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The influence of nitrogen and phosphorus on phytoplankton growth and assemblage composition in four coastal, southeastern USA systems

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ABSTRACT

Human population density, and related urbanization, is predicted to increase along coastlines worldwide. Varied land uses will likely influence nutrient delivery, mainly nitrogen (N) and phosphorus (P), to the coast and thereby phytoplankton assemblages. This study examined spatial and seasonal variability in phytoplankton community composition and growth responses to N (ammonium, nitrate, or urea) and/or P (orthophosphate) using *in situ* bioassays during 2011–2013. Study sites were in four southeastern US (South Carolina) coastal systems with distinct land uses: a forested tidal creek, a forested/agricultural tidal creek, an urbanized tidal creek, and a stormwater detention pond. Results showed that sites were primarily N-limited and diatoms typically contributed most to phytoplankton biomass (chlorophyll *a*). Phytoplankton communities at the more developed sites (urbanized creek and stormwater detention pond) not only exhibited higher biomass and growth rates with N, particularly urea, additions compared to the less-developed sites (forested and forested/agricultural tidal creeks), they often included harmful algal bloom species, particularly cyanobacteria, dinoflagellates, and raphidophytes. These findings suggest that phytoplankton community responses to N-form are site specific, influenced by surrounding land cover, and N inputs (e.g. fertilizers) may cause algal blooms. Results both underscore the role of development as a driver of coastal production and can be informative for water quality management.

1. Introduction

Estuaries receive nutrients from their surrounding environment through geological weathering, atmospheric deposition, biogeochemical remineralization, surface runoff, groundwater, and other processes. Anthropogenic activity has increased nutrient inputs from the land to receiving coastal ecosystems through runoff associated with urbanization, industry, and agriculture (Bricker et al., 1999, 2008), as the majority of human population growth and development worldwide occurs along coastlines (e.g. Nixon, 1995; Mallin et al., 2001; Agardy and Alder, 2005). Since nutrient (nitrogen – N and phosphorus – P) loading is associated with ecosystem impacts such as eutrophication, declining water quality, harmful algal blooms (HABs), hypoxia, and fish kills (Paerl et al., 1998; Bricker et al., 1999, 2008; Pinckney et al., 2001a; Anderson et al., 2002, 2008; Kennish, 2002; Heisler et al., 2008), continued development will likely increase the frequency and intensity of these events.

Development influences N and P delivery to coasts through factors such as greater impervious surface cover (e.g. Leopold, 1968; Arnold and Gibbons, 1996; Brabec et al., 2002; Holland et al., 2004)

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that reduce the capacity of streams to function as nitrate (NO_3^-) sinks, thereby enhancing NO_3^- delivery to receiving estuaries (e.g. Groffman et al., 2002). Fertilizer applications and sewage effluent from urban and agricultural areas are believed to introduce urea into coastal systems (Glibert et al., 2005, 2006). In the southeastern United States (US), for example, rates of land development often exceed those for human population growth (Allen and Lu, 2003; Holland et al., 2004; Buzzelli et al., 2007), such as for Charleston, South Carolina (SC), where change of land cover (1994–2030) is predicted to surpass population growth by 5 to 1 (Allen and Lu, 2003). Impervious surface cover is commonly offset by the construction of stormwater detention ponds to mitigate runoff (Lewitus et al., 2003; Brock, 2006; Drescher et al., 2007). These poorly-flushed systems stagnate, accumulate nutrients from runoff, and create environments conducive to dense and pervasive phytoplankton blooms, including HABs (Lewitus et al., 2003, 2008; Drescher et al., 2007; Serrano and DeLorenzo, 2008). However, several coastal regions remain largely unaltered (Mallin et al., 2001; Van Dolah et al., 2008; Keppler et al., 2015). This range of land uses likely influences N and P delivery to coastal waters, thereby phytoplankton assemblages, as concentrations of total N (TN), total P (TP), and phytoplankton biomass (chlorophyll, henceforth chl *a*) are often elevated within developed tidal creeks (Van Dolah et al., 2004, 2013; Bergquist et al., 2009, 2011; Keppler et al., 2015).

Nutrient loading can markedly impact coastal phytoplankton communities, in part because they are typically N-limited (Howarth, 1988; Mallin et al., 2004; Piehler et al., 2004; Howarth and Marino, 2006; Smith, 2006). However, P-limitation has been reported in some warm temperate (Flemer et al., 1998; Murrell et al., 2002) and tropical estuaries (e.g. Downing et al., 1999), associated with elevated N levels (e.g. Turner and Rabalais, 2013), and may be influenced by factors such as salinity and season (Murrell et al., 2002; Quigg et al., 2011). Since the concentration(s) and uptake of limiting nutrient(s) influence both phytoplankton production (Anderson et al., 2002; Howarth and Marino, 2006) and community composition (Tilman et al., 1982; Lagus et al., 2004), both N-form, dissolved inorganic N (DIN) or dissolved organic N (DON), and concentration relative to P entering coastal habitats, affect phytoplankton assemblages (Altman and Paerl, 2012). In the southeastern US, high DIN inputs to the developing Neuse River Estuary, North Carolina (NC) (Rudek et al., 1991; Stow et al., 2001; Paerl et al., 2010), caused blooms of chlorophytes, cryptomonads, and cyanobacteria (Pinckney et al., 1998), and phytoplankton in Pamlico Sound (NC) exhibited strongest productivity and biomass responses to DIN during bioassays (Piehler et al., 2004). Conversely, elevated DON has been linked with algal blooms, including HABs, in stormwater detention ponds, often coincident with low DIN to dissolved inorganic phosphorus (DIP) and TN to TP ratios (Lewitus et al., 2003, 2008; Serrano and DeLorenzo, 2008; Altman and Paerl, 2012; Greenfield et al., 2014). Cyanobacterial biomass is particularly responsive to DON (as urea), alone or in combination with ammonium (NH_4^+) (Glibert et al., 2004; Siegel et al., 2011), though urea may dissociate to ammonium. This is consistent with numerous studies showing both cultured phytoplankton and natural assemblages effectively utilizing organic N for growth (e.g. Antia et al., 1975, 1991; Berman and Bronk, 2003; Bradley et al., 2010a).

Several studies have examined linkages between upland land use and estuarine habitat and water quality (Mallin et al., 2000; Holland et al., 2004; Van Dolah et al., 2008; Sanger et al., 2015). Others considered how water quality and phytoplankton communities differ between systems (Noble et al., 2003; White et al., 2004; Johnson et al., 2006; Greenfield et al., 2012). Ongoing development will likely increase nutrient inputs to coastal waters, but the effects of nutrient form on phytoplankton communities across varying spatial and seasonal trends have not been thoroughly assessed. Given worldwide coastal urbanization, it is important to understand and predict how N and P affect phytoplankton assemblages, as responses to these nutrients are indicators of water quality, and consequently informative for management.

This project assessed spatial and seasonal variability in phytoplankton community composition in response to N-form using four SC coastal sites, each with distinct land uses. Specific objectives were to (1) quantify phytoplankton biomass and growth rate responses to various forms of N (NH_4^+, NO_3^-, and urea) across sites and seasons, and (2) elucidate taxa-specific responses to N form. We initially hypothesized that (1) diatoms and cyanobacteria would exhibit the strongest growth response to NH_4^+ and urea additions based on studies showing their affinity to reduced N forms (Syrett, 1981; Dortch, 1990; Peers et al., 2000; Flores and Herrero, 2005; Siegel et al., 2011), and (2) less developed sites would be more responsive to nutrient additions than comparatively developed systems.

2. Materials and methods

2.1. Site descriptions

Experiments described herein were conducted at four tidally-influenced sites along the South Carolina (SC) coast (Fig. 1) with comparable depths (~3 m mean tidal depth), salinities (mean ~10–21), and temperature ranges, but distinct land uses. Two relatively more developed (an urbanized tidal creek and detention pond) and two relatively less developed (a forested/agricultural creek and forested creek) sites were used.

2.1.1. Thousand Acre

Thousand Acre (33°17′56″N, 79°15′21″W; henceforth TA) is a forested/agricultural tidal creek situated within Winyah Bay, a coastal plain estuary (Goñi et al., 2003; Buzzelli et al., 2004). Winyah Bay is the fourth largest estuary on the US east coast with a drainage area of ~47,000 km^2, and surrounding land is forested, natural, managed, industrial, and agricultural wetland (Goñi et al., 2003, 2009; Buzzelli et al., 2004). Part of the North Inlet-Winyah Bay NERRS (National Estuarine Research Reserve System) long-term monitoring program within the Hobcaw Barony (the Belle W. Baruch Foundation), TA is ~5 km downstream from the city of Georgetown, which has a steel mill, a paper mill, and a municipal sewage facility (Lawrenz et al., 2010). The TN pool has been shown to be dominated by organic N, with NO_3^- also being a substantial component (Buzzelli et al., 2004).

2.1.2. Bull Creek

Bull Creek (32°49′38″N, 80°01′44″W; henceforth BC) is an urbanized tidal creek (Holland et al., 2004; Sanger et al., 2015) located on the southeastern end of the Ashley River, a 48 km long coastal plain tidal river (SC Department of Natural Resources, 2003). The Ashley River basin (~2300 km^2) drains marshes, forested wetlands, commercial, and residential development before reaching the city of Charleston (SC Department of Natural Resources, 2003; SC Department of Health and Environmental Control, 2005). The Ashley River has elevated nutrient levels, primarily TP (Van Dolah et al., 2004, 2013; Bergquist et al., 2009, 2011).

2.1.3. Kiawah Island pond number 075

Kiawah Island pond number 075 (32°36′44″N, 80°03′01″W; henceforth K075) is a tidally-influenced stormwater detention pond. It is bordered by homes, roadway, and a golf course, and it receives water from 15 drainage pipes (Brock, 2006). There are > 14,000 ponds in coastal SC alone (Smith, 2012), and HABs are