

Objectives of the Research Project

Land-use/land-cover (LULC) in watersheds and nitrogen cycling processes in aquatic ecosystems both mediate the flux of nitrogen (N) from coupled watershed-estuarine systems. LULC in a watershed dictates loading to an estuary as a result of its role in both the hydrologic and N cycle while estuarine processes, such as denitrification and ammonification serve as sinks and in the remobilization of N, respectively. Therefore in order to quantify the sources and fates of N pollution caused by anthropogenic alteration of landscapes it is necessary to understand the interplay between watershed N loading and estuarine ecosystem N processing.

In this research program the primary objective is to calculate estuarine nitrogen mass balances for three coupled watershed-estuarine systems of Mobile Bay that are undergoing differential nitrogen loading (i.e. watersheds having different predominant LULC). Calculation of these mass balances requires estimates of nitrogen loading to the estuary from its watershed, measurement of nitrogen cycling processes within the estuary, and estimates of nitrogen flux out of the estuary. Comparison of the calculated nitrogen budgets for the three systems will further elucidate the role of estuaries in mediating nitrogen flux from their watersheds.

Progress Summary/Accomplishments

Each of the three watershed-estuarine systems were classified as urban, agriculture, or forest using watershed delineations to clip areas of the USGS Multi-Resolution Land-Cover Characterization (MRLC) GIS. The MRLC data were derived from Landsat TM

imagery data obtained in the early 1990s and have a spatial resolution of 30 meters. The three predominant land-use/land-cover complexes and their watershed-estuarine systems are agriculture (Weeks Bay, Alabama), urban (Dog River, Alabama), and mixed-forest (Fowl River, Alabama). These three systems are adjacent to Mobile Bay and their watersheds lie entirely within the Alabama coastal plain.

Dog River, the urban system, drains a large portion of the city of Mobile, 25% of its watershed area is classified as urban, and has the highest population density and the most shoreline development. Weeks Bay, the agricultural system, has 60% of its watershed area classified as pasture/hay and row crops. Fowl River, the mixed-forested system is 41% evergreen/mixed forest, 19% forested wetland, and 33% pasture/hay and row crops.

N loading rates from each watershed and its sub-basins are being calculated from hydrochemical data gathered at 29 locations visited approximately every 3 weeks over a 2 year period and from estimates of discharge from USGS flow gauges and a watershed hydrology model. To date, 40 sampling trips have been completed with 1118 total stations sampled. Hydrochemical data collection included analysis for NO_3 , NO_2 , NH_4^+ , dissolved and particulate organic nitrogen as well as for PO_4 , dissolved and particulate organic phosphorus, chlorophyll a, and other standard hydrographic measures such as temperature, conductivity, and oxygen concentration. These hydrochemical data are being used in conjunction with spatial data residing in a high-resolution GIS in order to determine which landscape attributes contribute the most to nitrogen loading.

N processing rates in the three study estuaries were determined by measuring N cycling processes at 18 sites 7 times over an annual cycle. The six sites within each estuary were spaced along a riverine/estuarine salinity gradient. At each site surface and bottom waters were collected for nutrient analyses, hydrographic parameters were measured and water-column primary production, sediment denitrification, sediment ammonium flux, and sediment oxygen consumption were measured.

Estimates of N flux out of the estuary will be determined by utilizing a 1-D hydrodynamic model to develop residence time calculations for each estuary under different watershed flow regimes. It is expected that residence time will largely dictate the amount of N removed by estuarine denitrification, with high residence times occurring during low flow periods and lowest residence times occurring during high intensity rain events. As much of this study was performed during a period of severe drought along with other periods of abnormally high rainfall we have a wide range of flow regimes and residence times to evaluate in this study.

At this time all field sampling and laboratory analyses are complete and we are in the process of analyzing the data. These results show that N flux from the watersheds varies primarily with the concentration of nitrate where the median concentration in the agricultural watershed, the urban watershed, and the forested watershed were 75, 22, and 9 μM , respectively. Mean primary production rates are highest in the agricultural and urban estuaries, 1.91 and 1.77 $\text{g C m}^{-2} \text{d}^{-1}$, respectively, and lowest in the forested system, 0.89 $\text{g C m}^{-2} \text{d}^{-1}$. Sediment denitrification, ammonium flux, and oxygen consumption all

show the same trend with highest rates in the agricultural system and lowest rates in the forested system.

Across all sites, the trend is for sediment oxygen consumption to increase with increasing primary production ($r^2 = 0.52$), sediment NH_4^+ flux to increase with increasing sediment oxygen consumption ($r^2 = 0.60$), and denitrification rate to increase with increasing sediment NH_4^+ flux. These results indicate that sediment aerobic respiration is primarily responsible for NH_4^+ flux and that denitrification is, at least in part, proceeding as coupled nitrification-denitrification. Further analyses will examine sediment particulate carbon and nitrogen, sediment phaeophytin, bottom water NO_3^- , and bottom water O_2 as regulators of sediment processes.

Publications/Presentations

Lehrter, J. C. and J. R. Pennock. 2001. The magnitudes of nitrogen cycling processes in three coastal plain estuaries. Sixteenth Biennial Estuarine Research Federation Meeting, St. Pete Beach, FL.

Lehrter, J. C. and J. R. Pennock. 2002. Regulation of nitrogen cycling process rates by degree of freshwater influence. ASLO 2002 Summer Meeting, Victoria, BC.

(submitted)

Future Activities

We expect to complete the final phase of this project, calculation of the estuarine N mass balance models, by late summer 2002. The major tasks that remain are the calibration and validation of both the watershed hydrology model (HSPF) and the 1-D hydrodynamic model (HEM 1-D). Once these models are completed all the criteria necessary to calculate the mass balances will be in place.

Keywords:

nitrogen, phosphorus, mass balance, denitrification, watersheds, sediments, estuary, chemical transport, ecosystem, aquatic, environmental chemistry, hydrology, ecology, modeling, monitoring, gulf coast, Dog River, Fowl River, Weeks Bay, Alabama, AL, EPA Region 4

Project Overview

The Role of Land-Use/Land-Cover and River/River-Margin Denitrification in the Regulation of Nitrogen Delivery to the Mobile Bay Ecosystem

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Introduction

As a result of their position between land and sea, estuaries serve as the recipients of accumulated landscape and atmospheric derived materials and as such estuaries are directly impacted by anthropogenic alteration of landscapes. In the face of rapid population growth, concentrated in coastal regions, and a changing climate it is necessary to understand the linkages between watersheds and estuaries if we are to manage these coupled systems in a sustainable manner and reverse the trend of continual ecosystem fragmentation and degradation.

As alteration of watershed landscapes alters the flux of landscape materials to estuaries and, in particular, some land-use processes greatly elevate nutrient inputs, a primary concern in preserving estuaries in a state as near to pristine as possible is the excess addition of nutrients from the landscape and subsequent eutrophication effects (e.g. the Chesapeake Bay or Baltic Sea). Another major concern is suburban sprawl, along with attendant clearing of land and development along waterway and estuarine shorelines. The result of this change in landscape is increased peak runoff, increased loads of suspended sediment and nutrients, and loss of riparian and tidal wetlands, which attenuate overland rainfall runoff and sediment and nutrient flux.

The linkage between the biophysical properties of a landscape and the flux of materials originating from the landscape has been demonstrated empirically and in modeling studies many

times. Few studies, however, concurrently measure the biogeochemical processes needed for calculating material budgets and fewer still employ multiple comparison studies of material fluxes in coupled watershed-estuarine systems. In this study we utilize three watershed-estuarine systems with different predominant land-use/land-cover complexes to explore how estuaries operate biogeochemically under differential human impact and material loads.

Specifically, we seek to understand how estuaries process nitrogen and phosphorus, the nutrients associated with the eutrophication process, across gradients of loading from their watershed. To accomplish this, we have as our goal the construction of mass balance budgets for nitrogen and phosphorus. These mass balances account for inputs from the watershed to the estuary, processes within the estuary that serve as sinks for nutrients (e.g. the process of denitrification), and the flux of materials out of the estuary. We hypothesize that estuarine ecosystem nitrogen and phosphorus cycle process rates and the degree to which they mediate N and P flux from the estuary will be dependent on the freshwater residence times and N and P concentrations in the estuaries, both of which are regulated by nutrient loading from the watershed.

Study Sites

Three watershed-estuarine systems are being studied, the Weeks Bay, Dog River and Fowl River estuaries in southern Alabama. These three systems are adjacent to Mobile Bay and their watersheds lie entirely within the Alabama coastal plain. Using the USGS Multi-Resolution Land-Cover Characterization (MRLC) classification scheme derived from Landsat TM imagery data obtained in the early 1990s we have documented that these systems have three predominant land-use/land-cover complexes; agriculture (Weeks Bay, Alabama), urban (Dog River, Alabama), and mixed-forest (Fowl River, Alabama). Dog River, the urban system, drains a large portion of the city of Mobile, 25% of its watershed area is classified as urban, and has the highest population density and the most shoreline development. Weeks Bay, the agricultural system, has 60% of its

watershed area classified as pasture/hay and row crops. Fowl River, the mixed-forested system is 41% evergreen/mixed forest, 19% forested wetland, and 33% pasture/hay and row crops.

Methods

N loading rates from each watershed and its sub-basins are being calculated from hydrochemical data gathered at 29 locations visited approximately every 3 weeks over a 2 year period and from estimates of discharge from USGS flow gauges and a watershed hydrology model. To date, 40 sampling trips have been completed with 1118 total stations sampled. Hydrochemical data collection included analysis for NO_3 , NO_2 , NH_4^+ , dissolved and particulate organic nitrogen as well as for PO_4 , dissolved and particulate organic phosphorus, chlorophyll a, and other standard hydrographic measures such as temperature, conductivity, and oxygen concentration. These hydrochemical data are being used in conjunction with spatial data residing in a high-resolution GIS in order to determine which landscape attributes contribute the most to nitrogen loading.

N and P processing rates in the three study estuaries were determined by measuring N and P cycling processes at 18 sites (six sites per estuary) 7 times over an annual cycle. The six sites within each estuary were spaced along a riverine/estuarine salinity gradient. At each site surface and bottom waters were collected for nutrient analyses, hydrographic parameters were measured and water-column primary production, sediment denitrification, sediment ammonium and phosphate flux, and sediment oxygen consumption were measured.

Estimates of N and P flux out of the estuary will be determined by utilizing a 1-D hydrodynamic model to develop residence time calculations for each estuary under different watershed flow regimes. It is expected that residence time will largely dictate the amount of N removed by estuarine denitrification, with high residence times occurring during low flow periods and lowest residence times occurring during high intensity rain events. As much of this study was performed

during a period of severe drought along with other periods of abnormally high rainfall we have a wide range of flow regimes and residence times to evaluate in this study.

Results

We have found important differences in the magnitude of N cycling processes in these three coupled watershed-estuarine systems. The estuaries differ in several important ways, including: (1) the degree to which their coupled watershed landscapes contribute to N flux, (2) the degree of water exchange with adjacent Mobile Bay, and (3) their geomorphology. Watershed N concentrations, measured approximately twice monthly over an annual cycle at 7 sites in each watershed, were found to vary primarily in the load of nitrate, with the median concentrations in the agricultural watershed (Weeks Bay), the predominately urban watershed (Dog River), and the predominately forested watershed (Fowl River) being 75, 22, and 9 μM , respectively. Primary production rates are generally highest in the urbanized estuary, up to $5 \text{ g C m}^{-2} \text{ d}^{-1}$, and lowest in the forested system. Sediment NH_4 flux rates are highest in the estuary of the forested system, average is $0.8 \text{ mmol m}^{-2} \text{ d}^{-1}$, where sediment chlorophyll a values are also highest and lowest in the agricultural estuary, average is $0.2 \text{ mmol m}^{-2} \text{ d}^{-1}$. Sediment denitrification rates are highest in the agricultural estuary, average is $2 \text{ mmol N m}^{-2} \text{ d}^{-1}$, and lowest in the urbanized estuary, average is $0.8 \text{ mmol m}^{-2} \text{ d}^{-1}$.

These results suggest that increased loading of N to an estuary results in accelerated estuarine N processing. These differences in the magnitude of N cycling processes in the three sub-estuaries point to major differences in how these systems respond to N loading from the watershed and subsequently how well these systems serve as sinks for N. Once we have completed the calibration and validation of the 1-D hydrodynamic model it will be possible to calculate residence times for each estuary which will allow us to determine the role of estuarine ecosystems as nutrient sinks across gradients of nutrient pollution from the landscape.