Effects of the Invasive Species *Phragmites australis* on the Biogeochemical Cycle of Silica in the Platte River, Nebraska

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A thesis submitted in partial fulfillment of the requirements for the degree of
Bachelor of Arts
(Geology)

at
GUSTAVUS ADOLPHUS COLLEGE
2011

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Under the supervision of Professor Laura Triplett

Abstract

In comparison to other major cycles such as those of carbon, nitrogen and phosphorus cycles, the silicon cycle is less well understood. In this research, we quantified the amount of biogenic silica (ASi), that *Phragmites australis* sequesters in the form of phytoliths or other siliceous particles. The biogenic ASi content in surface sediment samples for five stands of *Phragmites*, three stands of willow, and three unvegetated sandbars was taken in the Platte River, Nebraska, which is located on the Great Plains in the Midwestern United States. Our data show that *Phragmites* has a significant impact on the uptake and storage of silica in comparison to willow and unvegetated sites. *Phragmites* sequestered 18,500 tons of silica in sediment over ~18,00 acres, while comparable areas of willow or unvegetated sediments would sequester, 4,625 and 1,541 tons, respectively.

Acknowledgments

The geology department at Gustavus Adolphus College has given me many unforgettable experiences in the past four years. Firstly, I want to thank my fellow peers. They made working in the classroom a real joy, and I will never forget the long hours spent making cross-sections with them. I would also like to the Jim Welsh, Julie Bartley and Eli Goeke for providing me with a dynamic background in geology. Each class with them left me with a newfound appreciation in each field of geology. Lastly I would like to thank Laura Triplett, who was my main source of inspiration in the fields of geomorphology and hydrogeology. A good majority of this work was done side by side with her and I am very thankful. I could not have asked for a better mentor.

Table of Contents: Page

Figures and Tables

Introduction

The biogeochemical cycle of silicon is not well understood in comparison to those of other elements such as the carbon, nitrogen, and phosphorus cycles. The nitrogen and phosphorus cycles are studied because of their high discharge by human activities such as agriculture. In addition, nitrogen and phosphorus have noticeable impacts on lakes and rivers, which is a possible reason why so much attention is focused on them. Silica, on the other hand, is generally not a pollutant, so it gets relatively little attention.

Silicon(Si), the second most abundant element in earth's crust is essential for many organisms. In humans, for example, Si is found in connective tissues and bones. Other organisms such as diatoms require Si for the development of their tests. Rivers transport two main forms of silica: dissolved silica (DSi) and amorphous silica (ASi). ASi refers to any type of silica that is not dissolved or mineral silica. During the weathering of silicate minerals, ortho-silicic acid (H_4SiO_4) is dissolved in the river (Struyf et. al. 2009). Plants take up DSi in the form of H_4SiO_4 through their roots and convert it to make phytoliths. Phytoliths are structures found in plants that are made up silica, but do not share a crystalline structure like minerals such as quartz. Much like spicules in sponges, phytoliths add support to the plant structure (Folk 1978). Changes in land-use and hydrological alterations may change the supply of silica to rivers from sources of rock weathering or erosion of soil containing phytoliths. This changes the overall ratios between nitrogen, phosphorus and silicon in bodies of water, which will shift species from diatoms to non-diatoms creating a decline in ecosystem quality (Unger et. al. 2006). The silica cycle is illustrated in Figure 1 and shows the current extent of knowledge regarding its modes of transportation (Basile-Doelsch et. al. 2005).

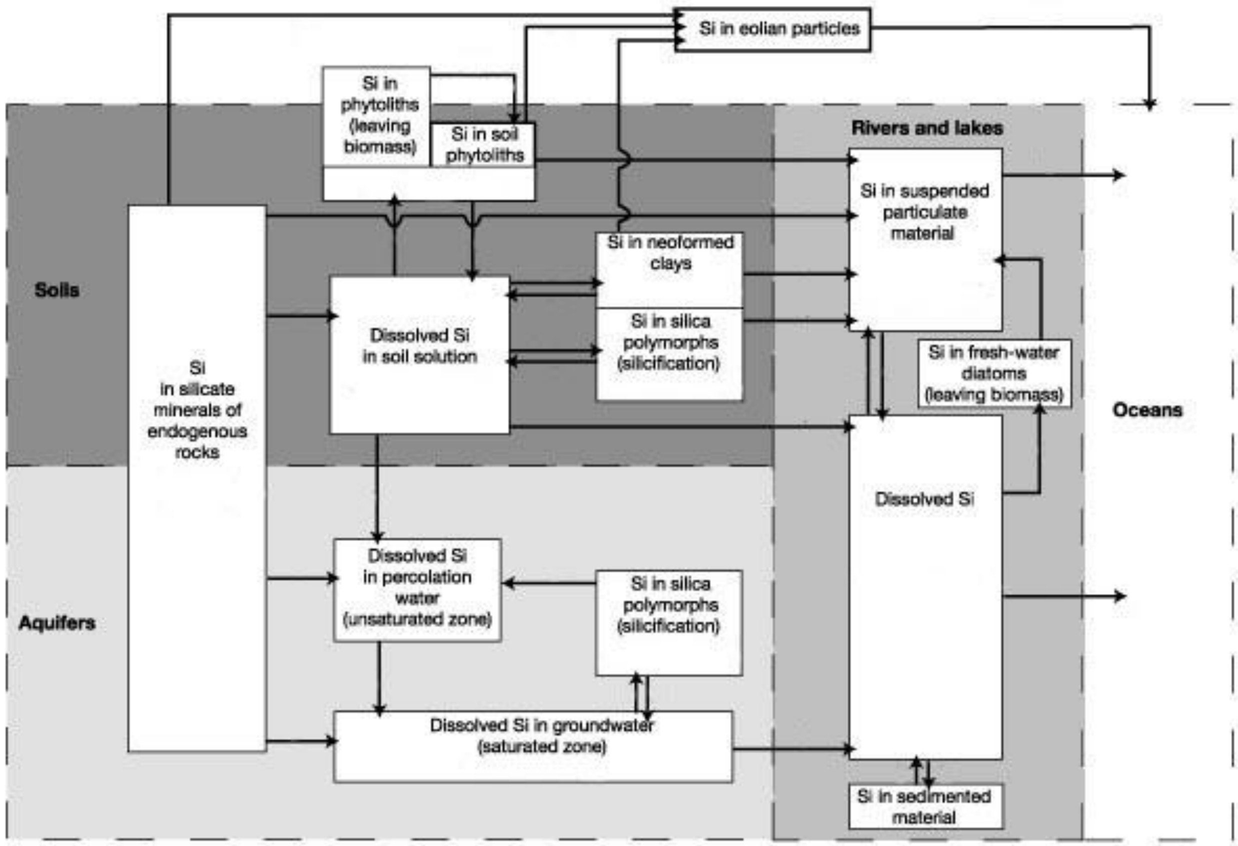

Figure 1-This diagram quantifies the amount of silicon that is transported to the ocean from lakes and rivers, which derive their silicon from soils and aquifers. This is the large picture of the silicon cycle. There are smaller ones within the transportation of silicon from terrestrial to marine environments.

One important component of the silica cycle is vegetation. Some types of vegetation like *Phragmites australi s*- an aquatic grass species native to Europe and Asia -are relatively high users of silica. A sudden introduction of this species of plant to a river ecosystem could shift the balance between silica being transported downstream and silica being sequestered in plant biomass and soils. Specifically, *Phragmites* will take up silica from the water to make phytoliths. When the vegetation dies and decays, the phytoliths may remain, stored temporarily in the sediment. This process takes dissolved silica out of its current transportation downriver. Vegetation takes more than just the dissolved silica out of transportation from a river because it also slows the velocity of the water, decreasing its carrying capacity. Phytoliths and diatoms produced upstream that have not yet dissolved will drop out of transportation and stay in the vegetated-sediment until a flow of water with a high enough velocity returns them to motion (Tal and Paola 2007).

The invasive species *Phragmites australis* has invaded areas of the Platte River that were previously unvegetated, or lightly vegetated by other species such as willow. If the invasive species *Phragmites* is acting as a temporary storage for silica, then decreases in dissolved silica will occur in downstream ecosystems. While silica is rarely a limiting nutrient in freshwater ecosystems, it is often limiting in estuarine and marine ecosystems. In this case, decreased silica transport to the Gulf of Mexico could negatively affect organisms at the bottom of the food chain there, like diatoms and radiolarian. In this research, I quantify and compare the amount of silica being sequestered in sediments colonized by *Phragmites*, willow, or left unvegetated, in order to better understand silica transport via rivers to oceans.

Geologic Setting/History

The Platte River located in central Nebraska was once a braided river, but due to water diversions, rapid channel narrowing, riparian woodland and the invasion of *Phragmites*, is now an anabranching stream (Johnson 1997). Nebraska is located in the Great Plains of the Midwestern United States (Figure 2).

Figure 2-Our study location was concentrated on a 60 mile stretch of the Platte near Kearney Nebraska.

Although flat now, mountains once occupied much of Nebraska. Only the eroded roots of metamorphic gneiss and igneous rock are left, now buried deep under sedimentary rocks. Paleozoic rocks came from the erosion of the mountains through transgression/regression cycles of seas and continental glaciers. Sediment transported by rivers coming from the newly formed Appalachian Mountains would deposit sediment to the sea's eastern shoreline, which at times was in eastern Nebraska. From 38 Ma to 2 Ma ago, sediment was deposited creating a gentle eastward slope covering 75% of Nebraska. (Maher et. al. 2003). During the Pleistocene glaciers covered the land, reshaping it and diverting rivers more to the south.

Digital elevation modeling (DEM) shows that the valley of the Platte River is well developed with a flat floodplain that has extensive drainage development. The Platte is braided due to some important factors: A relatively steep gradient, a coarse sediment load and a fluctuating discharge. Water retention in reservoirs created for flood control, power generation, water consumption and irrigation has altered the river, allowing vegetation to grow and stabilize banks, turning it into an anabranching stream (Maher et. al. 2003). A braided stream may become an anabranching stream under certain conditions; this happened to the Platte River when the flow significantly reduced. Channels became more defined, and migrating islands of sand were less often mobilized by high river discharges. The stabilization of these islands allowed for vegetation growth. Before the descendants of European settlers colonized Nebraska, the Platte was a wooded river running across prairie landscape (Boettcher 2000). Since then, rates of channel loss have been as high as 10% yr^{-1} during droughts. (Johnson 1994). This means that there is a decrease in the total number of channels on the Platte River as it goes from a free-flowing braided stream to a more stabilized anabranching stream.

Figure 3- Fig. 3a: Unvegetated section of the Platte River artificially maintained by bulldozing and herbicide application, similar in appearance the river before water diversions. Fig. 3b: Section of the Platte River now colonized by *Phragmites.*

Data from the USGS indicates that the Platte River in Louisville Nebraska has an average discharge of 158 cfs near Roscoe on the South Platte Riverand 3230 cfs near Overton Nebraska on the Platte River.

Methods and Materials

A trench shovel and a machete were used to retrieve ~30cm sediment 'cores'; a ruler was used to measure each section; a knife was used to section each core into 10cm intervals. Sediments were stored in airtight polypropylene containers (Figure 4). Eleven total sites were visited; 5 *Phragmites*, 3 willow and 3 unvegetated sites. At each site, three sediment cores were collected in order to quantify within-site variability, for a total of 33 sediment cores.

Figure 4- An example of a 30cm 'core' extraction and the dram that held one of the 10cm sections.

The top 10 centimeters of the cores were homogenized and dried at 100 deg C for 8 hours. Then, the samples were re-homogenized and stored in 15 mL polypropylene To measure Asi, .03g of sediment samples was placed in a 50-mL polypropylene centrifuge tube with 40 mL of . 5M NaOH. 1-mL aliquots of solution were extracted from the sample tubes at 15, 30, 60, and 120-minutes and put into 15 mL centrifuge tubes with 4 mL of deionized Si free water. Once the digestions were completed. 2 mL of ammonium molybdate solution, 3 mL of the sample, and 3 mL reducing solution were pipetted into each centrifuge tube. Three hours were allowed for the blue color to develop in each centrifuge tube. The samples were analyzed on the UV-visible spectrophotometer. Absorbance was measured at 812 nm. Three standards of known DSi were used to create calibration curves of $R^2 \geq 0.999$ that related absorbance and DSi. Absorbance was converted to mg/g.

The dry density of sediments was measured by performing a loss-on-ignition (LOI) adapted from Storer (1984). Sediments were heated to 100 deg C overnight, 550 deg C for four hours, and 1000 deg C for one hour. The loss in mass was measured between each step to quantify the amount of moisture in each sample and organic and carbonate content. Concentrations with dry density corrections were calculated by multiplying the concentrations (mg SiO_2 g^{-1} sediment) by the dry density of each sediment sample (g/ cm^{-3}).

ASi concentrations in sediment was converted to tons of BSi by multiplying the concentration (mg SiO2/cm^{-3}) by the depth (10 cm) by the area of Phragmites (18,641 acres mapped and sprayed with herbicide by the Nature Conservancy between 8-10 years).

Results

Sediments from the three site types (*Phragmites*, willow and unvegetated) are statistically different in terms of BSi concentration. Phragmites sites have more silica than willow sites, which in turn have more silica than unvegetated sites (Figure 5). The average BSi concentration in the *Phragmites* sediment is 2.87 mg SiO2 g^{-1}. The average BSi concentration in the willow sites is 0.52 mg SiO2 g^{-1}. The average BSi concentration in the unvegetated sites is 0.11 mg SiO2 g^{-1}. There is five and a half times more silica found in *Phragmites* sites than in willow sites, and 26 times more silica found in *Phragmites* sites than in unvegetated sites. The average BSi concentrations with dry density corrections in *Phragmites,* willow and unvegetated sites are 2.26, 0.56 and 0.18 mg SiO2 cm^{-3} sediment respectively. The average concentrations with dry density correction display similar ratios with the average concentrations without it.

Since 2002, The Nature Conservancy has mapped and sprayed 18,641 acres of *Phragmites* along the Platte River. Within that area, 18,500 tons of silica has been sequestered since *Phragmites* first became established about 8-10 years ago. In comparison, the same area had been occupied by willow or had been unvegetated, 4,625 tons and 1,541 tons of silica respectively would have been sequestered in those sediments.

Willow sites typically had a smaller organic soil layer than *Phragmites* sites. Unvegetated sites displayed no organic matter (Figure 7). Table 1 shows the numerical averages of the concentration, density and depth of organic matter (OM).

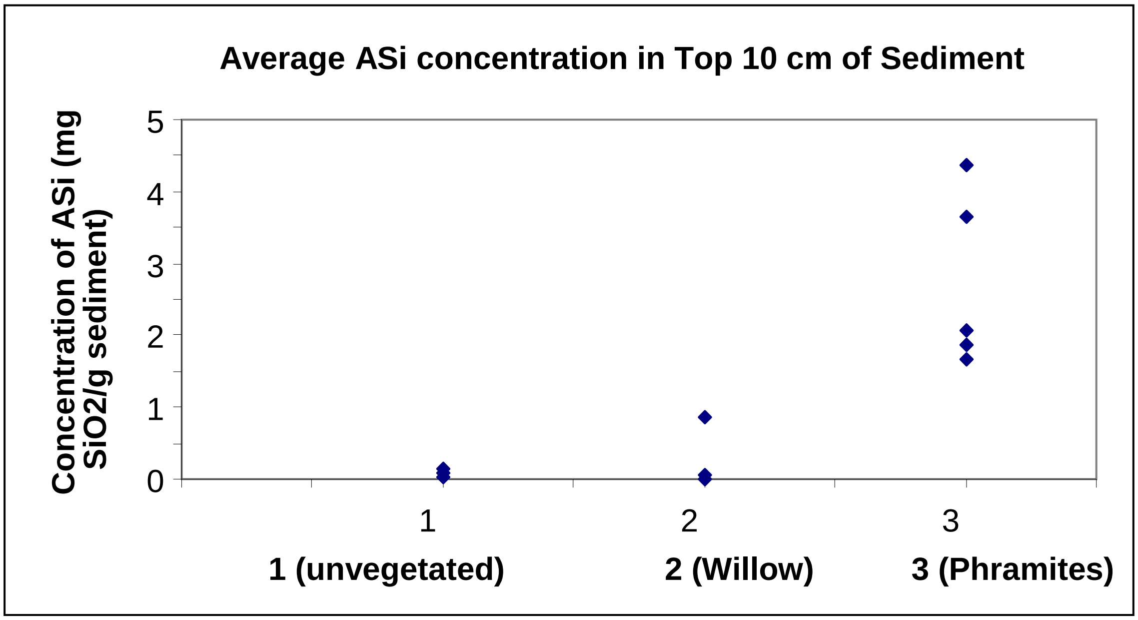

Figure 5- This table shows the average concentration of silica in the top ten centimeters of sediment. Phragmites concentrations are significantly higher than willow and unvegetated concentrations.

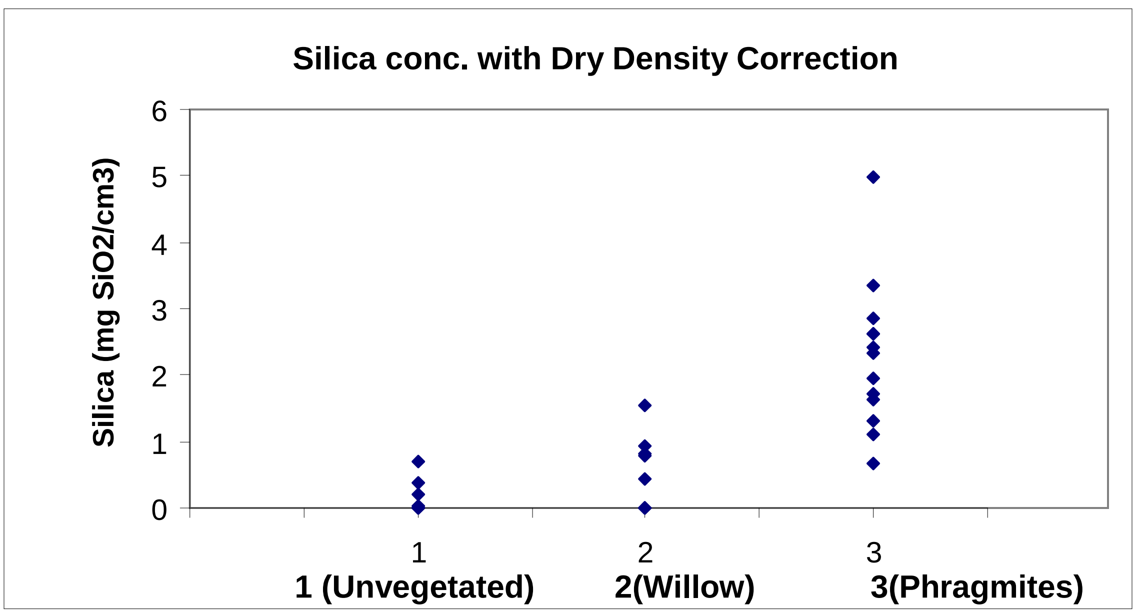

Figure 6- This table shows the average densities in the top ten centimeters of sediment. *Phragmites* sites still have significantly more silica than willow and unvegetated sites.

Site Type	Average Depth of OM (cm)	Average Concentration with Dry Density Correction (mg SiO2/cm3)	Average Concentration (SiO2/g of sediment)
Phragmites	9.4	2.26	2.87
Willow	7.55	.56	.52
Unvegetated	0	.18	.11

Table 1- Comparison of Characteristics

Discussion

In 8 years, *Phragmites* in the Platte River has sequestered 18,500 tons of ASi through a combination of phytolith production and physical trapping of the river's suspended load of ASi. To put this into perspective, it would take around 60 dump trucks to haul 18,500 tons of quartz (silica) sand. Viewed another way, during the period 1993-1995, the Platte River discharged approximately 18,000 tons of DSi yr^{-1} *(USGS 2011), so in one year, *Phragmites* sequesters about 1/8 of the river's dissolved load. All of that silica, which is a crucial nutrient for many organisms, is being prevented from flowing downstream. This is around 4 times more biogenic silica than would be stored in sediments at willow sites and around 12 times more than unvegetated sites. The amount of silica sequestered at vegetated sites as compared to unvegetated sites indicates that vegetation has a significant role in the uptake and storage of silica. Of the two types of vegetation, *Phragmites* has a much more significant impact on the uptake and storage of silica.

These masses of silica are only calculated from the sediment of each site. To get a more complete picture of silica sequestration, the amount of phytoliths stored in vegetation biomass must be taken into account. This would mean that the total amount of silica taken by *Phragmites* and willow sites would be even greater than the mass in unvegetated sites.

Struyf et. al 2005 determined that the *Phragmites* has an average concentration of 39.71 (mg SiO2 g^{-1} dry wt). The average aboveground litter mass found in *Phragmites* is around (6 kg m^{-2}) (Windham 2001). This means that the average amount of silica stored aboveground would be 0.238 (kg m^{-2}). Although the place and setting is different than the Platte River in Nebraska, Struyf and Windham's data can be used to get a hypothetical number to estimate how much silica is stored in the aboveground biomass of *Phragmites.*

In conclusion, the effect of vegetation on braided rivers is more than just an effect on the morphology of the river. Vegetation also affects the transport of nutrients transport like silica down a river. While silica sequestration by *Phragmites* in just the Platte River may not prove to have a significant impact on the Gulf of Mexico, the combination of other rivers like the Platte might add up to a significant change in nutrient availablility downstream. Our work shows that vegetation takes up a significant amount of a river's silica load, in this case, at least up to a years worth of the dissolved silica being transported by the river. These implications can be used as reference models for other similar rivers.

This research is but one piece uncovering the mechanisms of the silica cycle. We have shown that vegetation, specifically *Phragmites*, plays a significant role in the uptake and storage of silica. Knowing where silica is temporarily stored gives insight as to what happens to silica as it moves from terrestrial environments to marine environments.

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