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Analyzing Pitcher Plant Redness in Association with a Nutrient Gradient at Mud-Lake Bog

ABSTRACT

Often times, scientists simplify the nutrient cycles and availability in bogs as being "nutrient-poor." However, as more research emerges, the nutrient cycling in bogs appears to be more complicated than originally thought. The purpose of the study was to observe nutrient gradients within Mud-Lake bog and to examine the influence of available nutrients on species living in the harsh conditions. We sampled a 2800 m^2 plot at Mud-Lake bog in northern Michigan by creating transects, taking water samples at each site, and analyzing each sample for nitrate, ammonium, and phosphate concentrations. Additionally, we recorded pitcher plant (*Sarracenia* spp.) redness in order to determine if nutrient concentration has an influence on their color. The results revealed that there was no phosphate or ammonium gradient within our plot, but there was a nitrate gradient. This may be due to the presence of trees, like *Larix laricina* and *Picea mariana*, which contribute to nitrogen mineralization. The pitcher plant results indicated that there was no relationship between pitcher plant redness and any of the nutrients, suggesting that redness of pitcher plants is not a good indicator for nutrient poor areas within the bog. Wetlands have an important role in ecology, serving as a carbon sink, flood barrier, and habitat for organisms. Understanding nutrient cycles is essential to conserving and preserving bogs and other wetlands.

INTRODUCTION

Bogs represent a unique environment in Northern Michigan due to a thick layer of peat that often times isolates the bog surface community from groundwater and thus a source of nutrients. Ecologists primarily characterize bogs as being highly acidic and very nutrient-poor. A major source of acidity in the bog is sphagnum moss, which acidifies the water by releasing humic acids (Andrus 1986). Additionally, the thick layer of peat restricts groundwater flow from entering into the bogs, making rain, which is low in cations, the only source of water for the surface vegetation. This leads to low nutrient availability on the bog surface. High acidity and low nutrient availability limits the habitability of bogs for microbes, vegetation, insects, and animals (Damman 1986).

Despite low-nutrient availability, chemicals, such as nitrogen, phosphorus, and other trace elements, are more mobile in a bog than once thought. Despite an extremely low rate of decomposition, organic material does decompose and leach out elements, such as nitrogen and phosphorus. Damman (1978) suggested that a bog does not rely solely on rainwater to supply the bog vegetation with nutrients but that nitrogen, phosphorus, and potassium that are leached from the peat are recycled to the top of a sphagnum mat. He ascribes that nutrient cycles in bogs are more dynamic and complex than the simple understanding that bogs are nutrient-poor.

The nutrient availability of bogs influence the vegetation that can grow in the harsh environment. In most settings, either nitrogen or phosphorus are the limiting elements for plant growth. How successful plants are at obtaining available nitrogen and phosphorus, in the plant-usable forms of NO_3^-, NH_4^+, and PO_4^{3-}, often determine the competitiveness of the plants in an ecosystem (Iversen, Bridgham, and Kellogg 2010). A common genus that is found northern Michigan bogs are *Sarracinea*, or pitcher plants. Pitcher plants, a carnivorous plant, remain competitive in relatively nutrient-poor environments, like bogs, because they are able to supplement their nitrogen and phosphorus intake by consuming insects and absorbing their nutrients. Furthermore, intake of insect-derived nitrogen has been related to an increase in the ability of carnivorous plants to uptake nitrogen from the ground (Ellison and Gotelli 2001), making carnivorous plants a superior competitor in low-nutrient environments. Cresswell (1993) documented that pitcher plants that are red in pigmentation and larger in size were more successful at catching insects than pitcher plants that were green in color and smaller in size. Additionally, Ellison and Gotelli (2002) noted that many of the pitcher plants traits, such as the development of photosynthetic and carnivorous organs, are phenotypically plastic, meaning that depending on the environmental conditions, the pitcher plants may develop photosynthetic or carnivorous organs or some mixture of both. They also discussed that the development of carnivorous pitchers comes at a photosynthetic cost to the plant, since the carnivorous pitchers are less efficient at photosynthesis (Ellison and Gotelli 2002).

Inverness Mud-lake Bog, located in Cheboygan County, MI, represents an opportunity to better measure nutrient dynamics across a surface gradient in bogs. Mud-lake bog contains a sphagnum mat that floats on top of Mud Lake, and at the edge of the sphagnum mat on the east side of the lake, there is an area of trees, primarily *Larix larcina* and *Picea marina*, known as the "bog forest." A large field of sphagnum separates the narrow band of *Larix larcina* and *Picea marina* at the edge of the lake from the rest of the surrounding the forest. Hileman (1974) explored nutrients in Mud-lake bog and discovered that nitrogen availability was higher in the bog forest than in the surrounding sphagnum mat. However, to measure nitrogen availability, he compared nitrogen content of samples from the leaves of the large trees in the bog forest and the leaves of the sparse, smaller trees in the sphagnum mat and chose to not take water samples from the ground.

In this study, we attempted to expound on Hileman's study and explore the nutrient gradient of nitrogen and phosphorus in Mud-Lake bog by extracting water from the ground and examining its nutrient content. We expected to observe that the areas of sphagnum mat closer to the lake will have a higher nitrogen and phosphorus content than the areas in the center of the sphagnum mat because the sphagnum mat will be thinner at the edge of the lake and thus more susceptible to added nutrients from Mud-lake. As the sphagnum mat becomes thicker and more distant from Mud Lake, the nitrogen and phosphorus from Mud Lake will not be able to reach the surface of the mat and thus have less of an effect on the nutrient composition.

We also focused on the phenotypically plastic trait of the pigmentation of *Sarracinea* species. Since the normal success rate for a pitcher plant as it tries to catch insects is less than

0.1% (Newell and Nastase 1998), pitcher plants in higher nitrogen and phosphorus concentrations will be more green than red because the pitcher will allocate its resources to develop photosynthetic organs rather than carnivorous organs since it will not need to supplement its nitrogen and phosphorus intake by consuming insects.

METHODS

On the east side of Mud Lake, we marked off a 70 m by 40 m plot (fig. 1), extending from the edge of the lake to the forest surrounding the bog, in order to measure the nutrient gradient from the lake to the forest. At every 10 meters, we took water samples, pH measurements, and dissolved oxygen (DO) measurements, resulting in 40 samples total. To obtain pH and DO measurements, we pushed down the mat until there was sufficient enough water to use the pH and DO meters to take readings. In order to take water samples, we used a siphon pump to extract water from below the surface. The nutrient content of the extracted water from below the surface better represents the nutrients available to the roots of the pitcher plants than the nutrient content of the water on the surface of the mat. Furthermore, we used a fine mesh in order to filter out large organic particles from the water samples to avoid any contamination. We analyzed each water sample for phosphate, ammonium, and nitrate because these are the nitrogen- and phosphorus-based compounds that plants utilize. Using ArcGIS (Environmental Systems Research Institute, Inc., Redlands, CA), we mapped a nutrient gradient of our samples across an aerial photo of Mud-lake Bog.

In order to measure the redness of pitcher plants within the bog, at every 10 meters we took pictures of every pitcher plant found within a 1 m by 1 m quadrat. To reduce the effects of lighting on the pitcher plants, we blocked the sun and took the pictures of each pitcher plant in shadow. We uploaded these pictures to Photoshop (Adobe Systems, Inc., San Jose, CA) and analyzed the percent redness of each pitcher plant by counting the amount of red versus green pixels. We conducted a regression analysis between pitcher plant redness and nutrient availability for nitrate, ammonium, and phosphate. We also divided the 70 m by 40 m plot into four zones, in which zone 1 consisted of points at 0 m and 10 m from the lake, zone 2 consisted of points at 20 m and 30 m from the lake, zone 3 consisted of points at 40 m and 50 m from the lake, and zone 4 consisted of points at 60 m and 70 m from the lake, and conducted an ANOVA test for nitrate between each zone.

RESULTS

The pH of the bog remained relatively consistent across the entire plot. All the pH values fell between 3.21 and 4.47. Additionally, the DO measurements revealed a positive but insignificant trend from the lake to the surrounding forest (fig. 2, R^2= 0.026, p= 0.322).

The phosphate gradient (fig. 3) did not reveal any trend from the lake to the forest. A statistical regression affirmed an insignificant, negative relationship between phosphate concentrations and distance from the lake (fig. 4, R^2= 0.0097, p= 0.544). There was a noticeable trend between elevated phosphate concentrations immediately surrounding trees in the sphagnum mat (fig. 3.), but we did not gather enough data to confirm whether this relationship between trees and phosphate was significant or not.

The initial ammonium gradient (fig. 5) did not reveal any relationship between the distance from the lake and the ammonium concentrations. Similarly, the results of the regression analysis suggested no relationship between the two variables (fig. 6, R^2= 0.0136, p= 0.474).

In the nitrate gradient (fig. 7), there appeared to be an increase in nitrate as the data points were farther away from the lake. The polynomial regression analysis, which showed more significance than a linear regression analysis, revealed a significant trend between nitrate concentrations and distance from the lake (fig. 8, R^2= 0.8416, p= 0.000). At 0 m from the lake, concentrations started at a higher concentration, decreased in value slightly to 10 m from the lake, and then increased in concentration until 70 m from the lake. The follow-up ANOVA test between zones revealed a similarity between zones 1 and 2 and a significant difference between all other zones (fig. 9, F=22.304, df=28, p=0.000).

The pitcher plant redness gradient (fig. 10) did not initially reveal any relationship between distance and redness of pitcher plants. The regression between nitrate concentrations and pitcher plant redness did not suggest any correlation between the two variables (fig. 11, R^2= 0.015, p= 0.552). Further analysis of ammonium concentrations and pitcher plant redness (R^2= 0.003, p= 0.781) and phosphate concentrations and pitcher plant redness (R^2= 0.025, p= 0.327) indicates an insignificant correlation between nutrient concentrations and pitcher plant redness.

DISCUSSION

The absence of an ammonium and phosphate gradient did not support our first hypothesis. However, while we did not find a distinct gradient with ammonium and phosphate, there was an observable trend of phosphate in the bog when analyzing the ArcGIS. There appeared to be peaks of phosphate concentrations around small groups of trees in the middle of the sphagnum mat. Tyrell and Boerner (1987) observed a small increase in phosphorus levels leaching out from fallen *Picea mariana* leaves. In the bog, the areas around the small groupings of trees may have had an increase of phosphorus due to the leaching of fallen organic matter from the trees, including branches or leaves. The presence of the root of the trees also may have an effect on phosphorus levels. In pine bogs, the biomass of the roots of trees nearly double as they extend deeper below the surface, which is correlated with an increase of microorganism activity because the roots provide them with a source of carbon and nutrients for sustenance (Kellogg and Bridgahm 2002). Some microorganisms can act as decomposers in the brown web and are able to mineralize phosphorus into phosphate. Thus, the increased phosphorus concentration from leaching organic material from the trees in combination with an increase in microorganism activity explains why the presence of trees has an observable association with increased phosphate concentration.

However, among the three nutrients that we tested, the only significant gradient that we observed was a nitrate concentration gradient. This nitrate gradient supported our first hypothesis because we observe the lowest values towards the middle of the sphagnum mat. However, it does not appear that relative position to the lake is associated with a change in nutrient availability because the highest nitrate values were farthest away from the lake. Since the highest nitrate concentrations were more associated with the surrounding forest, this seems to suggest that some variable about the forest influenced nitrate concentrations. The surrounding forest was mainly composed of *Larix laricina* and *Picea mariana*. Dijkstra et. al (2009) asserted that monoculture populations of *Larix laricina* have high nitrogen mineralization rates, the rate at which organic material is converted back into plant usable forms, like nitrate and ammonium. Although the mineralization rate decreases as *Picea mariana* is introduced to a *Larix laricina* population, it appears that a community of both trees still has an effect on nitrogen mineralization rates (Dijkstra et. al 2009). The tree community of Mud-Lake bog is a mixture of both tree species, which in combination increases mineralization of nitrogen. This helps to explain why nitrate levels increase closer to the surrounding forest.

Another explanation to the nitrate gradient in Mud-Lake bog is the present of microbes. Ecologists have identified nitrifying, ammonifying, nitrogen fixing, and denitrifying bacteria that can live in the harsh conditions of the peatlands (Williams and Crawford 1983). The presence of these microbes may have a significant impact on nutrient cycling in peatlands, especially in regard to nitrogen. An increase presence of nitrifying bacteria in Mud-Lake bog that prefer forested areas of *Larix laricina* and *Picea mariana* could account for the nitrate gradient that exists there.

The results of the redness of the *Sarracinea* species in Mud-Lake bog did not support our original hypothesis. While we expected that redness of the pitcher plants to be associated with the nutrients of the bog, we did not find a significant relationship between redness and any of the nutrients. Since the color of pitcher plants is phenotypically plastic (Ellison and Gotelli 2002), these results suggest that redness is not associated with nutrient-poor areas of the bog. While some ecologists have concluded that redness affects prey capture for carnivorous plants, Joel, Juniper, and Dafni (1985) proposed that ultraviolet colors, not visible to human eyes, are what attract insects to pitcher plants. Additionally, Bennett and Ellison (2009) assert that it is nectar production, not color, that lures insects to pitcher plants. Therefore, analyzing ultraviolet material on pitcher plants or nectar production across the nutrient gradient may be a better indicator than color to recognize nutrient-poor areas in the bog.

Another explanation to the insignificant data in regards to the redness of the pitcher plants is that pitcher plants exist within a framework of biotic and abiotic conditions. Although there may be an excess of nutrients in some locations in the bog relative to others, the pitcher plants still have to compete with other plants and microbes for the excess nutrients (Chapin and Pastor 1994). Thus, if the pitcher plants are not able to uptake the excess nutrients as efficiently as other plants and microbes, the excess nutrients would have little or no effect on the morphology of the pitcher plants. Furthermore, Belyea (1996) discussed the idea that microhabitats exist within a bog. The environmental conditions, like pH or nutrient availability, of each microhabitat is based on the position of the microhabitat to the water table, the litter type found at the microhabitat, and the degree of humification of the peat (Belyea 1996). The presence of microhabitats may have contributed to a great variation of environmental conditions across the bog, a variation for which our spaced out sampling method did not account.

The nutrient cycling occurring in a bog is much more complicated than simply defining a bog as being “nutrient-poor.” Existence of observable trends within phosphate is consistent with the presence of trees, which may have an effect on microorganism communities and available nutrients in a bog. Our most significant trend, the nitrate gradient, suggested that the trees and decomposers that are able to endure the harsh conditions of the bog share a relationship that affects the cycling of nitrogen. Additionally, the lack of significance between redness of pitcher plants and other nutrients suggest that redness cannot be used to indicate low nutrient areas in a bog. Other factors, like ultraviolet colors or nectar production, may be a better indicator of low-nutrients but more study is required to come to this conclusion. The redness data could also suggest that pitcher plants are less successful at competing to uptake nutrients than other bog plants or that the existence of microhabitats across the bog are responsible for the variation in pitcher plant color. For future studies, ecologist should focus on the microbial communities of Mud-Lake bog and how that affects nutrient cycling. Furthermore, future studies could observe the presence of microhabitats and how that affects species and individual organisms by taking more precise samples across the bogs.

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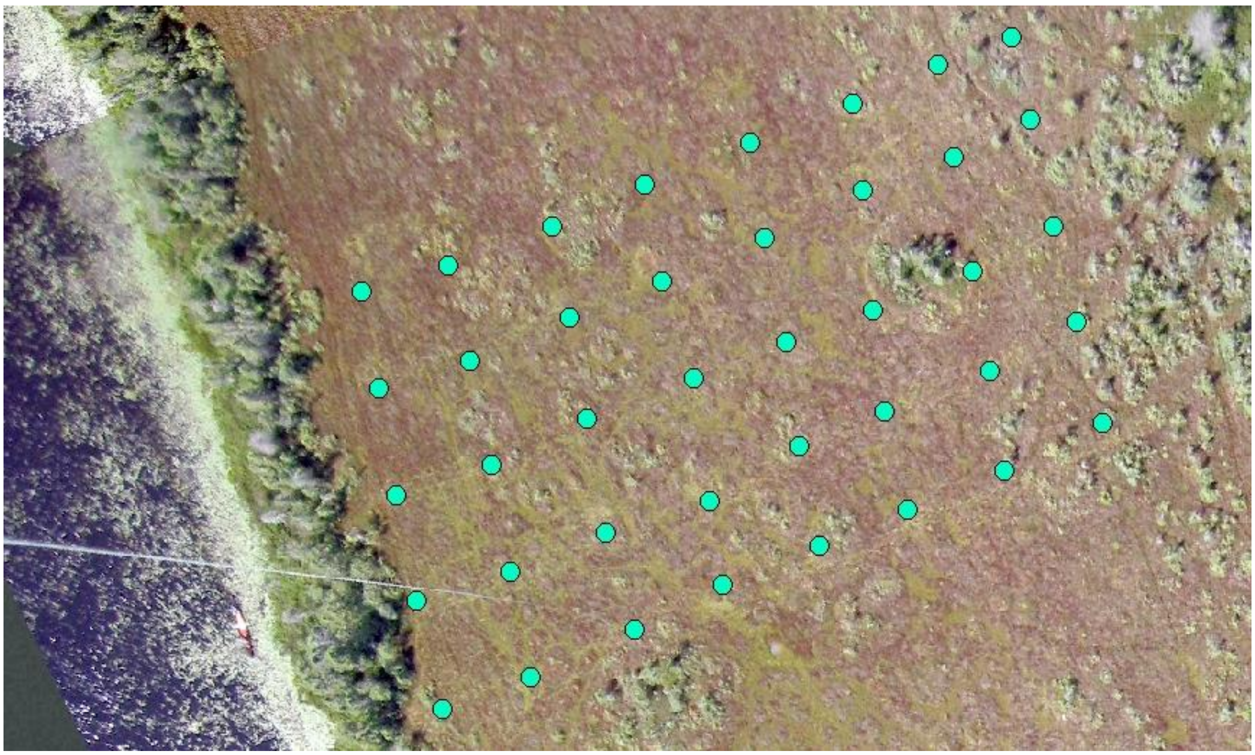

Figure 1 The 70 m x 40 m plot used in the experiment. Each dot represents the location where we placed a 1 m x 1 m quadrat

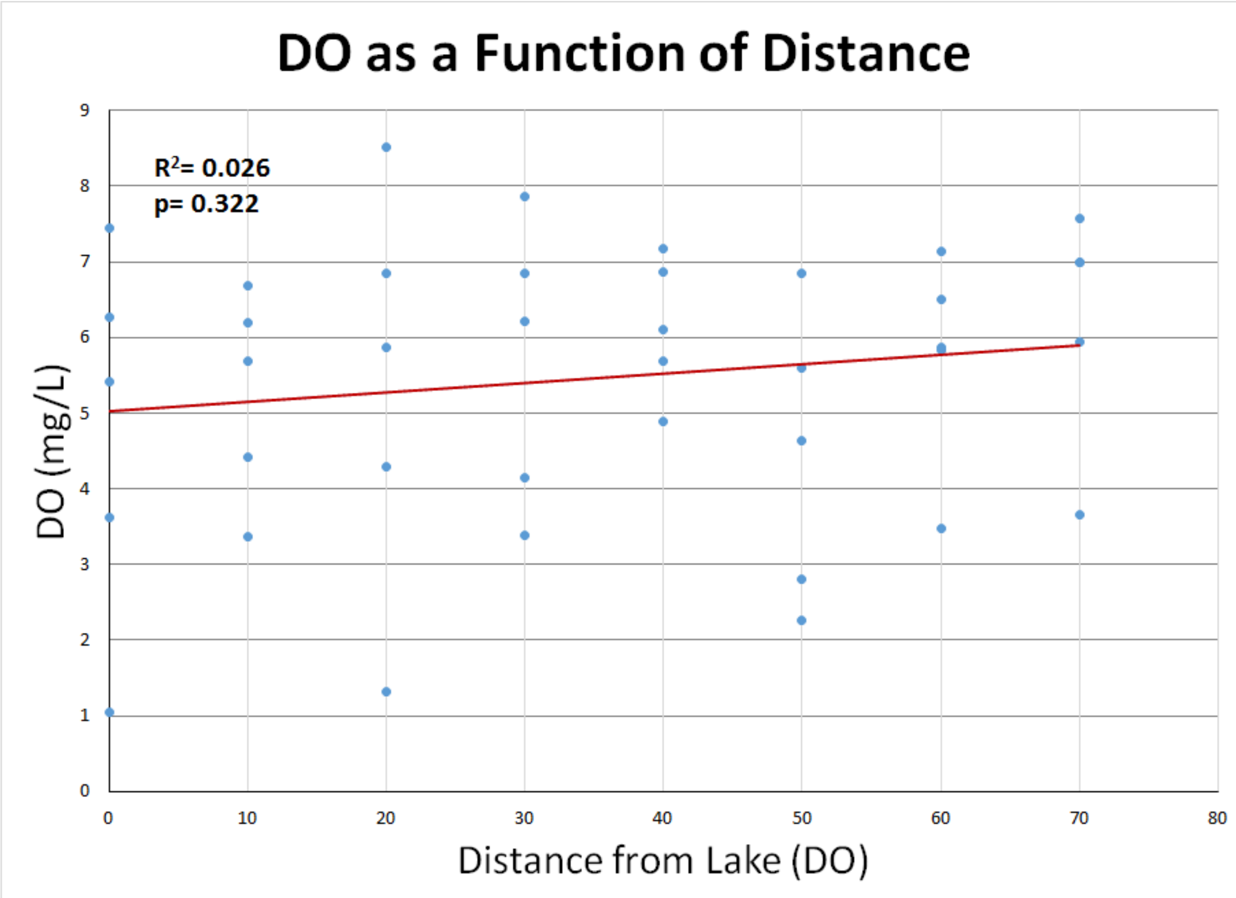

Figure 2 Dissolved oxygen concentration from the lake to 70 m beyond the lake

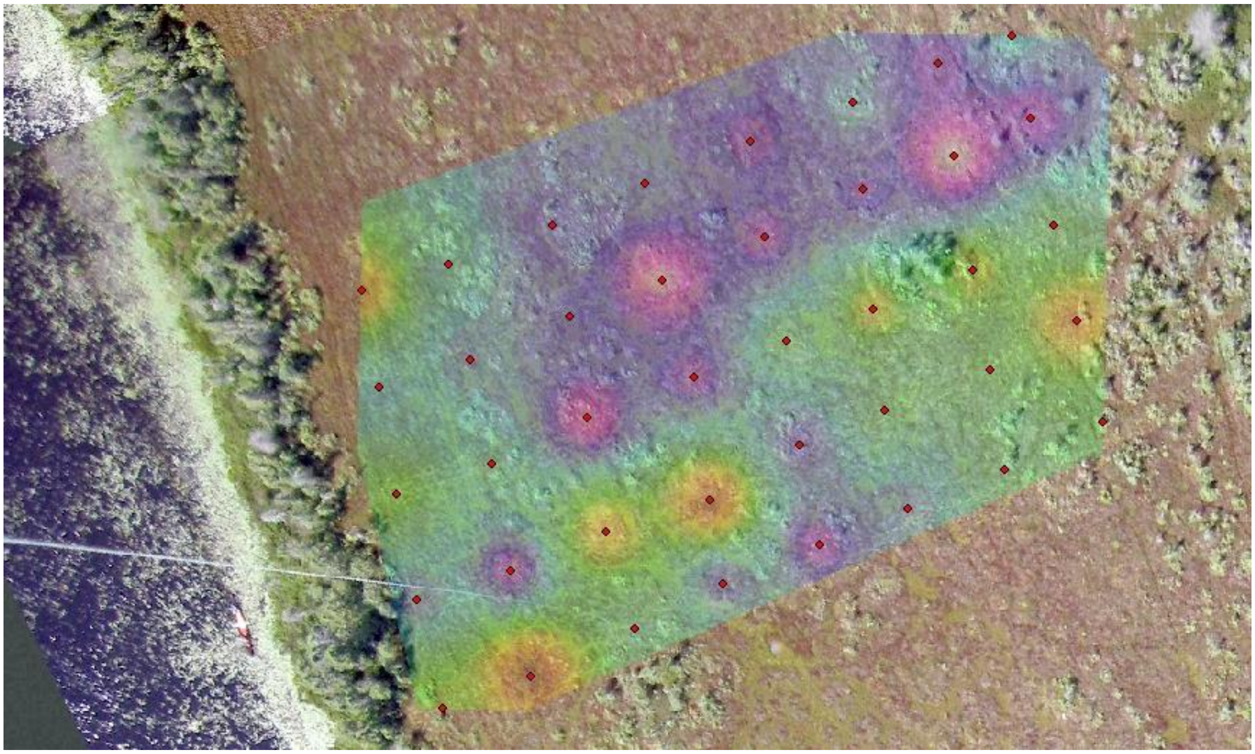

Figure 3 The phosphate gradient of the 70 m x 40 m plot. The phosphate range of concentrations extend from low values (white) to high values (dark red)

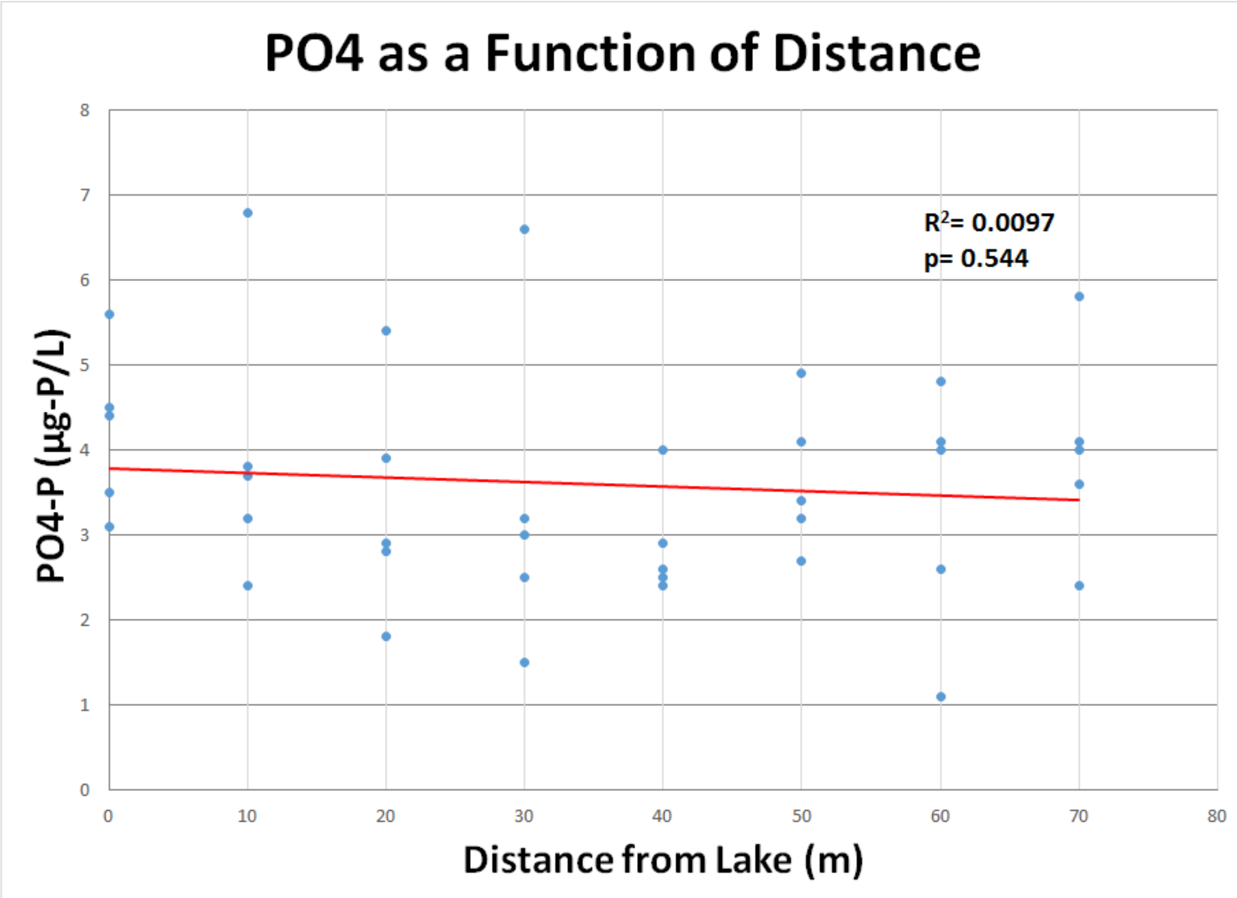

Figure 4 Phosphate concentration from the lake to 70 m beyond the lake

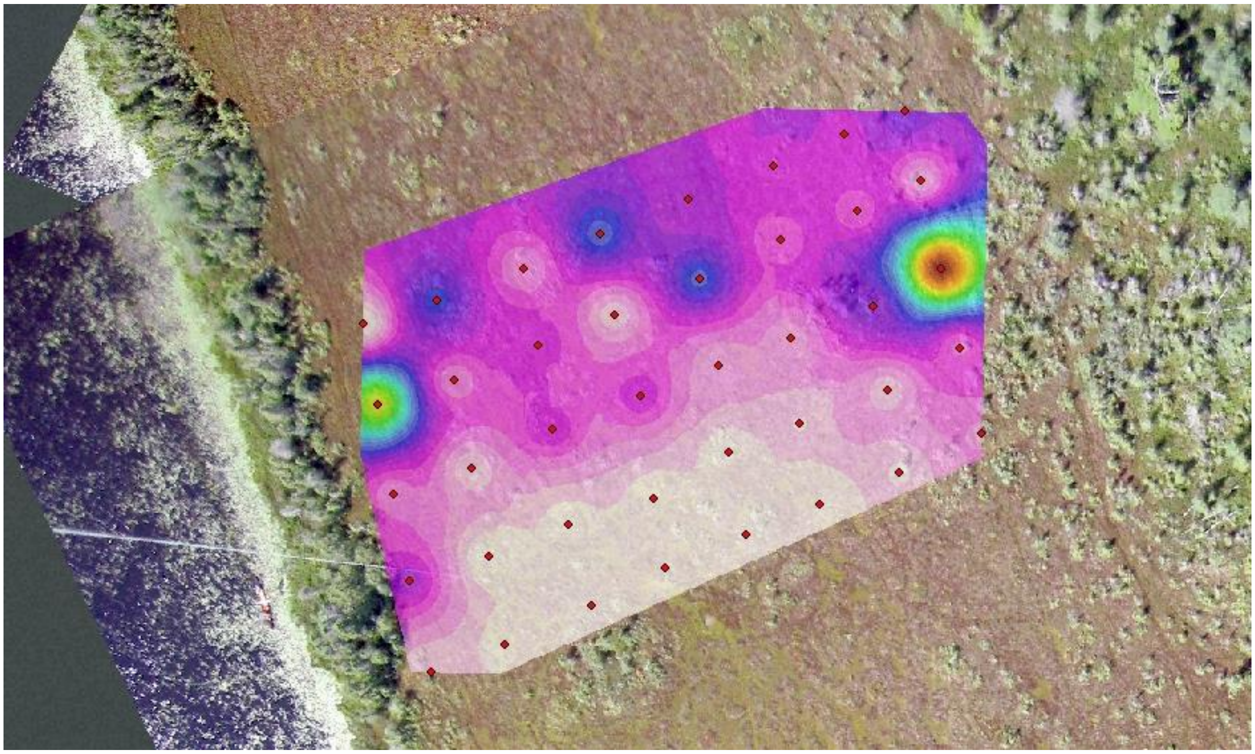

Figure 5 The ammonium gradient of the 70 m x 40 m plot. The ammonium range of concentrations extend from low values (white) to high values (dark red)

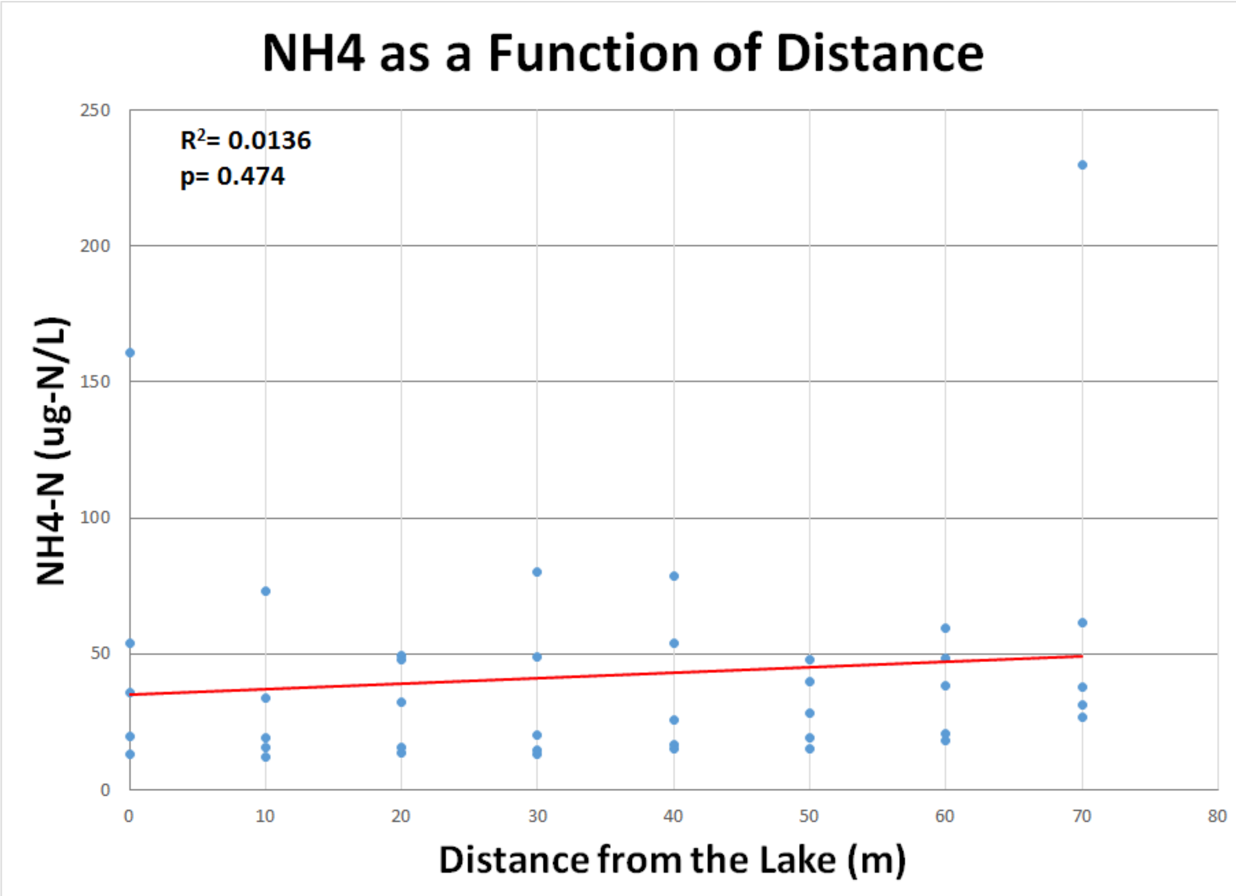

Figure 6 Ammonium concentration from the lake to 70 m beyond the lake

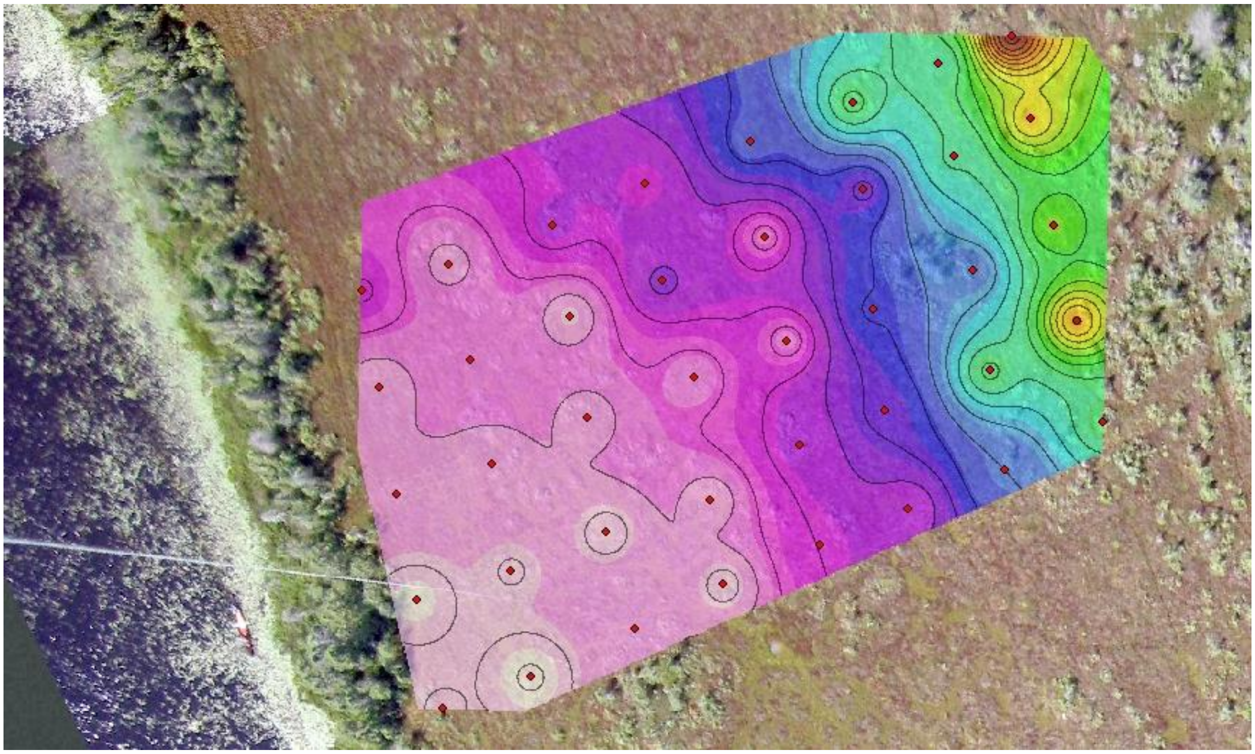

Figure 7 The nitrate gradient of the 70 m x 40 m plot. The nitrate range of concentrations extend from low values (white) to high values (dark red)

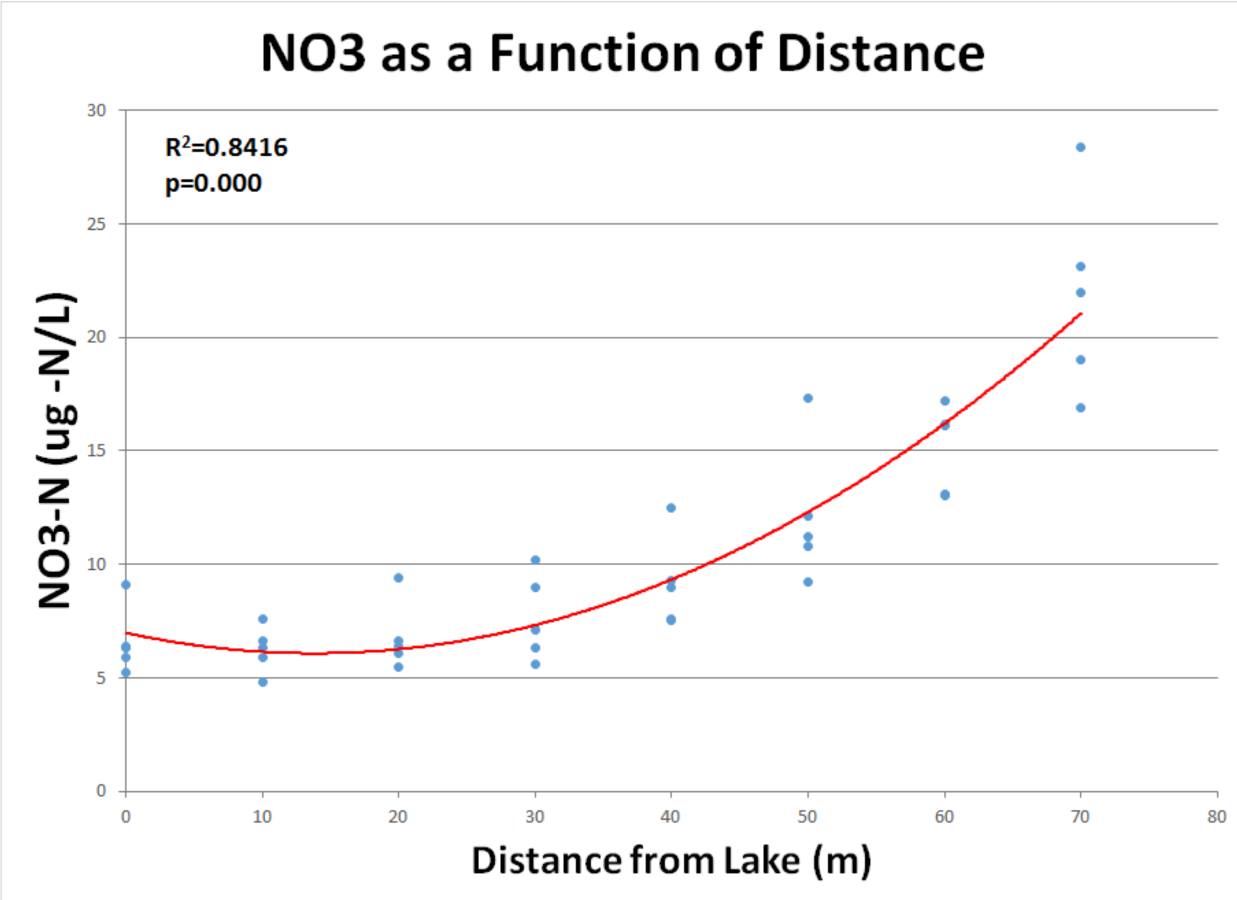

Figure 8 Nitrate concentration from the lake to 70 m beyond the lake

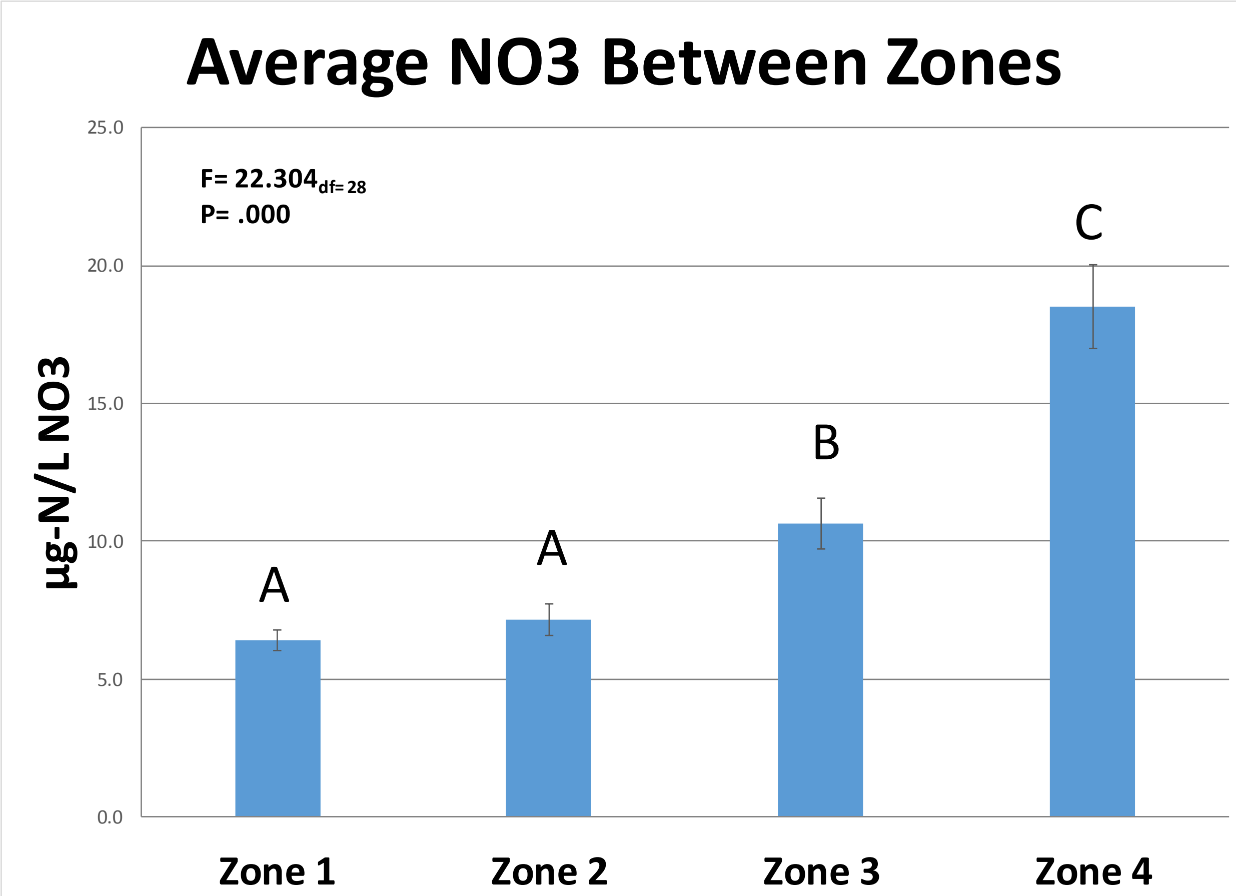

Figure 9 Average nitrate concentrations at each zone. Each zone represents every two rows from the lake, starting with the rows that are 0 m and 10 m away.

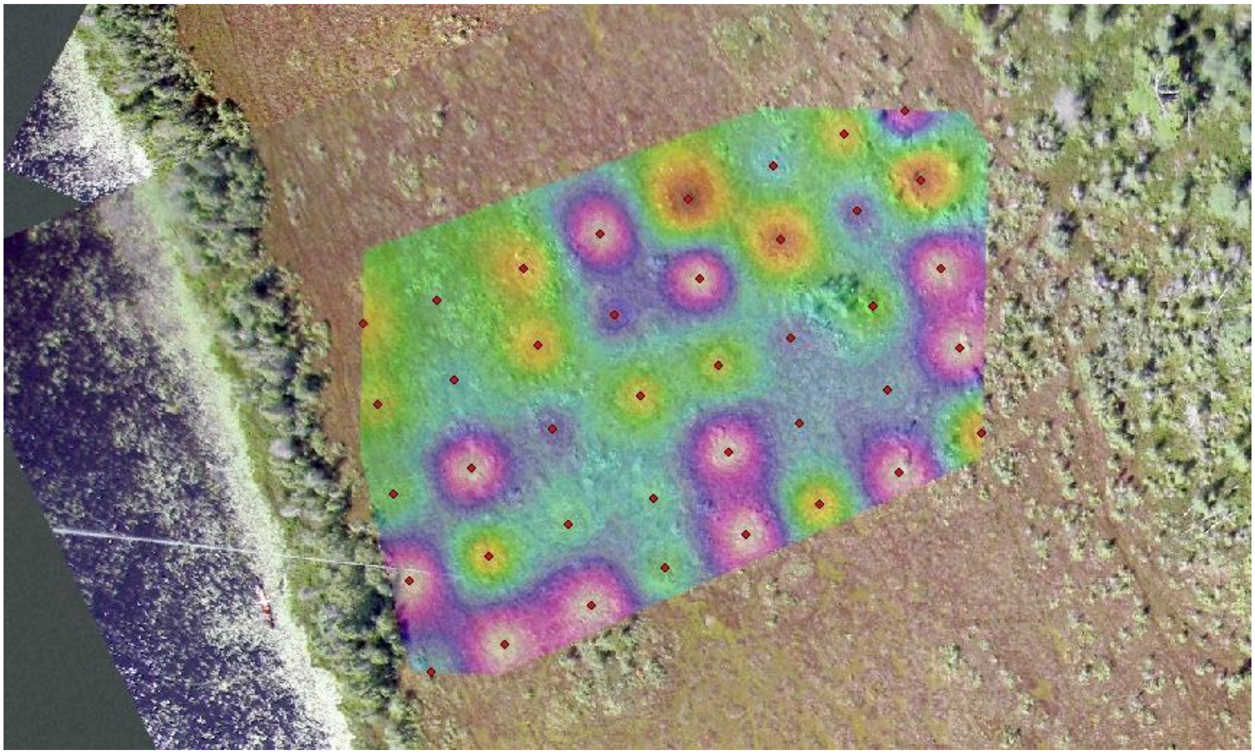

Figure 10 The pitcher plant redness gradient of the 70 m x 40 m plot. The pitcher plant redness extends from low values (white) to high values (dark red). In this map, white values represent quadrats with no pitcher plants

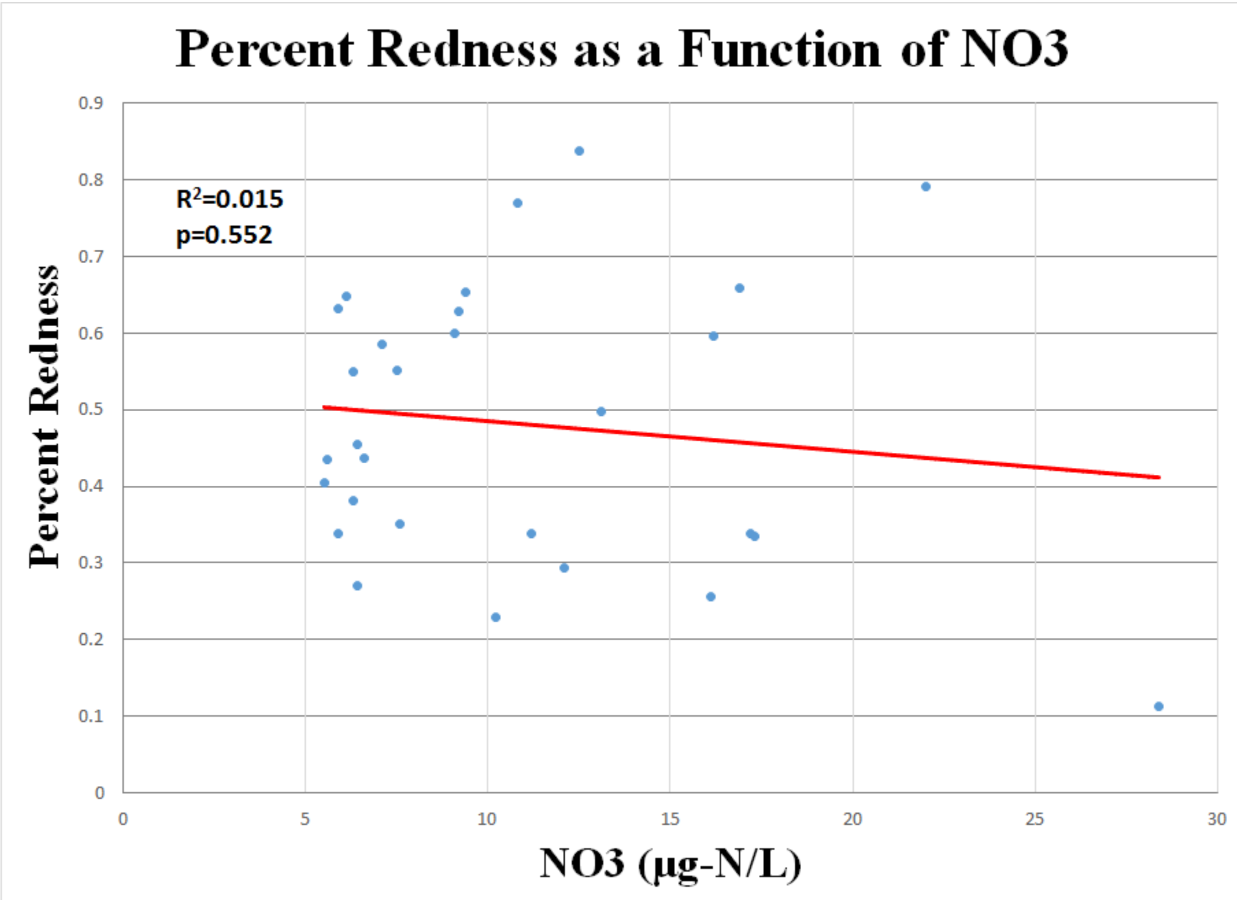

Figure 11 The percent redness of *Sarracenia* across varying nitrate concentrations