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Climate effects on phytoplankton floral composition in Chesapeake Bay

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ABSTRACT

Long-term data on floral composition of phytoplankton are presented to document seasonal and inter-annual variability in Chesapeake Bay related to climate effects on hydrology. Source data consist of the abundances of major taxonomic groups of phytoplankton derived from algal photopigments (1995–2004) and cell counts (1985–2007). Algal photopigments were measured by high-performance liquid chromatography (HPLC) and analyzed using the software CHEMTAX to determine the proportions of chlorophyll-a (*chl-a*) in major taxonomic groups. Cell counts determined microscopically provided species identifications, enumeration, and dimensions used to obtain proportions of cell volume (CV), plasma volume (PV), and carbon (C) in the same taxonomic groups. We drew upon these two independent data sets to take advantage of the unique strengths of each method, using comparable quantitative measures to express floral composition for the main stem bay. Spatial and temporal variability of floral composition was quantified using data aggregated by season, year, and salinity zone. Both time-series were sufficiently long to encompass the drought–flood cycle with commensurate effects on inputs of freshwater and solutes. Diatoms emerged as the predominant taxonomic group, with significant contributions by dinoflagellates, cryptophytes, and cyanobacteria, depending on salinity zone and season. Our analyses revealed increased abundance of diatoms in wet years compared to long-term average (LTA) or dry years. Results are presented in the context of long-term nutrient over-enrichment of the bay, punctuated by inter-annual variability of freshwater flow that strongly affects nutrient loading, *chl-a*, and floral composition. Statistical analyses generated flow-adjusted diatom abundance and showed significant trends late in the time series, suggesting current and future decreases of nutrient inputs may lead to a reduction of the proportion of biomass comprised by diatoms in an increasingly diverse flora.

1. Introduction

Nutrient over-enrichment supports increased phytoplankton biomass in coastal ecosystems, commonly expressed as high chlorophyll *a* (*chl-a*) concentrations. The accepted cause of increased biomass is anthropogenic eutrophication (Cloern, 2001), a term encompassing activities such as deforestation, expansion of agriculture and industry, urbanization, and wastewater discharge (Nixon, 1995). Recent analyses stimulated by a Chapman Conference of the American Geophysical Union (AGU) held in Rovinj, Croatia assembled phytoplankton data from >40 coastal ecosystems to identify global patterns of floral composition, biomass as *chl-a*, and primary productivity (PP) (Cloern and Jassby, 2010; Cloern et al., 2014). These ecosystems included Chesapeake Bay, a

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large estuary in the mid-Atlantic region of the United States exhibiting multiple symptoms of nutrient over-enrichment (Kemp et al., 2005).

Past studies of floral composition in the bay showed benthic producers dominated the food web prior to land clearing, followed by a shift to planktonic producers in the 20th century (Brush and Davis, 1984; Cooper and Brush, 1991, 1993). Early work identified diatoms as the predominant taxonomic group prior to signs of water-quality degradation (Wolfe et al., 1926; Cowles, 1930; Morse, 1947). Significant increases of total nitrogen (TN) and total phosphorus (TP) loading to the bay after World War II (Boynton et al., 1995; Hagy et al., 2004) led to increased *chl-a* as a measure of phytoplankton biomass (Harding and Perry, 1997; Harding et al., 2013). An overabundance of *chl-a* has been linked to several ecosystem impairments, including low dissolved oxygen (DO) (Hagy et al., 2004; Kemp et al., 2005; Murphy et al., 2011), loss of submerged aquatic vegetation (SAV) (Orth and Moore, 1983; Kemp et al., 2004; Gallegos and Bergstrom, 2005; Orth et al., 2010), and blooms of toxic cyanobacteria (Tango and Butler, 2008).

Responses of coastal phytoplankton to anthropogenic eutrophication are well documented (cf. Cloern, 2001), but there is a continuing need to distinguish long-term trends caused by nutrient over-enrichment from variability evoked by climate effects on hydrology (cf. Harding et al., submitted for publication). Notable examples where seasonal to inter-annual variability of phytoplankton is sensitive to climate effects on hydrology include San Francisco Bay (Cloern et al., 1983; Cloern and Dufford, 2005), the Neuse River estuary (Paerl et al., 2003, 2006a, 2010, 2013; Wetz et al., 2011), Hong Kong waters (Zhou et al., 2012), and Chesapeake Bay (Malone et al., 1988; Marshall and Alden, 1997; Boynton and Kemp, 2000; Adolf et al., 2006; Miller and Harding, 2007).

Floral composition of phytoplankton based on cell counts (Marshall and Alden, 1997) and algal photopigments (Adolf et al., 2006; Valdes-Weaver et al., 2006) differed significantly in dry and wet years in Chesapeake Bay. Aircraft and satellite measurements of ocean color showed significant effects of hydrological conditions on *chl-a* in Chesapeake Bay and the Neuse River – Albemarle-Pamlico Sound and New River Estuary (NC) (Acker et al., 2005; Harding et al., 2005; Miller and Harding, 2007; Paerl et al., 2007; Hall et al., 2013). A series of hurricanes in the late-1990s and 2000s led to episodic responses of phytoplankton biomass and floral composition in North Carolina estuaries (Peierls et al., 2003; Paerl et al., 2006a,b; Wetz and Paerl, 2008). Similar effects were reported for Chesapeake Bay, exemplified by Hurricane Isabel in 2003 whose passage led to an extensive fall bloom of diatoms and dinoflagellates covering >3000 km^2 (Miller et al., 2006a), with implications for food web dynamics (Houde et al., 2005; Roman et al., 2005).

These studies documented climate effects on phytoplankton in coastal ecosystems, including event-scale responses to episodic perturbations, but additional analyses are needed to separate these effects from long-term trends, the focus of this special issue. Data on floral composition are now available for Chesapeake Bay to support such analyses, consisting of 1–2 decades of observations on algal photopigments and cell counts. In this work, we report abundances of major taxonomic groups based on pigment analyses using high-performance liquid chromatography (HPLC) (1995–2004), microscopic identifications, cell counts, and size, volume, and carbon content (1985–2007), and concurrently collected water-quality data for the main stem bay. Specific results include: (1) trends of phytoplankton species known to be important components of the flora; (2) seasonal and inter-annual variability of major taxonomic groups; (3) responses of floral composition to climate effects on hydrology; (4) differences of cell-size distributions in dry and wet climate conditions; (5) prospects for future changes of floral composition based on projected decreases of nutrient inputs.

2. Materials and methods

2.1. Study site

Chesapeake Bay is the largest estuary in the United States with a watershed of 165,000 km^2 and a main-stem bay surface area of ~8000 km^2. Fig. 1 shows locations of major tributaries, cities, and sampling stations. The bay is a shallow, temperate, partially mixed estuary of the Susquehanna River entering from the north, with strong north–south gradients of salinity, nutrients, and light penetration. Lesser contributors of freshwater and solutes to the main stem bay include the Patapsco, Patuxent, Potomac, Rappahannock, York, and James Rivers on the western shore, and the Choptank, Pocomoke, and Nanticoke Rivers on the eastern shore.

2.2. Algal photopigments

Water samples were collected on seasonal cruises from 1995 to 2004, generating a total 540 samples for analyses of algal photopigments using high-performance liquid chromatography (HPLC).

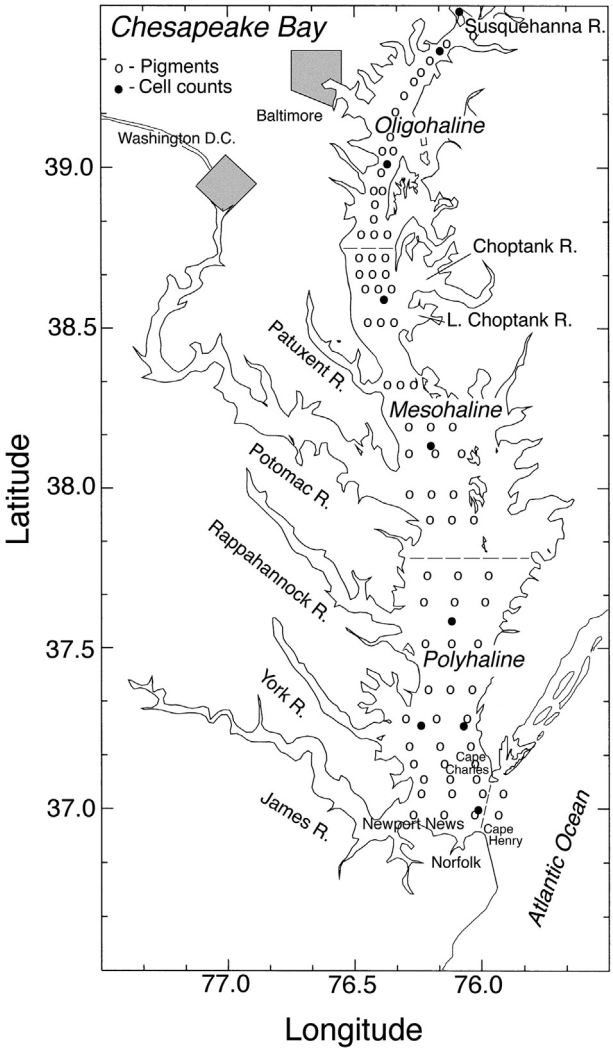

Fig. 1. Chesapeake Bay showing major rivers, cities, salinity zones, and sampling stations for pigments and cell counts.