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Harold G. Marshall
Old Dominion University, hmarshal@odu.edu

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Toxin Producing Phytoplankton in Chesapeake Bay

Harold G. Marshall, Department of Biological Sciences, Old Dominion University, Norfolk, Virginia 23529-0266

ABSTRACT

Three diatoms and nine dinoflagellates, known to be associated with toxin production, have been identified within Chesapeake Bay. Over the past several decades this number has increased to its present level so that they now represent approximately 1.7% the total number of phytoplankton species reported for the Bay.

INTRODUCTION

Hallegraeff (1993) and Smayda (1989) indicate there is a global increase in the occurrence and geographical distribution of marine phytoplankton blooms, including blooms produced by species that are toxin producers. Hallegraeff offers several reasons to explain the increased reports of bloom events. These are: 1) the scientific community is more alert regarding the presence of bloom producers and is now reporting blooms more frequently, 2) the greater use of coastal waters for aquaculture has provided additional favorable sites for blooms to develop, and represent additional sources for reporting toxic events, 3) there has occurred in recent years greater nutrient enrichment of coastal and estuarine waters that fosters increased phytoplankton abundance, including bloom events, and 4) the resting cysts of many algae can be transported in ballast water of ships that move from one global port to another, providing a mechanism for expanding the distribution range for species, including those that produce blooms.

For the past three decades the author has reported on the phytoplankton from Chesapeake Bay, plus many of the regional tributaries associated with this estuary, identifying 708 taxa from Chesapeake Bay (Marshall, 1994a). Since 1985, monthly phytoplankton collections have been taken at 7 stations within Chesapeake Bay. Reports based on the analysis of these collections have identified phytoplankton composition, productivity, plus spatial and temporal relationships to water quality variables and algal composition (Marshall, 1994a; Marshall and Alden 1990). The data obtained in this monitoring program, personal records, and other publications, have provided the information on toxin and bloom producing taxa used in this report. The purpose of this paper is to identify species in Chesapeake Bay that have been linked to toxin production in either field or laboratory studies.

Historical Records:

The earliest listing of phytoplankton taxa in Chesapeake Bay is by Wolfe et al. (1926), who reported on several seasonal collections within the Bay taken between 1916 and 1922. From these samples they noted 99 species. Subsequent systematic studies by Cowles (1930), Griffith (1961), Patten et al. (1963), Mulford (1967), and Marshall (1967) gradually added to the phytoplankton species identified in Chesapeake Bay . From these earlier papers the diatoms *Amphora coffeaeformis*, *Nitzschia* (*Pseudo-nitzschia*) f. *multiseries*, and the dinoflagellates *Cochlodinium heterolobatum*, *Dinophysis acuminata*, *D. acuta*, *D. caudata*, *Prorocentrum minimum*, have since been recognized as potential toxin producers (Steidinger, 1993). Also noted by Morse (1947) and Mulford (1967) is *Gonyaulax catenella* Whedon-Kofoid (now classified as *Alexandrium catenella* (Whedon-Kofoid) Balech) and *Gonyaulax polyedra* Stein in the Patuxent River, and a single record of *G. polyedra* at the Chesapeake Bay entrance by Marshall (personal records). They both produce toxins, with *A. catenella* one of the causative agents for paralytic shellfish poisoning (Steidinger, 1993).

Phytoplankton Blooms:

The term phytoplankton bloom is generally applied to a rapid increase in abundance within the phytoplankton community. There are seasonal blooms where cell concentrations increase annually within entire bodies of water usually during spring, summer, or fall. In contrast, there are blooms that are more limited in their scope and composition. The term bloom used in this paper refers to a situation where over a relatively short period of time, there is a major increase in the cell concentrations of usually one primary species, with this growth more localized, and limited in its development and duration (e.g. days, few weeks). The water color during these events will typically have a red, brown, or green coloration, depending on the species producing the bloom, and its abundance. Cell concentrations of the primary bloom producer will vary with the taxon, and its cell size. Some of the large dinoflagellates will reach bloom concentrations at 10^5 cells l^{-1}, whereas with other taxa, bloom concentrations may level off at 10^6 to 10^8 cells l^{-1}. Blooms are commonly recognized as isolated surface patches of various sizes, or be concentrated along tidal fronts, appearing as streaks of discolored water.

Marshall (1989) reviewed the records of bloom events in the Chesapeake Bay from 1963 through 1989. The majority (67%) of these blooms occurred in tributaries to the Bay (near their river mouths), and 25% were located within the Bay, with the remaining (8%) in adjacent ponds and outside the Bay entrance. Blooms were recorded in each season, but the majority occurred during Summer (54%), followed by Fall (26%), Spring (15%), and Winter (5%). These blooms were not associated with toxin production, major fish kills, or shellfish poisoning, and may be produced by toxin or non-toxin producing species. Yet, there is wide variation in the ability of toxin producing species to produce toxins, and in the strength of toxins they produce (Hallegraff, 1993). The presence of a species reported to produce a toxin does not mean a potent toxin will be produced.

Dinoflagellates:

The following are dinoflagellates recorded since 1985 from Chesapeake Bay that have been associated with toxin production.

During mid-summer to early fall in 1992, a bloom of the dinoflagellate *Cochlodinium heterolobatum* Silva (=*Cochlodinium polykrikoides* Margalef) spread from the mouth of the York River into and out of the lower Chesapeake Bay, and was then transported in near shore waters southward to North Carolina. Concentrations reached 10^5 - 10^6 cells l^1 and at one time was spread over 215.7 km^2 of the central and western Chesapeake Bay (Marshall, 1994b). Prior to this event, blooms of this species were generally localized in the York River (Mackiernan, 1968; Zubkoff and Warinner, 1975; Zubkoff et al., 1979; Zubkoff, 1982). Since 1992, *Cochlodinium heterolobatum* has apparently expanded its regional range, and has become established as an annual bloom producer in several rivers of the lower Chesapeake Bay, where previously it had not been reported (e.g. James, Elizabeth, Pagan, and LaFayette Rivers). The cells reproduce rapidly, often occurring in rows of 2,4, or 8 connected cells. The blooms generally last several days and often extend into nearby inlets. This species is expected to produce summer blooms annually in the local rivers, and a more frequent appearance in the lower Chesapeake Bay is expected to occur. Although no major toxic events were associated with these blooms in Chesapeake Bay, Yuki and Yoshimatsu (1989) have linked this species with deaths in fish culturing grounds in Japan, and Steidinger (1993) lists this dinoflagellate as a toxin producer. This species will reach bloom concentrations at river sites generally in late July with major development typically occurring in August. It is often accompanied by several non-toxin producing dinoflagellates in lesser abundance, including *Scrippsiella trochoidea* and *Gymnodinium splendens*, along with cryptomonads and several diatom taxa.

Prorocentrum minimum (Pavillard) Schiller is well documented in the early reports of Bay phytoplankton, in addition to an account of a small *Prorocentrum* mentioned by Cowles (1930), that was probably *P. minimum*. *Prorocentrum minimum* is reported to produce a toxic substance directly responsible for fish and shellfish kills (Okaichi and Imatomi, 1979; Steidinger, 1993). Tyler and Seliger (1978) have associated this species with seasonal blooms in the upper Chesapeake Bay and its transport to these sites within sub-pycnocline waters. In the lower Bay this species is generally ubiquitous, and increases in abundance in spring, reaching higher levels in summer and fall. It is also a frequent sub-dominant species during bloom events and is one of the most common dinoflagellates in the Bay (Marshall, 1994a).

The genus *Dinophysis* is represented in the Chesapeake Bay by five species that are known to produce okadaic acid, or other toxins causing diarrhetic shellfish poisoning (Yasumoto, 1990; Steidinger, 1993). These substances when concentrated in clams, oysters, etc. may cause this illness in humans who eat the infected shellfish. These include *Dinophysis acuminata* Claparède and Lachmann, *D. acuta* Eherenberg, *D. caudata* Saville-Kent, *D. fortii* Pavillard, and *D. norvegica* Claparède and Lachmann. These species are present within Atlantic coastal waters and their cells may be found frequently in sub-pycnocline waters entering Chesapeake Bay. Major outbreaks of diarrhetic shellfish poisoning have occurred in european waters due to *D. acuminata* and off Nova Scotia by *D. norvegica* (Kat, 1985; Rao et al., 1993). Although not abundant, and often rarely noted, each of these *Dinophysis* spp. have been recorded in the lower Chesapeake Bay. In addition, *Dinophysis tripos* Gourret, reported by Yasumoto (1990) as a toxin producer, has also been identified from shelf waters in the vicinity of the Chesapeake Bay entrance (Marshall, 1982).

Gyrodinium aureolum Hulburt has a broad geographic distribution and is known as a toxin producing bloom species that has been associated with massive fish and invertebrate mortality (Tangen, 1977; Jones et al., 1982). This species was first reported in Chesapeake Bay by Marshall (1980a), but was not noted again till over a decade later in an isolated inlet at the U.S. Naval Amphibious Base in Virginia Beach (Marshall, 1994b). Its presence there was possibly due to ballast water discharged in the harbor.

The most recent event regarding a potent toxin producing dinoflagellate was the discovery of *Pfiesteria piscicida* Steidinger and Burkholder from Jenkins Creek in the upper Chesapeake Bay (Lewitus et al., 1995). It is a polymorphic species, possessing flagellated, amoeboid, and cyst life stages, with the cysts in the substrate activated into motile cells by the presence of fish (e.g. by their excreta)(Burkholder et al., 1992). These cells attach to the fish and produce the toxin that will poison them, and then return to the substrate and form cysts. This species has produced extensive fish kills in North Carolina estuaries with its toxin producing various neurosensory ailments in humans (Burkholder et al., 1995; Franklin, 1995).

Although mentioned above in the earlier literature, the following species were not found in the present monitoring program (1985-1996): *Alexandrium* (*Gonyaulax*) *catenella* (Whedon-Kofoid) Balech) and *Gonyaulax polyedra* Stein. Marshall (1982) has also reported *Gymnodinium breve* Davis, the agent causing neurotoxic shellfish poisoning, off the Chesapeake Bay entrance, but this species has not been noted since for this area. This is primarily a tropical and sub-tropical species that is not expected to be common in these waters.

Diatoms:

To date, four diatoms that are recognized as domoic acid producers, have been recorded for Chesapeake Bay. These are *Pseudo-nitzschia multiseries* (Hasle) Hasle, *P. pseudodelicatissima* (Hasle) Hasle, *P. seriata* (Cleve) Peragallo, and *Amphora coffeaeformis* (C. Agardh) Kützing.

Amphora coffeaeformis is a pennate diatom rarely reported in the Bay, but has been found in the barrier islands of Virginia (Marshall, 1980b). This species is not considered a major bloom threat, although it has been associated with domoic acid production.

Over 30 years ago Hasle (1965) first identified the diatom *Nitzschia pungens* f. *multiseries* Hasle from water samples that included those taken in lower Chesapeake Bay. This is a small pennate diatom, found usually in colonial chain-like filaments of 3 to 4 cells in length. It is so similar to the ubiquitous *Nitzschia* (*Pseudo-nitzschia*) *pungens* Grunow that it would be very difficult to distinguish the difference between these two species with light microscopy. In fact, it has not been reported in Chesapeake Bay since Hasle (1965). *Nitzschia pungens* f. *multiseries* gained international attention in 1987 when a food poisoning event in Canada was traced to cultured blue mussels (*Mytilus edulis*) containing high concentrations of domoic acid produced by this diatom (Bates et al., 1989). Domoic acid is the agent that is transmitted to shellfish by these diatoms, which causes amnesic shellfish poisoning in humans. *N. pungens* f. *multiseries* and related species, have recently been reclassified (Hasle, 1995) into another genus and is now identified as *Pseudo-nitzschia multiseries* (Hasle) Hasle. In examining current phytoplankton samples with electron microscopy, Marshall (1994a) did not find *Pseudo-nitzschia multiseries*, but reported an abundance of *Pseuso-nitzschia pseudodelicatisssima*, noted for the first time in Chesapeake Bay, and this species is another domoic acid producer (Martin et al., 1990).

Pseudo-nitzschia pseudodelicatissima (Hasle) Hasle, *P. seriata* (Cleve) Peragallo, and the non-toxin producer *P. pungens* are common members of this genus in lower Chesapeake Bay. Past records of these species have probably included *P. pseudodelicatissima* with *P. pungens*. Annual mean abundance for *P. seriata* and *P. pungens* (combined with *P. pseudodelicatissima*) over a 10 year period are 3.3×10^4 and 9.9×10^4 cells l^{-1} respectively. Of the three, both *P. pungens* and *P. pseudodelicatissima* appear to be increasing in abundance and *P. pseudodelicatissima* has become established over the past decade in Chesapeake Bay. *Pseudo-nitzschia multiseries* (Hasle) Hasle may still be existing somewhere in the Bay, but is not abundant compared to these other members of the genus at this time. There are no records to date of any of these species producing toxic blooms in Chesapeake Bay. It is feasible that the absence of toxin production by these species is because these are local strains that do not produce high levels of domoic acid, or the appropriate environmental conditions that may initiate this bio-product have not been present.

Non-toxic bloom producers:

The Bay also contains numerous non-toxin producers within its phytoplankton that have seasonal blooms which on occasion have resulted in reduced oxygen levels within the water column, and could negatively impact the fauna. The dinoflagellate species seasonally include: Early spring *Heterocapsa triquetra*, *Katodinium rotundatum*, Summer: *Ceratium furca*, *Prorocentrum minimum*, *Scrippsiella trochoidea*, *Gymnodinium splendens*, Fall: *Noctiluca scintillans*, *Prorocentrum minimum* and others. Most prominent with these dinoflagellates, would be seasonal developmental peaks (spring, summer, fall) of the diatoms *Skeletonema costatum* and *Cyclotella choctawhatcheeana*, *Rhizosolenia fragilaria*, *Asterionella glacialis*, *Leptocylindrus minimus*, etc., in addition to the ubiquitous cryptomonads and autotrophic picoplankton. The various species (mostly cyanobacteria) in the autotrophic picoplankton become very abundant during summer. Their summer concentrations may reach 10^9 cells l^{-1} with a basic abundance level during other seasons between 10^5-10^6 cells l^{-1} (Marshall, 1995). The settling of high concentrations of any of these bloom cells and other summer components within the water column and to the bottom substrate is a contributing factor to summer hypoxia conditions that occur in the deep basins within the Chesapeake Bay. The relationships of many of these seasonal blooms to nutrients, total suspended solids, light availability, etc., within the Chesapeake Bay have been discussed by Fisher et al. (1988), Harding et al. (1986), Marshall and Alden (1993), and others. In addition to these algae, the ciliated protozoan *Mesodesmium rubrum*, which contains a red cryptophycean as an endosymbiont, also produces extensive blooms in the Bay. For instance, in October 1995, cell concentrations during a bloom covered a large extent of the lower Chesapeake and reached concentrations of 5.1 x 10^5 cells l^{-1}.

DISCUSSION

The Chesapeake Bay estuary does not presently have a historical record of major phytoplankton toxic induced events. However, there are 3 diatoms and 9 dinoflagellates known to produce toxins that have been reported within the last decade in Chesapeake Bay (Table 1). Historically, 2 additional dinoflagellates and 1 diatom known to be toxin producers have been reported in earlier literature from within Chesapeake Bay, for a total of 15 toxin class species of record. With a total of 708 phytoplankters identified in the Bay (Marshall, 1994), the 12 species represent 1.7% of the present population, or if the earlier 3 species are included 2.1% of the total taxa, as toxin producers. Sournia et al. (1991) report there are globably approximately 4400 marine phytoplankton species, with 50 to 60 of these (1.1 - 1.3%) described as toxin producers (Steidinger, 1993). The presence of these potential toxin producers in Chesapeake Bay is slightly greater than the global relationship noted above. However, due to the more

TABLE 1. Phytoplankton recorded within the Chesapeake Bay system that have been reported in the literature to be toxin producers.

A. Recorded between 1985 and 1996.

I. Diatoms:

Amphora coffeaeformis (C. Agardh) Kützing
Pseudo-nitzschia pseudodelicatissima (Hasle) Hasle
Pseudo-nitzschia seriata (Cleve) Peragallo

II. Dinoflagellates:

Cochlodinium heterolobatum Silva
Dinophysis acuminata Claparède and Lachmann
Dinophysis acuta Ehrenberg
Dinophysis caudata Saville-Kent
Dinophysis fortii Pavilard
Dinophysis norvegica Claparède and Lachmann
Gyrodinium aureolum Hulburt
Pfiesteria piscicida Steidinger and Burkholder
Prorocentrum minimum Pavillard and Schiller

B. Recorded prior to 1985

I. Diatoms:

Pseudo-nitzschia multiseries (Hasle) Hasle

II. Dinoflagellates:

Alexandrium catenella (Whedon-Kofoid) Balech
Gonyaulax polyedra Stein

favorable conditions for growth, a larger number of toxin producers would be expected within estuaries such as Chesapeake Bay than in global seas. This level of representation in Chesapeake Bay, may be expected within other comparable ēstuaries.

Although there is an apparent absence of toxin related events at this time in the Chesapeake Bay, the potential for these to occur exists from species already present in this ecosystem, in addition to new species that may be introduced. There is also evidence that concentrations of potential toxin producers now living in the Bay are increasing. Several *Dinophysis* spp. and *Psuedo-nitzschia pseudodelicatissima*, which represent potential sources for outbreaks of diarrhetic and amnesic shellfish poisoning respectively, are gradually becoming more common in Bay. The rapid increase in the range and frequency of blooms by other species, such as *Cochlodinium heterolobatum*, indicates species once more limited in their range of development, can over a short time period become a dominant component within the phytoplankton community. It is species of this type, gaining a more dominant role within the ecosystem, that may have more significant long term impact on the water quality and trophic relationships in these waters. Their success may be due to increased anthropogenic factors (e.g. nutrient enrichment within the watershed), or changing environmental parameters that favor their development. These conditions may also enhance the development of newly observed and dangerous species such as *Pfiesteria piscicida*, which has the potential for expanding its distribution within the estuary. New phytoplankton taxa are certainly expected to be recognized for the Chesapeake Bay, and among these other toxin producing species are also likely to be found.

The enigma regarding many phytoplankton species is that not all of the potential toxin producers will produce toxins, or blooms in their respective habitats. For instance, high concentrations of a particular dinoflagellate may be a toxin producer and contaminate shellfish in an estuary or entire coastal region, but the same morphological species at another site may not produce toxins. This difference may be due to some environmental factor, or more likely a combination of particular environmental conditions, that alter a physiological response in these cells to produce, or not produce a particular bio-product (e.g. a toxic substance). Another explanation is that there are numerous species, that contain within their populations, physiological deviants from the norm (physiological species, or different strains of a species), with or without the capability of producing toxins. Such differences within these populations would not be considered unusual, since the incidents of mutational events that may impact their genetic make-up and cell metabolism would be expected to occur.

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LITERATURE CITED

Bates, S., C. Bird, A. de Freitas, R. Foxall, M. Gilgan, L. Hanic, G. Johnson, A. McCulloch, P. Odense, R. Pocklington, M. Quilliam, P. Sim, J. Smith, D. Subba Rao, E. Todd, J. Walter, and J. Wright. 1989. Pennate diatom *Nitzschia pungens* as the primary source of domoic acid, a toxin in shellfish from eastern Prince Edward Island, Canada. Canadian J. Fisheries and Aquatic Sci. 46:1203-1215.

Burkholder, J., E. Noga, C. Hobbs, H. Glasgow and S. Smith. 1992. New phantom dinoflagellate is the causative agent of major estuarine fish kills. Nature (Lond.) 358:407-410.

Burkholder, J., H. Glasgow, and C. Hobbs. 1995. Fish kills linked to a toxic ambush-predator dinoflagellate: distribution and environmental conditions. Mar. Ecol. Prog. Ser. 124:43-61.

Cowles, R. 1930. A biological study of the offshore of Chesapeake Bay. Bulletin U.S. Bureau of Fisheries 46:277-381.

Fisher, T., L. Harding, D. Stanley, and L. Ward. 1988. Phytoplankton, nutrients, and turbidity in the Chesapeake, Delaware and Hudson estuaries. Estuarine, Coastal and Shelf Science 27:61-93.

Franklin, D. 1995. The poisoning at Pamlico Sound. Health. Sept. pp.109-115.

Griffith, R.E. 1961. Phytoplankton of Chesapeake Bay. An Illustrated Guide to the Genera. Chesapeake Biol. Lab., Md. Dept. Res. and Ed., Contri. No. 172, 79 pp.

Hallegraeff, G.M. 1993. On the global increase of harmful algal blooms and their apparent global increase. Phycologia 32:79-99.

Harding, L., B. Meeson and T. Fisher. 1986. Phytoplankton production in two east coast estuaries: Photosynthesis-light functions and patterns of carbon assimilation in Chesapeake and Delaware Bays. Estuarine, Coastal and Shelf Science 23:773-806.

Hasle, G.R. 1965. *Nitzschia* and *Fragilariopsis* species studied in the light and electron microscopes. II. The group *Pseudonitzschia*. Skrifter Utgitt av Det Norske Videnskaps-Akad. I. Oslo, I. Mat.-Naturv. Klass. Ny Serie. 18. pp. 1-48, 17 plates.

Hasle, G.R. 1995. *Pseudo-nitzschia pungens* and *P. multiseries* (Bacillariophyceae):Nomenclatural history, morphology, and distribution. J. Phycology 31:428-435.

Jones, K., P. Ayres, A. Bullock, P. Roberts, and P. Tett. 1982. A red tide of *Gyrodinium aureolum* in sea locks at the Firth of Clyde and associated mortality of pond-reared salmon. J. Mr. Biol. Assoc. U.K. 62:771-782.

Kat, M. 1985. *Dinophysis acuminata* blooms, the distinct cause of Dutch mussel poisoning. In: D. Anderson, A. White and D. Baden (eds.) Toxic Dinoflagellates. Elsevier, N.Y. pp. 73-77.

Lewitus, A., J. Hawkins, M. Dykstra, E. Noga, D. Moye and R. Cone. 1995. Discovery of the "Phantom" dinoflagellate in Chesapeake Bay. Estuaries. 18:373-378.

Mackiernan, G.B. 1968. Seasonal distribution of dinoflagellates in the lower York River, Virginia. M.A. Thesis. College of William and Mary, Williamsburg, Virginia. 104 pp.

Marshall, H.G. 1967. Plankton in James River estuary, Virginia. I. Phytoplankton in Willoughby Bay and Hampton Roads. Chesapeake Science, 8:90-101.

Marshall, H.G. 1980a. Seasonal phytoplankton composition in the lower Chesapeake Bay and Old Plantation Creek, Cape Charles, Virginia. Estuaries, 3:207-216.

Marshall, H.G. 1980b. Phytoplankton studies within the Virginia Barrier Islands. I. Seasonal study of phytoplankton in Goose Lake, Parramore Island. Virginian J. Sci. 31:61-64.

Marshall, H.G. 1982. The composition of phytoplankton within the Chesapeake Bay plume and adjacent waters off the Virginia coast. Estuar. Coastal Shelf Sci. 15:29-43.

Marshall, H.G. 1989. An appraisal of bloom producing phytoplankton in the Chesapeake Bay. Special Rpt. Old Dominion University Research Foundation, Norfolk, Va., 28 pp.

Marshall, H.G. 1994a. Chesapeake Bay phytoplankton: I. Composition. Proc. Biol. Soc. Wash. 107: 573-585.

Marshall, H.G. 1994b. Succession of dinoflagellate blooms in the Chesapeake Bay, U.S.A. In: P. Lassus, et al. (eds.) Harmful Marine Algal Blooms, Intercept Ltd., Andover. pp. 615-620.

Marshall, H.G. 1995. Autotrophic picoplankton distribution and abundance in the Chesapeake Bay. Marine Nature 4:33-42.

Marshall, H.G. and R. Alden. 1990. Spatial and temporal diatom assemblages and other phytoplankton within the lower Chesapeake Bay, U.S.A. In: H. Simola (ed.) Proceedings of the 10th International Diatom Symposium. Koeltz Sci. Books, Koenigstein, Germany, pp. 311-322.

Marshall, H.G. and R. Alden. 1993. A comparison of phytoplankton assemblages in the Chesapeake and Delaware estuaries (USA), with emphasis on diatoms. Hydrobiologia 269/270:251-261.

Morse, D.C. 1947. Some observations on seasonal variations in plankton population, Patuxent River, Maryland. Univ. Maryland Natural Resources Inst., Chesapeake Biol. Lab. Publ. 65:1-31.

Mulford, R. 1967. Phytoplankton in Chesapeake Bay. Chesapeake Science. 13:S74-81.

Martin, J.L., K Haya, L. Burridge, and D. Wildish. 1990. *Nitzschia pseudodelicatissima*-a source of domoic acid in the Bay of Fundy, eastern Canada. Mar. Ecol. Prog. Ser. 67:177-182.

Okaichi, T. and Y. Imatomi. 1979. Toxicity of *Prorocentrum minimum* var. *mariae-lebouriae* assumed to be a causative agent of short-necked clam poisoning. In: D. Taylor and H. Seliger (eds.) Toxic Dinoflagellate Blooms, Elsevier/North Holland, N.Y. pp. 385-388.

Patten, B., R. Mulford, and J. Warinner. 1963. An annual phytoplankton cycle in the lower Chesapeake Bay. Chesapeake Science. 4:1-20.

Rao, D., Y. Pan, V. Zitko, G. Bugden, and K. Mackeigan. 1993. Diarrhetic shellfish poisoning (DSP) associated with a subsurface bloom of *Dinophysis norvegica* in Bedford Basin, eastern Canada. Mar. Ecol. Prog. Ser. 97:117-126.

Smayda, T.J. 1989. Primary production and global epidemic of phytoplankton blooms in the sea: A linkage? In: E.M Cosper, V.M. Bricelj and E.J. Carpenter (eds.) Novel phytoplankton blooms: causes and impacts of recurrent brown tide and other unusual blooms. Springer-Verlag, pp. 449-483.

Sournia, A., M. Chretiennot-Dinet, and M. Ricard. 1991. Marine phytoplankton: how many species in the world ocean? J. Plankton Research, 9:63-76.

Steidinger, K.A. 1993. Some taxonomic and biologic aspects of toxic dinoflagellates. In: I. Falconer (ed.) Algal Toxins in Seafood and Drinking Water. Academic Press, London. pp.1-28.

Tangen, K. 1977. Blooms of *Gyrodinium aureolum* (Dinophyceae) in North European waters. accompanied by mortality of marine organisms. Sarsia 63:123-133.

Tyler, M. and J. Seliger. 1978. Annual subsurface transport of a red tide dinoflagellate to its bloom area: water circulation patterns and organisms distrbution in the Chesapeake Bay. Limnol. Oceanogr. 23:227-246.

Wolfe, J., B. Cunningham, F. Wilkerson and J. Barnes. 1926. An investigation of the microplankton of Chesapeake Bay. J. Elisha Mitchell Scientific Society, 42:25-54.

Yasumoto, T. 1990. Marine microorganisms toxins- an overview. In: E. Graneli, B. Sundstrom, L. Edler and D. Anderson (eds.) Toxic Marine Phytoplankton, Elsevier Sci. Publ. Co., N.Y. pp. 3-8.

Yuki, K. and S. Yoshimatsu. 1989. Two fish-killing species of *Cochlodinium* from Harima nada, Seto Inland Sea, Japan. In: T. Okaichi, D. Anderson, T. Nemoto (eds.) Red Tides: Biology, Environmental Science and Toxicology. Elsevier Sci. Publ. Co., N.Y., pp. 451-454.

Zubkoff, P. 1982. Redwaters of the Chesapake Bay, 1979-1981. ICES Sp. Rept., 24 pp.

Zubkoff, P. and J. Warinner. 1975. Synoptic sightings of red waters of the lower Chesapeake Bay and its tributary rivers (May 1973-September 1974). In: V. LoCicero (ed.) Proceedings of the First International Conference on Toxic Dinoflagellate Blooms. Mass. Sci. Tech. Found., Wakefield, Mass., pp. 105-111.

Zubkoff, P., J. Munday, R. Rhodes and J. Warinner. 1979. Mesoscale features of summer (1975-1977) dinoflagellate blooms in the York River, Virginia (Chesapeake Bay estuary). In: D. Taylor and H. Seliger (eds.) Toxic Dinoflagellate Blooms. Elsevier Publ. Co. Amsterdam. pp. 279-286.