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Nitrogen budgets of the Long Island Sound estuary

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Highlights

- First nitrogen(N) budgets for Long Island Sound (LIS).
- 60% of N entering LIS is buried or denitrified.
- 40% of N is exported to coastal ocean.
- LIS is a net exporter of N though inter annual variation is large.
- Seasonally LIS can be either a net importer or exporter of N.

Abstract

Nitrogen (N) inputs to coastal ecosystems have significant impacts on coastal community structure. In N limited systems, increases in N inputs may lead to excess productivity and hypoxia. Like many temperate estuaries, Long Island Sound (LIS), a major eastern U.S. estuary, is a N limited system which has experienced seasonal hypoxia since the 1800s. This study is the first effort to constrain the total N cycle in this estuary. The approach utilizes data collected over the last two decades in the

LIS time series with hydrodynamic model results to generate both monthly and annual N budgets between 1995 and 2016. Of the total N that is delivered to LIS through rivers and atmospheric inputs, 40% is exported to the adjacent continental shelf on the order of $10.8\pm8.9\times10^{6}$ kgN/year. Of this export, 41% is dissolved organic N, 29% is particulate organic N, 32% is nitrate+nitrite, and −3% is ammonium. The remaining 60% of the N delivered to LIS is either buried in sediments or lost through denitrification. This inferred internal loss rate is equivalent to 5.4 gN/(m^2year). This study serves as an example of the significant inter-annual variations that estuarine budgets undergo as efforts to understand coastal biogeochemical cycles move forward.

Introduction

Coastal zone biogeochemical cycles are closely coupled. Though these regions are relatively nutrient rich, there are always limiting nutrients that set constraints on productivity rates and thus regulate both the amount and pathways by which elements are utilized and exported to the open ocean. Many temperate coastal zones have been identified as nitrogen (N) limited (Howarth and Marino, 2006; Sitta et al., 2018). Coupled with increased N loads from growing coastal communities, these coastal zones are now experiencing higher productivity, leading to seasonal eutrophication (Paerl, 1997; Valiela and Bowen, 2002; Glibert et al., 2006; Reed et al., 2015; Ellis et al., 2017). Additionally, there are predicted shifts in precipitation patterns associated with standard climate scenarios that will substantially elevate riverine total nitrogen (TN) loads to coastal zones across the continental U.S. by as much as 19±14% and, as much as 28±20% in the Northeast US by the end of the 21st Century (Sihna et al., 2017; Paerl et al., 2018). Yet, the forcings and feedbacks associated with both land use changes and altered freshwater inputs on N cycling in coastal zones remain poorly understood. In the midst of growing coastal populations, shifting coastal climates, and shifting biogeochemical loads, there is a need to understand the fluxes and utilization of N to develop adaptive measures and guide management.

The Long Island Sound (LIS) is a tidal estuary that spans 177 km from west to east and 34 kmat its widest point (along its north-south axis). Depths range from 10 to 70 m and average at 21 m. A total of 18 rivers drain into LIS though 70% of the freshwater is from the Connecticut River at the eastern end of the estuary. The primary tidal exchange is through eastern LIS directly with the Mid-Atlantic Bight though exchange also occurs at its western end through the East River which is a narrow (~1 km) and shallow (~10 m) tidal straight (Gay et al., 2004). LIS is a nitrogen limited, urbanized estuary that has experienced seasonal hypoxia since the early 1800's following the first significant land use changes for agriculture (Varekamp et al., 2018). Hypoxia is most intense during summers at the LIS western boundary, though in some years it extends to the mid estuary. Targeted management efforts (New York State Department of Environmental Conservation (NY-DEC) and Connecticut Department of Energy and Environmental Protection (CT-DEEP) 2000) have reduced total wastewater treatment N loads entering LIS from Connecticut (CT) and New York to 58% of the levels in the 1990s; the targets levels were reached in the last decade after wastewater treatment plant upgrades. Lower extents of hypoxia in recent years correspond with these load reductions, though highly hypoxic years still occur (www.longislandsoundstudy.net ↗).

Currently the coupling between N cycling and oxygen utilization leading to hypoxia in LIS is not well understood. As a first step, Vlahos and Whitney (2017) completed an organic carbon balance on LIS, which showed the dynamic nature of the estuary in terms of freshwater inputs wherein dry years led to a highly heterotrophic estuary and wet years led to autotrophy and net organic carbon (OC) export. The timescales involved in N utilization are faster than those for OC and therefore one would expect a decoupling between N cycling and OC in the LIS system. N also undergoes several redox related transformations in natural systems and is continuously being transferred between its oxidized forms as nitrate (NO_3^-) or nitrite (NO_2^-), its reduced form as ammonium (NH_4^+), its organically bound particulate or dissolved forms (PON, DON), and its intermediate gas forms as nitrogen gas (N_2) or nitrous oxide (N_2O). As particulate forms lead to particle settling and burial and gaseous forms lead to outgassing, N cycling is dynamic and multifaceted. The form of N in marine systems has large impacts on its fate and bioavailability. Generally, primary producers favor the inorganic forms (Heil et al., 2007; Glibert and Berg, 2009) and during times of severe N limitation will turn to utilizing DON. Alternatively, dinoflagellates, cyanobacteria, and raphidophytes may preferentially assimilate DON (Glibert et al., 2006; Bronk et al., 2007; Heisler et al., 2008; Reed et al., 2015). Generally, it is well understood that within ecosystems, available N forms may alter and shape community structure. Also, recent warming trends in LIS (Staniec and Vlahos, 2017) may shift metabolic rates within these communities.

This study extends the LIS biogeochemistry assessment by calculating N budgets for LIS from 1995 to 2016. The goal is to understand the relative importance of the N sources and sinks in a broader geochemical context, to understand temporal trends in LIS N budgets, to quantify N exports to the adjacent continental shelf, and to deduce the extent of denitrification and burial in the LIS system across these decadal timescales. It is anticipated that this study may serve as a baseline for the region and comparison for other regions globally.

Section snippets

General approach

The LIS estuary was divided into western, central, and eastern regions (WLIS, CLIS and ELIS, Fig. 1) after Vlahos and Whitney (2017). The regions were selected such that boundaries coincided with the CT-DEEP's time series stations (CT-DEEP et al., 2017). The CT-DEEP, as part of the Long Island Sound Study water quality program, has monitored N since the early 1990s for parameters that include inorganic nitrogen (NO_3^-+NO_2^- = NO_x^-, NH_4^+), PON (as PN) and DON. These concentrations were combined …

Average annual budgets

Fig. 3 shows the overall N mass balance for LIS over the study period. Freshwater inputs carry the dominant source of N to LIS (77%). Atmospheric inputs are significant (12%), particularly in WLIS and CLIS where they contribute roughly 17% and 26% of the inputs respectively. Of the atmospheric inputs, both wet and dry deposition are significant, though dry represents roughly 60%. The East River tidal strait is a net source of N and contributes 11% of the total net inputs to LIS, however, this …

Discussion

The impact of coastal estuaries in the biogeochemical cycling of N has important implications for both coastal and open ocean productivity, particularly in lieu of the frequency of N limitation in marine systems. Based on this study, a significant proportion of TN delivered to LIS (60%) is “lost” within the estuary through denitrification or sediment burial. The loss rate is consistent with estimates of other estuaries of the Atlantic coast (Nixon et al., 1996; Hayn et al., 2014) and European …

Conclusions

This study has generated the first complete N balance for the LIS estuary. LIS exports $10.8 \pm 8.9 \times 10^6$ kgN/year of N to the adjacent shelf. Of this, the majority (70%) is exported through ELIS as dissolved organic and particulate organic N. Nitrate+nitrite are also important forms of N exported primarily in late fall and winter and ammonium does not represent a significant N export/import. The exported TN represents 40% of N inputs to LIS. The remaining 60% of N inputs is inferred to be …

Acknowledgements

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Research data for this article

Data not available / Data will be made available on request

ⓘ Further information on research data ↗

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> *Citation Excerpt :*
> …Both major rivers had S275–295 values reaching as low as 0.0127 nm−1. Rivers have been shown to have a significant influence on LIS carbon budgets (Vlahos and Whitney, 2017), nitrogen fluxes (Vlahos et al., 2020), and optical complexity (Aurin et al., 2010). Yet, their impact on DOM quality and distribution across the LIS urban-to-rural and freshwater-to-marine continuum has not been thoroughly examined.…

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