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Dinoflagellate Cysts within Sediment Collections from the southern Chesapeake Bay, and Tidal Regions of the James, York, and Rappahannock Rivers, Virginia.

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ABSTRACT

The upper 2 cm of sediment core samples from 70 stations in the tidal waters of three Virginia rivers and at 23 stations in the lower Chesapeake Bay were sampled for dinoflagellate cysts. The river sediment cysts were dominated by three common bloom producing species (*Heterocapsa triquetra, Scrippsiella trochoidea,* and *Cochlodinium polykrikoides*), whereas these were in low concentration in the Chesapeake Bay sediments which contained mainly dinoflagellate cysts of neritic and oceanic taxa. The mean sediment concentrations from stations in the James, York, and Rappahannock rivers were respectively 1174.8, 536.2, and 323.6 cysts g^{-1}. The mean cyst concentration in the Chesapeake Bay sediment was 714.8 g^{-1}. Cysts of 2 potentially harmful species were recorded from the sediment, with the river sediments identified as seed beds and a source for re-occurring algal blooms in these waters.

INTRODUCTION

Dinoflagellates are common components of the phytoplankton flora of the Chesapeake Bay estuarine complex with ca. 190 dinoflagellate taxa reported in these waters (Marshall et al. 2005). The life cycles for many of these species include a dominant vegetative stage consisting of a motile planktonic zoospore, cells associated with reproduction, in addition to the formation of a temporary non-motile and dormant stage when a cyst is formed. These cysts (dinocysts) may settle in the sediment where they remain viable for variable periods of time, and with many subsequently activated to excyst and form motile cells that will continue their development in the water column. Due to the resistant nature of these cysts to decay, many that do not excyst will remain basically unchanged morphologically, and often become fossil representatives of waters that overlaid these substrates. Historical distribution records for dinoflagellate cysts, relict diatoms and their changing composition over time have been determined from Chesapeake Bay sediment samples (Brush 1984; Cooper 1995; Willard et al. 2003). Studies of fossil dinoflagellate cysts have been conducted by both paleontologists and phycologists with each originally using a different approach in cyst classification. This produced contrasting nomenclature in the literature and a dual classification system (de Verteuil and Norris 1996a). Additional confusion in identification may come from morphological variability among the cysts in the various strains of these taxa.

Early records from Miocene sediment deposits of dinoflagellate cysts from the Chesapeake Group have been reported by de Verteuil and Norris (1996a, b). They indicated abundance levels for various taxa at sites in the Chesapeake Bay. Edwards and Powars (2003) discussed damage to dinocysts in Chesapeake Bay sediment that occurred during the late Eocene when a meteorite struck this region. Using late-Holocene sediment records, Willard et al. (2003) related dinocysts and pollen presence to climate changes that have occurred in this region. Data from other core sediments in the lower Chesapeake Bay were included in a broader oceanic study by Wall et al. (1977), in addition to Tyler et al. (1982) in the Potomac River. Wall et al. (1977) described cyst representation in an extensive examination of surface sediments from the United States Atlantic coast. In their study, the dominant taxa at the Chesapeake Bay entrance were *Operculodinium centrocarpum* (Deflandre and Cookson) Wall, *Peridinium* spp., *Spiniferites elongatus* Reid, and *Spiniferites mirabilis* (Rossignol) Sargeant. They associated these taxa with temperate estuaries that were moderately stratified to salinity values that were lower when compared to adjoining coastal waters. *Operculodinium centrocarpum* was also the most abundant sediment cyst in estuaries north of Cape Hatteras, whereas, the southern distribution limit of *S. elongatus* was Chesapeake Bay. Other common species included *Spiniferites bulloideus* (Deflandre and Cookson) Sargeant and *Spiniferites ramosus* (Ehrenberg) Loeblich and Loeblich. Using botanical terminology, the *Spiniferites* group would likely be placed in a *Gonyaulax* "complex", with a major component composed of either *Gonyaulax spinifera* (Claparede & Lachmann) Diesing, or *G. scrippsae* Kofoid, or both of these. In botanical nomenclature, *O. centrocarpum* has been placed within the *Protoceratium reticulatum* (*Gonyaulax grindleyi*) group (Wall et al. 1977) and *Peridinium* spp. as *Protoperidinium* spp.

The maximum number of species Wall et al. (1977) found in any one sample was 20, with cyst density in the estuarine and shelf sediments along the northeastern United States ranging from ca. 1,000 to less than 5,000 cysts g^{-1}sediment. In contrast to emphasizing a broad array of different cysts in the sediment, Tyler et al. (1982) described bloom occurrence and encystment of the dinoflagellate *Gyrodinium uncatenum* Hulburt in the Potomac River, Virginia. They identified physical forces within the river that influenced the distribution of the cysts following bloom conditions. These include the subsequent transport of these cells below the pycnocline to a benthic frontal region upstream and settling in the river sediment. This indicated numerous seed beds within the river that are available to subsequently repopulate the water column. During their sediment analysis they noted the greatest cyst abundance occurred within the upper 4 cm of the sediment, with highest concentrations in the upper 2 cm. The number of *G. uncatenum* cysts in the upper 4 cm from 9 stations ranged from 1 to 280 cysts cm^{-3}. High species diversity among dinoflagellate cysts have frequently been reported from sediment deposits. For instance, Godhe et al. (2000) recorded 43 cyst taxa of which 38 belonged to the Gonyaulacales from southwest India, and Joyce (2004) identified 26 dinocyst types from the Scapa Flow, Orkney, Scotland (composed

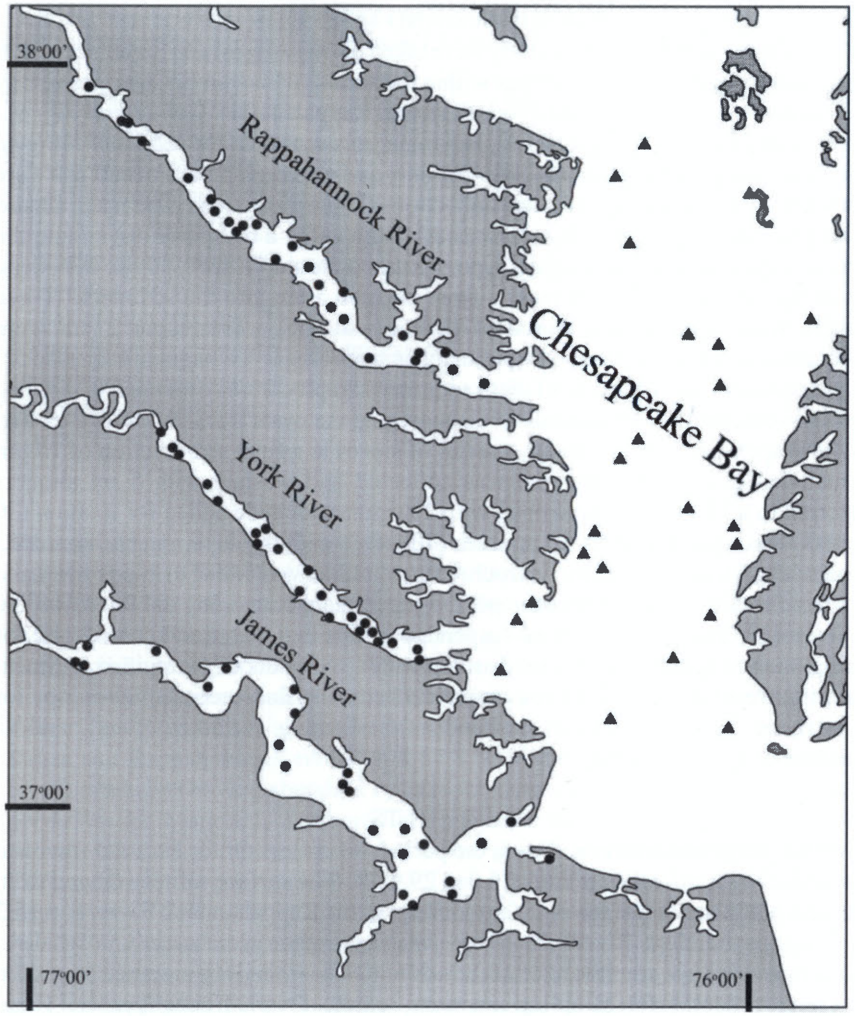

FIGURE 1. Location of sites where sediment samples were taken in the Chesapeake Bay (▲), and the James, York, and Rappahannock rivers (●) during August/September 1996.

mainly of Gonyaulacales, Gymnodiniales, and Peridiniales), with their abundance from 12 stations ranging from 37 to 1524 cysts ml^{-1} wet sediment.

The objectives of this paper are to examine the presence, composition, and abundance of dinoflagellate cysts in sediment samples from locations in the southern region of Chesapeake Bay, and from three of its major Virginia tributaries (the James, York, and Rappahannock rivers).

MATERIALS AND METHODS

The sediment samples for this study were taken during August and September 1996 from a random selection of 23 stations within the southern portion of Chesapeake Bay and 70 stations in the James (24), York (21), and Rappahannock (25) rivers (Fig. 1). Several additional sites were sampled, but found incompatible for sediment retrieval due to their locations within oyster beds. Salinity and water temperature readings were taken when on station during sediment collections. These collections were made aboard the Old Dominion University R/V Linwood Holton using a box corer driven into the sediment with attached lead weights. Upon return to the ship's deck, plastic cylinders, 3 cm in diameter and 10 cm in length, were inserted 5 cm into the sediment. These cylinders were capped, and stored in darkness at 4°C. The upper 2 cm were subsequently processed for microscopic analysis according to Yamaguchi et al. (1995). Five gram (wet weight) aliquots of these sediment samples were suspended in distilled water and sonicated for 10 seconds to disaggregate the cysts from particulate matter, with the suspension passed through a series of sieves to a final size fraction of 10 µm that included cysts. This material was collected and washed with 5 ml aliquots transferred to a 15 ml centrifuge tube, with 1% glutaraldehyde added for fixation (30 minutes), then centrifuged for 15 minutes (700 x g), with the supernatant discarded. One ml of a stock solution of the fluorochrome primuline was added to this product and left in the dark for 1 hour. After storage, the supernatant containing the fluorochrome was discarded. The pellets were re-suspended in distilled water and centrifuged for washing, then re-suspended in 5 ml distilled water. Aliquots of the stained sediment suspension were transferred to a counting chamber using fluorescence microscopy for cyst analysis. The cysts were recorded as numbers g^{-1} sediment (wet), and as percentage of cysts collected.

RESULTS

Surface water temperatures during the periods of collection for both the river and Chesapeake Bay stations were from 24.0 to 29.4 °C. The surface salinity ranged from 1.2 to 22.8 ppt in the James River, 5.0 to 17.7 ppt in the Rappahannock River, and 15.2 to 22.0 ppt in the York River. The Bay station salinities were mainly polyhaline, ranging from 17.2 ppt southward to higher salinities near the Bay entrance (e.g. 27.0 ppt). Station depths for sampling the river sediment varied considerably. These included shallow, near shore regions of ca. 1.1 m (James) to mid-channel depths of 25.0 m (Rappahannock). In the lower Bay, sampling site depths ranged from 2.7 to 29.7 m.

TABLE 1. Mean percentage of total dinocysts from sediment samples taken at stations in the Rappahannock, York, and James rivers, and southern stations in Chesapeake Bay during August/September 1996.

Common Cyst Producers	Rapp.	York	James	Bay
Heterocapsa triquetra	69.5	57.8	73.4	1.6
Gonyaulax "complex"	1.4	3.3	3.7	67.3
Cochlodinium polykrikoides	0.5	21.7	8.2	0.2
Polykrikos kofoidii	4.4	3.3	7.0	4.9
Scrippsiella trochoidea	4.1	3.8	2.7	2.2
Protoperidinium spp.	1.7	2.0	1.0	8.6
Gyrodinium spp.	-	1.1	0.1	0.5
Pyrodinium bahamense v. *compressum*	-	-	-	0.1
Pyrophacus horologium	-	-	-	0.1
Unidentified dinocysts	18.4	7.0	3.9	14.5

The representation of cysts (percentage of the total) from the major taxon categories is listed in Table 1. Botanical protocols were followed for cyst identifications in contrast to those used in paleontological listings. The mean station concentrations in these rivers were 1,174.8, 536.2, and 323.6 cysts g^{-1} sediment respectively for the James, York, and Rappahannock rivers. The most common cysts within the river sediments were those of *Heterocapsa triquetra* (Ehrenberg) Stein, a common bloom producer in these rivers (Marshall et al. 2005). It represented 73.4 and 69.5 % of the cysts in the James and Rappahannock rivers, and 57.8 % in the York (Table 1). Other annual bloom producers having abundant cysts in the river sediments included *Cochlodinium polykrikoides* Margelef, *Scrippsiella trochoidea* (Stein) Loeblich and *Polykrikos kofoidii* Chatton. Of these, cysts of *C. polykrikoides* were especially abundant in the York and James rivers, representing 21.7 and 8.2 % of the total cysts in sediment from these rivers. Cysts within the Bay sediments were mainly of coastal and oceanic species, and included a *Gonyaulax* "complex" and a *Protoperidinium* spp.group, both less noted in the river sediments. Cyst concentrations of the common river species had very low representation in the Bay, e.g. *Heterocapsa triquetra* represented only 1.6% of the cysts in the Bay sediments. Within both river and Bay samples there were also unidentified dinoflagellate cysts.

Cyst concentrations in the three rivers ranged from 15 to 4,970, 95 to 1,250, and 50 to 645 g^{-1} sediment respectively, for the James, York, and Rappahannock rivers. Higher cyst concentrations in the James River occurred at its downstream stations, with their numbers decreasing moving upstream to the lower salinity (< 12 ppt) locations. A similar decrease in cyst abundance occurred at the upstream stations in the York and Rappahannock rivers.

The mean cyst concentration in Chesapeake Bay was 714.8 g^{-1}sediment. The highest numbers (10^3 g^{-1}) occurred at the more saline stations closest to the Bay entrance, with peak abundance at 2,165 cysts g^{-1}sediment. These concentrations decreased moving northward in the Bay where abundance levels were ca. 200 to 600 cysts g^{-1}. The greatest representation of cysts in the Bay sediment came from the *Gonyaulax* "complex" (67.3 %), and a *Protoperidinium* spp. group (8.6%), which were represented by a variety of oceanic/coastal species. These included: *Gonyaulax* spp., *Gyrodinium* spp., *Protoperidinium conicum* (Gran) Balech, *P. depressum* (Bailey) Balech, *P. leonis* (Pavillard) Balech, and *P. pentagonum* (Gran) Balech. Other taxa noted in the Bay sediment included *Pyrodinium bahamense* v. *compressum* (Böhn) Steidinger and *Pyrophacus horologium* Stein. In general, coastal and oceanic taxa cyst abundance was greatest at the Bay entrance, and decreased moving northward in the Bay. Less numerous in Chesapeake Bay sediments were cysts of taxa that were common in the river sediment. These were *Scrippsiella trochoidea*, *Heterocapsa triquetra*, and *Cochodinium polykrikoides*, which represented respectively only 2.2, 1.6, and 0.2 % of the total Bay cysts. In a similar fashion, the taxa within the "*Gonyaulax*"complex" and the *Protoperidinium* spp. group had low representation compared to other cysts in the tributaries, being generally found in the lower segments of these rivers. The dinoflagellate cysts also included an "unidentified" category. These cysts were in different degrees of decomposition, and lacked adequate morphological features for complete identification. Additional taxa may be represented in this cyst category, but were not recognizable.

DISCUSSION

Major differences were noted in the representation of dominant dinoflagellate cysts in sediment from the three rivers compared to cysts dominant in the Chesapeake Bay sediment. The most abundant river cysts were those produced by the major bloom producing species in these waters. Their cysts dominated the surface sediment (upper 2 cm) from these rivers with higher concentrations in the lower segments of these rivers, and included *Heterocapsa triquetra*, *Cochlodinium polykrikoides*, *Scrippsiella trochoidea*, and *Polykrikos kofoidii*. Their annual blooms regularly produced cysts that entered the sediment of these rivers resulting in "seed" beds for the reoccurring generations of these taxa in the water column. The sediment analysis indicated the importance of these river regions as reservoirs for dinoflagellate cysts, and the origin of potential bloom producing species in the water column.

In contrast, the Chesapeake Bay sediment cysts were derived mainly from neritic and oceanic taxa. Their origin in the Bay would come mainly from sub-pycnocline waters entering from the Atlantic coastal shelf. Tyler and Seliger (1978) and Tyler et al. (1982) have described dinoflagellates being transported in this manner along the main stem of the Bay and the Potomac River. However, there was only a moderate presence of cysts common to a neritic or oceanic origin in the lower segments of these rivers, and a general lack of the dominant river species in the Bay sediments. Even though blooms of the river species may extend into Chesapeake Bay, their cysts were not abundant in the Bay sediment. The cyst producing taxa included *Cochlodinium polykrikoides* and *Pyrodinium bahamense* v. *compressum* Wall and Dale as potential toxin producing species. Of these, *C. polykrikoides* has produced extensive and long lasting blooms in the York and James rivers, in addition to their associated tributaries (Marshall et al. 2008).

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