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# Nutrient Gradient within Mud Lake Bog and How that Affects the Pigment Patterns of *Sarricenia*

## ABSTRACT

The bogs in Northern Michigan are unusual ecosystems that contain a thick layer of peat that separates the surface vegetation from the nutrient-rich groundwater below it. Because of the thick layer of peat, nutrient-poor rain is the sole source of water for the surface vegetation, which allows the bog to stay nutrient-poor. In order to measure nutrient dynamics throughout bogs, we decided to investigate the Inverness Mud-lake bog, located in Cheboygan County, MI. We conducted water pH, DO, phosphate, nitrate, and ammonium abundance tests on bog water in the sphagnum mat, and analyzed the percent of pitcher plant redness across these factors as well. We found no correlation between pitcher plant redness and anything else, nor any other factor against another factor, except for nitrates, which showed a significantly positive correlation between abundance and distance from the lake.

## INTRODUCTION

The bogs in Northern Michigan are unusual ecosystems that contain a thick layer of peat that separates the surface vegetation from the nutrient-rich groundwater below it. Bogs, including the one studied, tend to be more acidic than other ecosystems, and lacking in nutrients. Within the bog, there are usually sphagnum mosses that exude humic acid which acidify the water (Andrus 1986). Because of the thick layer of peat, nutrient-poor rain is the sole source of water for the surface vegetation, which allows the bog to stay nutrient-poor. This lack of nutrients and high acidity makes it difficult for normal organisms to inhabit the bog (Damman 1986).

Despite this lack of nutrient input, the nutrient system of the bog is more complicated than once thought, with the decomposition of organisms allowing elements such as phosphorus and nitrogen to leach out of the ecosystem. In addition to that, these nutrients also cycle vertically to the top of the sphagnum mat (Daman 1978).

Most of the time nitrogen and phosphorus are the limiting factors for vegetation growth in terrestrial ecosystems. Because of this, the competitive success of bog vegetation can be seen in how efficiently the plant can take in nutrients in the plant-usable forms of $NO_3^-$, $NH_4^+$, and $PO_4^{3-}$(Iversen, Bridgham, and Kellogg 2010). One major genus that is present in the bog is the pitcher plant (*Sarracenia*). Since the pitcher plants do not receive an adequate amount of essential nutrients from the sphagnum mat, it has evolved pitcher-shaped leaves that fill with rainwater and attract and passively drown insects (*Gray* 2012). This function of carnivory makes pitcher plants a very strong competitive species in the bog because it is able to supplement its needs for nitrogen and phosphorus with nutrients derived from the organisms it consumes. In addition to that, Ellison and Gotelli (2001) showed that the pitcher plants' 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 also documented that many of the pitcher plants' traits exhibit a fair amount of phenotypic plasticity, such as photosynthetic/carnivorous organ development. The presence of this plasticity implies that the development of these organs is under the influence of environmental conditions. This could be seen as pitcher plants showing more efficiency in one activity over the other, with increased specialization of carnivory coming with a decrease in photosynthetic efficiency (Ellison and Gotelli 2012).

In order to measure nutrient dynamics throughout bogs, we decided to investigate the Inverness Mud-lake bog, located in Cheboygan County, MI. At the eastern edges of the bog there is bog-forest composed primarily of *Larix larcina* and *Picea marina*. Moving westward from there, Mud-lake bog has a large mat of sphagnum that goes from the primary treeline to a thin, secondary treeline, and out onto Mud Lake. Previous investigation done at Mud-lake bog by Hileman (1974) on nutrient availability was conducted on the nitrogen content of leaf samples of the large trees in the bog-forest and of the sparse, smaller trees in the sphagnum mat, and not of the water of the mat. In our investigation, we continued Hileman's study into the nutrients of Mud-lake bog by investigating the nutrient availability of nitrogen & phosphorus and water chemistry across the sphagnum mat. We predicted that there would be a negative correlation between distance from the lake and nutrient availability because the sphagnum mat will be thinner at the edge of the lake, making the water in the mat more subject to nutrient input from the lake. We predicted that the nutrients would decrease going east from the lake because the mat will become thicker and limit nutrient flow from the lake.

Another aspect of our investigation was how the water variation across the bog affects the phenotypic plasticity of *Sarracinea* pigmentation. Since the normal success rate for a pitcher plant as it tries to catch insects is less than 0.1% (Newell and Nastase 1998), we predicted that pitcher plants in higher nitrogen and phosphorus concentrations will be more green than red because the pitcher plant will be more focused on photosynthesis than carnivory.

## METHODS

To establish an area to conduct investigation, we created a 70 x 40 m transect in the eastern side of Mud-lake bog (fig. 1). We did this in order to cover an area from treeline to treeline, which is where we hypothesized the gradient to exist. At ten-m intervals, we collected water samples, recorded water pH and dissolved oxygen (DO), and photographed each pitcher plant within a 1 x 1 m quadrat. This resulted in a total of 40 sampling points in the transect. Because there isn't much standing water in the sphagnum mat of Mud-lake bog, we pushed down the mat until there was sufficient enough water to use the pH and DO m to take readings. To collect the water samples we used a siphon pump and a fine, mesh filter to extract water from below the surface of the sphagnum mat without collecting large organic particles in order to avoid any contamination of the samples. We did this because the nutrient content of the extracted water 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 due to the nutrient-blocking properties of the mat. We analyzed each water sample for phosphate, ammonium, and nitrate, the nitrogen- and phosphorus-based compounds that plants utilize. Using ArcGIS (Environmental Systems Research Institute, Inc., Redlands, CA), we input this data in order to visualize a nutrient gradient of our samples across an aerial photo of Mud-lake Bog.

In order to measure the redness of the pitcher plants, we photographed each pitcher plant within a 1 x 1 m quadrat with a high-definition camera. We blocked out the light in each of the photos in order to reduce the effects of light variability. We then used Photoshop (Adobe Systems, Inc., San Jose, CA) to analyze the percent redness of each pitcher plant by comparing the amount of red pixels versus green pixels. After that, we conducted a regression analysis between pitcher plant redness and nutrient availability for nitrate, ammonium, and phosphate. Finally, we divided our transect into four equally-sized zones going from the lake to the tree line. Zone 1 consisted of the sites from 0 - 10 m from the lake, zone 2 of the points 20 - 30 m away, zone 3 of the points at 40 - 50 m from the lake, and zone 4 of points 60 - 70 m from the lake, and conducted an ANOVA test for nitrate between each zone.

## RESULTS

The bog's pH was pretty consistent throughout the entire transect, ranging from 3.21 to 4.47. The DO of the bog had a positive but insignificant trend going from the lake to the forest (fig. 11, $p = .322$, $R^2 = .026$).

The phosphate measurements (fig. 2) did not have any trend from lake to forest, the results of a statistical regression (fig. 3) produced an insignificant, negative relationship between phosphate concentrations and distance from the lake (p = .544, $R^2$ = .0097). The ammonium measurements (fig. 4) did not contain any correlation between the distance from the lake and the ammonium concentrations. Mirroring that, the results of the regression analysis (fig. 5) produced no relationship between the two variables (p = .474, $R^2$ = .0136,).

The nitrate gradient (fig. 6) showed a positive correlation between nitrate and increasing distance from the lake. The polynomial regression analysis (fig. 7), which resulted in a higher significance than our linear regression analysis, produced a significant trend between these two factors (p = >.001 $R^2$ = .8416). 0 m from the lake, concentrations started higher, decreased slightly at 10 m from the lake, but then increased in concentration for the rest of the transect. The ANOVA test of each zone's nitrates (fig. 8) produced a similarity between zones 1 and 2, and a significant difference between all other zones (p = >.001, F = 22.304, df = 28,).

Pitcher plant redness (fig. 9) did not have any correlation between redness and distance from the lake. The regression we ran between nitrate concentrations and pitcher plant redness (fig. 11) did not correlate between percent redness and nitrate levels. When regressed against all other nutrient levels, there still was no correlation between redness and other chemical factors measured (Ammonium: p = .781, $R^2$ = .003; Phosphate: p =.553 $R^2$ = .013; DO: p = .847, $R^2$ = .001).

## DISCUSSION

Despite the lack of correlation between phosphate abundance and distance from lake, there were still a few visible hotspots in the ArcGIS map. When we visualized this occurrence overlaid on top of the aerial map of the sphagnum mat, we were able to see that these hotspots occurred on the occasional tree or tree stand scattered throughout the bog, suggesting that the presence of tree communities correlates with a rise in phosphate abundance. This, coupled with the knowledge that fallen *Picea* leaves leach small amounts of phosphate into the ground (Tyrell and Boerner 1987), could explain this correlation. Further investigation into this correlation in the context of the Mud-lake bog could be conducted to expound on the relationship between these trees and the bog.

Furthermore, it has been shown that as trees grow in the bog, their root biomass greatly increased as they expanded deeper into the soil (Kellogg and Bridgahm 2002), providing organic material for microorganismal communities. As the trees die, the microorganisms then mineralize the phosphorus stored in the roots of the tree into phosphate that is found in the soil. Because of this occurrence, it could be inferred that the roots of the trees could also be to blame for the phosphate hotspots.

The nitrate gradient that we observed could be caused in part by the tree community of the bog-forest. Peat-land bacteria have also been found, and could play some role in the nitrate gradient due to their ammonifying, denitrifying, and nitrogen fixing properties (Williams and Crawford 1983). Dijkstra et al. (2009) found that when *Larix laricina* was growing by itself, ground in its immediate vicinity experienced a high nitrogen mineralization rate, but when the *L. laricina* is growing together with *Picea mariana*, the sites have low nitrogen mineralization rates. Since both species of trees were present throughout the bog, it could be hypothesized that if a high proportion of *Larix laricina* were found near the high-nitrate values of the bog-forest, and a mixed proportion of both species near the low-nitrate levels of the lake, that the nitrate gradient correlates with the distribution of trees. Further research could be done examining the tree community composition at the lake side and the bog-forest side of the sphagnum mat.

Since our data does not imply any significant relationships between *Sarricenia* pigmentation and nutrient values, we investigated some other potential possibilities for what may affect the pitcher pigmentation. It has been suggested that, like other species of vegetation, *Sarricenia* may attract insects via ultraviolet radiation, rather than the visible light spectrum (Joel, Juniper, Dafni, 1985). This implies that the visible color of the *Sarricenia* pitchers does not relate to nutrients because they compensate for low soil nutrient availability using methods other than visible light. Bennett and Ellison (2009) also advocated that *Sarricinea* attracts insect prey through their nectar production. This would produce the same conclusion that because the visible light spectrum is not involved in attracting prey the visible light spectrum is not related to nutrient availability.

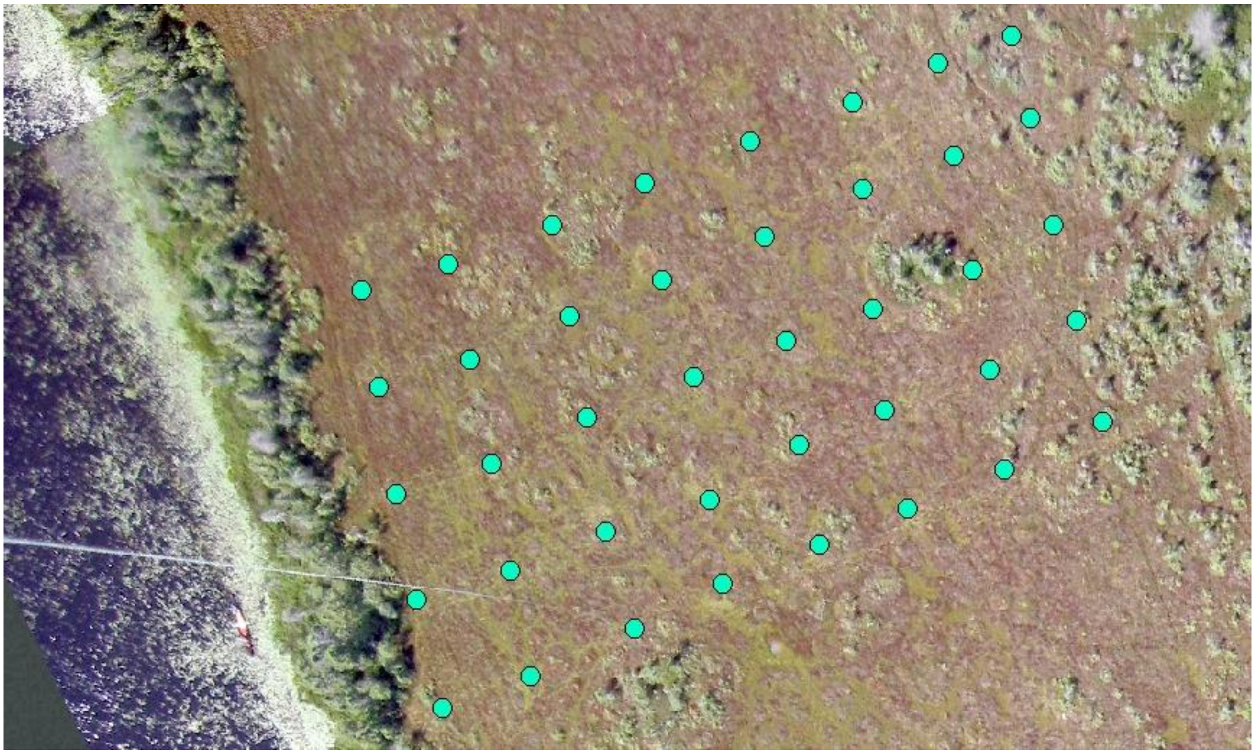

Figure 1, an aerial view of the transect in Mud-lake bog marked with all sampling sites

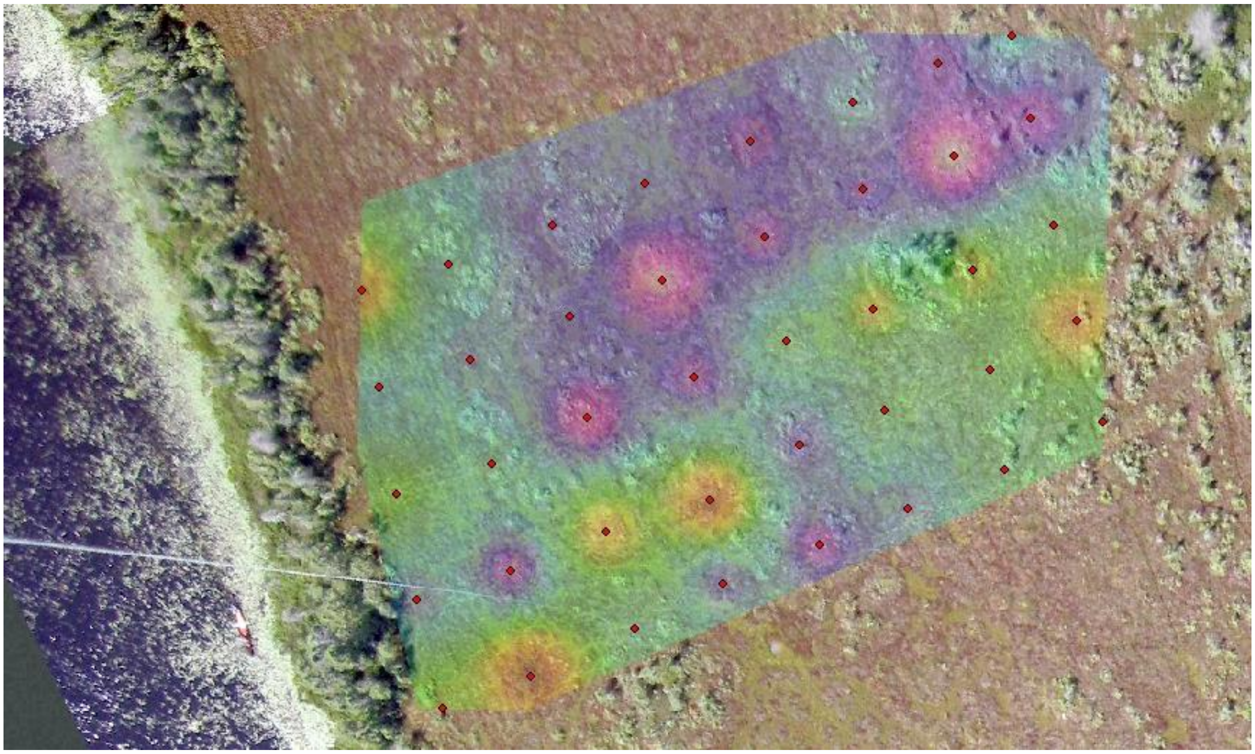

Figure 2, a heat map of phosphate across Mud-lake bog

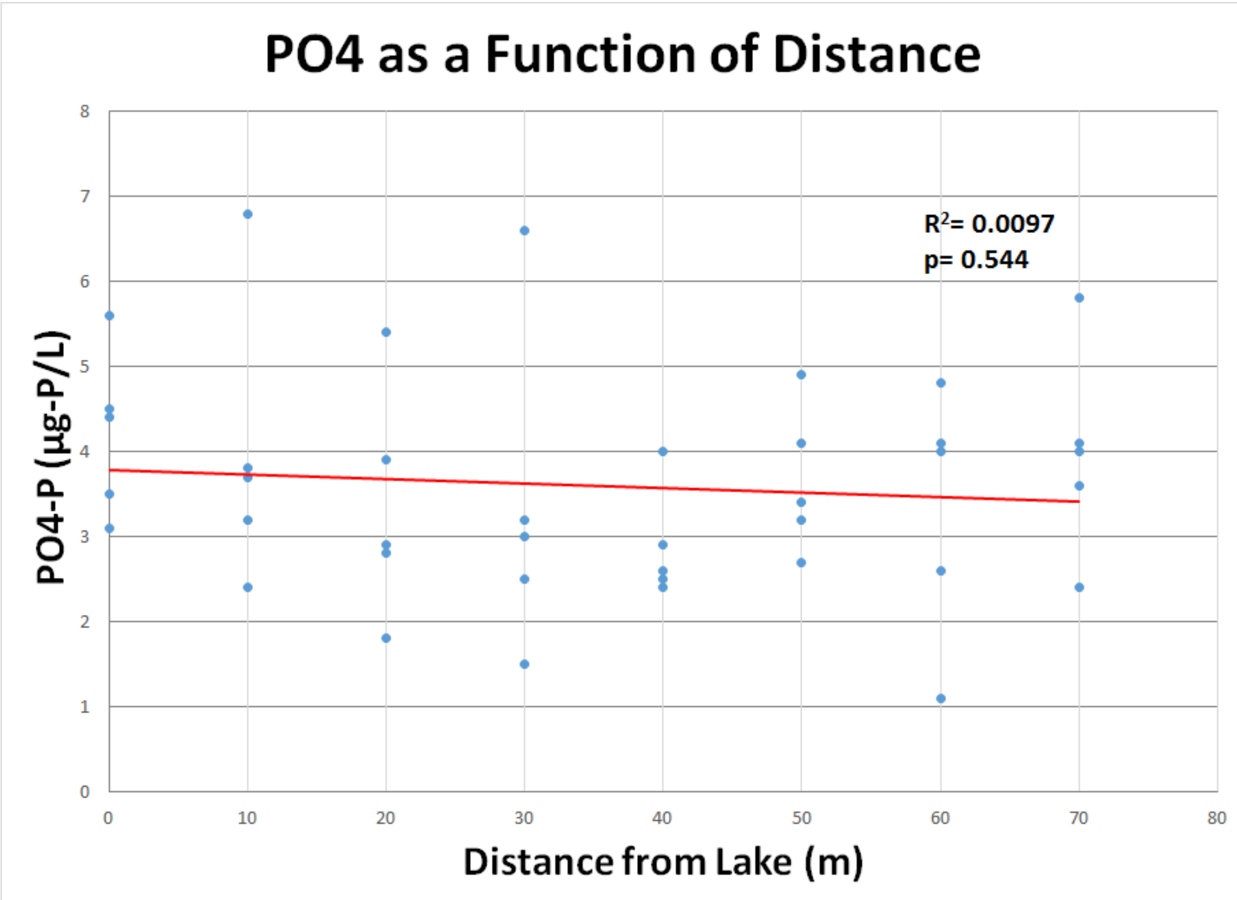


Figure 3, a regression of phosphates against lake distance

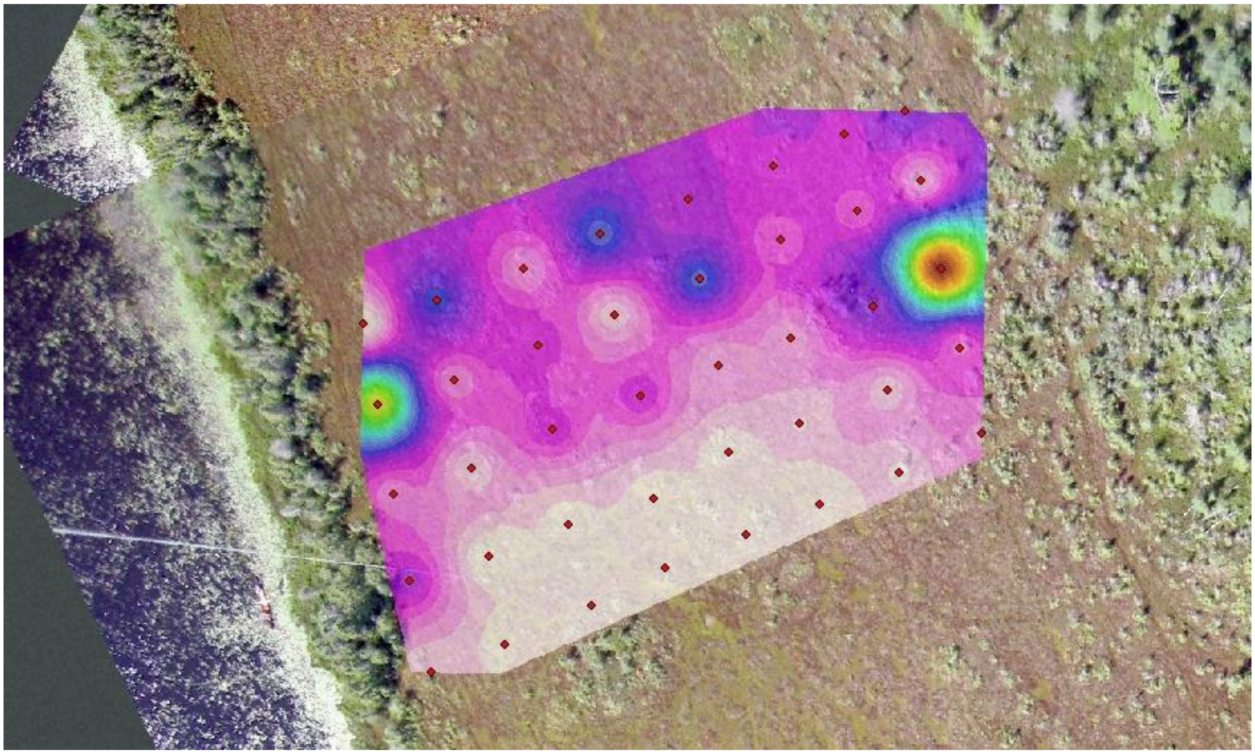

Figure 4, a heat map of ammonium across Mud-lake bog

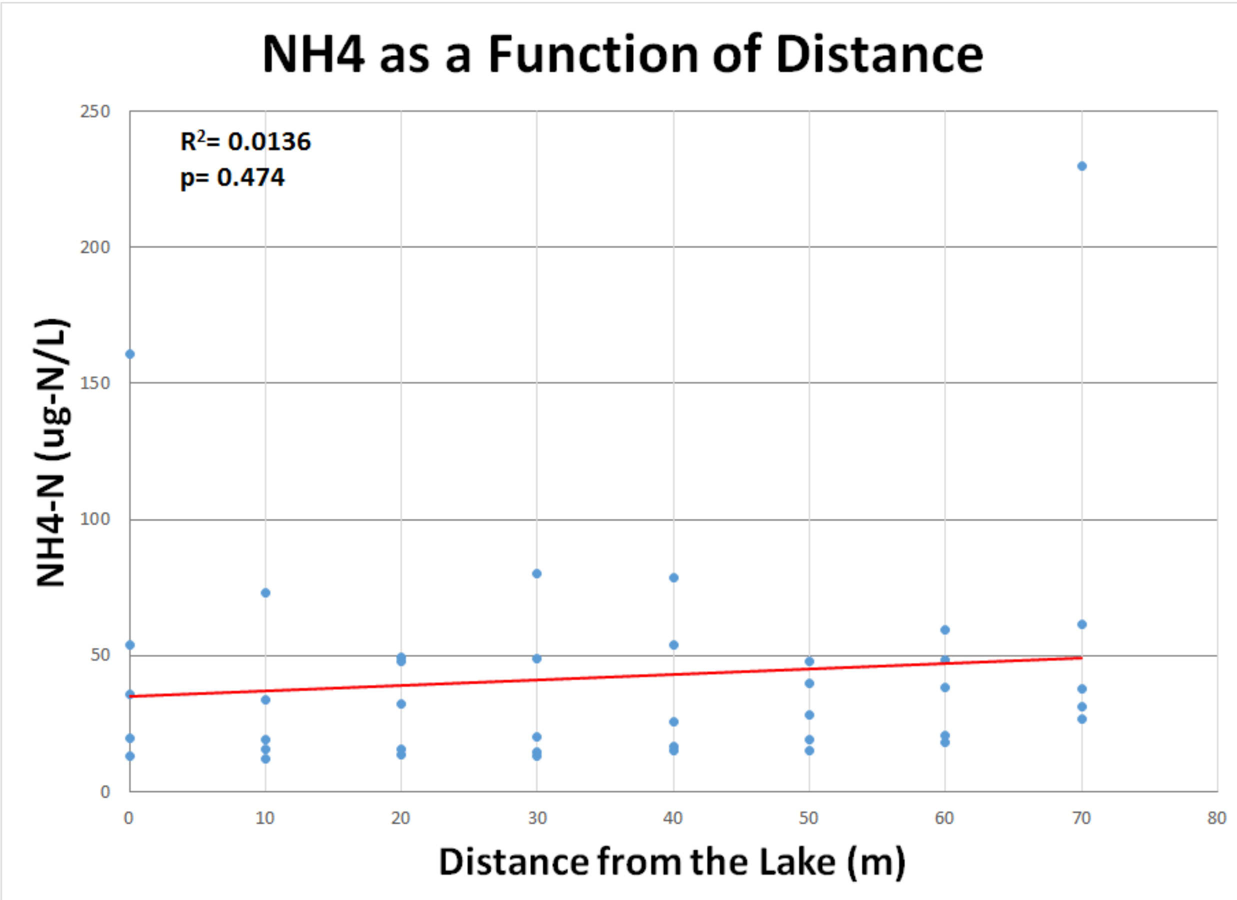


Figure 5, a regression of ammonium against lake distance

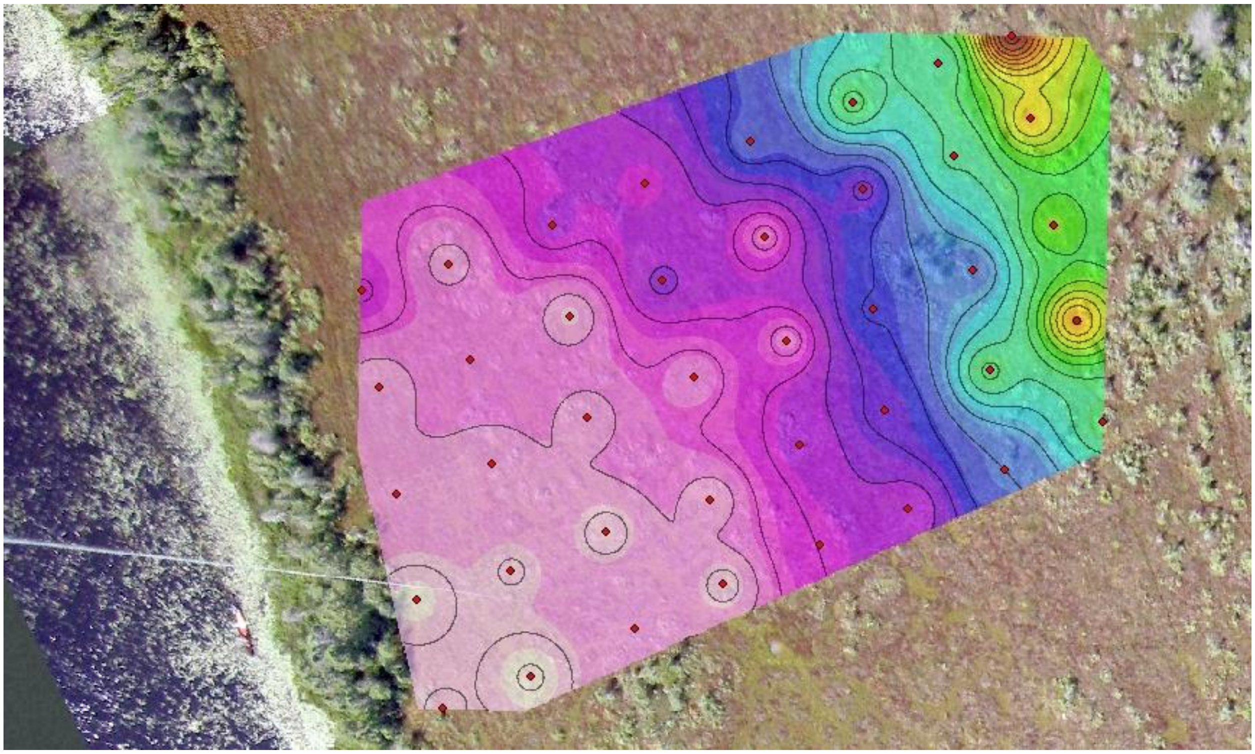

Figure 6, a heat map of nitrate across Mud-lake bog

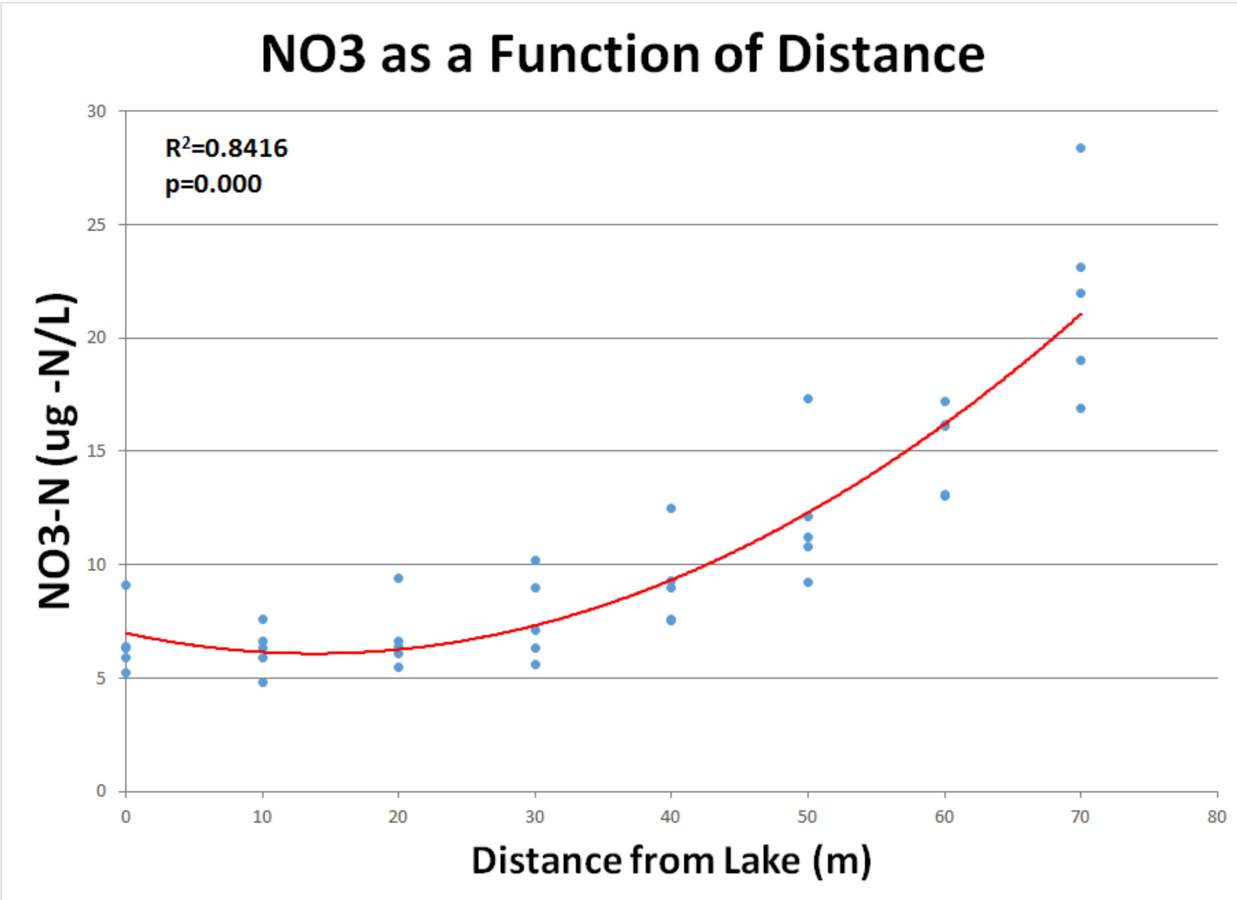


Figure 7, a regression of nitrates against lake distance

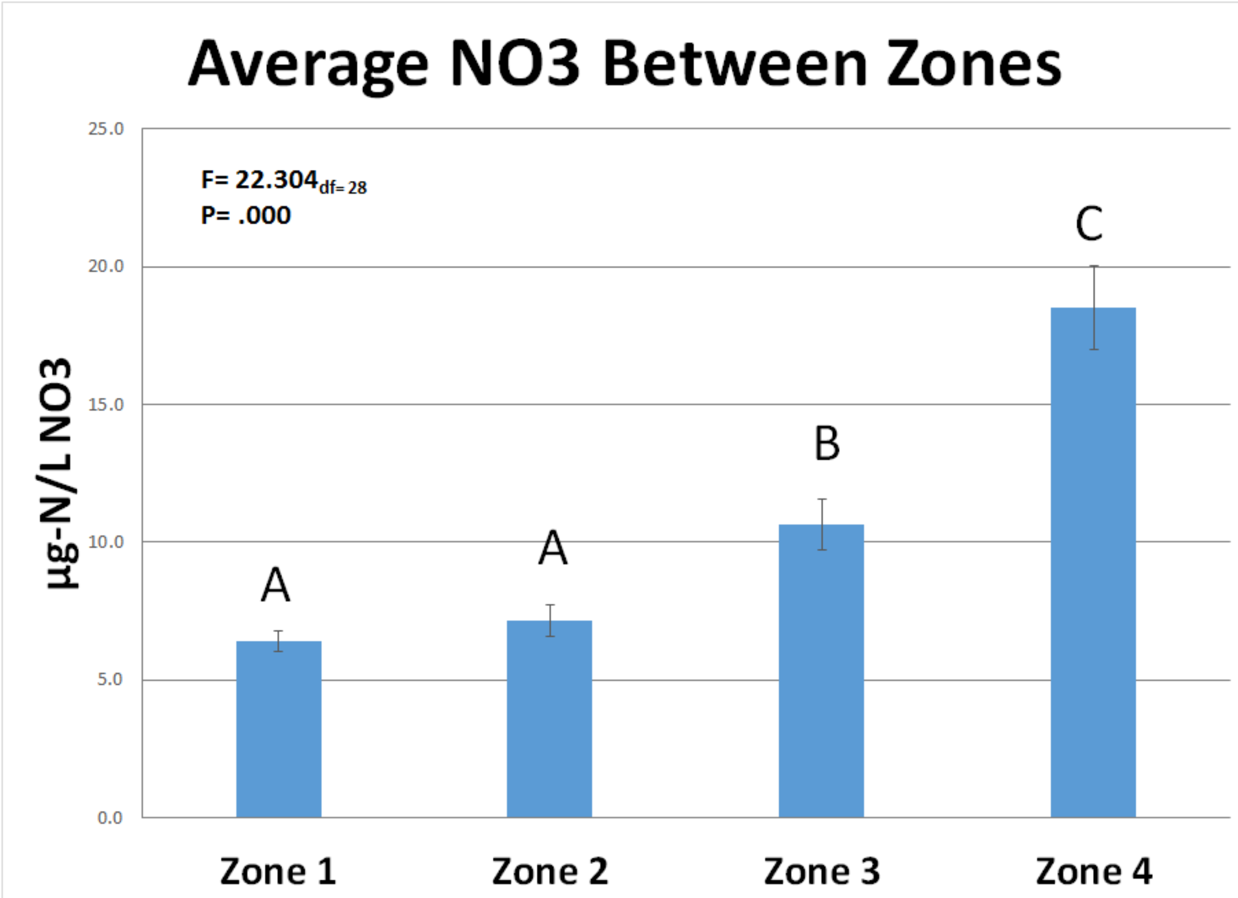


Figure 8, an ANOVA of nitrate across the four zones

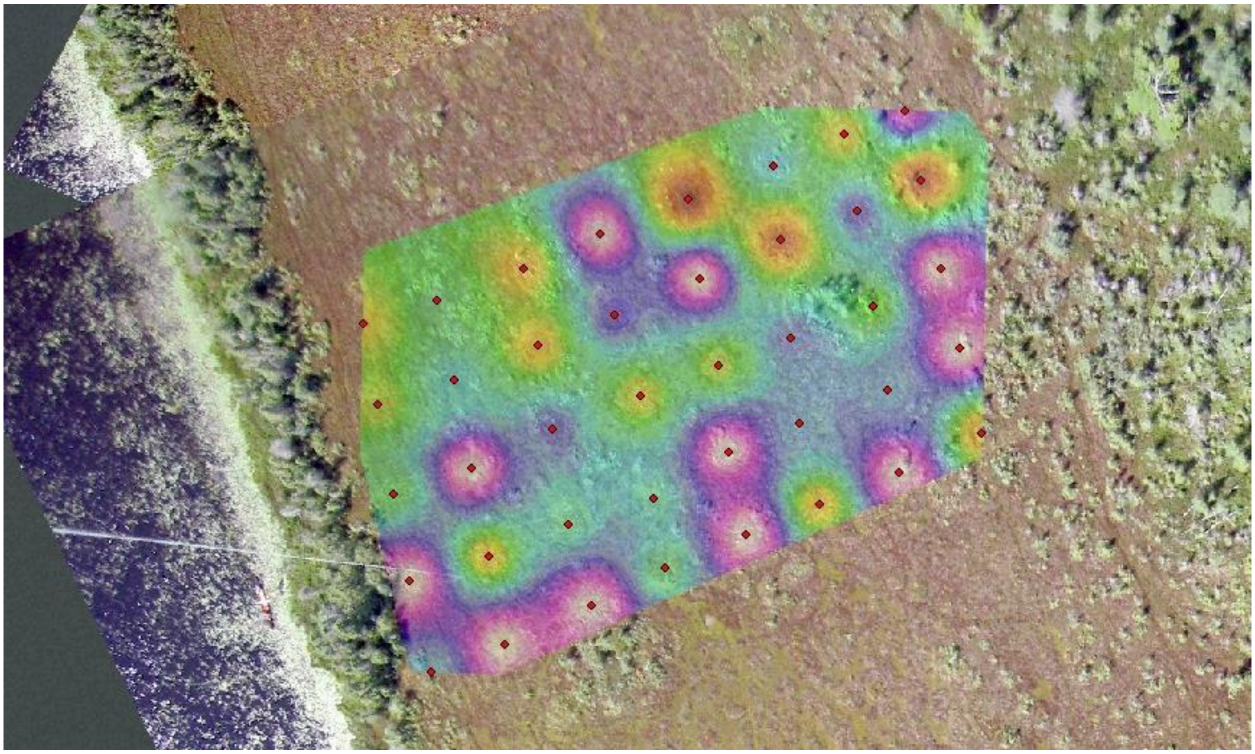

Figure 9, a heat map of pitcher plant redness across Mud-lake bog

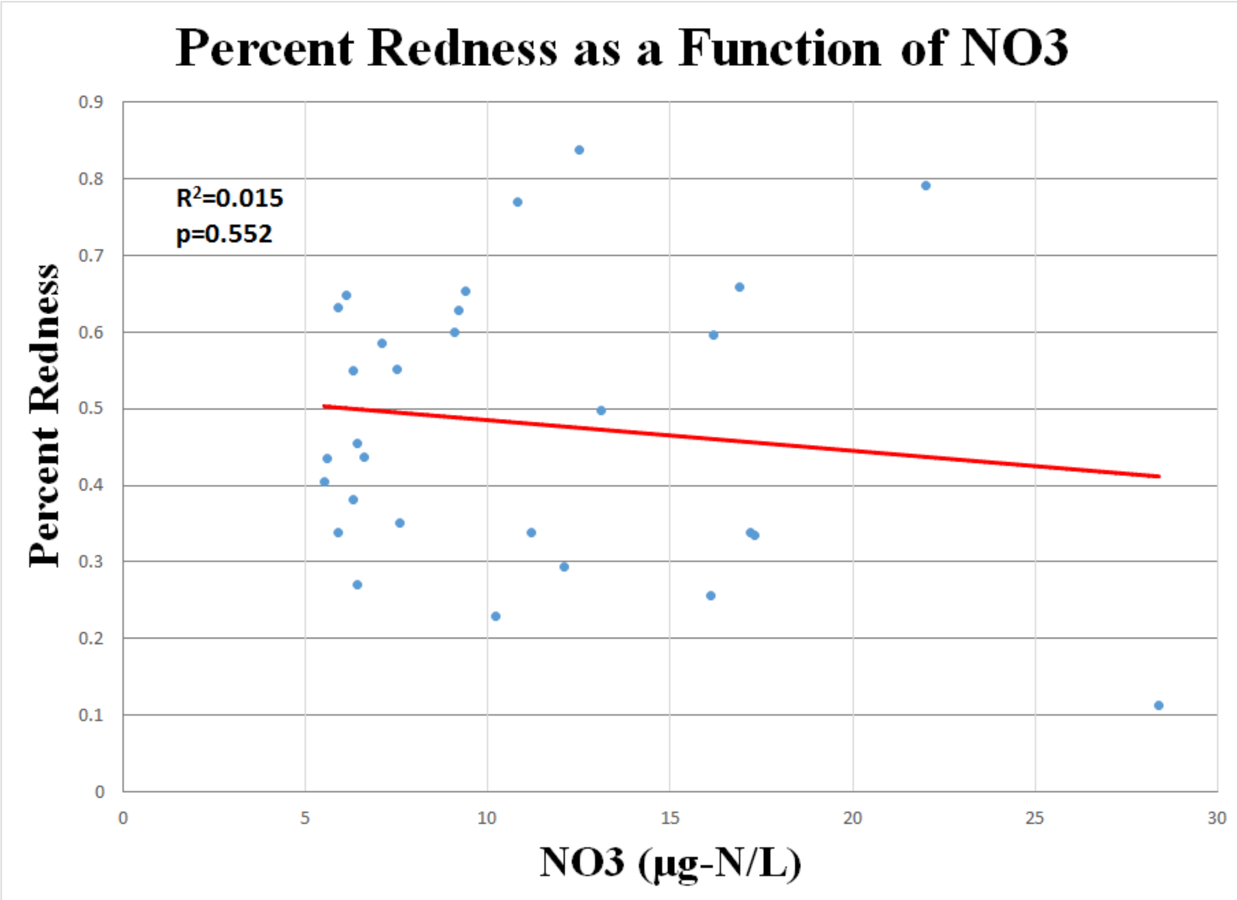


Figure 10, a regression of pitcher plant redness and Nitrate

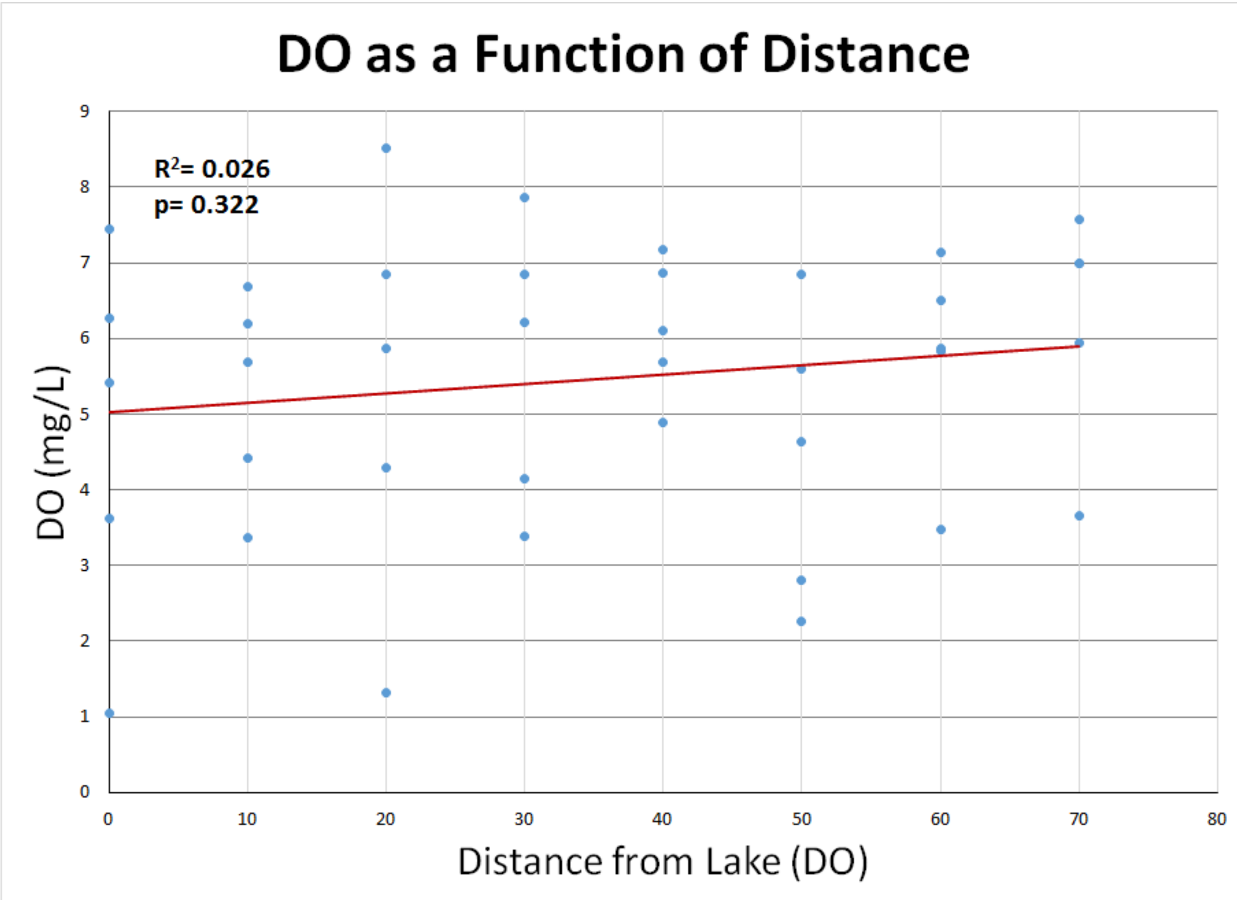


Figure 11, a regression of DO against lake distance

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