Oyster Pond: Concentrations, effects and sources of groundwater nutrients

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ABSTRACT:

Increased land derived nutrient loading to estuaries in the Cape Cod region of Massachusetts have raised nutrient concentrations and led to eutrophication and low dissolved oxygen. In this study we estimated inputs of the nutrients nitrate, ammonium, and phosphate to the six different sub-watershed of Oyster Pond in Falmouth, Massachusetts. The average nitrate concentration of groundwater was high where there were more houses. Inter-annual changes in nutrient concentrations were not prominent, other than an increase in nitrate concentration associated with a well-developed sub-watershed. Using a nitrogen loading model we estimated the amount of nitrogen coming from wastewater, atmospheric deposition, and fertilizer and found that 67% of the nitrogen entering the pond comes from wastewater. The largest contribution to the N load of the whole watershed, 41%, comes from the Treetops sub-watershed. A survey of the northern section of Oyster Pond, where Treetops is located, detected more septic system plumes entering the water from more developed areas. The Treetops area of the watershed is the most developed and contributes the most nitrogen to groundwater. Changing the septic systems of the Treetops housing development to one more efficient at removing nitrogen from the wastewater could potentially reduce the contribution of this area to total N-loads by 20-50%.

Introduction

Over the last 50 years, development in the Cape Cod region of Massachusetts has led to the urbanization of a large part of formerly forested area (Valiela and Bowen 2003). This change has brought with it a higher proportion of nitrogen throughput from land to coastal estuaries. Increased nitrogen, as NO_3 and NH_4, and phosphorus, as PO_4, loads have become a major environmental concern for these estuaries, which experience eutrophication and hypoxic conditions (Bowen and Valiela 2004). High nutrient levels stimulate phytoplankton and macroalgal blooms (Weber et al. 2002). One of the consequences of these blooms is abnormally large quantities of decomposing biomass, which deplete dissolved oxygen in the water and have cascading effects through the estuaries food web (Paerl 1997).

Among the affected areas is Oyster Pond, a coastal lagoon adjacent to Vineyard Sound in Falmouth, Massachusetts. The pond is connected to the sound by a lagoon and a small channel located at the southern end of the pond. Oyster Pond is slightly saline, about 2-3 ppt, and is bordered by development on all sides except the south-western corner, which borders the beach. Groundwater seeping through the permeable sediments underlying the watershed surface is the major nitrogen transport mechanism to the pond (Emery 1998). Atmospheric deposition, fertilizer, and wastewater are the principal contributors of nitrogen to the watershed of coastal water bodies such as Oyster Pond (Valiela et al. 1997). Nitrogen delivered to the watershed moves through the vadose zone, into the aquifer, and out into the pond through the seepage face. Some of the nitrogen is lost in the soil during transport (Al-Qatami et al. 2001). A study in nearby Waquoit

Bay indicates that, considering the net result of nitrogen inputs and losses, wastewater are the largest source (48%) of nitrogen input (Valiela et al. 1997), and similar conditions may apply to Oyster Pond.

Previous surveys of groundwater around Oyster Pond have shown high concentrations of nitrogen associated with areas of increased urban development (Al-Qatami et al. unpublished; Good unpublished). In previous research, the Oyster Pond watershed was split into six sub-watersheds to facilitate comparisons between these different areas around the pond (Fig. 1).

In this paper, we had a number of questions:

1. What are the nutrient concentrations and loads in Oyster Pond's groundwater?
2. Are there inter-annual increases in nutrient concentrations?
3. What are the sources of nitrogen?
4. Where are septic system plumes entering the pond?
5. How does urbanization affect nitrogen loads?

Methods

To measure concentrations of nutrients in groundwater and estimate land derived loads of NO_3, NH_4, and PO_4 entering Oyster Pond, we sampled groundwater. We collected 32 samples of groundwater from sites around the perimeter of Oyster Pond (Fig. 1) using a piezometer driven about 50-100cm into the ground, at locations above the high water mark and near the shore. To make sure we analyzed samples of groundwater moving from the aquifer, we accepted groundwater samples only if the salt concentration was lass than 1 ppt, and if

they did not smell of sulfides. The samples of groundwater were filtered and the NO_3, NH_4, and PO_4 concentrations were measured using standard calorimetric methods in a Lachet Autoanalyzer.

We calculated the measured loads for each sub-watershed by multiplying the mean concentrations of NO_3, NH_4, and PO_4 times the annual recharge of groundwater (Valiela et al. 2000). These results were taken to be measured nutrient loads, which were compared to modeled nutrient loads.

We used the results on nutrient content of groundwater for two purposes. First, to define the nutrient output from each sub-watershed, we compiled the values into means for water leaving each sub-watershed. Second, we used the nutrient concentrations to obtain a validation of model estimates of N loads, needed because we used model predictions in a later part of this work.

To assess the relative contribution of nitrogen via wastewater, atmospheric deposition, and fertilizer, we used a Nitrogen Loading Model (NLM) (Valiela et al. 1997) that model uses input data on land use for each sub-watershed, and calculates the percent of the N load that is derived from wastewater, atmospheric deposition, and fertilizer use.

To ascertain if plumes from septic systems actually entered Oyster Pond, we used a septic leachate detector carried by a boat traveling along the edge of the pond in sub-watersheds 2 and 3 (Fig. 1). This device has been used in previous studies of lake water (Kerfoot and Skinner, 1981; Jourdonnais and Stanford, 1985; Grant, 1995). Plumes of elevated concentrations of leachate were located by running water from the pond through a fluorometer, which

detected compounds from urine and whiteners in cleaning products (Grant, 1995). The plumes were indicated as peaks on a track recorded using the data output form the fluorometer. To determine the number of plumes in the two sub-watersheds we counted the number of peaks on the graph that were twice as high as the baseline variation.

To look at the effects of development on concentrations of nitrogen we plotted the NO_3 concentration of the samples from each site against the number of houses in each sub-watershed. Having demonstrated that the NO_3 concentration increases with an increase in the number of houses, with the Treetops sub-watershed having the largest number of houses, we then used the NLM to suggest a management option for Treetops. The NLM predicted the change in the contribution of nitrogen in wastewater to the N load in Oyster Pond if a RUCK® septic system were used instead of the conventional system currently used by the Treetops housing development using the nitrogen retention efficiencies.

Results and Discussion

Groundwater nutrient concentrations

Phosphate concentrations in groundwater were low throughout the area surrounding Oyster Pond; there were no concentrations above 4 µm. Average phosphate (PO_4) concentrations were not significantly higher in any of the sub-watersheds (Fig. 2).

Average ammonium (NH_4) concentrations were not significantly high in any of the sub-watersheds. NH_4 concentrations were low compared to nitrogen levels throughout the pond (Fig. 2).

The Spohr Gardens, Mosquito Creek, Quonset, and Lagoon sub-watersheds had average nitrate (NO_3) concentrations below 30 µm. The Treetops sub-watershed had a significantly higher average nitrogen concentration than the other sub-watersheds (Fig. 2).

Nutrient loads

We converted the nutrient concentrations to loads because loads give a better representation of the actual amount of nutrients entering the pond from the entire area of a watershed. The nitrate loads from the groundwater were highest in the Treetops sub-watershed (447 kg y^{-1}); the next highest input came from Quonset at 22.7 kg y^{-1}. (Table 1). The lowest nitrate load came from the Lagoon area, which also has the lowest population density.

Ammonium loads were highest on the western side of the pond, in the Spohr Gardens and Mosquito Creek sub-watersheds. However, the high ammonium loads corresponding to these areas have relatively large standard errors, suggesting the influence of outlying samples (Table 1).

The highest phosphate load came from Treetops, but phosphate loads were low relative to nitrate and ammonium loads throughout the pond.

Inter-annual comparison of nutrient concentrations

Most NO_3 concentrations for 2001 and 2004 fall near the 1:1 line, which suggests that there has been no significant change in the majority of the sub-watersheds, (Fig. 3). The concentration of NO_3, however, doubled in the Treetops sub-watershed. There were minor increases and decreases in PO_4 and NH_4 concentrations, but there were no significant trends in either from 2001 to 2004.

Nitrogen loading model

Estimates of N obtained using a nitrate-loading model (Caraco and Cole 1999, modified as described in Valiela et al. 2004) were compared to measured nitrate loads (Fig. 4). The model estimates closely resembled the measured estimates, providing some confidence that the model exercise dealt with reasonable approximation to the measured nitrogen loads.

We modeled the total nitrogen load for each sub-watershed using NLM (Valiela 1997). The nitrogen load was derived for each sub-watershed. The largest input came from the Treetops watershed: 41.3% of the total 988.8 kg N yr^{-1} N-load (Table 2). The NLM model also broke down the different nitrogen sources of the pond into atmospheric deposition, wastewater, and fertilizer (Fig. 5). Wastewater was the largest source of nitrogen at 67% of the total land-derived nitrogen load from each sub-watershed.

Presence of septic plumes in Oyster Pond

The septic leachate detector results from the Mosquito Creek and Treetops sub-watersheds showed a large difference between the numbers of

peaks detected in the two areas (Fig. 6). We found 6 septic system plumes in Mosquito Creek and 23 plumes in Treetops (Table 3). The number of plumes in a sub-watershed increased with the number of septic tanks for housing units on lots bordering the pond. 75% of the septic tanks in Mosquito Creek and 74% of the septic tanks in Treetops were detected as plumes. The plumes represent less than half of the total number of housing units in each sub-watershed. This shows that the septic leachate detector gives a reasonable estimate of the septic systems contributing plumes form directly long the shoreline. This method is less accurate for predicting overall differences in total number of houses between whole sub-watersheds.

Relationship of NO_3 concentrations to number of houses

Concentrations of NO_3 in groundwater were found in our measurements to increase with number of houses (Fig. 7). The Lagoon and Cumloden sub-watershed had a small number of houses compared to the other sub-watersheds. Because of this, they had the lowest concentrations of NO_3 in their groundwater. In comparison, Treetops, the sub-watershed with the largest number of houses, also had the largest NO_3 concentrations.

Alternative for disposal wastewater from Treetops

Given that we found more effluent plumes in the vicinity of the Treetops sub-watershed (Fig. 6), and that the concentration of NO_3 (Fig. 2) and the N loads for wastewater (Table 2) both showed larger contributions of nitrogen from the Treetops sub-watershed, it seems reasonable to speculate on how this contribution might be managed. One alternative is to install a septic system with

a higher nitrogen retention capacity (Table 4). The conventional system used currently by Treetops removes an average of 39% of the nitrogen from the wastewater. If the wastewater was to be treated by a more efficient septic system, for example the RUCK® system, 21-51% more nitrogen would be removed (Bowen and Valiela 2004). This would reduce the contribution from the Treetops sub-watershed to the total N load in the watershed from 390.6 kg y^{-1} to 195.2-311.4 kg y^{-1}. This is a 20-50% reduction.

Literature Cited

Al-Qatami, H., A. Hsu, M. Smith, J. Smith-Gillen and A. Solari. 2001. Land-
derived nitrogen to Oyster Pond estuary. Unpublished report.

Bowen, J.L. and I. Valiela. 2004. Nitrogen loads to estuaries: using loading
models to assess the effectiveness of management options to restore
estuarine water quality. *Estuaries* 27: 482-500.

Good, S.R. 2002. Oyster Pond: Links between watershed land-use and nitrogen
loading rates, and a discussion of management issues. Unpublished
report.

Grant, W.F. 1995. Movement of septic system effluent from lake developments
into near-shore areas of 18 Indiana lakes. Unpublished report.

Jourdonnais, J.H. and J.A. Stanford. 1985. Verification of shoreline sewage
leachates in Flathead Lake, Montana. Unpublished report.

Kerfoot, W.B. and S.M. Skinner, Jr. 1981. Septic leachate surveys for lakeside
sewer needs evaluation. *Journal Water Pollution Control Federation* 53:
1717-1725.

Millham, N.P. and B.H. Howes. 1994. Freshwater flow into a coastal embayment:
groundwater and surface water inputs. *Limnology and Oceanography* 39:
1928-1944.

Paerl, H.W. 1997. Coastal eutrophication and harmful algal blooms: Importance
of atmospheric deposition and groundwater as (new) nitrogen and other
nutrient sources. *Limnology and Oceanography* 42: 1154-1165

Valiela, I., G Collins, J. Kremer, K. Lajtha, M. Geist, B. Seely, J. Brawley, and

C.H. Sham. 1997. Nitrogen loading from coastal watersheds to receiving estuaries: New method and application. *Ecological Applications* 7: 358-380.

Valiela, I., M. Geist, J. McClelland, and G. Tomasky. 2000. Nitrogen loading from watersheds to estuaries: Verification of the Waquoit Bay Nitrogen Loading Model. *Biogeochemistry* 49: 277-293.

Valiela, I. and J.L. Bowen. 2003. Shifts in Winter Distribution in Birds: Effects of Global Warming and Local Habitat Change. *Ambio* 32: 476-480.

Weber, C.F., S. Barron, R. Marino, R.W. Howarth, G. Tomasky, and E.A. Davidson. 2002. Nutrient limitation of phytoplankton growth in Vineyard Sound and Oyster Pond, Falmouth, Massachusetts. *Biological Bulletin* 203: 261-263.