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Managed nutrient reduction impacts on nutrient concentrations, water clarity, primary production, and hypoxia in a north temperate estuary

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ABSTRACT

Except for the Providence River and side embayments like Greenwich Bay, Narragansett Bay can no longer be considered eutrophic. In summer 2012 managed nitrogen treatment in Narragansett Bay achieved a goal of reducing effluent dissolved inorganic nitrogen inputs by over 50%. Narragansett Bay represents a small northeast US estuary that had been heavily loaded with sewage effluent nutrients since the late 1800s. The input reduction was reflected in standing stock nutrients resulting in a statistically significant 60% reduction in concentration. In the Providence River estuary, total nitrogen decreased from 100 μm to about 40 μm, for example. We tested four environmental changes that might be associated with the nitrogen reduction. System apparent production was significantly decreased by 31% and 45% in the upper and mid Bay. Nutrient reductions resulted in statistically improved water clarity in the mid and upper Bay and in a 34% reduction in summer hypoxia. Nitrogen reduction also reduced the winter spring diatom bloom; winter chlorophyll levels after nutrient reduction have been significantly lower than before the reduction. The impact on the Bay will continue to evolve over the next few years and be a natural experiment for other temperate estuaries that will be experiencing nitrogen reduction. To provide perspective we review factors effecting hypoxia in other estuaries with managed nutrient reduction and conclude that, as in Narragansett Bay, physical factors can be as important as nutrients. On a positive note managed nutrient reduction has mitigated further deterioration in most estuaries.

1. Introduction

As the expensive engineering efforts reduce nutrients in coastal systems, the documentation toward restoration becomes increasingly relevant to justify. Some systems fail to follow a simple trajectory from degradation to restoration (Duarte et al., 2009; Conley, 2012). In large stratified Chesapeake Bay, inorganic nutrients were a primary driver of hypoxia through growth, sinking and decomposition of algal cells, but the removal of bivalve filter feeders, climate change and changing physical factors have continued to contribute to hypoxia (Kemp et al., 2009). However, other systems indicate improvement with reduced chlorophyll levels, improved water clarity and in some cases the re-growth of seagrass beds (Staehr et al., 2017; Taylor et al., 2011; Greening and Janicki, 2006). Here, we offer one more case where the effort may be evaluated.

In the late 1990s and early 2000s, studies in Narragansett Bay

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revealed incidences of low oxygen concentrations during the summer in the Providence River area, the upper Bay and coves such as Greenwich Bay (Bergondo, 2004; Bergondo et al., 2005; Deacutis et al., 2006; Melrose et al., 2007; Codiga et al., 2009). The Providence River and Seekonk River estuaries at the head of the Bay have low oxygen reports dating back to 1923 (Desbonnet and Lee, 1991; U.S. Public Health Service, 1960). Estimates of prehistoric nutrient concentration suggest that reactive nitrogen and phosphorus had been increased 5 fold and 2 fold, respectively, from human activities by the 1990s (Nixon, 1997).

Eutrophication and low oxygen resulting in the 2003 fish kill in the Greenwich Bay portion of Narragansett Bay caught the public's attention and provided impetus for managed nitrogen reduction (Deacutis et al., 2006). The Rhode Island Department of Environmental Management (RI DEM) implemented nitrogen reductions in waste water treatment facilities (WWTF) beginning in 2005 (RIDEM, 2005). By summer 2012 the overall goal of a 50% reduction of the WWTF effluent DIN load was achieved in Narragansett Bay (Liberti, A. 2014 RI DEM, personal communication). Management regulations have mandated tertiary treatment at WWTF year round but threshold limits of 5 ppm nitrogen only apply in warmer months when the process is most efficient.

This study presents the change in nutrient standing stocks in Narragansett Bay and four environmental changes associated with oligotrophication: apparent production, water clarity, frequency of summer hypoxia and intensity of the winter-spring diatom bloom. The variables were examined Bay-wide and presented in a north-south format for comparisons to nutrient concentrations and provide an estimation of gradient changes within the Bay ecosystem. This manner of presentation has the advantage of making outlier areas evident. Since our study began after the initial nutrient reduction, two annual surveys (1979–1980 and 1997–1998) conducted before this study were mined for data for the before treatment in this study.

1.1. The study area – Narragansett Bay

Narragansett Bay, with a length of 45 km and mean depth of 8.3 m, lies in a north-south orientation on the coast of Rhode Island and opens into Rhode Island Sound (Fig. 1). The 4660 km^2 watershed extends from Rhode Island into Massachusetts and provides an average freshwater input of 37 $m^3\ s^{-1}$ (Kremer and Nixon, 1978). The Bay includes several distinct regions: the northern Seekonk - Providence estuaries, upper Bay, and the lower Bay divided by islands into the West and East Passages. The East Passage borders the entrance to the Mt Hope Bay-Sakonnet Passage complex.

Tidal waters account for about 13% of the volume of the Bay. Offshore waters enter from Rhode Island Sound mainly into the deeper East Passage of the Bay. They flow north to the Providence area along the bottom and slowly mixing to the surface. The range of salinity in the Bay is small, about 22–30 ppt, owing to the low fresh water input compared to the large tidal volume. Water in the upper Bay and East Passage moves west due to prevailing winds and Coriolis force. The resulting flow then propagates south on the surface in the West Passage (Kincaid et al., 2008). Average residence time of water in the Bay is about 40 days (Pilson, 1985).

Historically WWTF located in the watershed and the urban northern portion of the Bay have contributed high nutrient loads to the Bay resulting in a gradient of high nutrient concentrations in the upper Bay to low nutrients in Rhode Island Sound (Oviatt, 2008). Primary production, chlorophyll-a, zooplankton abundances and frequency of hypoxia events have followed a similar gradient of higher values up Bay and decreasing values down Bay (Oviatt, 2008).

2. Methods

2.1. Nutrients

From late summer 2005 through 2014, 13 surface stations around Narragansett Bay (Fig. 1) were sampled to measure ammonia, nitrate, nitrite, phosphate, total phosphorus and total nitrogen. Sampling was conducted monthly during cold months and bi-monthly during June, July, August. These surveys were compared to a dissolved inorganic nutrient survey conducted in 1979-80 and a total nitrogen and total phosphorus survey in 1997–1998 over annual cycles (Oviatt et al., 1984, 2002).

Samples were collected using an acid cleaned plastic container within 0.5 m of the surface and stored on ice until return to the laboratory. Upon return during the afternoon of the same day 40 ml dissolved inorganic nutrients were filtered using 0.45-μm Nucleopore filters. A second aliquot of 40 ml whole water was collected for TN and TP. All samples were frozen at −4 °C until analysis.

Samples were analyzed with a colorimetric method on a Technicon auto-analyzer before 2008 and an Astoria SFA auto-analyzer after 2008. The two instruments were inter-calibrated with samples over a three-year period (Krumholz, 2012). Total nutrient samples were mineralized with alkaline persulfate before being analyzed (Patton and Kryskalla, 2003). Ammonia, nitrate and nitrite were analyzed using methods from Astoria-Pacific (2005), Scott et al. (2005) and Schmidt and Clement (2009). Phosphate was analyzed using methods from Scott et al. (2005).

2.2. Field monitoring network for oxygen and apparent system production

Since the early 2000s, a summer monitoring network of fixed and buoy sites was developed to observe and record water quality variables at several station throughout the Bay (Fig. 1). The Rhode Island Department of Environmental Management (RI DEM) developed the program in partnership with the Narragansett Bay Commission, the Narragansett Bay National Estuarine Research Reserve and the University of Rhode Island, Graduate School of Oceanography. The RI DEM has used the data from this network to assess levels of low oxygen conditions for the upper Bay.

For this study the network data were used to estimate primary production. System apparent production is defined as water column net community production during the day (Oczkowski et al., 2016). Surface and bottom sensors were deployed at each site, with the exception of GSO and CP winter stations that had only surface sensors deployed. Sensors took measurements every 15 min for depth, temperature, salinity, oxygen, chlorophyll-a fluorescence (surface only), and pH using Yellow Springs Incorporated (YSI) brand instruments at all stations. Stations are serviced on a 2-week interval to remove bio-fouling (for water quality procedures see RIDEM, 2014). The buoy stations are operational from May through October (PD, BR, CP, SR, MV, QP, PQ, MHB). Four of the stations operated year round (CP, GB, T-W, GSO). Daily averages of the data are stored and available online: http://www.narrbay.org/d_projects/buoy/buoydata.htm (accessed May 2015).

2.3. Model for system apparent production

Net apparent system metabolism estimates were calculated from oxygen data (RIDEM, 2007, 2014) from each station in the network from 2006 to 2015 using a Dawn-Dusk (DD) estimation (Odum and Hoskin, 1958). System apparent production was estimated from surface sensors using dawn and dusk measurements daily June through August (92 d):