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Research paper

Septic systems contribute to nutrient pollution and harmful algal blooms in the St. Lucie Estuary, Southeast Florida, USA

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ABSTRACT

Nutrient enrichment is a significant global-scale driver of change in coastal waters, contributing to an array of problems in coastal ecosystems. The St. Lucie Estuary (SLE) in southeast Florida has received national attention as a result of its poor water quality (elevated nutrient concentrations and fecal bacteria counts), recurring toxic *Microcystis aeruginosa* blooms, and its proximity to the northern boundary of tropical coral species in the United States. The SLE has an artificially large watershed comprised of a network of drainage canals, one of which (C-44) is used to lower the water level in Lake Okeechobee. Public attention has primarily been directed at nutrient inputs originating from the lake, but recent concern over the importance of local watershed impacts prompted a one-year watershed study designed to investigate the interactions between on-site sewage treatment and disposal systems (OSTDS or septic systems), groundwaters, and surface waters in the SLE and nearshore reefs. Results provided multiple lines of evidence of OSTDS contamination of the SLE and its watershed: 1) dissolved nutrients in groundwaters and surface waters were most concentrated adjacent to two older (pre-1978) residential communities and the primary canals, and 2) sucralose was present in groundwater at residential sites (up to 32.0 μg/L) and adjacent surface waters (up to 5.5 μg/L), and 3) $\delta^{15}N$ values in surface water (+7.5 ‰), macroalgae (+4.4 ‰) and phytoplankton (+5.0 ‰) were within the published range (>+3 ‰) for sewage N and similar to values in OSTDS-contaminated groundwaters. Measured $\delta^{15}N$ values in *M. aeruginosa* became increasingly enriched during transport from the C-44 canal (~5.8 ‰) into the mid-estuary (~8.0 ‰), indicating uptake and growth on sewage N sources within the urbanized estuary. Consequently, there is a need to reduce N and P loading, as well as fecal loading, from the SLE watershed via septic-to-sewer conversion projects and to minimize the frequency and intensity of the releases from Lake Okeechobee to the SLE via additional water storage north of the lake. These enhancements would improve water quality in both the SLE and Lake Okeechobee, reduce the occurrence of toxic harmful algal blooms in the linked systems, and improve overall ecosystem health in the SLE and downstream reefs.

1. Introduction

Despite their ability to provide invaluable ecological services to human populations, coastal and estuarine ecosystems are being degraded on a global scale. Humans have significantly increased the concentrations of nitrogen (N) and phosphorus (P) in freshwaters flowing into the coastal zone (Nixon, 1995; Vitousek et al., 1997; MEA, 2005), exacerbating eutrophication, harmful algal blooms (HABs), and subsequent habitat loss (NRC, 2000; Glibert et al., 2005; Bricker et al., 2007; Heisler et al., 2008). The complexity of this problem was exemplified by Rothenberger et al. (2009) who showed that, while hog farming practices were an important contributor of eutrophic and unsafe conditions in the Neuse River (i.e. toxic *Pfiesteria* blooms (Burkholder and Glasgow, 2001)), wastewater treatment plants (WWTPs) and population growth were also significant nutrient contributors. Similarly, increasing nutrient inputs from urban, agricultural, and industrial sources have synergistically promoted blooms of the potentially toxic cyanobacterium *Microcystis aeruginosa* on a global scale (Paerl and Otten, 2013; Li et al., 2017; Liyanage et al., 2016; Preece et al., 2017). Some of the most chronic blooms have occurred in Lake Erie (Wynne and Stumpf, 2015), San Francisco Estuary (Lehman et al., 2015), Cape Fear River (Isaacs et al., 2014, Polera, 2016), Patos Lagoon Estuary, Brazil (Yunes et al., 1996), and Lake Taihu, China (Chen et al., 2003).

Findings from these and other impacted areas showed that both growth and toxicity of non-nitrogen fixing (Paerl et al., 2011)

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M. aeruginosa are directly linked to eutrophication and exemplify the need for simultaneous reduction of N and P inputs to freshwater and estuarine systems (Conley et al., 2009; Ma et al., 2014; Gobler et al., 2016). In estuarine waters with salinity >10 this species experiences a decrease in cellular growth and abundance and an increase in cell mortality ultimately prompting toxin release (Warhurst, 2014; Preece et al., 2017). Until recently, high P inputs alone associated with low N:P ratios (<44:1) have been thought to promote growth of *M. aeruginosa* blooms (Downing et al., 2005; Horst, 2014; Horst et al. 2014; Parrish, 2014). Recent work by Lehman et al. (2015) and a review by Gobler et al. (2016) also clearly demonstrated the importance of inorganic N, especially ammonium (NH_4^+), in the formation of *Microcystis* blooms. Contrary to previous consensus, Gobler et al. (2016) reports that *Microcystis* has multiple physiological adaptations that allow bloom formation in inorganic P – depleted waters. Like growth, production of the N-rich hepatotoxin microcystin is also driven by N:P ratios, but primarily as they relate to N assimilation (Downing et al., 2005; Gobler et al., 2016). Because microcystin is N-rich, toxic strains of *Microcystis* require more N than non-toxic strains (Davis et al., 2010). Downing et al. (2005) show that N:P ratios between 8 and 51 promoted the highest microcystin content. The direct relationship between microcystin levels and dissolved reactive N concentrations, both NH_4^+ (Donald et al., 2011) and nitrate (NO_3^-; Horst et al., 2014), provided evidence of wastewater (also referred to as sewage) inputs during these blooms. Like wastewater itself, elevated microcystin levels exacerbated by wastewater have the potential to impact both human and ecosystem health (Rastogi et al., 2014).

In southeast Florida, the St. Lucie Estuary (SLE) has received national attention and has been the subject of litigation for chronic human health impacts and severely degraded ecosystem health. The system is exceptional in its anthropogenic complexity, reoccurrences of economically and ecologically devastating *M. aeruginosa* blooms, frequent health advisories for high fecal bacteria counts, and proximity to the northern extent of tropical coral species along the east coast of the United States (Fig. 1A, B). Through a partnership between the U.S. Environmental Protection Agency and the Florida Department of Environmental Protection (FDEP), the SLE has been identified as an impaired waterbody and Total Maximum Daily Loads have been established for total nitrogen (TN), total phosphorus (TP), dissolved oxygen (DO), and fecal coliforms (Parmer et al., 2008; White and Turner, 2012). The SLE receives freshwater inputs from an artificially large watershed as the result of a network of canals constructed in the early to mid 1900s to alleviate flooding and increase development potential

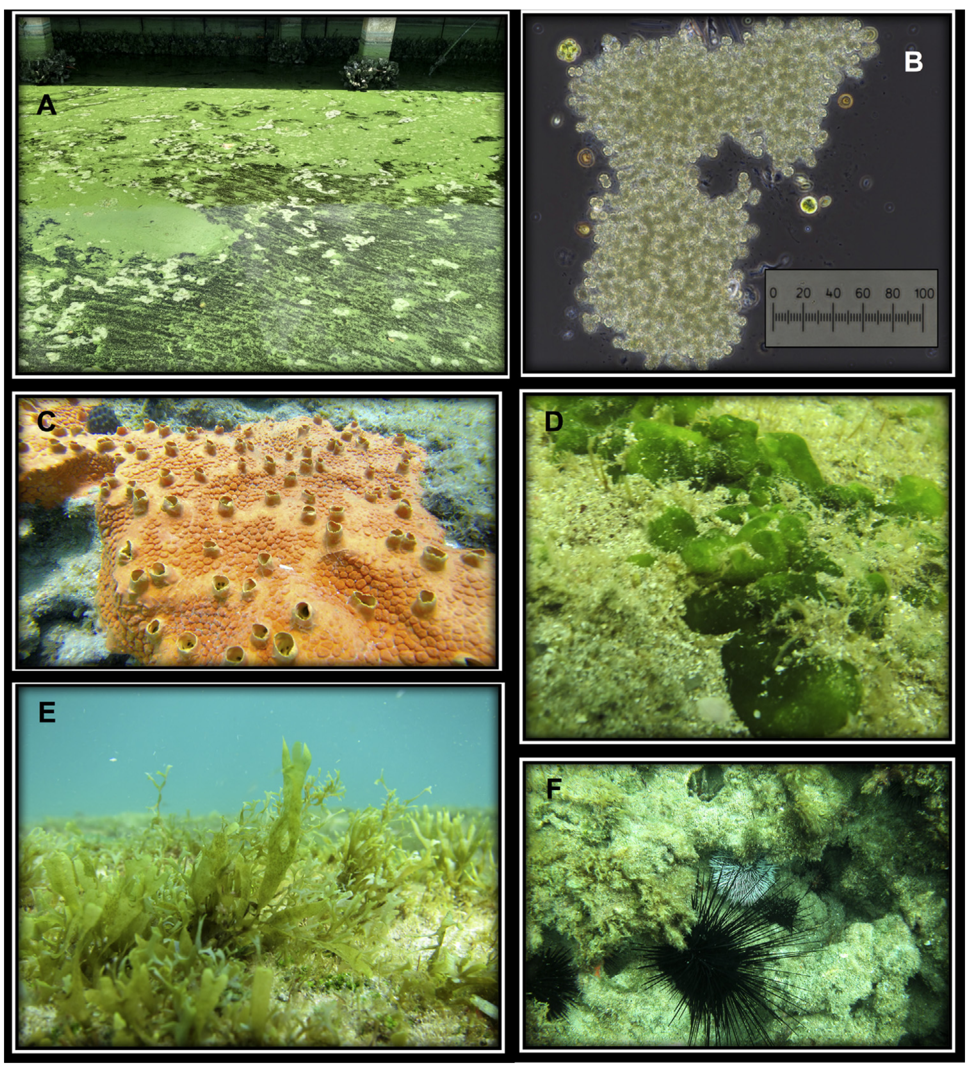

Fig. 1. Ecosystem responses to eutrophication in the St. Lucie Estuary (SLE) and nearshore reefs: (A, B) *Microcystis aeruginosa* in the SLE with 40x magnification scale bar in micrometers (μm) and (C) Clionid sponge, (D) *Codium intertextum*, (E) *Dictyota* spp., (F) four common species of sea urchins (*Diadema antillarum*, *Tripneustes ventricosus*, *Echinometra viridis*, *Eucidaris tribuloides*) along the nearshore reefs. Photo credits: (A, B) James Sullivan, (D) Brian Lapointe, (C, E, F) Laura Herren.