in the literature. Scientists and government officials in many countries routinely monitor their coastal waters for harmful algae in order to prevent harvesting of contaminated seafood. But this is not the case for Nigeria, a coastal state in the Gulf of Guinea, West Africa. The present work reports findings from a first attempt to monitor potentially harmful algae in the coastal waters of Nigeria. Samples were collected from specific locations that included a coastal sea, a lagoon, estuaries and creeks along Nigeria's coastline in November 1999 and April 2001. Potentially harmful dinoflagellates recorded during these periods included 3 *Ceratium* species, 5 *Dinophysis* species, 3 *Gonyaulax* species, 1 *Gymnodinium* sp, 1 *Lingulodinium* species, 4 *Prorocentrum* species and 1 *Scrippsiella* species. The potential ecological and human health risks associated with similar species in the literature are highlighted.

**Key words:** Dinoflagellates, Gulf of Guinea, Harmful algal blooms, Nigeria

## Introduction

There is a growing belief that 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 of HAB organisms, they are also believed to exhibit an increase in frequency of occurrence (see Smayda 1990, Taylor 1993, Boesch et al. 1997, Anderson et al. 2001, Sellner et al. 2003, Gallegos & Bergstrom 2005, Warner & Madden 2007). This apparent global increase of HAB events is a worrisome phenomenon for environmentalists, public health officials, world fisheries, and coastal aquaculture.

Dinoflagellates are a part of the major HAB organisms. They belong to the diverse group of unicellular eukaryotes (Leander & Keeling 2004), which are motile and largely photosynthetic. Some are mixotrophic, exhibiting both autotrophic and phagotrophic mode of feeding (Sherr & Sherr 2002). They are present among periphyton, phytoplankton, and the benthic communities. Their ecology and biology have permitted them to be among the most successful aquatic protists, capable of surviving different conditions of resource availability (e.g., Aishao et al. 2000). They are a major group of primary producers that constitute the basic source of energy in aquatic food webs. Zooplankton, shellfish and some fish benefit directly or indirectly from the nourishment provided by dinoflagellates. Some dinoflagellates are, however, harmful to other aquatic biota, and to man who relies heavily on the aquatic environment for food and recreation (Ajuzie 2002, 2007, 2008). They are harmful when:

(a) they produce toxins (Taylor 1993, Pitcher & Matthews 1996, Lu & Hodkiss 2004, Colin & Dam 2005) that (i) contaminate seafood, (ii) kill other aquatic biota, (iii) produce toxic aerosols, and/or (iv) their toxins intoxicate human consumers of seafood;

(b) they form obnoxious blooms (Shumway 1990) that (i) degrade water quality, (ii) clog gills of fish and shellfish (Roberts et al. 1983, Leivestad & Serigstad 1988), (iii) consume most of the oxygen in the water with concomitant biota kills (Dethlefsen & Westernhagen 1983, Matthews & Pitcher 1996), and/or (iv) increase light attenuation (shading effect) to the disadvantage of bottom organisms (Boesch et al. 1997, Geohab 2001, Gallegos & Bergstrom 2005).

The term bloom in HAB might imply that dangerous algae provoke environmental and public health problems only when they occur in huge numbers, in the range of say several thousands to millions of cells $L^{-1}$. This, however, is not always the case (SMAYDA 1990, BOESCH et al. 1997). Concentrations of only a few hundreds of cells $L^{-1}$ of toxigenic dinoflagellates produce harmful effects (NEHRING et al. 1995, SOURNIA 1995). Such toxic species when consumed by fish or shellfish or when in contact with other aquatic biota, kill them by destroying the tissue architecture of gills, digestive system and circulatory system (see ROBERTS et al. 1983, YASUMOTO et al. 1990, WILDISH et al.1991, AJUZIE & HOUVENAGHEL 2003, AJUZIE 2008). In the wild, toxic dinoflagellates are inimical to the survival of larval fish and, thus, to juvenile recruitments into a local fishery (ROBINEAU et al. 1993). They are capable of wiping out an entire year-class of fish in nursery grounds (see BOESCH et al. 1997).

Toxic dinoflagellates do not always kill the predator (KELLY et al. 1992, PILLET et al. 1995). Some bivalves and fish after ingesting toxigenic dinoflagellates concentrate phycotoxins in their tissues (see SHUMWAY 1995). The bioaccumulated phycotoxins undergo biological magnification as predators in the aquatic food web feed on phycotoxin-laden preys. Eventually, persons eating shellfish or fish that have concentrated phycotoxins in their tissues become intoxicated as well (see HALLEGRAEFF et al. 1995, SHUMWAY 1995, SELLNER et al. 2003). Human victims of phycotoxin-related seafood poisoning might suffer ill-health from any of the following syndromes: amnesic shellfish poisoning (ASP), ciguatera fish poisoning (CFP), diarrheic shellfish poisoning (DSP), neurotoxic shellfish poisoning (NSP), and paralytic shellfish poisoning (PSP) – the list is not exhausted. The economic and welfare costs associated with catering for persons suffering from any of these syndromes can be quite high. For example, in Canada the medical and lost productivity costs for the dinoflagellate-caused PSP have been estimated to be over \$226 000 annually (TODD 1995). Irrespective of these impacts, the potential interactions between HAB species and humans are on the increase (KIRKPATRICK et al. 2002).

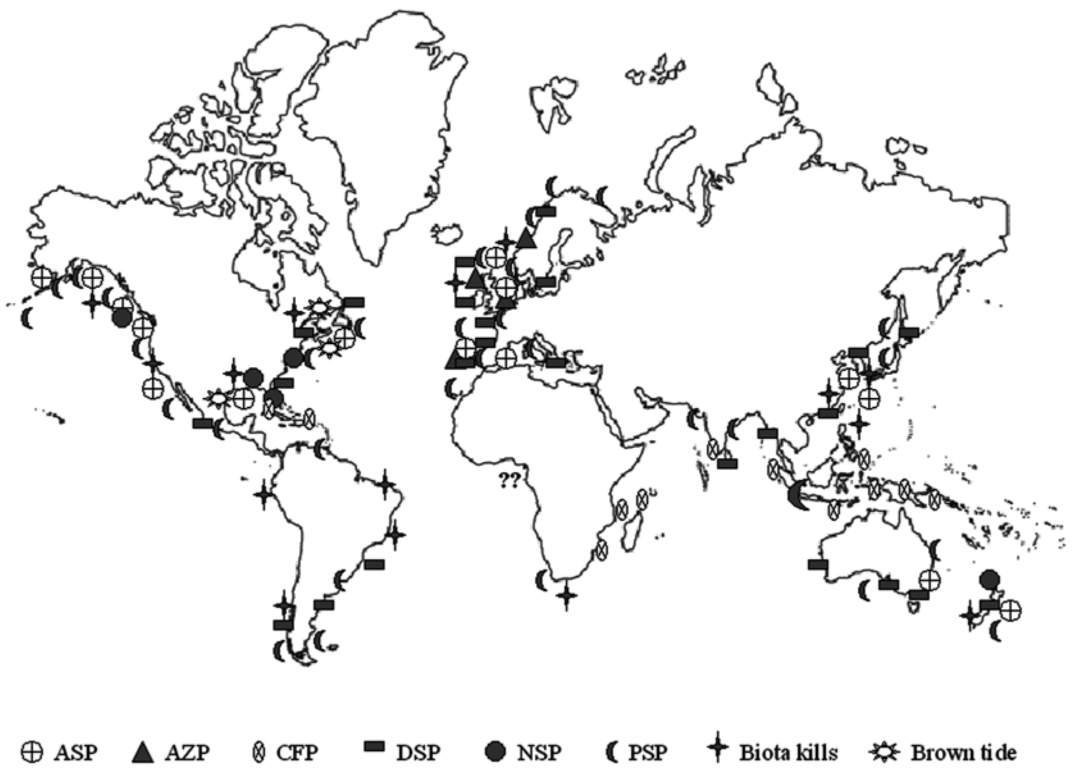


Fig. 1. Geography of HAB events: (ASP) Amnesic shellfish poisoning; (AZP) Azaspiracid shellfish poisoning; (CFP) Ciguatera fish poisoning; (DSP) Diarrheic shellfish poisoning; (NSP) Neurotoxic shellfish poisoning; (PSP) Paralytic shellfish poisoning.

People never stop going to beaches or eating seafood. Thus, there is the need to constantly monitor coastal waters for the timely detection of HABs. Scientists in some coastal countries have taken the lead in the monitoring of HAB species in their respective countries. Some of such workers include Pauley et al. (1993), Aune et al. (1995), Belin et al. (1995), Jackson & Silke (1995), Pitcher & Matthews (1996), Boesch et al. (1997), Mackenzie et al. (1996), Yamamoto & Yamasaki (1996), Luckas et al. (2005) and Tang et al. (2006). If harmful dinoflagellates are detected early enough in coastal waters, it might pave the way for prompt precautionary measures (which can help in the prevention, control and/or mitigation of their impacts on the human population) to be taken by public health officials.

Despite the fact that HABs have grave consequences on the environment, public health and local economy, some coastal states like those located in the Gulf of Guinea, with particular reference to Nigeria, apparently do not monitor HAB species in their coastal waters. Figure 1 illustrates the global distributions of problems caused by HAB species. No event is recorded for the Gulf of Guinea area. Does this mean that HAB species are absent from the region? The question marks posted there represent the inquiring mind who wants to know what the actual situation is, in this region. Nwankwo (1997) observed that there are increasing documented cases of dinoflagellate-induced harmful algal bloom events in many parts of the world, but that such information is not available in Nigeria due to limited awareness of the danger they pose, and limited information on their occurrence, distribution and taxonomy. This observation by Nwankwo constituted a major drive that spurred us to undertake this study. The main aim was to contribute to our knowledge on the biogeography of HAB dinoflagellates in the literature. The work reported here was designed for a qualitative description (Smayda 1995) of the dinoflagellates.

## Materials and methods

### The study area

Nigeria has an extensive coastline that is characterized by dense evergreen forest cover. It runs from Lagos State in the Southwest, and passing through Warri and Port Harcourt (the Niger Delta) to Calabar in the Southeast (Fig. 2). The coastline, which is located within latitudes 4°58' and 6°24'N and longitudes 3°24' and 8°19'E, has a total length of about 850 km. It is typified by the presence of bays and lagoons in the Southwest, and creeks and estuaries in the Niger Delta and Southeast (Nwankwo 1997). The coastal sea is influenced by the Guinea and Equatorial Counter Currents, as well as heavy rains that normally last from April to October. The study area is densely populated. Lagos alone has an overwhelming population of over 9 million inhabitants. A diverse range of human activities (including manufacturing industries, agriculture, lumbering, oil/gas explorations and transports, aquaculture, and raw sewage disposal) causes pollutants to enter the waters. Poor sewage handling and poor agricultural practices contribute immensely to eutrophication of coastal waters. Eutrophication, in turn, exacerbates aquatic pollution and microalgal proliferation (see Dortch 2003, Smith 2003).

In the Lagos area, samples were collected from the near-shore waters of the Atlantic Ocean at Bar Beach, and at four stations in the Lagos Lagoon (i.e., Takwa Bay that links the lagoon to the open ocean, Ijora where untreated sewage is discharged on a daily basis, and the upstream stations at Lekki and Majidun). In Warri and Port Harcourt areas, samples were collected from creeks fringed by thick mangrove forests. The Warri stations included Buoy 4, Forcados, and Burutu. Burutu is an upstream station with human habitats along its shores. Buoy 4 and Forcados are comparatively remote areas on the downstream axis. The Port Harcourt stations included Iwofe River Channel, Abalama, Rock, and Samaa, which are fishing grounds and water transport routes. At the Calabar area, samples were collected in the Cross River Estuary, which is fringed by both mangrove plants and nipa palms (*Nypa fruticans*). The stations included the upstream Calabar River Channel, Buoy 24, and a downstream station at James Town. The estuary is a major shrimpping ground in Nigeria, as well as a major shipping route between Nigeria and other African countries like Cameroon, Equatorial Guinea and Gabon.

### Sampling and methods

During the months of November 1999 and April 2001 near surface water hauls were taken at the various sampling stations using a 20µm-mesh phytoplankton net tied to a recipient. Sediment samples were collected with a bottom grab. The water samples were fixed in borax-buffered formaldehyde, while sediment grabs were placed in dark plastic bags and stored in a box. All samples were flown to Belgium, and analysis carried out our laboratory at Université Libre de Bruxelles, Brussels. At the laboratory the sediment grabs were stored in a refrigerator until they were analyzed. For analysis, the sediments were suspended in filtered seawater and washed through graded sifters, the final of which was a 20µm-mesh sifter. The residue on the 20 µm-mesh sifter was re-suspended in a small volume of filtered seawater. Aliquots of the treated sediment

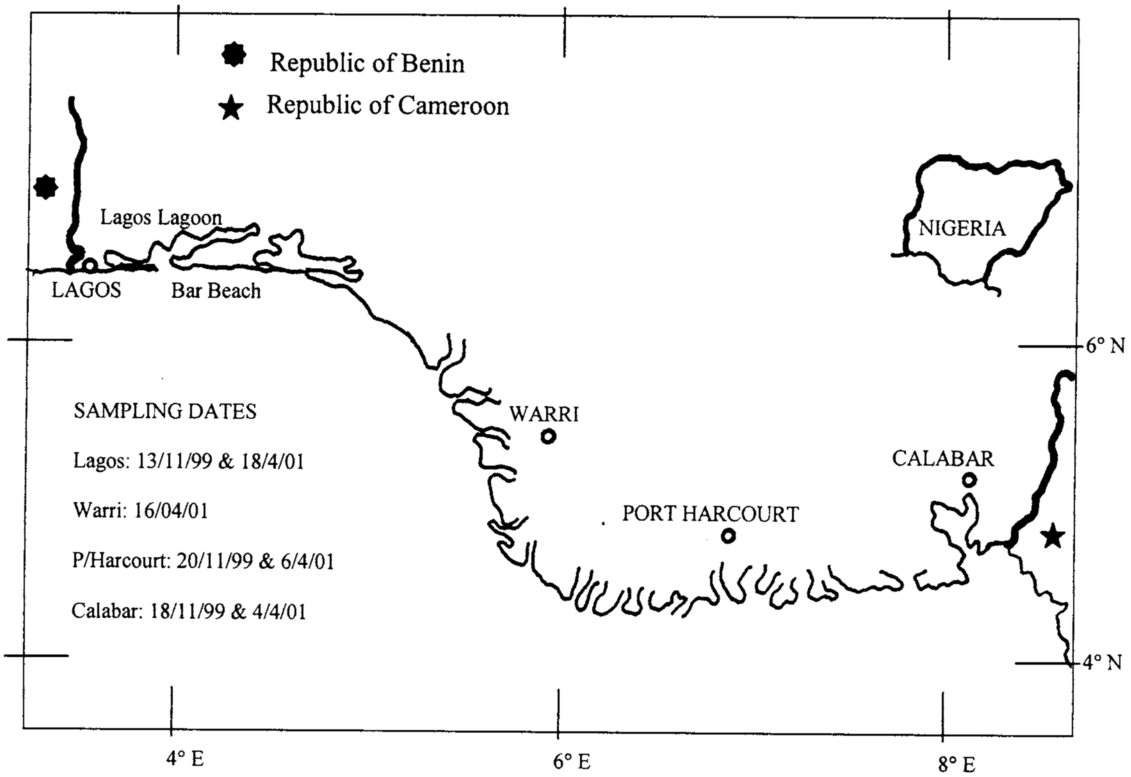


Fig. 2.Nigeria's coastline.

and surface water samples were examined with the aid of compound microscopes (both upright or inverted). Microphotographs of the dinoflagellates of interest were taken by employing a camera that was fixed at the top of the microscopes. Various reference materials that included STEIDINGER et al. (1967), DODGE (1982), TAYLOR (1987), HALLEGRAEFF et al. (1995) and TOMAS (1997) were used to identify the dinoflagellates.

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

## Results

### Salinity, nutrients and water temperature

Salinities (Table 1) ranged from 2 to 34‰, with upstream waters in the brackish water systems having the lowest salinities. The ocean water at Bar Beach had the highest salinity (34‰). Nutrient measurements and, thus, N:P ratios were the same for both sampling periods. Water temperatures were between 30 and 32°C, and depended on both cloud- and forest cover. Data for these parameters are given in Table 1.

### The dinoflagellates

A total of 18 potentially harmful dinoflagellates were recorded in Nigeria's coastal waters during this exercise. They included organisms within the genera *Ceratium* SCHRANK, *Dinophysis* EHRENBERG, *Gonyaulax* DIESING, *Gymnodinium* STEIN, *Lingulodinium* WALL, *Prorocentrum* EHRENBERG, and *Scrippsiella* BALECH (Fig. 3). Nine potentially toxic, and nine potential bloom-forming dinoflagellates were recorded (Table 2). The spatial distributions of the organisms are also presented in Table 2. No potentially harmful dinoflagellate was observed in the Iwofe waters, the Port Harcourt Area.

## Discussion

During HAB monitoring, the sampling strategy must match the specific objectives of the investigator (SMAYDA 1995). This work was basically designed to provide a qualitative account of potentially harmful dinoflagellates in Nigeria's coastal waters. The phytoplankton-net-haul

Table 1. Physical and chemical parameters at the various sampling stations.

| Station / Period | Water t °C A | Water t °C B | Salinity ‰ A | Salinity ‰ B | N:P ratio A | N:P ratio B |
|---|---|---|---|---|---|---|
| **Lagos area** | | | | | | |
| Bar Beach | 30 | 30 | 34 | 34 | 32.3 | 32.3 |
| Takwa Bay | 30 | 30 | 31 | 32 | 31.0 | 31.0 |
| Ijora | 30 | 30 | 10 | 27 | 12.0 | 12.0 |
| Lekki | 30 | 30 | 2 | 25 | 14.3 | 14.3 |
| Majidun | 30 | 30 | 2 | 20 | 16.0 | 16.0 |
| **Warri area** | | | | | | |
| Forcados | ns | 30 | ns | 10 | ns | 4.4 |
| Buoy 4 | ns | 30 | ns | 10 | ns | 24.0 |
| Burutu | ns | 30 | ns | 5 | ns | nd |
| **Port Harcourt area** | | | | | | |
| Samaa | 30 | 32 | 4 | 20 | 14.1 | 14.1 |
| Rock | 30 | 32 | 4 | 20 | 14.1 | 14.1 |
| Abalama | 30 | 32 | 2 | 15 | 14.1 | 14.1 |
| IRC | 30 | 32 | 2 | 12 | 14.1 | 14.1 |
| **Calabar area** | | | | | | |
| James Town | 30 | 31 | 6 | 21 | 18.2 | 18.2 |
| Boy 24 | 30 | 31 | 4 | 18 | 18.2 | 18.2 |
| CRC | 30 | 31 | 2 | 10 | 7.4 | 7.4 |

N/B: (A) December 1999; (B) April 2001; (ns) not sampled; (nd) not detected; (IRC) Iwofe River Chanel; (CRC) Cross River Chanel

approach was deemed necessary since we needed, in this first instance, to know which species are present in these waters, which stretched some hundreds of kilometres. Information gathered so far will be used in future monitoring efforts to design quantitative investigations.

The low salinity values recorded for the various stations in November 1999 appear abnormal. This is because November is normally within the dry season period in Nigeria, when salinities of the coastal waters are less diluted by freshwater inputs. However, it was gathered that the 1999 rainy season lasted till November in Lagos. So, the prolonged precipitations and runoffs were apparently responsible for the low salinities. On the other hand, salinities in April were on the high side because the rains were yet to start pouring by the time sampling was done. The temperature readings reflect the warm climate of Nigeria.

This is a very first attempt to investigate the presence of HAB dinoflagellates in Nigeria's coastal waters. It is expected to mark the beginning of a full-fledged HAB monitoring programme in the country. None of the dinoflagellates was observed in the creek waters of Iwofe in the Port Harcourt area. The visited creek has relatively fast flowing waters with visible oil films. The flowing nature of the creek waters may have been responsible for the apparent absence of potentially harmful dinoflagellates. Waters with unrestricted flow usually have less phytoplankton standing crops than do flow restricted waters (BADYLAK & PHLIPS 2004). Most of the recorded species are appearing for the first time in the literature for Nigeria's coastal waters. The only exceptions are *Ceratium furca* (EHRENBERG) CLAPARÉDE et LANCHMANN, *Ceratium fusus* (EHRENBERG) DUJARDIN, *Ceratium tripos* (MÜLLER) NITZSCH, *Dinophysis caudata* SAVILLE-KENT, *Gonyaulax spinifera* (CLAPARÉDE et LANCHMANN) DIESING and *Prorocentrum micans* EHRENBERG. These six dinoflagellate species are

Table 2. Spatial distribution of the dinoflagellates and their potential harmful effects.

| Species (Distribution) | Harmful effects (References) |
|---|---|
| *Ceratium furca* (BB, TB in LA) | Biota kills (MATTHEWS & PITCHER 1996) |
| *C. fusus* (BB in LA & Forc. in WA) | Biota kills (TAYLOR et al. 1995) |
| *C. tripos* (BB in LA) | Oxygen depletion (TAYLOR et al. 1995) |
| *Dinophysis acuta* (BB in LA) | Toxic (JOHANSSON et al. 1996) |
| *D. caudata* (BB in LA & JT in CA) | Toxic (KARUNASAGAR et al. 1989) |
| *D. rotundata* (BB in LA) | Toxic (LEE et al. 1989) |
| *D. tripos* (BB in LA) | Toxic (LEE et al. 1989) |
| *Dinophysis* sp. (BB in LA) | Potentially toxic |
| *Gonyaulax diegensis* (Ijora in LA) | Oxygen depletion (TAYLOR et al. 1995) |
| *G. scrippsae* (BB in LA) | Oxygen depletion (TAYLOR et al. 1995) |
| *G. spinefera* (JT in CA) | Oxygen depletion (TAYLOR 1993) |
| *Gymnodinium* sp (BB in LA) | Potentially toxic |
| *Lingulodinium polyedrum* (JT in CA) | Toxic (TUBARO et al. 1998) |
| *Prorocentrum lima* (Ijora in LA) | Toxic (JACKSON et al. 1993) |
| *P. micans* (BB in LA & JT in CA) | Biota kills (MATTHEWS & PITCHER 1996) |
| *P. minimum* (TB, Ij., Maj. in LA & Forc. in WA) | Toxic (TSENG et al. 1993) |
| *P. sigmoides* (BB in LA) | Oxygen depletion (LAM & HO 1989) |
| *Scrippsiella trochoidea* (TB, Ij., Maj. In LA) | Oxygen depletion (HALLEGRAEFF 1991) |

Note: (BB) Bar Beach; (JT) James Town; (TB) Takawa Bay; (Forc.) Forcados; (Ij.) Ijora; (Maj.) Majidun; (CA) Calabar Area; (LA) Lagos Area; (WA) Warri Area.

among the 82 dinoflagellate species recorded in Nwankwo's inventory (NWANKWO 1997). The other 12 species are not on this list.

## The genus *Ceratium*

***Ceratium furca*** (EHRENBERG) CLAPARÉDE et LANCHMANN (Fig. 3a)
Apparently, *Ceratium furca* is a high salinity tolerant species, which tends to prefer conditions where nitrogen (N) rather phosphorus (P) serves as the growth-limiting nutrient. *C. furca* is non-toxic, but it has the potentials to form massive blooms (FAUST 2000). Such blooms are capable of killing aquatic biota. In 2001 *C. furca* blooms killed 100s to 1000s of gilthead sea bream (*Sparus auratus*) in aquaculture net pens in the Kuwait Bay (GLIBERT et al. 2002). Similarly, a high biomass bloom of this species was reported to have killed huge numbers of fish and rock lobster at St. Helena Bay, South Africa (MATTHEWS & PITCHER 1996, KUDELA et al. 2005).

***Ceratium fusus*** (EHRENBERG) DUJARDIN (Fig. 3b)
*Ceratium fusus* tolerates a wider range of salinity more than the two other *Ceratium* spp reported in this study. Both N and P are equally growth-limiting nutrients for *C. fusus*. In the less saline waters P is expected to be the growth-limiting nutrient, while in the more saline waters N is expected to control its growth. *C. fusus* is non toxic (TAYLOR et al. 1995). However, it is a fish killer (LU & HODGKISS 2004). It kills aquatic animals by depleting water oxygen content during high biomass blooms.

***Ceratium tripos*** (MÜLLER) NITZSCH (Fig. 3c)
*Ceratium tripos*, like *C. furca*, was observed in water samples collected at Bar Beach. Apparently, N is the growth-limiting nutrient for this species. A bloom of this species can provoke both hypoxic and anoxic conditions (TAYLOR et al. 1995), events that deplete oxygen in water and cause biota kills. For example, when a bloom of *C. tripos* depleted the oxygen content in the New York Bight, it resulted to a massive mortality of marine animals (MAHONEY & STEIMLE 1979). These three *Ceratium* species are considered cosmopolitan organisms (GRAHAM 1941, DODGE & MARSHALL 1994). They constitute dominant red tide species in many coastal waters, where they increasingly cause ecological havocs (see BAEK et al. 2008).

## The genus *Dinophysis*

Although all the *Dinophysis* species recorded here, *Dinophysis acuta* EHRENBERG (Fig. 3d), *Dinophysis caudata* SAVILLE-KENT (Fig. 3e), *Dinophysis rotundata* CLAPARÉDE et LANCHMANN (Fig. 3f), *Dinophysis tripos* GOURRET (Fig. 3g), and *Dinophysis* sp. (Fig. 3h), were present in water samples collected from the coastal sea at Bar Beach, *D. caudata* appears to tolerate a wider range of salinity (21-34 ‰) than the rest. *D. caudata* was also recorded in water samples collected in the brackishwater of the Cross River Estuary. The apparent growth-limiting nutrient for the *Dinophysis* species is N. These species are all potentially toxic. It is well established that several *Dinophysis* species produce both dinophysistoxins and okadaic acid, all of which cause DSP (Hallegraeff et al. 1995, Guillou et al. 2000, Bravo et al 2001). Sellner et al. (2003) reported that *Dinophysis* need only be present at 100s of cells per litre to contaminate shellfish.

### The genus *Gonyaulax*

Both *Gonyaulax diegens* Kofoid (Fig. 3i) and *Gonyaulax spinifera* (Claparéde et Lanchmann) Diesing (Fig. 3k) were observed in brackish water samples. *Gonyaulax scrippsae* Kofoid (Fig. 3j), on the other hand, seems to be restricted to the marine environment. While N might control the growth of both *G. scrippsae* and *G. spinifera*, P might be the growth-limiting nutrient for *G. diegens*. Though Taylor et al. (1995) reported that *Gonyaulax* species killed marine fauna in Hong Kong, South Africa and elsewhere by means of oxygen consumption, *G. spinifera* has been recently associated with yessotoxin (YTX) production (Rhodes et al. 2006). YTXs intoxicate shellfish, but they have not been reported to cause human ill health (Espenes et al. 2004, Blanco et al. 2005). Nevertheless, YTXs are cardiotoxic to mice when intraperitoneally injected into the animal (Terao et al. 1990, 1993). At the cellular level, they induce apoptosis in human neuroblastoma (Alfonso et al. 2003).

### The genus *Gymnodinium*

***Gymnodinium* sp.** (Fig. 3l)
The unidentified *Gymnodinium* species is likely to be a new species. It is larger than most *Gymnodinium* species that resemble it. Examples of such species include the smaller and egg-shaped *Gymnodinium striatissimum* Hulburt, and the freshwater *Gymnodinium carinatum* Schilling. The specimen was observed in oceanic water samples collected at Bar Beach. N is likely to be the growth-limiting nutrient for this organism. Most *Gymnodinium* species are toxic, producing NSP or PSP toxins (Chang 1995, Gago et al. 1996, Mackenzie et al. 1996, Band-Schmidt et al. 2006). They also produce toxic aerosols that might cause asthma in human beings (see Taylor et al. 1995).

### The genus *Lingulodinium*

***Lingulodinium polyedrum*** (Stein) Dodge (Fig. 3m)
Although *Lingulodinium polyedrum*, a cosmopolitan species (Godhe et al. 2002, Blanco et al. 2005), is regarded as a marine dinoflagellate by Prezelin & Sweeney (1979), this study shows that it occurs, too, in brackish waters (see Tables 1 and 2). N rather than P is expected to be the growth-limiting nutrient for this species. Like *G. spinifera*, *L. polyedrum* produces YTXs (see Tubaro et al. 1998, Draisci et al. 1999, Paz et al. 2004). Additionally, it has the potentials of a bloom-forming species (Amorim et al. 2001, Smayda & Reynolds 2001).

### The genus *Prorocentrum*

***Prorocentrum lima*** (Ehrenberg) Dodge (Fig. 3n)
*P. lima,* though it can be seen as epiphyte and in the water column Maranda et al (2007a,b), is typically a cosmopolitan benthic species, which is associated with sand and sediments (Lebour 1925, Faust 1993, Yoo 2004). *P. lima* recorded in this study was present in sediment grabs collected at Ijora, a notorious raw sewage disposal site in the Lagos lagoon. One of the organisms attached itself to a centric diatom, thus confirming the epiphytic nature of *P. lima*. P level was higher than that of N at the site of collection. Thus, P is likely to control the growth of *P. lima* in the Lagos Lagoon. *P. lima* is toxic. It produces okadaic acid and dinophysistoxins (Bravo et al. 2001, Nascimento et al. 2005). Hence, it is one of the main dinoflagellate species responsible for DSP outbreaks (Quilliam et al. 1993, Foden et al 2005). To date, all cultured species of *P. lima* produce DSP toxins (McLachlan et al. 1997, Morton et al. 1999, Maranda et al. 2007b). Mbourdeau et al. (1995) even suggested that *P. lima* is capable of contributing to ciguatera fish poisoning in view of the okadaic acid it produces.

***Prorocentrum micans*** Ehrenberg (Fig. 3o)
The species was present in water samples collected from both brackishwater and marine environments.

N is apparently the growth-limiting nutrient for the species. Although some authors including CABRINI et al. (1995) and NWANKWO (1997) referred to *P. micans* as a toxic dinoflagellate, toxicity in this species has not been demonstrated (see JACKSON et al. 1993, ÖHMAN & LINDHOLM 1995). However, blooms of *P. micans* have been reported to kill aquatic biota. A bloom of this species alongside that of *C. furca* caused fish mortalities in South Africa's coastal waters in 1994 when they caused anoxic conditions that resulted in the suffocation of the animals (MATTHEWS & PITCHER 1996, KUDELA et al. 2005).

***Prorocentrum minimum*** (PAVILLARD) SCHILLER (Fig. 3p)

*P. minimum* seems to be widely distributed in Nigeria's coastal waters. In the literature, *P. minimum* is referred to as a common, bloom-forming dinoflagellate that has a wide geographical distribution (HEIL et al. 2005). Though it seems to tolerate a wide range of salinity in the brackish water systems of Nigeria, it was not seen in water samples from the coastal sea at Bar Beach. This observation is consistent with that of PERTOLA et al. (2005) who reported that *P. minimum* relates negatively to salinity, and adapts well to low salinity. It also corroborates the finding of TANGO et al. (2005) who reported that *P. minimum* blooms at low salinities in Chesapeake Bay. Apparently, N and P are both growth-limiting nutrient for this species. *P. minimum* is toxic. It produces neurotoxins (GRZEBYK et al. 1997). It is also a strong suspect of venerupin, a hepatotoxin that provokes venerupin shellfish poisoning syndrome (CEMBELLA & LAMOREUX 1993). Toxins of this dinoflagellate might block calcium channels (DENARDOU-QUENEHERVE et al. 1999), and by so doing provoke certain ailments (e.g., gastro-intestinal illness), and death. The toxins also can accumulate in nearly equivalent amounts in the hepatopancreas and meat of cultured mussels (DENARDOU-QUENEHERVE et al. 1999). *P. minimum* also produces the haemolytic fatty acid 18:5n3 (PLACE et al. 2000). Detrimental ecosystem effects associated with *P. minimum* range from wildfish and zoobenthos mortalities to farmed shellfish mortalities, attributable to both indirect biomass effects like provocation of anoxia, and toxic effects (LU & HODGKISS 2004, HEIL et al. 2005, TANGO et al. 2005). Blooms of *P. minimum* also have impacts on submerged aquatic vegetation, through shading effects by which the massive blooms prevent sunlight from reaching such submersed vegetation (GALLEGOS & BERGSTROM 2005, TANGO et al. 2005).

***Prorocentrum sigmoides*** BOHM (Fig. 3q)

*Prorocentrum sigmoides* seems to be a saltwater alga. Apparently, N is the growth-limiting nutrient for the species. *P. sigmoides* has never been reported to be a toxin producer, but it is a fish killer (LU & HODGKISS 2004). It is capable of forming extensive blooms (YUZAO et al. 1993), which can consume dissolved oxygen and cause biota kills.

### The genus *Scrippsiella*

***Scrippsiella trochoidea*** (STEIN) LOEBLICH (Fig. 3r)

This species tolerates both marine and brackishwater conditions. It was present in water samples collected from the coastal sea at Bar Beach, and the Lagos Lagoon. *S. trochoidea* is not a toxin producer, but it has been associated with aquatic biota kills. It is reported to have caused anoxic fish kills in Sydney Harbour, Australia (HALLEGRAEFF 1991).

## Conclusion

In this paper, a very first effort to monitor HAB species in Nigeria's coastal waters is reported. This work also contributes to our knowledge on the biogeography of HAB dinoflagellates. There appears to be no evidence of human seafood poisoning case in the literature for Nigeria. Nevertheless, diarrhoea is common (ALI-DINAR 1999, OBADINA 1999, AJUZIE 2002, http://www.un.org/ecosocdev/geninfo/afrec/vol13no1/jun99.htm,). Among the various shellfish-poisoning syndromes, DSP is the one that is readily confused with other gastrointestinal maladies caused by bacteria and viruses (HALLEGRAEFF 1995). Thus, further work is needed to ascertain the toxicity or otherwise of the potentially toxic species recorded in this study. There is also a need for further investigations to see if other potentially toxic species (e.g., *Alexandrium* spp, responsible for PSP) that are known to be cosmopolitan are present in Nigeria.

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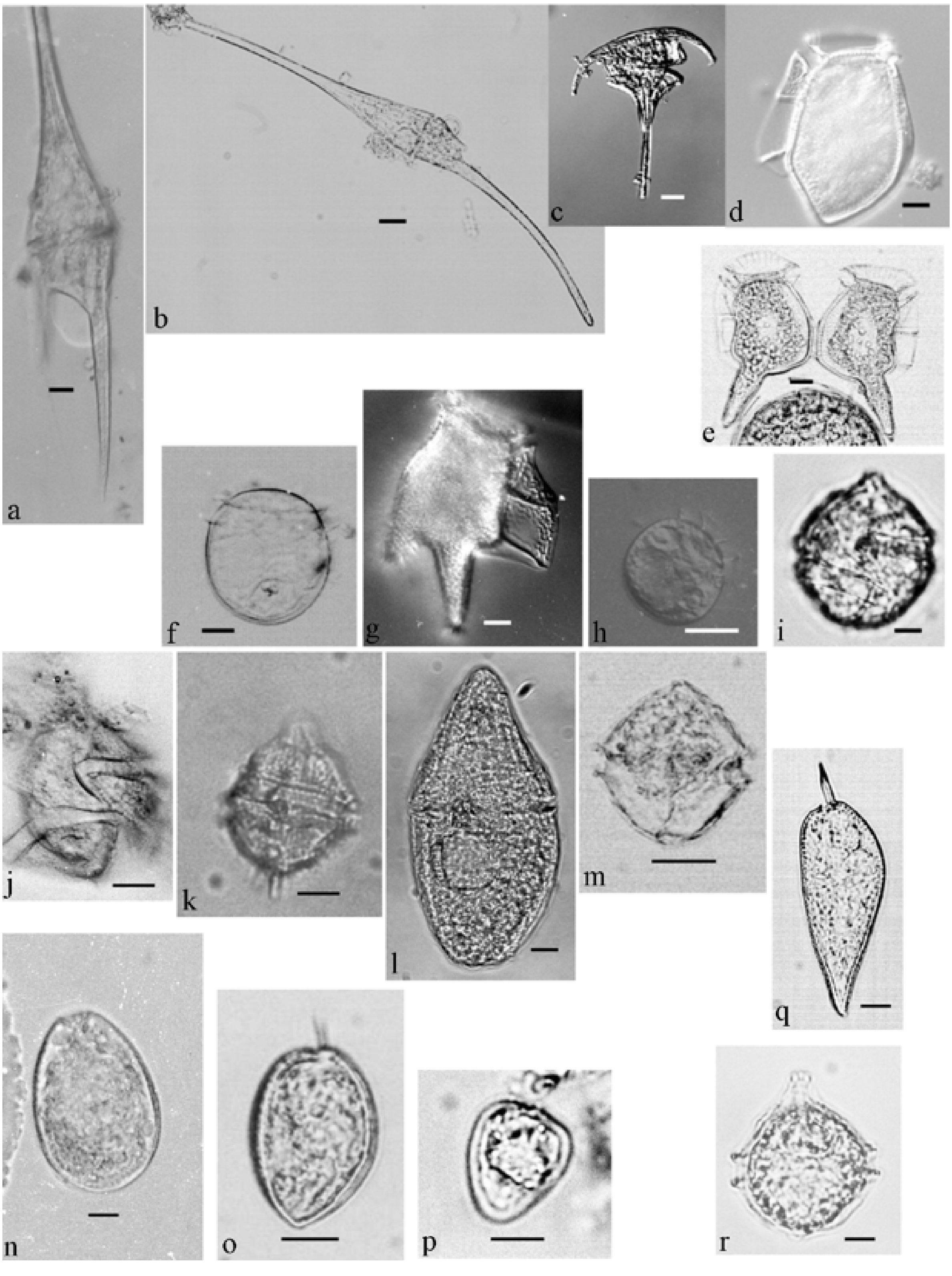

Fig. 3. Potentially harmful dinoflagellates in Nigeria's coastal water: (a) *Ceratium furca*, scale bar10 µm; (b) *Ceratium fusus,* scale bar 50 µm; (c) *Ceratium tripos*, scale bar 25 µm; (d) *Dinophysis acuta*, scale bar 25 µm; (e) *Dinophysis caudata*, scale bar 25 µm; (f) *Dinophysis rotundata*, scale bar 5 µm; (g) *Dinophysis tripos*, scale bar 25 µm; (h) *Dinophysis* sp., scale bar 25 µm; (i) *Gonyaulax diegensis*, scale bar 10 µm; (j) *Gonyaulax scrippsae*, scale bar 20 µm; (k) *Gonyaulax spinifera*, scale bar 10 µm; (l) *Gymnodinium* sp., scale bar 25 µm; (m) *Lingulodinium polyedrum*, scale bar 15 µm; (n) *Prorocentrum lima*, scale bar 5 µm; (o) *Prorocentrum micans*, scale bar 10 µm; (p) *Prorocentrum minimum*, scale bar 5 µm; (q) *Prorocentrum sigmoides*, scale bar 10 µm; (r) *Scrippsiella trochoidea*, scale bar 10 µm.

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## References

AISHAO, L., STOECKER, D.K. & COATS, D.W. (2000): Spatial and temporal aspects of *Gyrodinium galatheanum* in Chesapeake Bay: distribution and mixotrophy. – J. Plankt. Res. 22: 2105–2124.

AJUZIE, C.C. (2002): Studies on the harmful algal bloom phenomenon: a first perception and monitoring in Nigerian coastal waters, and the effects of the DSP-producing dinoflagellate *Prorocentrum lima* (Ehrenberg) Dodge on other aquatic biota. – 260 pp., D.Sc. Thesis, Université Libre de Bruxelles, Belgium.

AJUZIE, C.C. (2007): Palatability and fatality of the dinoflagellate *Prorocentrum lima* to *Artemia salina*. – J. Appl. Phycol. 19: 513–519.

AJUZIE, C.C. (2008): Toxic *Prorocentrum lima* induces abnormal behaviour in juvenile sea bass. – J. Appl. Phycol. 20: 19–27.

AJUZIE, C.C. & HOUVENAGHEL, G.T. (2003): *Prorocentrum lima* is toxic to juveniles of the European sea bass *Dicentrarchus labrax*. – In: BATES, S.S. (ed.): Proceedings of the Eight Canadian Workshop on Harmful Marine Algae. – pp. 37–45, Canadian Technical Report of Fisheries and Aquatic Sciences 2498.

ALFONSO, A., DE LA ROSA, L., VIEYTES, M.R., YASUMOTO, T. & BOTANA, L.M. (2003): Yessotoxin, a novel phycotoxin, activates phosphodiesterase activity – effect of yessotoxin on cAMP levels in human lymphocytes. – Biochem. Pharmacol. 65:193–208.

ALI-DINAR, A.B. (1999): Nigeria: Diarrhoea the leading killer. IRIN-WA Update 446 of events in West Africa. – http://www.africa.upenn.edu/Newsletters/irinw446.html

AMORIM, A., PALMA, A.S., SAMPAYO, M.A. & MOITA, M.T. (2001): On the *Lingulodinium polyedrum* bloom in Setúbal Bay, Portugal. – In: HALLEGRAEFF, G.M., BLACKBURN, S.J., BOLCH, C.J. & LEWIS, R.J. (eds): Harmful Algal Blooms 2000. – pp. 133–136, IOC of UNESCO.

ANDERSON, D.M., ANDERSEN, P., BRICELJ, M.V., CULLEN, J.J., & RENSEL, J.E. (2001): Monitoring and Management Strategies for Harmful Algal Blooms in Coastal Waters. – APEC #201-MR-01.1, Asia Pacific Economic Program, Singapore, and Intergovernmental Oceanographic Commission Technical Series No. 59, Paris.

AUNE, T., DAHL, E. & TANGEN, K. (1995): Algal monitoring, a useful tool in early warning of shellfish toxicity. – In: LASSUS, P., ARZUL, G., ERARD, E., GENTIAN, P. & MARCAILLOU, C. (eds): Harmful Marine Algal Blooms. – pp. 765–770, Lavoisier Publishing, Paris.

BADYLAK, S. & PHLIPS, E. (2004): Spatial and temporal patterns of phytoplankton composition in subtropical coastal lagoon, the Indian River Lagoon, Florida, USA. – J. Plankt. Res. 26: 1229–1247.

BAEK, S.H., SHIMODE, S. & KIKUCHI, T. (2008): Growth of dinoflagellates, *Ceratium furca* and *Ceratium fusus* in Sagami Bay, Japan: The role of temperature, light intensity and photoperiod. – Harmful Algae 7: 163–173.

BAND-SCHMIDT, C., BUSTILLOS-GUZMÁN, J., MORQUECHO, L., GÁRATE-LIZÁRRAGA, I., ALONSO-RODRÍGUEZ, R., REYES-SALINAS, A., ERLER, K. & LUCKAS, B. (2006): Variations of PSP toxin profiles during different growth phases in *Gymnodinium catenatum* (Dinophyceae) strains isolated from three locations in the Gulf of California, Mexico. – J. Phycol. 42: 757–768.

BELIN, C., BELIAEF, B., RAFFIN, B., RABIA, M. & IBANEZ, F (1995): Phytoplankton time-series data of the French phytoplankton monitoring network: toxic and dominant species. – In: LASSUS, P., ARZUL, G., ERARD, E., GENTIAN, P. & MARCAILLOU, C. (eds): Harmful Marine Algal Blooms. – pp. 771–776, Lavoisier Publishing, Paris.

BLANCO, J., MOROÑO, A. & FERNÁNDEZ, M.L. (2005): Toxic episodes in shellfish, produced by lipophilic phycotoxins: an overview. – Revista Galega dos Recursos Mariños (Monog) 1: 1–70.

BOESCH, D.F., ANDERSON, D.M., HORNER, R.A., SHUMWAY, S.E., TESTER, P.A. & WHITLEDGE, T.E. (1997): Harmful algal blooms in coastal waters: options for prevention, control and mitigation. – NOAA Coastal Program Decision Analysis Series 10. – pp. 1–46, NOAA Coastal Ocean Office, Silver Spring, MD.

BOURDEAU, P., DURAND-CLEMENT, M., AMMAR, M. & FESSARD, V. (1995): Ecological and toxicological characteristics of benthic dinoflagellates in a ciguateric area (Saint Barthelemy: French West Indies). – In: LASSUS, P., ARZUL, G., ERARD, E., GENTIAN, P. & MARCAILLOU, C. (eds): Harmful Marine Algal Blooms. – pp. 133–137, Lavoisier Publishing, Paris.

BRAVO, I., FERNÁNDEZ, M.L., RAMILO, I. & MARTINEZ, A. (2001): Toxin composition of the toxic dinoflagellate *Prorocentrum lima* isolated from different locations along the Galician coast (NW Spain). – Toxicon 39: 1537–1545.

CABRINI, M., CATALETTO, B., GANIS, P., PECCHIAR, I. &

Fonda, U.S. (1995): Relationships between toxic phytoplankton and environmental factors in the gulf of Trieste: multifactorial analysis. – In: Lassus, P., Arzul, G., Erard, E., Gentian, P. & Marcaillou, C. (eds): Harmful Marine Algal Blooms. – pp. 139–144, Lavoisier Publishing, Paris.

Cembella, A.D. & Lamoureux, G. (1993): A competitive inhibition enzyme-linked immunoassay for the detection of paralytic shellfish toxins in marine phytoplankton. – In: Smayda, T.J. & Shimizu, Y. (eds): Toxic Phytoplankton Blooms in the Sea. – pp. 857–862, Elsevier, Amsterdam.

Chang, F.H. (1995): The first records of *Gymnodinium* sp. nov. (cf. *breve*) (Dinophyceae) and other harmful phytoplankton species in the early 1993 blooms in New Zealand. – In: Lassus, P., Arzul, G., Erard, E., Gentian, P. & Marcaillou, C. (eds): Harmful Marine Algal Blooms. – pp. 27–32, Lavoisier Publishing, Paris.

Colin, S.P. & Dam, H.G. (2005): Testing for resistance of pelagic marine copepods to a toxic dinoflagellate. – Evol. Ecol. 18: 355–377.

Denardou-Queneherve, A., Grzebyk, D., Pouchus, Y.F., Sauviat, M.P., Alliot, E., Biard, J.F., Berland, B. & Verbist, J.F. (1999): Toxicity of French strains of the dinoflagellate *Prorocentrum minimum* experimental and natural contaminations of mussels. – Toxicon 37: 1711–1719.

Dethlefsen, V. & Von Westernhagen, H. (1983): Oxygen deficiency and effects on bottom fauna in the eastern German Bight, 1982. – Meeresforsch 33: 104–106.

Dodge, J.D. (1982): Marine Dinoflagellates of the British Isles. – 303 pp., Her Majesty's Stationery Office, London.

Dortch, Q. (2003) Nutrients and harmful algal blooms: general issues and examples from the northern gulf of Mexico. – J. Phycol. 39: 13–13.

Draisci, R., Ferretti, E., Palleschi, L., Marchiafava, C., Poetti, R., Milandri, A., Ceredi, A. & Pompei, M. (1999): High levels of yessotoxin in mussels and presence of yessotoxin and homoyessotoxin in dinoflagellates of Adriatic Sea. – Toxicon 37: 1187–1193.

Espenes, A., Aasen, J., Satake, M., Smith, A., Eraker, N. & Aune, T. (2004): Toxicity of yessotoxin towards mice upon repeated oral exposure. – Fifth International Conference on Molluscan Shellfish Safety, Book of Abstracts. – p. 31, Galway, Ireland 2004.

Faust, M.A. (1993): Alternate asexual reproduction of *Prorocentrum lima* in culture. – In: Smayda, T.J. & Shimizu, Y. (eds): Toxic Phytoplankton Blooms in the Sea. – pp. 115–120, Elsevier, Amsterdam.

Faust, M.A. (2000): Biodiversity of planktonic dinoflagellate species in mangrove ponds, Pelican Cays, Belize. – J. Phycol. 36: 22–22.

Foden, J., Purdie, D.A., Morris, S. & Nascimento, S. (2005): Epiphytic abundance and toxicity of *Prorocentrum lima* populations in the Fleet Lagoon, UK. – Harmful Algae 4: 1063–1074.

Gago, A., Rodriguez-Vázquez, J.A., Leao, J.M., Comesaña, M., Quilliam, M.A. & Thibault, P. (1996): 1985-1995: A decade of studies of PSP and DSP toxins in Spanish mussels by chemical methods. – In Yasumoto, T., Oshima, Y. & Fukuyo, Y. (eds): Harmful and Toxic Algal Blooms. – pp. 7–10, UNESCO, Paris.

Gallegos, C.L. & Bergstrom, P.W. (2005): Effects of a *Prorocentrum minimum* bloom on light availability for and potential impacts on submersed aquatic vegetation in upper Chesapeake Bay. – Harmful Algae 4: 553–574.

Geohab (2001): Global Ecology and Oceanography of Harmful Algal Blooms, Science Plan. – Glibert, P. & Pitcher, G. (eds): SCOR and IOC. – 86 pp., Baltimore and Paris.

Glibert, P.M., Landsberg, J.H., Evans, J.J., Al-Sarawa, M.A., Faraj, M., Al-Jarallah, M.A., Haywood, A., Ibrahem, S., Klesius, P., Powel, C. & Shoemaker, C. (2002): A fish kill of massive proportion in Kuwait Bay, Arabian Gulf, 2001: the roles of bacterial disease, harmful algae, and eutrophication. – Harmful Algae 1: 215–231.

Godhe, A., Rehnstam-Holm, A.-S., Karunasagar, I. & Karunasagar, I. (2002): PCR detection of dinoflagellate cysts in field sediment samples from tropic and temperate environments. – Harmful Algae 1: 361–373.

Grzebyk, D., Denardou, A., Berland, B. & Pouchus, Y.F. (1997): Evidence of a new toxin in the red-tide dinoflagellate *Prorocentrum lima.* – J. Plank. Res. 19: 1111–1124.

Guillou, L., Nezan, E., Gentien, P. & Barbier, G. (2000): Molecular study of the toxic algae *Dinophysis* spp. from the French coast. – J. Phycol. 36: 27–27.

Hallegraeff, G.M. (1991): Aquaculturists' Guide to Harmful Australian Microalgae. – 111 pp., CSIRO, Australia.

Hallegraeff, G.M. (1995): Harmful algal blooms: a global overview. – In: Hallegraeff, G.M., Anderson, D.M. & Cembella, A.D. (eds): Manual on Harmful Marine Microalgae, IOC Manuals and Guides 33. – pp. 1–22, UNESCO, Paris.

Hallegraeff, G.M., Anderson, D.M. & Cembella, A.D. (eds) (1995): Manual on Harmful Marine Microalgae. IOC Manuals and Guides No. 33. – 551 pp., UNESCO, Paris.

Heil, C.A., Glibert, P.M. & Fan, C. (2005): *Prorocentrum minimum* (Pavillard) Schiller: a review of a harmful algal bloom species of growing worldwide importance. – Harmful Algae 4: 449–470.

JACKSON, A.E., MARR, J.C. & MCLACHLAN, J.L. (1993): The production of diarrhetic shellfish toxins by an isolate of *Prorocentrum lima* from Nova Scotia, Canada. – In: SMAYDA, T.J. & SHIMIZU, Y. (eds): Toxic Phytoplankton Blooms in the Sea. – pp. 513–558, Elsevier, Amsterdam.

JACKSON, D. & SILKE, J. (1995): *Dinophysis* spp and the occurrence of diarrhetic shellfish poisons in Ireland. – In: LASSUS, P., ARZUL, G., ERARD, E., GENTIAN, P. & MARCAILLOU, C. (eds): Harmful Marine Algal Blooms. – pp. 789–794, Lavoisier Publishing, Paris.

JOHANSSON, N., GRANÉLI, E., YASUMOTO, T., CARLSSON, P. & LEGRAND, C. (1996): Toxin production by *Dinophysis acuminata* and *D. acuta* cells grown under nutrient sufficient and deficient conditions. – In: YASUMOTO, T., OSHIMA, Y. & FUKUYO, Y. (eds): Harmful and Toxic Algal Blooms. – pp. 277–280, UNESCO, Paris.

KARUNASAGAR, I., SEGAR, K. & KARUNASAGAR, I. (1989): Potentially toxic dinoflagellates in shellfish harvesting areas along the coast of Karnataka State (India). – In: OKAICHI, T., ANDERSON, D.M. & NEMOTO, T. (eds): Red Tides: Biology, Environmental Science and Toxicology. – pp. 65–68, Elsevier, Amsterdam.

KELLY, A.M., KOHLER, C.C. & TINDALL, D.R. (1992): Are crustaceans linked to the ciguatera food chain? – Environ. Biol. Fish. 33: 275–286.

KIRKPATRICK, B., FLEMING, L.E., STEPHAN, W.B., BACKER, L., CLARK, R., SQUICCIARINI, D., WEISMAN, R. & VAN DE BOGERT G. (2002): Public outreach materials regarding harmful algal blooms and their possible effects on human health. – J. Phycol. 38: 18–19.

KUDELA, R., PITCHER, G., PROBYN, T., FIGUEIRAS, F., MOITA, T. & TRAINER, V. (2005): Harmful algal blooms in coastal upwelling systems. – Oceanography 18: 185–197.

LAM, C.W.Y. & HO, K.C. (1989): Red tides in Tolo Harbour, Hong Kong. – In: OKAICHI, T., ANDERSON, D.M. & NEMOTO, T. (eds): Red Tides: Biology, Environmental Science and Toxicology. – pp. 49–52, Elsevier, Amsterdam.

LEANDER, B.S. & KEELING, P.J. (2004): Early evolutionary history of dinoflagellates and apicomplexans (Alveolata) as inferred from HSP90 and actin phylogenies. – J. Phycol. 40: 341–350.

LEBOUR, M.V. (1925): The dinoflagellates of Northern Seas. – 250 pp., Plymouth Marine Biological Association.

LEE, J.S., IGARASHI, T., FRAGA, S., DAHL, E, HOVGAARD, P. & YASUMOTO, T. (1989): Determination of diarrhetic shellfish toxins in various dinoflagellate species. – J. Appl. Phycol. 1: 147–152.

LEIVESTAD, H. & SERIGSTAD, B. (1988): Some observations on the effects of *Chyrosochromulina polylepis* on the osmoregulation in fish. – 29 pp., Rep. BKO 8803, Norwegian Institute of Marine Research.

LU, S. & HODGKISS, I.J. (2004): Harmful algal bloom causative collected from Hong Kong waters. – Hydrobiologia 512: 231–238.

LUCKAS, B., DAHLMANN, J., ERIER, K., GERDTS, G., WASMUND, N., HUMMERT, C. & HANSEN, P.D. (2005): Overview of key phytoplankton toxins and their recent occurrence in the North and Baltic Seas. – Environ. Toxicol. 20: 1–17.

MACKENZIE, L., HAYWOOD, A., ADAMSOM, J., TRUMAN, P., TILL, D., SEKI, T., SATAKE, M. & YASUMOTO, T. (1996): Gymnodimine contamination of shellfish in New Zealand. – In: YASUMOTO, T., OSHIMA, Y. & FUKUYO, Y. (eds): Harmful and Toxic Algal Blooms. – pp. 97–100, UNESCO, Paris.

MAHONEY, J.B. & STEIMLE, F.W. (1979): A mass mortality of marine animals associated with a bloom of *Ceratium tripos* in the New York Bight. – In: TAYLOR, D.L. & SELIGER, H.H. (eds): Toxic Dinoflagellate Blooms. – pp. 225–230, Elsevier, Amsterdam.

MARANDA, L., CORWIN, S. & HARGRAVES, P.E. (2007a): *Prorocentrum lima* (Dinophyceae) in northeastern USA coastal waters: I. Toxin load in the epibiota and in shellfish. – Harmful Algae 6: 632–641.

MARANDA, L., CORWIN, S., DOVER, S. & MORTON, S.L. (2007b): *Prorocentrum lima* (Dinophyceae) in northeastern USA coastal waters: II. Abundance and distribution. – Harmful Algae 6: 623–631.

MATTHEWS, S.G. & PITCHER, G.C. (1996): Worst recorded marine mortality on the South African coast. – In: YASUMOTO, T., OSHIMA, Y. & FUKUYO, Y. (eds): Harmful and Toxic Algal Blooms. – pp. 89–92, UNESCO, Paris.

MCLACHLAN, J.L., BOALCH, G.T. & JAHN, R. (1997) : Reinstatement of the genus *Exuviaella* (Dinophyceae, Protocentrophycidae) and an assessment of *Prorocentrum lima*. – Phycologia 36: 38–46.

MORTON, S.L., LEIGHFIELD, T.A., HAYNES, B.L., PETITPAIN, D.L., BUSMAN, M.A., MOELLER, P.D.R., BEAN, L., MCGOWAN, J., JOHN, W., HURST, J. & DOLAH, F.M.V. (1999): Evidence of diarrhetic shellfish poisoning along the coast of Maine. – J. Shellfish Res. 18: 681–686.

NASCIMENTO, S.M., PURDIE, D.A. & MORRIS, J. (2005): Morphology, toxin composition and pigment content of *Prorocentrum lima* strains isolated from a coastal lagoon in southern UK. – Toxicon 45: 633–649.

NEHRING, S., HESSE, K.-J. & TILLMANN, U. (1995): The German Wadden Sea: A problem area for nuisance blooms. – In: Lassus, P., Arzul, G., Erard, E., Gentian, P. & Marcaillou, C. (eds): Harmful Marine Algal Blooms. – pp. 199–204, Lavoisier Publishing, Paris.

Nwankwo, D.I. (1997): A first list of dinoflagellates (Pyrrhophyta) from Nigerian coastal waters (creeks, estuaries, lagoons). – Pol. Arch. Hydrobiol. 44: 313–321.

Obadina, T. (1999): Country focus: Nigeria–deterioration in education and health services. – Africa Recovery 13: 1.

Öhman, P. & Lindhom, T. (1995): Occurrence of *Prorocentrum micans* and *Kryptoperidinium foliaceum* in SW Finland. – In: Lassus, P., Arzul, G., Erard, E., Gentian, P. & Marcaillou, C. (eds): Harmful Marine Algal Blooms. – pp. 219–222, Lavoisier Publishing, Paris.

Pauley, K.E., Seguel, M.R., Smith, J.C., McLachlan, J.L. & Worms, J. (1993): Occurrences of phycotoxins and related phytoplankton at winter temperatures in the Southeastern Gulf of St. Lawrence, Canada. – In: Smayda, T.J. & Shimizu, Y. (eds): Toxic Phytoplankton Blooms in the Sea. – pp. 311–316, Elsevier, Amsterdam.

Paz, B., Riobó, P., Fernández, A.L., Fraga, S. & Franco, J.M. (2004): Production and release of yessotoxins by the dinoflagellates *Protoceratium reticulatum* and *Lyngulodinium polyedrum* in culture. – Toxicon 44: 251–258.

Pertola, S., Kuosa, H. & Olsonen, R. (2005): Is the inversion of *Prorocentrum minimum* (Dinophyceae) related to the enrichment of the Baltic Sea? – Harmful Algae 4: 481–492.

Pillet, S., Pereira, A., Braekman, J.C. & Houvenaghel, G. (1995): Patterns in long-term accumulation of okadaic acid and DTX1 in blue mussels, *Mytilus edulis*, experimentally fed with DSP containing alga *Prorocentrum lima*. – In: Lassus, P., Arzul, G., Erard, E., Gentian, P. & Marcaillou, C. (eds): Harmful Marine Algal Blooms. – pp. 487–492, Lavoisier Publishing, Paris.

Pitcher, G. & Matthews, S. (1996): Noxious *Gymnodinium* species in South African waters. – Harmful Algae News 15: 1–3.

Place, A., Adolf, J.E. & Lund, E. (2000): Modulation of very-long chain (C28) highly unsaturated fatty acids in *Prorocentrum minimum* (Dinophyceae) by selenium. – J. Phycol. 36: 55–55.

Prezelin, B.B. & Sweeney, B.M. (1979): Photoadaptation of photosynthesis in two bloom-forming dinoflagellates. – In: Taylor, D.L. & Seliger, H.H. (eds): Toxic Dinoflagellate Blooms. – pp. 101–106, Elsevier, Amsterdam.

Quilliam, M.A., Gilgan, M.W., Pleasance, S., Defreitas, A.S.W., Douglas, D., Fritz, L., Hu, T., Marr, J.C., Smyth, C. & Wright, J.L.C. (1993): Confirmation of an incident of diarrhetic shellfish poisoning in Eastern Canada. – In: Smayda, T.J. & Shimizu, Y. (eds): Toxic Phytoplankton Blooms in the Sea. – pp. 547–552, Elsevier, Amsterdam.

Rhodes, L., Mcnabb, P., De Salas, M., Briggs, L., Beuzenberg, V. & Gladstone, M. (2006): Yessotoxin production by *Gonyaulax spinifera*. – Harmful Algae 5: 148–155.

Roberts, R.J., Bullock, A.M., Turner, M., Jones, K., Tett, P. (1983): Mortalities of *Salmo gairdneri* exposed to cultures of *Gyrodinium aureolum*. – J. Mar. Biol. Assoc. UK 63: 741–743.

Robineau, B., Gagné, J.A., Fortier, L. & Villeneuve, A. (1993): Co-distribution of the toxic dinoflagellate *Alexandrium excavatum* and fish larvae in the Northwest Gulf of St. Lawrence. – In: Smayda, T.J. & Shimizu, Y. (eds): Toxic Phytoplankton Blooms in the Sea. – pp. 323–327, Elsevier, Amsterdam.

Sellner, K.G., Doucette, G.J. & Kirkpatrick, G.J. (2003): Harmful algal blooms: causes, impacts and detection. – J. Ind. Microbiol. Biotechnol. 30: 383–406.

Sherr, E.B. & Sherr, B.F. (2002): Significance of predation by protists in aquatic microbial food webs. – Antonie Leeuwenhoek 81: 293–308.

Shumway, S.E. (1990): A review of the effects of algal bloom on shellfish and aquaculture. – J. World Aquacutl. Soc. 21: 65–104.

Shumway, S.E. (1995): Phycotoxin-related shellfish poisoning: bivalve molluscs are not the only vectors. – Reviews in Fisheries Science 3: 1–31.

Smayda, T.J. (1990): Novel and nuisance phytoplankton blooms in the sea: evidence for a global epidemic. – In: Granéli, E., Sundström, B., Edler, L. & Anderson, D.M. (eds): Toxic Marine Phytoplankton. – pp. 29–40, Elsevier, Amsterdam.

Smayda, T.J. (1995): Environmental monitoring. – In: Hallegraeff, G.M., Anderson, D.M. & Cembella, A.D. (eds): Manual on Harmful Marine Microalgae, IOC Manuals and Guides 33. – pp. 405–431, UNESCO, Paris.

Smayda, T.J. & Reynolds, C.S. (2001): Community assembly in marine phytoplankton: application of recent models to harmful dinoflagellate blooms. – J. Plankt. Res. 23: 447–461.

Smith, V.H. (2003): Eutrophication of freshwater and coastal marine ecosystems: a global problem. – Environ. Sci. Pollut. Res. Int. 10: 126–139.

Sournia, A. (1995): Red tide and toxic marine phytoplankton of the world ocean: an inquiry into biodiversity. – In: Lassus, P., Arzul, G., Erard, E., Gentian, P. & Marcaillou, C. (eds): Harmful Marine Algal Blooms. – pp. 103–112, Lavoisier Publishing, Paris.

STEIDINGER, K.A., DAVIES, J.T. & WILLIAMS, J. (1967): Dinoflagellate studies on the inshore waters of the west coast Florida. – Florida Board of Conservation, Professional Papers Series No. 9: 4–47.

TANG, D.L., DI, B.P., WEI, G., NI, I.-H., OH, I.M. & WANG, S.F. (2006): Spatial, seasonal and species variations of harmful algal blooms in the South Yellow Sea and East China Sea. – Hydrobiologia 568: 245–253.

TANGO, P..J, MAGNIEN, R., BUTLER, W., LUCKETT, C., LUCKENBACH, M., LACOUTURE, R. & POUKISH, C. (2005): Impacts and potential effects due to *Prorocentrum minimum* blooms in Chesapeake Bay. – Harmful Algae 4: 525–531.

TAYLOR, F.J.R. (ed) (1987): The Biology of Dinoflagellates. – 785 pp., Blackwell Scientific Publications, Oxford.

TAYLOR, F.J.R. (1993): Current problems with harmful phytoplankton blooms in British Columbia waters. – In: SMAYDA, T.J. & SHIMIZU, Y. (eds): Toxic Phytoplankton Blooms in the Sea. – pp. 699–703, Elsevier, Amsterdam.

TAYLOR, F.J.R., FUKUYO, Y. & LARSEN, J. (1995): Taxonomy of harmful dinoflagellates. – In: HALLEGRAEFF, G.M., ANDERSON, D.M. & CEMBELLA, A.D. (eds): Manual on Harmful Marine Microalgae, IOC Manuals and Guides 33. – pp. 283–317, UNESCO, Paris.

TERAO, K., ITO, E., OARADA, M., MURATA, M. & YASUMOTO, T. (1990): Histopathological studies on experimental marine toxin poisoning. The effects on mice of yessotoxin isolated from *Patinopecten yessoensis* and of a desulfated derivative. – Toxicon 28: 1095–1104.

TERAO, K., ITO, E., OHKUSU, M. & YASUMOTO, T. (1993): A comparative study of the effects of DSP-toxins on mice and rats. – In: SMAYDA, T.J. & SHIMIZU, Y. (eds): Toxic Phytoplankton Blooms in the Sea. – pp. 581–586, Elsevier, Amsterdam.

TODD, E.C.D. (1995): Estimated costs of paralytic shellfish, diarrhetic shellfish and ciguatera poisoning in Canada. – In: LASSUS, P., ARZUL, G., ERARD, E., GENTIAN, P. & MARCAILLOU, C. (eds): Harmful Marine Algal Blooms. – pp. 831–834, Lavoisier Publishing, Paris.

TOMAS, C.R. (ed) (1997): Identifying Marine Phytoplankton. – 858 pp., Academic Press, London.

TSENG, C.K., ZHOU, M.J. & ZOU, J.Z. (1993): Toxic phytoplankton studies in China. – In: SMAYDA, T.J. & SHIMIZU, Y. (eds): Toxic Phytoplankton Blooms in the Sea. – pp. 347–352, Elsevier, Amsterdam.

TUBARO, A., SIDARI, L., LOGGIA, R.D. & YASUMOTO, T. (1998): Occurrence of yessotoxin-like toxins in phytoplankton and mussels from northern Adriatic Sea. – In: REGUERA, B., BLANCO, J., FERNÁNDEZ, M.L. & WYATT, T. (eds): Harmful Algae, Xunta de Galicia and IOC. – pp. 470–472, UNESCO, Paris.

WARNER, M.E. & MADDEN, M.L. (2007): The impact of shifts to elevated irradiance on the growth and photochemical activity of the harmful algae *Chattonella subsalsa* and *Prorocentrum minimum* from Delaware. – Harmful Algae 6: 332–342.

WILDISH, D.J., BOUVET, F., PETERSON, R.H. & MARTIN, J.L. (1991): The effect of marine microalgal extracts on the salmon smolt electrocardiogram. – In: GORDON, D.C. (ed.): Proceedings of the Second Canadian Workshop on Harmful Marine Algae. – p. 28, Canadian Technical Report of Fisheries and Aquatic Sciences 1799.

YAMAMOTO, M. & YAMASAKI, M. (1996): Japanese monitoring system on shellfish toxins. – In: YASUMOTO, T., OSHIMA, Y. & FUKUYO, Y. (eds): Harmful and Toxic Algal Blooms. – pp. 19–22, UNESCO, Paris.

YASUMOTO, T., UNDERDAL, B., AUNE, T., HORMAZABAL, V., SKULBERG, O.M. & OSHIMA, Y. (1990): Screening for haemolytic and ichthyotoxic components of *Chrysochromulina polylepis* and *Gyrodinium aureolum* from Norwegian coastal waters. – In: GRANÉLI, E., SUNDSTRÖM, B., EDLER, L. & ANDERSON, D.M. (eds): Toxic Marine Phytolplankton. – pp. 436–440, Elsevier, Amsterdam.

YOO, J.S. (2004): Morphological variation of dinoflagellate *Prorocentrum lima* (Ehrenberg) Dodge with geographical difference. – J. Environ. Biol. 25: 51–58.

YUZOA, Q., ZIAPING, Z., YING, H., SONGHUI, L., CONGJU, Z. & YAQING, L. (1993): Occurrence of red tides on the coasts of China. – In: SMAYDA, T.J. & SHIMIZU, Y. (eds): Toxic Phytoplankton Blooms in the Sea. – pp. 43–46, Elsevier, Amsterdam.


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