Marine Pollution Bulletin xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Effect of nutrient pollution on dinoflagellate cyst assemblages across estuaries of the NW Atlantic

Andrea M. Price[a,*], Michael R.S. Coffin[b], Vera Pospelova[c], James S. Latimer[d], Gail L. Chmura[a]

[a] Department of Geography, McGill University, 805 Sherbrooke Street West, Montréal, Québec H3A 0B9, Canada
[b] Department of Biology, University of Prince Edward Island, Charlottetown, PEI C1A 4P3, Canada
[c] School of Earth and Ocean Sciences, University of Victoria, OEASB A405, P.O. Box 1700 STN CSC, Victoria, British Columbia V8W 2Y2, Canada
[d] US Environmental Protection Agency, Narragansett, RI 02882, USA

ARTICLE INFO

Keywords:
Nutrient loading
Plankton
Prince Edward Island
Environmental indicators
Water quality
Palynology

ABSTRACT

We analyzed surface sediments from 23 northeast USA estuaries, from Maine to Delaware, and nine estuaries from Prince Edward Island (PEI, Canada), to determine how dinoflagellate cyst assemblages varied with nutrient loading. Overall the abundance of cysts of heterotrophic dinoflagellates correlates with modeled nitrogen loading, but there were also regional signals. On PEI cysts of *Gymnodinium microreticulatum* characterized estuaries with high nitrogen loading while the sediments of eutrophic Boston Harbor were characterized by high abundances of *Spiniferites* spp. In Delaware Bay and the Delaware Inland Bays *Polysphaeridium zoharyi* correlated with higher temperatures and nutrient loading. This is the first study to document the dinoflagellate cyst eutrophication signal at such a large geographic scale in estuaries, thus confirming their value as indicators of water quality change and anthropogenic impact.

1. Introduction

With increasing urbanization and growth of agriculture, nutrient pollution has become a major concern in many coastal regions (e.g., Carpenter et al., 1998; Rabalais, 2002). Excess nutrients (eutrophication) can result in increased phytoplankton production, harmful algal blooms, higher production of organic matter, depleted dissolved oxygen levels (hypoxia or anoxia), mass mortality of marine organisms, and changes in community structure (e.g., Turner and Rabalais, 1994; Turner et al., 1998; Glasgow and Burkholder, 2000; Anderson et al., 2008). These changes can be detrimental to marine ecosystems and affect the economic value of waters through loss of tourism, fishing, and aesthetic enjoyment. Eutrophication is becoming more widespread in the US (Scavia and Bricker, 2006), with approximately 65% of assessed estuaries now moderate to highly eutrophic (Bricker et al., 2007), while at least 40 estuaries of Canada's Prince Edward Island (PEI) have experienced one or more anoxic events in the last ten years (Bugden et al., 2014).

Understanding relationships between nutrient inputs and biological responses in estuaries are useful to determine how much nitrogen is required to change from one trophic status to another. Yet nutrient concentrations in coastal waters do not always reflect the total amount of nutrients entering a water body, as they can be rapidly taken up by phytoplankton and aquatic vegetation, such that even a heavily degraded water body may have low nutrient concentrations (e.g., Cloern, 2001; Rabalais et al., 2002; Dodds, 2003; Howarth and Marino, 2006; Bricker et al., 2007). There are two primary methods for evaluating nutrient input into, or effects on, coastal waters: 1) using nutrient loading models (e.g., Frink, 1991; Latimer and Charpentier, 2010; Seitzinger et al., 2010; Moore et al., 2011) and 2) using indicators to act as early warning signs of water quality degradation (e.g., Bricker et al., 2007; Castro and Freitas, 2011). The eutrophication condition of an estuary is commonly assessed using a combination of indicators such as chlorophyll-*a*, macro-algae, low bottom water dissolved oxygen, nuisance/toxic blooms, and submerged aquatic vegetation such as seagrasses (Short et al., 2006; Bricker et al., 2007). While incorporating multiple indicators of eutrophication, i.e., a tiered approach, is best for describing trophic status (e.g., Bricker et al., 1999, 2007; Bugden et al., 2014), acquiring data on multiple parameters is often challenging. Furthermore, many of these variables temporally vary, e.g., daily to seasonally, and thus require data collection to occur at frequent intervals to capture their annual range. Using sediment-bound fossilized microplankton as indicators of eutrophication alleviate many of the aforementioned shortcomings of alternative sampling methods. Organic-walled dinoflagellate cysts, which represent an integrated assemblage over time, have successfully been used as indicators of

* Corresponding author at: Department of Oceanography and Coastal Sciences, Louisiana State University, Nicholson Extension, Baton Rouge, LA 70803, USA.
E-mail address: andrea.price@mail.mcgill.ca (A.M. Price).

http://dx.doi.org/10.1016/j.marpolbul.2017.06.024
Received 30 May 2017; Accepted 6 June 2017

eutrophication in coastal waters (e.g., Dale and Fjellså, 1994; Matsuoka et al., 2003; Pospelova et al., 2004; Pospelova and Kim, 2010; Lu et al., 2017) and provide biological data not available through conventional plankton surveys.

Dinoflagellates are an important component of planktonic communities. Approximately 50% of dinoflagellate species are heterotrophic and the rest are autotrophic or mixotrophic (Dale, 2009). Many dinoflagellates produce a resting cyst which, once produced in the water column, sinks to the sea-floor. Organic-walled dinoflagellate cysts are resistant to biological, chemical and physical degradation (e.g.,

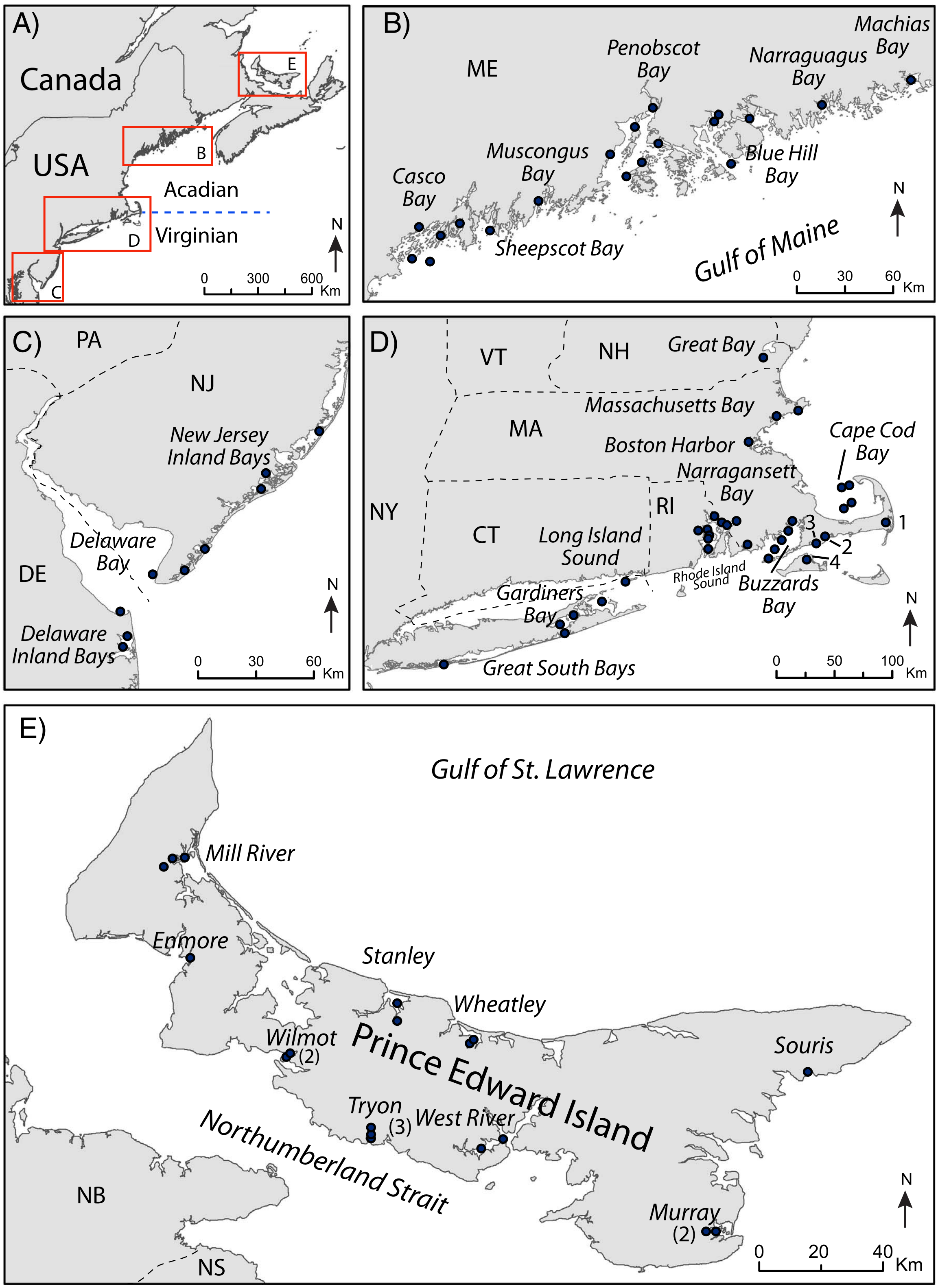

Fig. 1. (A) Map of the study area. The dashed line shows the boundary between the Acadian and Virginian biogeographic provinces. (B–E) Insets of the study area. Solid dots indicate sampling locations. (D) 1. Chatham Harbor. 2. Popponesset Bay. 3. Waquoit Bay. 4. Vineyard Pond.
(Figure modified from Price et al. (2016)).