



Remote sensing of phytoplankton community composition along the northeast coast of the United States

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ABSTRACT

Satellite imagery has proven to be a powerful tool for measuring chlorophyll *a* in surface waters. While this provides an estimate of total phytoplankton biomass, it does not distinguish between phytoplankton groups, many of which have functional differences and therefore affect biogeochemical cycles differently. Phytoplankton pigment analysis has been used to quantify a wide range of photosynthetic and accessory pigments, and chemotaxonomic analysis (e.g. CHEMTAX) has been used to successfully quantify functional taxonomic groups in nature based on pigment distributions. Here, we combine CHEMTAX analysis with satellite-derived distributions of specific phytoplankton pigments to describe the distributions of particular components of the phytoplankton community in the northeast coast of the United States from space. The spatial and seasonal variations in phytoplankton community structure elucidated through satellite remote sensing methods generally agreed with observations of abundance estimates of cell counts. Diatoms were generally the most abundant phytoplankton in this region, especially during Winter–Spring and in the inner shelf, but phytoplankton populations shifted to increasing abundance of other taxa during Summer, especially offshore. While still preliminary, satellite-derived taxa-specific information with proper regional controls holds promise for providing information on phytoplankton abundance to a taxonomic group level which would greatly improve our understanding of the impacts of human activity and climate change on ecosystems.

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1. Introduction

Satellite ocean color remote sensing is a valuable tool for studying large-scale variations of phytoplankton biomass which in turn affects biogeochemical cycling of elements (IOCCG, 1999, 2000; McClain, 2009). Global distributions of total chlorophyll *a* concentration ([TChl_a]) and extrapolations of primary production have been previously quantified from satellite observations, especially for the oceanic Case 1 waters (Behrenfeld & Falkowski, 1997; Behrenfeld et al., 2005; McClain, 2009; O'Reilly et al., 1998, 2000). However, because of the limitations of satellite spectral resolution in distinguishing between plant pigments, the distribution and seasonal variation in phytoplankton community composition observed from satellite measurements are limited (Aiken et al., 2008, 2009; Alvain et al., 2008; Brewin et al., 2010, 2011; Hirata et al., 2008, 2011; McClain, 2009; Pan et al., 2010; Roy et al., 2011).

Phytoplankton community composition is important for determining biogeochemical function because different taxonomic groups have unique physiologies that affect their growth rates, C and N

uptakes, competitive success, and biogeochemical functions in the environment. For example, blooms of large chain-forming diatoms can contribute disproportionately to the sinking biogenic particle flux of carbon than small phytoplankton such as cyanobacteria. Thus, a taxonomic level of analysis can improve our understanding of phytoplankton species distribution, primary productivity, and carbon export flux estimates (Aiken et al., 2008, 2009; Alvain et al., 2008; Brewin et al., 2011; Hirata et al., 2008, 2011; McClain, 2009; Roy et al., 2011; Uitz et al., 2009). This level of analysis is also useful in assessing regional variations in phytoplankton distribution as well as the effects of climate variability and change on the seasonal and spatial variation of phytoplankton species. For example, the distributions of phytoplankton functional groups, particularly dinoflagellates and prymnesiophytes, are often thought to correlate to dimethylsulfide (DMS), a precursor of cloud condensation nuclei (Townsend & Keller, 1996).

Phytoplankton taxonomy is traditionally assessed by microscopy, which requires significant amounts of time and expertise. Species too fragile to be preserved or small in size (in particular, picophytoplankton) are challenging to identify by routine microscopic methods and this introduces biases to taxonomic assessments done using these methods. Advances in high-performance liquid chromatography (HPLC) methods have allowed the detection of an increasing number of phytoplankton pigments. This information can allow

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quantification of phytoplankton community composition, at least to a functional group level, because many plant pigments are particular to specific taxonomic groups or even species (Jeffrey et al., 1997; Mackey et al., 1996).

Chemotaxonomic assessment of phytoplankton assemblages has been further facilitated through development of algorithms to partition bulk [TChl_a] into taxonomic groups based on pigment composition of the community (Mackey et al., 1996). CHEMTAX (Mackey et al., 1996), a Matlab® (The Mathworks, Inc.) program, analyzes the relative pigment ratios for each taxonomic group, especially those pigments found only in one or two taxonomic groups (e.g. alloxanthin in cryptophytes, peridinin in peridinin-containing dinoflagellates, and zeaxanthin primarily in cyanobacteria and prochlorophytes; Jeffrey et al., 1997). However, CHEMTAX does not provide the same resolution as microscopy, because the latter can identify many groups to the species level. Overlapping pigment compositions can further complicate the capability for CHEMTAX to separate taxonomic groups, i.e. to separate chlorophytes from prasinophytes. Although there exist these limitations to CHEMTAX, it has been successful in describing variations of major phytoplankton taxonomic groups for many water types including: oceanic waters (e.g. the Southern Ocean and the northeastern Atlantic), and coastal waters (e.g. the New Jersey coast, the Chesapeake Bay estuary, United States southeastern estuaries, and European coastal waters) (Adolf et al., 2006; Gibb et al., 2001; Lewitus et al., 2005; Mackey et al., 1996; Moline & Blackwell, 2004; Schlüter et al., 2000; Wright et al., 1996).

Studies of phytoplankton taxonomy are typically limited to discrete stations sampled during irregular ship surveys, and so we know little about the spatial and temporal variations of phytoplankton assemblages (Aiken et al., 2008, 2009; Alvain et al., 2008; Brewin et al., 2010, 2011; Hirata et al., 2008, 2011). Pan et al. (2010) showed that many important phytoplankton pigments could be empirically estimated from ocean color remote sensing within reasonable

agreement to the field observations along the northeast coast of the United States (U.S.). In this study, phytoplankton community composition by chemotaxonomy (e.g. CHEMTAX) in the U.S. northeast coast was estimated using satellite retrieval of phytoplankton pigment composition (Pan et al., 2010).

The northeast coast of the U.S. is a highly productive and optically complex region that is significantly influenced by freshwater outflow (e.g. from the Chesapeake Bay, Delaware Bay, and Hudson–Raritan Rivers) and by alongshore flow and tidal forcing (Mannino et al., 2008; O'Reilly & Zetlin, 1998; Pan et al., 2008, 2010). Phytoplankton species composition varies seasonally: diatoms generally dominate during Winter–Spring, while other taxa, such as dinoflagellates and cyanobacteria, increase in proportions during Summer (Adolf et al., 2006; Marshall, 1984a, 1984b; Marshall & Cohn, 1987; Marshall et al., 2006; Moline & Blackwell, 2004). The objectives of this study were: (1) to develop a quantitative method to describe phytoplankton community composition using satellite ocean color remote sensing; and (2) to determine the spatial and temporal variability of phytoplankton community composition, and its impact on biogeochemical processes in the U.S. northeast coast.

2. Materials and methods

2.1. Field experiments

This study focused on the U.S. northeast coast within the longitude and latitude boundaries of 77°W to 65°W and 35°N to 45°N, respectively (Fig. 1). The study area includes the Gulf of Maine (GoM) and the Middle Atlantic Bight (MAB), in which the MAB is separated into the New York Bight (NYB) and the southern MAB (SMAB) (Fig. 1). Multiple cruises were conducted in this region from 2004 to 2009 (Table 1 and Fig. 1).

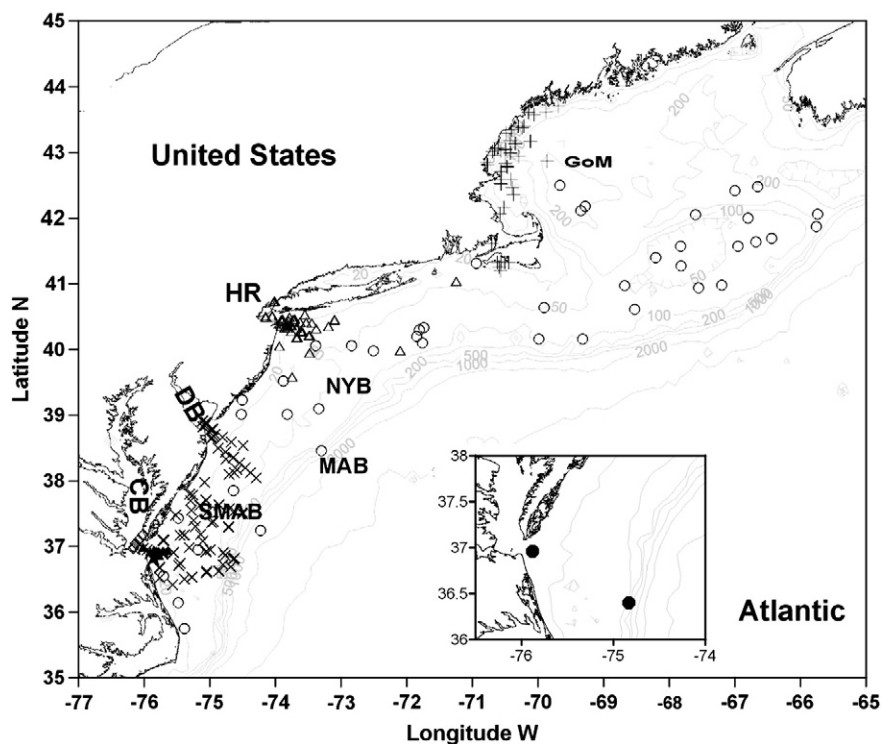


Fig. 1. Map of the study area and station locations within the northeast coast of the United States. The locations of stations sampled included the serial cruises in the Gulf of Maine (GoM; +), New York Bight (NYB) for a series of Ocean Color Validation cruises (OCV; Δ), Southern Middle Atlantic Bight (SMAB) for a series of Bio-physical Interactions in Ocean Margin Ecosystems cruises (BIOME; x), Chesapeake Bay Plume cruises (CBP; ▲), and Chesapeake Bay Hydrological survey cruises (CBH; ◇), and the Climate Variability on the East Coast cruise-1 (ClIVEC-1; ○) along the northeast coast. CB: Chesapeake Bay; DB: Delaware Bay; HR: Hudson–Raritan Rivers. Two locations (●) used for time-series analysis of satellite derivations in the CB estuarine are shown in the inset.

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