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Water quality upstream and downstream of a commercial oyster aquaculture facility in Chesapeake Bay, USA

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ABSTRACT

Oyster aquaculture is an expanding industry in the Chesapeake Bay. Oysters remove nitrogen (N) and phosphorus (P) from the water column through filtration and conversion of phytoplankton into shell and tissue, but also continuously excrete these same nutrients back into the water column as inorganic compounds readily available for plant or algal uptake. The objective of this study was to assess multiple water quality parameters upstream and downstream of a commercial oyster aquaculture facility in the mesohaline region of the Chesapeake Bay. Results of the study indicated a 78.4% average increase in total ammonia nitrogen (TAN) concentration and a 19.4% decrease in chlorophyll-*a* (Chl-*a*) concentration downstream of the facility. There was no significant change in the concentration of reactive phosphate (RP), nitrate–nitrogen (NO_3^-–N), or nitrite–nitrogen (NO_2^-–N) as water passed through the facility. It was determined that velocity of water through the facility had no influence on the change in TAN or Chl-*a* concentration from upstream to downstream of the facility. Increased reduction in Chl-*a* concentration from upstream to downstream was related to higher upstream concentrations of Chl-*a*. There was no correlation between increased rates of Chl-*a* removal and downstream TAN. Results of this study suggest that oyster aquaculture can significantly increase the amount of available inorganic nitrogen in the water column immediately downstream of a facility, independent of upstream availability of phytoplankton and flow velocity of water through the facility.

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1. Introduction

Oysters play a critical role in the aquatic nitrogen (N) and phosphorus (P) cycles through benthic–pelagic coupling processes (Newell et al., 2005). The Eastern Oyster, *Crassostrea virginica*, is a suspension-feeding bivalve, meaning it filters suspended particles from the water column, preferentially ingesting some while rejecting others as pseudofeces (Galtsoff, 1964; Haven and Morales-Alamo, 1970; Newell and Jordan, 1983; Ward et al., 1994). The main processes to be considered when discussing the role of *C. virginica* in the N and P cycles are: the filtration of suspended matter including phytoplankton; the process of feces and pseudofeces deposition; excretion of N and P by the oysters; and the incorporation of N and P into the oyster shell and tissue (Fig. 1). This study is focused on filtration of phytoplankton and excretion of N and P.

Nitrogen is excreted by *C. virginica* as ammonia (NH_3), nitrate (NO_3^-), nitrite (NO_2^-), urea, and amino acids; excretion occurs at different rates at different temperatures, with higher rates of excretion during warmer seasons, and decreased rates of excretion during cooler weather (Hammen, 1968, 1969; Srna and Baggaley, 1976; Pietros and Rice, 2003; Dame et al., 1992). The majority of N excreted by *C. virginica* is in the form of NH_3 (Hammen et al., 1982). Multiple studies have investigated rates of inorganic N excretion by *C. virginica*, with variable results (Table 1). P is similarly excreted by *C. virginica*, but at lower levels not normally much above background concentrations (Dame et al., 1991).

Since oysters convert organic N held in algae, bacteria, and detritus into biologically available N released through excretion, there are potential environmental implications downstream of aquaculture facilities as a result of increased N availability. These implications could include increased productivity of algae downstream of the facility, along with the potential for alteration of phytoplankton community structure as a result of changed nutrient stoichiometry, light availability, and reduced competition. Several

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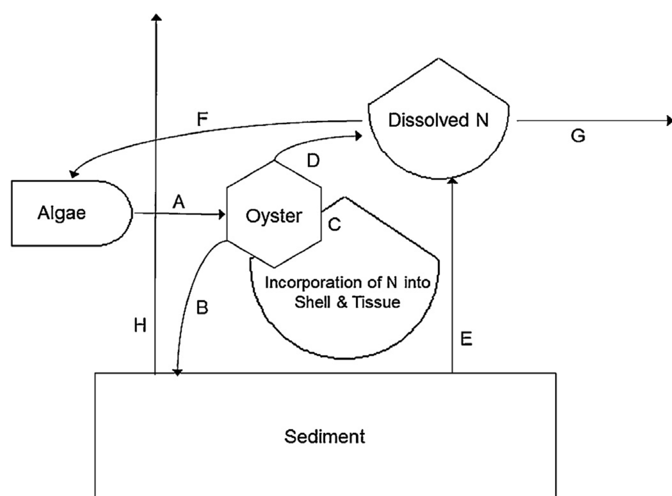

Fig. 1. Simplified nitrogen cycle in an oyster aquaculture facility. (A) Algae and particulate organic matter are filtered by oysters. (B) Feces and pseudofeces composed of rejected food particles are released and sink to the sediment. (C) Nitrogen in consumed algae is either incorporated into oyster shell and tissue, or (D) released into the water column. (E) Pseudofeces deposited to the sediment can alter release of dissolved N to the water column, or (H) be released to the atmosphere through denitrification processes. Dissolved N can either be (F) used by algae, or (G) carried downstream of the facility.

Table 1
Comparison of TAN excretion rates by *Crassostrea virginica* from previous studies with results from this study.

Study	Calculated excretion rate (μmol NH_3–N/g dryweight day^{-1})
Srna and Baggaley (1976)	25
Hammen (1968)	11.7–38.328 ($\bar{x}$ = 25.028)
Dame et al. (1992)	38.75
Pietros and Rice (2003)	67.39
This study	**30.29 ± 0.68** (μmol TAN/g dryweight day^{-1})

previous studies have demonstrated increased productivity of algae and microbial communities due to altered and regenerated nutrient pools when intertidal invertebrates were present (Pfister, 2007; Bracken, 2004; Bracken and Nielsen, 2004). Similarly, the type of N available can also influence phytoplankton community structure (Altman and Paerl, 2012; Glibert, 2012; Glibert and Terlizzi, 1999; Gobler et al., 2012). Thus, understanding the influence of a large-scale oyster aquaculture facility on the nutrient chemistry of the surrounding water body is critical in determining the environmental impact of this type of industry.

In the past 20 years, there has been a large-scale effort in Maryland and Virginia to restore the Chesapeake Bay oyster population to near historic levels. Part of this effort has included the growth and development of the oyster aquaculture industry. Recent research regarding oysters and N in both the Chesapeake Bay and globally has focused on the prospect of increased rates of denitrification promoted by restored oyster reefs and aquaculture operations (Higgins et al., 2013; Kellogg et al., 2013; Smyth et al., 2013), and N removal during oyster harvest (Higgins et al., 2011). Data from these studies has been used to estimate improvements in environmental quality with increased oyster populations in subsequent investigations (Bricker et al., 2014). While these studies have assessed potential water quality improvement by oysters, regenerated N from oyster excretion has been largely ignored in aquaculture settings.

Meseck et al. (2012) investigated the potential effects of a floating upwelling system (FLUPSY) with juvenile oysters on water quality in a small embayment in New York. The study reported that concentrations of nutrients were no higher around the FLUPSY than other areas of the embayment, but that the C:N ratio was altered, and there were higher concentrations of chlorophyll-*a* (Chl-*a*) – an indicator of phytoplankton productivity – near the FLUPSY, indicative of enhanced nutrient cycling. Li et al. (2012) demonstrated that the same site did not influence phytoplankton abundance in the surrounding water, and that there were no "legacy effects" of the facility (Li et al., 2013a).

There were two main objectives of this study: to determine if cultured oysters excrete N at a similar rate compared to wild oysters in previous studies, and to assess for differences in water quality upstream and downstream of a commercial oyster aquaculture facility. Hypotheses for this study were: the oysters used at the aquaculture facility would excrete N at a rate comparable to wild oysters; water will have increased concentrations of total ammonia nitrogen (TAN) and reactive phosphorus (RP), decreased concentration of dissolved oxygen (DO) and Chl-*a*, and no change in temperature, salinity, NO_3^-–N concentration, and NO_2^-–N concentration downstream of the facility. It was also hypothesized that slower flow of water through the facility would be associated with larger increases in TAN and RP concentration, as well as greater reduction in Chl-*a* and DO concentration.

2. Materials and methods

2.1. Description and location of study site

Fieldwork was conducted at a commercial oyster aquaculture facility located near the mouth of Choptank River on Maryland's Eastern Shore (Fig. 2) from May to October 2013. There is a tidal influence at the facility (0.5–0.8 m), and the water is well mixed. Flow of water through the facility is typically parallel to the shoreline from S to N. Flow patterns occasionally reverse during strong tides or storm events. Water at the facility is brackish, with average salinities ranging from 10 to 15 ppt annually (Chesapeake Bay Program, 2012) and temperatures ranging from 3 to 30 °C throughout the year. The average water depth ranges from 0.5 to 1.5 m.

The facility employs floating raft aquaculture, with between 8 and 10 million oysters in culture. Approximately 1 million of the oysters are harvested and sold annually. The oysters cultured at the facility are a triploid of *C. virginica*, as opposed to the native diploid of the same species. The floating rafts cover an area of approximately 5850 m^2 (approximately 45 m from E to W, and 130 m from N to S), and are located completely within the top 0.05–0.10 m of the water column.

2.2. Oyster excretion experiment

To assess TAN excretion rates of the oysters at the aquaculture facility, an adaptation of methods used in previous studies of oyster excretion were employed (Hammen, 1968; Srna and Baggaley, 1976). The experimental treatment (n = 3) consisted of 12 market size oysters, taken from the aquaculture facility and placed in an 8 L plastic tub containing 4–6 L of water collected from the river near the aquaculture facility (river water was compared to deionized water in an earlier experiment, and no difference in excretion rate was evident, so river water was used for each sampling date). The oysters used were representative of those sold by the aquaculture facility, at approximately 60–80 mm length, A battery-powered air pump was used in each tub to maintain oxygenation and provide mixing. Oysters were allowed to acclimate to the tub, and the first 30 ml sample was collected using a pipette when all oysters were visibly open (approximately 20–30 min after being placed in the tub), and again every 30 min over a two-hour period. Samples were filtered through a Whatman GF/F filter, placed on ice, and returned to the lab.

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