Project Proposal: The effects of salt-water intrusion on the release of legacy phosphorous from coastal farmland and wetlands

Overview and Background

The rapid rates of relative sea level rise in the Chesapeake Bay region, double the global average (Ezer and Corlett 2012), present a challenge to low-lying developed lands. Coastal communities in Maryland's lower eastern shore (Dorchester, Wicomico, and Somerset Counties) are particularly affected. The intrusion of saltwater into agricultural land may have unanticipated consequences on nutrient loads, and could require adaptive management land practices by farmers in order to meet nutrient loading requirements.

Whereas N tends to move quickly into and out of agricultural systems, a portion of P inputs may accumulate at various locations along the terrestrial-aquatic continuum, such as in soils, tidal marshes, ditches, and plant biomass (Sharpley et al. 2013). Accumulated P may be remobilized years, or even decades later, acting as a persistent, but unpredictable source of P to water bodies downstream (McDowell et al. 2002). Often termed *legacy P*, this accumulated P is particularly difficult to manage because of the lag times between initial storage and remobilization (Kleinman et al. 2011). In some cases, legacy P may mask the effects of current nutrient management practices (Spears et al. 2012), and thus lead to the "failure" of water quality initiatives even after significant economic investment. My research will shed light on some of the key drivers of legacy P release in the Chesapeake Bay watershed.

In the Chesapeake Bay, there is a critical need to understand what may happen when large reserves of legacy P meet rising sea levels and saltwater intrusion. Recent studies indicate that repeated annual saltwater intrusion in agricultural land doubled the amount of ammonium-N released from soils as a result of increasing salinity (Ardón et al. 2013). Elevated sulfate concentrations in saltwater may remobilize particle-bound P though ion exchange or production of iron sulfides (Jordan et al. 2008, Hartzell and Jordan 2012, Williams et al. 2014). On the lower eastern shore of Maryland, historically high fertilizer applications (Taylor and Pionke 2000) especially in the form of P-rich poultry litter (Fisher et al. 2010), has primed the soil for P release upon saltwater intrusion. My research will combine laboratory and greenhouse experiments with historical data in order to improve my predictions of P release with sea level rise. Thus, this research will provide both Maryland farmers and key conservation groups with critical information for managing past and future P inputs to the Bay.

Benefit to Coastal Wetlands

Roughly 46% of the total land area in the Choptank River Watershed is cultivated (US EPA 2014) primarily for corn, soybean, wheat, and barley. Large areas of low-lying lands in the Choptank are particularly vulnerable to sea level rise and marsh migration. We currently lack a basic understanding of the effects of saltwater intrusion on P release from historically fertilized fields. Though generally unaccounted for in management schemes, the legacy of past land management practices can have a large effect on the sinks and sources of P in a watershed. Times of land use change, as during saltwater intrusion into freshwater farmland, are the moments when legacy P would become an important nutrient source. However, to identify and predict those times and places likely to release P, we need better understanding about influence of soil characteristics and biochemical processes on bound P. I propose to investigate the role of oxygen, sulfate, salinity, and plant species in P releases from soils in laboratory and greenhouse experiments, and to explore these connections in a large historical database of water quality. My study will provide basic biochemical models that when coupled with historical water quality and land use data will help predict critical source areas of phosphate release. Such data and models are necessary to develop targeted nutrient management practices for the Choptank River Watershed.

My research will provide much-needed data on the pace and potential consequences of salt marsh migration. Remediating water quality and controlling eutrophication are high-value ecosystem services provided by tidal marshes. As marshes encroach on farmland, agricultural runoff and nutrient rich groundwater bypass previously intervening forest, carrying higher nutrient loads to marsh plants and soils, and the estuary. In response to losing their arable land to saltwater intrusion, salt marsh migration, and invasion by the common reed *Phragmites australis* (L Fykes *personal communication*), many farmers on the lower eastern shore install levees, ditches, and tide gates to keep the marsh out. While this may be an appropriate strategy in some regions, it also has tradeoffs, such as reduced resiliency to storms and floods. The decision to retain or convert farmland should be a give and take of the vulnerability of the land to saltwater intrusion, the ecosystem services such as flood protection to be gained by marsh migration, and the anticipated nutrient release from farmland conversion. The agricultural sector in the lower eastern shore is tasked with substantially reducing its nutrient load (e.g. by more than 25% in Dorchester County; MDE 2012), and conversion of farm fields that are major sources of legacy P could severely hamper attaining these goals. My project will determine where farms and marshes are prone to be nutrient sources and where they are prone to be nutrient sinks, thereby informing targeted Best Management Practices (BMPs) across the lower eastern shore of Maryland. The proposed research sets out to describe the basic biogeochemical drivers in this complex landscape and how to support both agronomic and environmental objectives.

Measurable Objectives and Hypotheses

- Objective 1: Determine the rate of phosphate release from soils in response to different levels of legacy phosphorus, salinity, sulfate, and oxygen. ***I hypothesize that phosphate levels will be highest in anaerobic saline soils with high sulfate concentrations and lowest in aerobic freshwater soils due to differences in ion exchange.*** I will conduct a microcosm experiment to test this hypothesis.
- Objective 2: Determine the effect of plant species on phosphate release from soils in response to different levels of organic phosphorus fertilizer, and salinities. ***I hypothesize that phosphate levels will be highest in the soils growing corn under high salinity conditions and lowest in marsh plants under freshwater conditions.*** I will conduct a macrocosm greenhouse experiment to test this hypothesis.

- Objective 3: Relate experimental results to historical data on phosphorus and salinity levels and land use change in order to describe how phosphate levels increase or decrease based on increased salinity due to mean water level rise in the region. ***I hypothesize that existing historical water quality data and the results of experiments will show a clear correlation between increased salinity of the watershed and phosphate increase in the water column. This will provide an explanation for how the system has changed over time and suggest how it will continue to change with future climate and land use trends.***

Methods

Experiment 1: Soil laboratory microcosms

Microcosm experiments will be conducted to demonstrate an increase in phosphate levels under freshwater (0 ppt) and brackish (10 ppt) salinities (Obj 1; Hypoth 1). Soils will be homogenized with varying concentrations of seawater to evaluate ion exchange under either aerobic or anaerobic conditions. Sulfate addition will allow the effects of anaerobic metabolism on phosphate mobility to be assessed. Soils will be pre-mixed to contain 0, 50 or 100% of P saturation (to represent different levels of legacy P from poultry litter additions). In a factorial experimental design, each P treatment will be mixed with (1) no salt control, (2) salt only-solution, (3) sulfate-only solution, (4) salt and sulfate solution to test the individual and combined effects of salt water and accompanying sulfate on P release. I will replicate each treatment four times, for a total of 96 microcosms (2 oxygen levels x 3 P levels x 4 water treatments x 4 replicates). Soils will be collected three days prior to experimentation, and a culinary blender will be used to create the slurries for each treatment. Slurries will be stored in 500 mL Erlenmeyer flasks, sealed with either a gas-permeable membrane (aerobic) or airtight septa after purging with purified nitrogen gas (anerobic). Slurries will be mixed 5-10 times a day and 10 mL will be collected from each microcosm every two days for 28 days. Slurries will be analyzed for chloride, sulfate, and phosphate on an ion chromatograph (Metrohm Inc. per US EPA methods).

Experiment 2: Soil and plant greenhouse mesocosms

To examine the effect of plant species on nutrient dynamics (Obj 2; Hypoth 2), I will establish mesocosms into modified 5 gallon buckets which contain either a mixture of (1) marsh plants - *P. virgatum*, *S. patens*, and *P. australis*, (2) corn (*Zea Mays L.*), or (3) an unplanted control. Mesocosms will receive one of three fertilizer treatments (0, 50% average application rate and 100% average application rate) as poultry litter at two salinity levels (0 ppt, and 10 ppt for marsh plants and 0 ppt and 1 ppt for corn). Soils will be amended with urea to bring nitrogen levels up to 75 kg N ha^{-1} to avoid N limitation. Mesocosms will be replicated four times, for a total of 48 buckets (2 salinities x 2 species levels x 3 fertilizer levels x 4 replicates). Marsh plants will be grown in the University of Maryland greenhouse from seed collected at or near the field site. Four two-inch seedling plugs of each species will be transplanted into each bucket. Corn will be direct seeded into the plots 7 days after litter amendment. Small suction lysimeters (Irrometer Co.) will be installed in each bucket to 20 cm depth to collect pore water throughout the study. IRIS tubes will be installed to evaluate reducing conditions in the soils (Rabenhorst 2012). Soil solutions will be collected every 2 days throughout the study duration (5 months) and will be analyzed for chloride, sulfate, and phosphate as described above. Any replicates in which plants do not survive the first two weeks will be replaced. I will harvest and measure aboveground plant biomass at the end of the study and analyze total nitrogen and phosphorus in harvested plant tissue.

Statistical analysis
Data from the each experiment will be analyzed using a linear mixed effects model to determine the drivers of phosphate release from soils and their storage in plant tissues. I will create a predictive model to estimate the potential release of P from soils under different fertilizer, salinity, and oxygen regimes. These data will be paired with historical data below to make predictions as to the location of phosphorus "hotspots" within the Chesapeake Bay watershed.

Historical data analysis and synthesis
The Chesapeake Bay Program has publicly available water quality data dating from 1949 to present day (http://data.chesapeakebay.net/). I will use this preexisting data to identify changes in water quality parameters, specifically phosphorus and salinity, over time at Choptank River monitoring stations. I will overlay water quality trend data with land use data from Maryland Department of the Environment (http://www.mdp.state.md.us/OurWork/landUse.shtml). I expect to see phosphate levels increase as salinity increases overall, and especially in areas where farmland management practices have changed over time. Others have used the Sea Level Affecting Marshes Model (SLAMM) (https://coast.noaa.gov/digitalcoast/tools/slamm) to predict inundation and marsh migration in the absence of agricultural conversion (Shepard et al. 2014). I will use this tool to estimate worst and best case scenarios of farmland conversion and phosphate release. I will compare my empirical models from the lab and greenhouse experiments to analysis of overlapping geographical data to explore the connections between certain uses of land and water quality of adjacent bodies of surface water (Obj 3; Hypoth 3).

Dissemination of Results
I will communicate my findings to the county Soil Conservation Districts and the Maryland Department of Agriculture, who develop and implement the agricultural part of the Watershed Implementation Plans and BMPs. My characterization of nutrient retention in migrating salt marshes may show them to be valuable nutrient sinks, which could be included in a revised BMP. Alternatively, marshes may serve as a nutrient sources, which require the establishment of new practices to limit direct nutrient release into wetlands. Development of alternative BMPs that include marsh migration would reduce the responsibility on farmers and help Maryland meet Total Maximum Daily Load (TMDL) water quality targets. If nutrient pollution will result from marsh migration onto farmland, plans to meet the TMDL nutrient targets for 2017 and 2025 may need to be revised. I will also attend the 2016 ESA conference to share my findings and present my work

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