

Abiotic Factors Influencing the Abundance and Distribution of Marsh Marigolds Along Carp Creek

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Abstract: Ecology is the study of distribution and abundance of living organisms resulting from abiotic and biotic interactions in nature. Plant growth is determined by abiotic factors that construct its fundamental niche, defined as the range of conditions and resources within which individuals of a species can persist. If a plant species exhibits patchy distribution and plot size behavior, this may illustrate global or local variations in distribution of abiotic factors within the habitat. This study focuses on the local Northern Michigan macrophyte, *Caltha palustris*, which illustrates patchy distribution behavior along the reach of Carp Creek. We investigated this phenomenon by testing affects of specific abiotic factors upon distribution and density of *C. palustris*. These abiotic factors included the following: soil and water pH, soil moisture, dissolved oxygen, redox potential, and phosphate and nitrate concentration in the soil. Our findings suggest that soil pH and soil nitrate concentrations may determine distribution of *C. palustris*, but the other tested abiotic factors did not significantly influence marsh marigold distribution. Our findings also imply that dissolved oxygen may determine density of *C. palustris* plots; however, the other abiotic factors did not show such correlation.

Introduction:

Ecology is the study of the distribution and abundance of living organisms resulting from biotic and abiotic factors in nature. Plant growth and success depends upon the presence of several abiotic, or non-living, environmental factors. The relative importance and interaction of these factors varies according to a global and local scale, as well as to a particular species. The long-term average distribution of relative abundance may reflect a dynamic equilibrium based on niche specialization of the component species (Crawley 1997). Every species requires a specific nutrient content and chemical composition to grow. The combination of these factors determines an organism's fundamental niche, defined as the range of conditions and resources within which individuals of a species can persist (Ricklefs 2001). The borders of a fundamental niche are determined by physiological tolerances to abiotic factors; therefore, abiotic factors have been found to be the determinant aspects for growth of some plant species (Karowe 2003).

Plant distribution and relative abundance within its environment is thus determined by the combination of abiotic factors, some being more important than others. On a local scale, what specific abiotic factors determine a species' fundamental niche? In certain habitats, what factors contribute to increased success in one area and not others?

Previous studies document specific ranges of tolerances for certain abiotic factors. One such study conducted in the Pacific Northwest investigated the abiotic factors of temperature and altitude on the Alpine larch (*Larix lyallii*) habitat. The larch habitat was shown to be limited to montane altitudes and subsequent colder temperatures, evidenced by the damage it incurred through higher maximum temperatures encountered outside its native habitat (Arno & Habeck 1972).

A study investigating the limiting factor of water on three dwarf willow species in the alpine regions of the world uncovered evidence suggesting that the water-holding capacity of soil varies sharply from place to place (Dawson 1990). This study is one example of a limitation in which water controls the distribution of species at a local level (Crawley 1997).

A study of the annual herb *Stephanomeria exigua* (Asteraceae) discussed the impacts of homogeneity and heterogeneity of local environmental conditions on individual plants in natural populations. Evidence suggested that both density and patch type with or without heterogeneity had a significant effect on plant mass (Crawley 1997). Therefore, it is important to take into account the stability of factors in assessing plant growth.

All three studies indicate the importance of abiotic factors in the distribution and abundance of organisms. In the specific case of aquatic to semi-aquatic plant species, such as macrophytes, which are large-rooted aquatic plants, plant distribution varies according to the availability of resources. It also varies with the biological and chemical contents of the water source and the manner of delivery of nutrients through hydrological processes such as lakes, rivers, wetlands and streams (Giller & Malmqvist 1998).

Plants do not always utilize nutrient-rich patches, and the fact that they do not always exploit these patches by proliferation highlights the complex economics of patch exploitation. If the patch is within the fundamental niche, why aren't the plants found there? It is a common assumption that plants will utilize every nutrient-rich patch, but patchy distributions of species in nature are the rule, not the exception (Crawley 1997).

Abiotic Factors:

Much of the patchiness of abundance and distribution of plant species is determined by abiotic factors. Plant growth is influenced by nutrient content, soil and water pH, dissolved oxygen, and re-oxidation potential.

Nutrient Content

The nutrient composition of a habitat depends on the geology of the area, precipitation, groundwater input, run-off and soil chemical composition. Nutrients carried in suspension through the hydrological system are embedded in the sediment of stream banks. Nitrogen, a nutrient vital to plant growth, is a structural component of proteins and nucleic acids. Phosphorus, a nutrient essential to growth and reproduction, is a structural component of nucleic acids and phospholipids. Both nutrients are vital for plant growth and success (Ricklefs 2001). The erosion and deposition of these substrate particles governs the quality and quantity of nutrients provided for the local biota for

several reasons. In terms of quantity, the deposition of ions that become nutrients for plants, held with particles in solution, increases with deposition of particles in an area. In terms of quality, erosion of the stream bank and its chemical composition determines the nutrients made available to depositional areas downstream.

pH

The pH is inversely proportional to the concentration of hydrogen ions in solution. Ion concentration in stream water is derived from precipitation, groundwater, run-off and soil chemistry. Acidity increases as the concentration of ions increases, subsequently decreasing the pH value. Plants along lotic, or running water, systems depend on a specific pH range of both the soil and water (Giller & Malmqvist 1998). This is important to biological processes because plant enzymes perform best under a specific pH range, and the pH of the soil that surrounds its nutrient-absorbing roots and nearby water will be incorporated into the plant. If it is outside the ideal range, the enzymes will not operate correctly, and the plant fitness will decrease.

Dissolved Oxygen:

Dissolved oxygen is essential to the respiratory metabolism of most aquatic organisms. It affects the solubility and availability of nutrients, and therefore the productivity of aquatic ecosystems (Ministry of Environment, et al. 1998). Oxygen enters water by diffusing from the air at the surface and continually cycling via the water current. Oxygen is the by-product of photosynthesis; therefore, the amount of oxygen is positively correlated with the number of photosynthesizing plants nearby. Turbulent streams have higher levels of dissolved oxygen than stagnant pools. Oxygen concentration also varies according to time of day, impediments in the stream, amount of precipitation and water levels (Giller & Malmqvist 1998).

Redox

Redox potential is important to plant growth because it affects nutrient availability. Nutrients in the soil and water, such as phosphate and nitrate, are generally bound in compounds that plants cannot absorb. Oxidation-reduction reactions can make these nutrients dissociate and become available for plants. These reactions involve changes in the oxidation states of the chemicals that take part in the reaction. Redox potential measures the water to determine the electrochemical environment. Negative

redox potential results indicate a reducing environment, signifying that more nutrients are freed up for plants to absorb. A positive redox potential result indicates an oxidizing environment, signifying that nutrients are bound in compounds that plants cannot absorb. Redox potential determines the nature of important solutes in water (Manahan 1991).

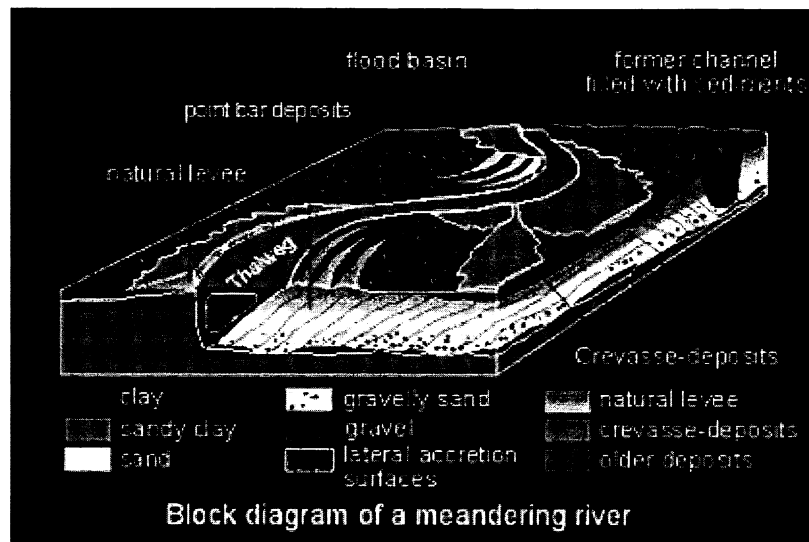
Test Subject & Site Specifics:

The study examined the species *Caltha palustris* along the banks of Carp Creek in Northern Michigan to investigate which abiotic factors determine the distribution and abundance of semi-aquatic plants. *C. Palustris*, commonly known as the Marsh Marigold, is widely distributed throughout Eurasia, Alaska, the Pacific Northwest, Central Canada, the northeastern Midwest, New England and the Middle Atlantic States. These aquatic macrophytes are found at lake margins, alongside rivers and streams and in wetlands. This distribution suggests that the plants grow best in relatively moist soil. Macrophytes are categorized as marginal and shallow water vegetation. They are found near banks or rooted in shallow substrates, and are confined to low-gradient streams and rivers with fine sediments for root establishment (Giller & Malmqvist 1998). The purpose of the study was to determine which abiotic factors contribute to the distribution and potential correlation between the density and location of marigold plots along the banks of their creek habitat.

Carp Creek, in Burt Lake Township, was chosen as the area of study based on the proximity of its reach to the University of Michigan Biological Station and the patchiness of distribution of *C. palustris* along its banks. Carp Creek is a first order stream, and like all streams, its structure is dependant upon the source—or inlet—of the water, and the speed and stability of water flow through the system. Stream flow also influences aquatic plant growth by affecting the sediment content and dissolved oxygen levels. Extremely fast flow leads to high oxygen content, so less sediment can settle to the floor for organisms to use as habitat. However, stagnant water may have high amounts of settled sediment, but not enough dissolved oxygen to support life (Giller & Malmqvist 1998). In the case of Carp Creek, the headwaters are spring fed and flow in a steady meandering path over its three-kilometer reach. The springs originate from both the surface and the epilimnetic waters of Douglas Lake (Fortner & White 1988).

A meandering lotic system such as Carp Creek travels over the soft substrate of a floodplain and has two areas of interest essential to plant growth: the point bar and cut bank (Figure A). The point bar, or stable side, is the area of deposition along the bank where sediment, nutrients and ions suspended in the water are deposited. These deposits make the point bar very conducive to plant growth. The cut bank, or cliff side, is the periphery of the creek characterized by erosion and high turbulence. This leads to lesser stability of substrate and lower rates of nutrient deposition (Giller & Malmqvist 1998).

Figure A: Diagram of meandering stream



Groundwater infiltration and surfacing by springs of Carp Creek combine with surface flow to generate high levels of suspended nutrients and ions that are brought up with the stream current. The bedrock composition of the area thirty feet below the surface is composed of sandstone and limestone. This affects the nutrient content and its subsequent pH because it affects the chemical composition of the groundwater that rises through these springs. The limestone bedrock, composed entirely of calcium carbonate, supplies carbonates for alkaline buffering (USGS 1998). Alkalinity is the ability of water to buffer itself against sources of acidity. This buffering capability prevents decreased access to nutrients that might bind to ions in a more acidic solution, and prevents the water from acidifying. Lotic macrophyte distribution and abundance, specifically *Caltha palustris*, is adapted to and dependent upon these physiochemical characteristics and hydrological nutrient delivery (Fortner & White 1988).

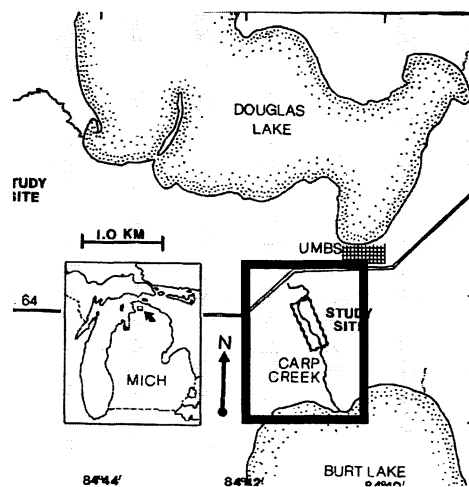
Materials and Methods:

Materials:

- Soil tins
- Turkey basting device
- pH meter
- Dissolved oxygen meter
- Re-oxidation potential meter
- PVC pipe
- Measuring tape
- Markers
- Waders
- Drying oven
- Chemistry materials used to conduct N and P concentration tests

Carp Creek was divided into three sections. The headwaters (upstream) percolate from Douglas Lake through a gorge ~1.6 kilometers away from the lake. The middle section (midstream) extends from ~2 kilometers away from the top of the gorge to Hogsback Road. The mouth (downstream) extends from Hogsback Road to Burt Lake (Figure B). 9-12 patches of *C. Palustris* at each site were marked for study. These patches were divided into three categories covering 25 square feet each: large patch, small patch, and bare patch. Large patches contained 20 or more *C. Palustris* plants. Small patches contained 15 or less *C. Palustris* plants. Bare patches did not contain *C. Palustris* plants.

Figure B: Map of study site



The dark rectangle surrounds Carp Creek

The sampling methods called for a small or large patch with a corresponding bare patch 10-20 feet downstream on the same side of the creek. This way, the site with *C. Palustris* could be compared to its corresponding bare patch to see if different abiotic factors contributed to the presence or absence of the plant. Three large patches and three small patches, each with corresponding bare patches, were sampled in the headwaters. Nine patches were sampled in the middle section: two small and one large patch with corresponding bare patches, and one small and two large patches without corresponding bare patches. Nine patches were sampled in the mouth section: three small with corresponding bare patches, and three large without.

The following abiotic factors were measured: soil pH, soil moisture, water pH, dissolved oxygen, redox potential, and the nitrate and phosphate content in the soil. Soil samples were taken from 6 inches below the surface in each site. Three to five grams of soil from each sample were added to 50 mL of water in order to measure soil pH in the lab. The mixture settled for half an hour, and the pH of the water floating above the soil was recorded.

To measure soil moisture, two to eight grams of soil from each sample were measured out, dried in an oven for over twenty-four hours and weighed again. The difference between the final weight and the initial weight divided by the initial weight multiplied by 100 gave the percent composition of moisture in the soil samples $[(I-F)/I * 100]$.

Water pH was measured on-site with a portable pH meter. Dissolved oxygen and redox potential measurements were taken on-site. PVC pipes were placed 6 inches down into the soil to let groundwater seep in. The wells were basted once before testing in order to acquire a fresh sample. The measurements were taken with dissolved oxygen and re-oxidation meters.

Results:

Statistical Analysis

The study used a paired t-test to test the potential relationship of the abiotic factors to the distribution of *C. palustris*. Each pair consisted of one site with plants and

its corresponding site without. The paired t-test compared the two types of sites to look for a statistically significant difference between them.

Linear regressions and influence plots were used to map the relationship between variable and abundance. Only sites with *C. palustris* could be used for these tests because differences in density were tested. This study used this analysis to test the whole creek as well as potential similarities or differences among the three individual sections: upstream, midstream, and downstream. All graphs are included in Addendum A; the referenced graphs are highlighted below.

Distribution Data

Variable	Number of Sites	Minimum	Maximum	Mean	Standard Deviation
Water pH w/ plants	16	8.2	8.94	8.58	0.21
Water pH w/o plants	10	8.34	8.7	8.56	0.12
Dissolved Oxygen w/ plants	17	0.11	7.86	2.76	2.41
Dissolved Oxygen w/o plants	11	0.16	2.51	1.2	0.86
Re-oxidation Potential w/ plants	17	-245	205	-21.35	119.64
Re-oxidation Potential w/o plants	11	-230	58	-75.55	95.86
PO4 w/ plants	18	26.2	1,905.88	454.15	440.983
PO4 w/o plants	11	41.3	1,600.41	292.15	453.942
NO3 w/ plants	18	413	19,183.67	318.803	5,005.26
NO3 w/o plants	11	350.21	17,575.76	6,397.954	6,281.478
Soil pH w/ plants	18	6.65	7.49	6.94	0.29
Soil pH w/o plants	12	6.55	6.8	6.69	0.08
Soil Moisture w/ plants	18	0.22	0.83	0.49	0.21
Soil Moisture w/o plants	12	0.19	0.87	0.5	0.24

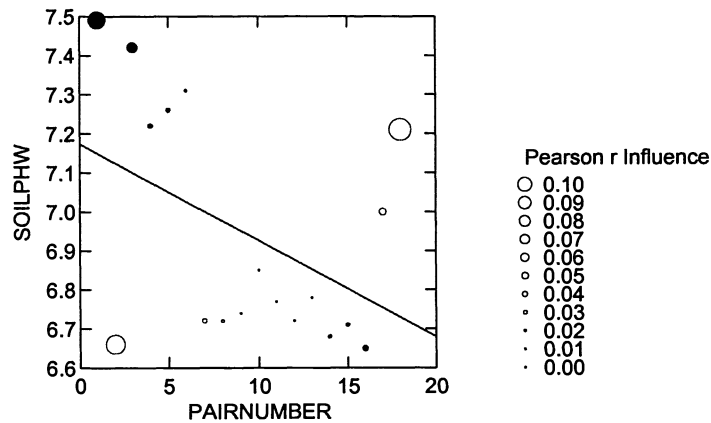
(Table 1) Data collected from 30 total sites along Carp Creek. Minimum, maximum and mean values reported as the following: water pH (-log [H⁺]), dissolved oxygen (mg/L), redox potential (mV), phosphate (µg/kg), nitrate (µg/kg), soil pH (-log [H⁺]), and soil moisture (% water content).

Table 2: Effect of variables on *C. palustris* distribution

Variable	P-value
Water pH	0.82
Dissolved Oxygen	0.18
Re-oxidation Potential	0.45
PO ₄	0.13
NO ₃	0.04
Soil pH	0.03
Soil Moisture	0.77

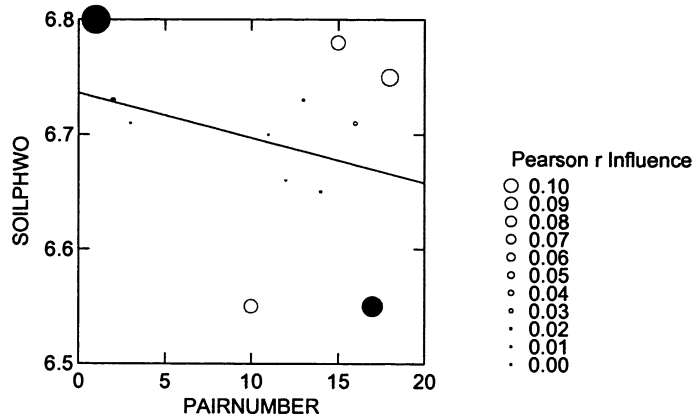
(Table 2) P-values from paired t-tests. NO₃ and soil pH are less than or equal to 0.05, suggesting statistically significant influence on distribution. Dissolved oxygen and PO₄ may have some influence, but are not statistically significant.

Soil pH of sites with *C. palustris* increases moving downstream



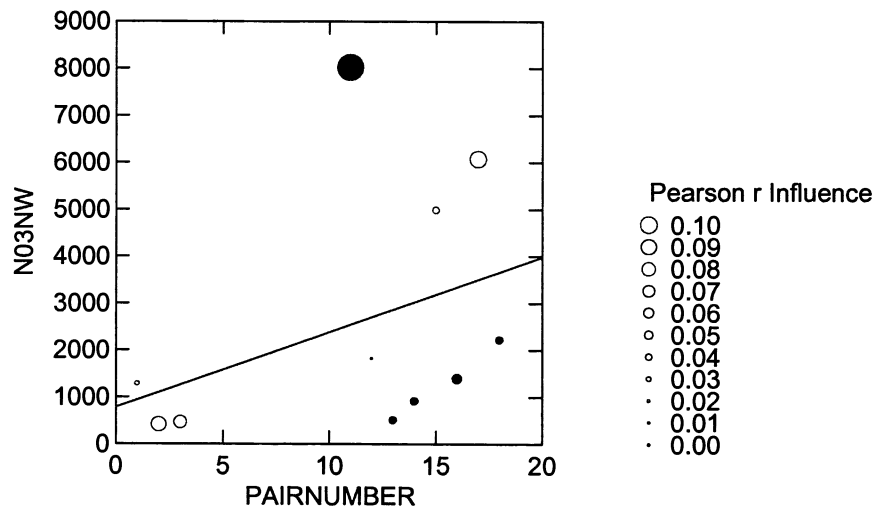
(Figure 2a) Influence plot showing best-fit line for t-test for soil pH of sites with plants along entirety of Carp Creek. Results reported for all sites with *C. palustris* present. Site 1 is at the mouth of the creek; site 18 is at the headwaters.

Soil pH of sites without *C. palustris* increases moving downstream



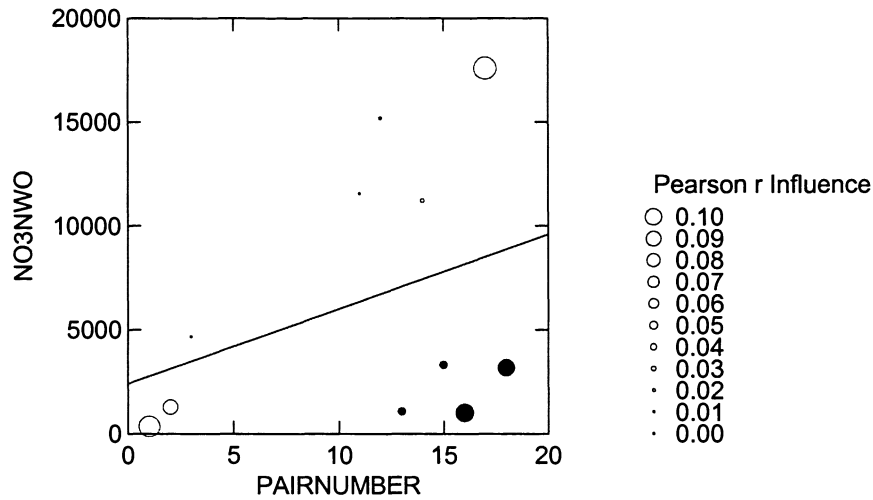
(Figure 2b) Influence plot showing best-fit line for t-test for soil pH along entirety of Carp Creek. Results reported for all sites without *C. palustris*. Site 1 is at the mouth of the creek; site 18 is at the headwaters.

NO₃ concentration of sites with *C. palustris* decreases moving downstream



(Figure 3a) Influence plot showing best-fit line for t-test for soil nitrate content with plants along entirety of Carp Creek. Results reported for all sites with *C. palustris*. Site 1 is at the mouth of the creek; site 18 is at the headwaters.

NO₃ concentration of sites without *C. palustris* decreases moving downstream



(Figure 3b) Influence plot showing best-fit line for t-test for soil nitrate content without plants along entirety of Carp Creek. Results reported for all sites without *C. palustris*. Site 1 is at the mouth of the creek; site 18 is at the headwaters.

Abundance Data:

Linear Regression Values for Tested Abiotic Factors			
Variable	Slope	R-squared	P-value
Water pH	-19.760	0.110	0.190
Dissolved oxygen	-2.730	0.220	0.050
Re-oxidation potential	-0.020	0.030	0.500
PO4 concentration	-0.007	0.047	0.389
NO3 concentration	-0.001	0.092	0.238
Soil pH	1.060	0.000	0.930
Soil moisture	6.310	0.010	0.710

(Table 3) Linear regression values for tested abiotic factors along entire length of Carp Creek. Slope indicates positive or negative correlation for best fit line; R-squared indicates influence each of factor on density of *C. palustris*; P-values greater than 0.05 indicate that slope is not statistically different than slopes of zero, strongly suggesting no correlation between variable and plant density.

Distribution:

Water pH

Statistical analysis shows no significant correlation between water pH and distribution of *C. palustris* along the entire reach of Carp Creek (p=0.82, Table 2).

Soil pH

There is a strong relationship between soil pH and distribution of *C. palustris* along the whole creek ($p=0.03$, Table 2). The study has a 97% confidence in rejecting the null hypothesis that soil pH and distribution are not related. Data shows a negative linear best-fit line for soil pH in sites with and without plants (Fig 2a & 2b). Soil pH increases from the headwaters towards downstream, regardless of presence or absence of *C. palustris*. Sites containing marsh marigolds consistently had a higher soil pH than their corresponding sites without (Table 1).

Redox potential

There is no significant difference in oxidation-reduction potential between sites with *C. palustris* and those without (Table 2). Maximum and minimum potential from the sites with marsh marigolds and the sites without are very similar (Table 1).

Nitrate

Nitrate concentration in the soil greatly affects the distribution of marsh marigolds ($p=0.04$). *C. palustris* plants appear to prefer soils with higher amounts of nitrate (Table 2). Regardless of the presence of marsh marigolds, however, nitrate concentration decreases going downstream (Figures 3a & 3b).

Soil moisture

No significant relationship exists between soil moisture and distribution ($p=0.77$). There is no significant difference between the means of sites with and without *C. palustris* (Table 1).

Dissolved oxygen

Dissolved oxygen may slightly affect marsh marigold distribution, but not significantly (Table 2). Sites with marsh marigolds express a wider range of dissolved oxygen preference than sites without plants (Table 1).

Abundance:

Water pH

Linear regression statistical analyses indicate a lack of strong correlation between plant density and water pH (Table 3). Although the p-value is low ($p=0.19$), it is not statistically significant; therefore, the null hypothesis that there is no correlation between

patch density of marsh marigolds and water pH must be accepted. The study concluded that the abundance and distribution of *C. palustris* is not likely to be determined by water pH.

Soil pH

Soil pH does not appear to affect plant density (Table 3). The study could find no correlation between the variable and the abundance of the marsh marigolds.

Redox Potential

Redox potential also does not affect plant density (Table 3).

Nitrate

Nitrate concentration did not heavily affect plant density (Table 3). The slope of -0.001 makes the line of regression nearly horizontal, implying that patch density does not change with changing nitrate levels.

Soil Moisture

There is no strong evidence to correlate soil moisture with plant density ($p=0.77$). The p-value is very high, and a positive slope of six fails to suggest a correlative relationship ($p= 0.710$, Table 3).

Dissolved Oxygen

The study found a negative correlation between plant density and dissolved oxygen (Table 2). Dissolved oxygen levels decreased as plant density increased.

Discussion:

Distribution and Abundance:

Water pH

The water pH range of the thirty sites along Carp Creek is 8.2 to 8.94 (Table 1). This range is within the typical range of Northern Michigan streams and rivers, which average a pH range of 7-9. This relatively high pH is very likely to be the result of the alkalinity of the creek. Alkalinity is the ability of water to buffer itself against sources of acidity through carbonate compounds. Most of Northern Michigan lies above limestone bedrock composed entirely of calcium carbonate, which supplies carbonates for alkaline buffering (USGS 1998). Groundwater that enters the stream through springs carries the carbonates suspended in solution. The presence of these carbonates in solution

conceivably results in the high pH range that we observed. The consistency of the pH range along the creek and the patchy distribution of the plants observed suggest that other factors are influencing the distribution.

Soil pH

The results illustrating that the minimums and maximums of soil pH for all sites overlap in range, such that the overall minimum is from a site without marsh marigolds, and the maximum is from a site with plants. Also, the mean pH of sites with plants is greater than the mean pH of sites without. Evidence suggests that marsh marigolds tend to prefer slightly acidic soil with a pH 5-7 (Rook 2002). However, the pH of sites with plants ranged from a pH of 6.65 to 7.49, signifying that their pH range may have enlarged. This suggests that marsh marigolds are present in the site that is more neutral, or less acidic, within the observed pairs. This further suggests that there may be a local adaptation of marsh marigolds to the environment of Carp Creek. The sites without plants have a lower pH and may be just below the local lower threshold of the plants range, justifying the absence of plants.

The lack of correlation of plant density to soil pH may not be dependent on soil pH, but rather on other environmental factors such as light, temperature, other local biota, geophysical characteristics and an influence by water pH.

Dissolved Oxygen

Dissolved oxygen concentration is subject to diurnal and seasonal fluctuations that are due, in part, to variations in temperature, photosynthetic activity and river discharge (Ministry of Environment, Lands and Park 1998). Most of the testing was performed during the mid-afternoon hours, and therefore the dissolved oxygen concentration measured during these hours may not be representative of the temperature or light availability the plants require for photosynthesis. This may be a major factor in accounting for the lack of relationship between dissolved oxygen of the sites with and without plants. On the other hand, Table 1 shows a significant difference between the means of sites with plants (7.56 mg/L) versus sites without (2.81mg/L). Heavy plant growth can lead to super-saturation during the day (Giller & Malmqvist 1998). In general, it is probable that the presence of plants insinuates a greater concentration of dissolved oxygen in the water than absent sites.

Additionally, the plots with a large density were generally located near springs, which are known to contain less dissolved oxygen than the stream to which they percolate. This may help explain the negative correlation between plant density and dissolved oxygen as evidenced in Table 3, which indicates that as plant density increases, dissolved oxygen concentration decreases. Therefore, one could assume that the plots with a large number of plants, especially those located near springs, had lower dissolved oxygen than those plots without *C. palustris*. Additionally, however, the dissolved oxygen measurements could be the result of inaccurate testing errors due to extra atmospheric reactions on the surface of the water resulting from stagnant water in the PVC tubes. Further investigation into the following abiotic factors known to influence dissolved oxygen concentrations may encourage more in-depth analysis of the distribution and abundance of marsh marigolds: stream turbulence, atmospheric reactions on the water surface, in-stream impoundments and temperature.

Re-oxidation

The oxidation-reduction potential illustrates the willingness of an ion to either accept or donate electrons (Cronk & Frennessy 2001). Redox reactions either free up or sequester nutrients that plants need to grow and survive, such as nitrate and phosphate. Negative redox potential indicates that more reduction reactions are occurring, converting nutrients bound in insoluble compounds into soluble forms. Positive redox potential indicates that more oxidation reactions are occurring, making nutrients unavailable to plants. The negative correlation between redox potential and density of marsh marigolds may occur because large amounts of marsh marigolds thrive in areas of low redox potential. Conversely, the large patches of marsh marigolds tested may have already absorbed the available nutrients, driving down the redox potential. The varying levels of redox potential may also relate to the dissolved oxygen concentration and pH of the water.

Phosphate

Phosphate does not strongly affect presence or absence of *C. palustris* ($p=0.134$), nor does it affect plant density ($p=0.39$). Phosphate is typically one of the main limiting nutrients in soil for plant growth. The lack of correlation or relationship to *C. palustris* distribution and density may then be because phosphate does not occur in low enough

quantities to be a limiting factor along Carp Creek. Another possible reason for the relatively non-varying levels of phosphate concentrations may be the abundance of springs along the creek. Phosphate becomes available as it leaches through the soil via springs, but plants tend to absorb it so it is usually found in low concentrations in stream waters (Giller & Malmquist 1998). The abundance of springs is relatively uniform from upstream to downstream, indicating that phosphate comes up through springs, but is instantly taken up by the plants around it. This would maintain a more constant phosphate concentration along the creek as observed from the results. In-depth analysis of phosphate influence may relate to the lack of correlation for abundance or density.

Nitrate

Nitrate concentration in the soil is the result of two main factors in nature: nitrogen-fixing bacteria that convert atmospheric nitrogen to a useable form for plants, and the decomposition of biotic components of the environment (Cox 2002). This suggests that in the sites where *C. palustris* is present, the soil either has higher concentrations of nitrogen fixing bacteria, or more decaying organic material. Data indicates that nitrate concentration increases in the upstream direction *C. palustris* may prefer the site with the higher nitrate concentration than the corresponding bare site with a lower nitrate concentration (Figure 3a & 3b). A possible cause for the increasing concentrations of nitrate in the upstream direction is the corresponding increase in black organic material in the soil. The downstream area was sandier and less organic. Soil composition observations of the sites were consistent with the idea that increased nitrate concentrations result from increased presence of decaying organic matter.

The data indicates that there is no correlation between plant density and nitrate concentrations. Previous studies, however, indicate that there may be a correlation between success of *C. palustris* and nitrate. In that case, as soil moisture increased, nitrate increased in response along with growth success of *C. palustris* (Grootjans, et al. 1985). Further investigations of nitrate concentrations in combination with soil moisture along Carp Creek may lend more information to the study marsh marigold abundance.

Soil Moisture

A study done in 1985 regarding "Influence of drainage on N-mineralization and vegetation response in wet meadows" found that *C. palustris* retreats when soil moisture

decreases and recovers when soil becomes wet again (Grootjans, et al. 1985); in other words, marsh marigolds need wet, moist soils to survive. However, no relationship was displayed between plant distribution and soil moisture, nor did an evident correlation with plant density exist. There may be numerous reasons for these results, including the following: precipitation, creek level and time of year. Precipitation fluctuates throughout the growing season and has the ability to increase or decrease soil moisture as well as the creek level. It is possible that the rain three days prior to the single sampling affected the soil moisture. It is also possible that the insufficiency of multiple soil sampling contributed to a non-representative sample.

Moreover, the 1985 study indicated that meadows of *C. palustris* contain many other plant species and grow on wet soils with a relatively high nutrient availability. This suggests that higher nitrate concentrations in particularly moist soils may show a stronger influence on *C. palustris* distribution and abundance than do drier, nutrient-rich soils.

Overall Discussion Issues

Results indicate that there are confounding variables that complicate and limit discussion of all variables individually and in combination. These confounding variables lead to alternative hypotheses that suggest options for further study. One of these confounding variables is the question of whether *C. palustris* distribution and abundance is determined by the abiotic factor tested, or if the abiotic factor is determined by the presence, absence or abundance of the plant. In the specific cases of nitrate and soil pH, statistically significant results indicate that these abiotic factors are related to plant distribution. According to the null hypothesis proposed in the introduction, this would suggest that distribution is likely to be determined by the abiotic factor in question, such as dissolved oxygen. However, the presence or absence of plants or the abundance of plants may determine the levels of abiotic factors. Further study of these factors in the controlled environment of a manipulative experiment may clarify these relationships.

Another confounding variable includes possible interactions between *C. palustris* and other abiotic factors that were not tested. This may possibly explain the lack of relationships or correlations found in the results. Other abiotic factors include light, temperature, and alkalinity. Untested biotic factors could have delineated clearer relationships or complicated the results. One example may be competition between *C.*

palustris and other plants, such as the hemlock, horsetail, and cattails observed in many of the test plots. A third confounding variable is the possibility that several factors simultaneously operate on distribution and abundance. Variables may be operating on the presence/absence or density of plants in combination with each other. Further testing for correlations between factors themselves and then in relation to distribution and abundance could resolve this issue.

Other suggestions for further study include a larger sample size as well as extending the time period of study. Ideally, future studies will sample over the entire growing period of *C. palustris* to obtain more representative results.

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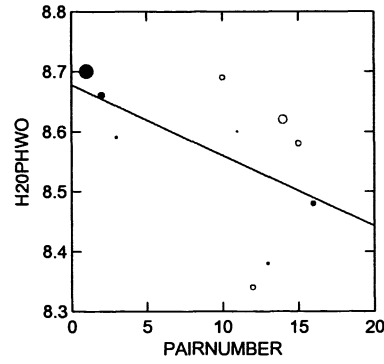
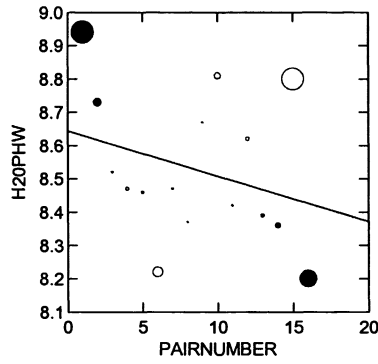
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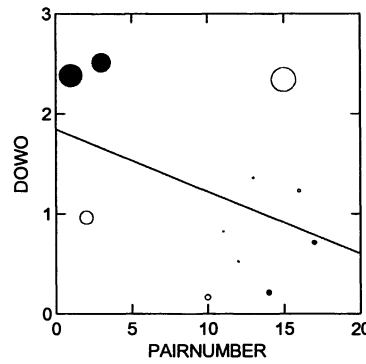
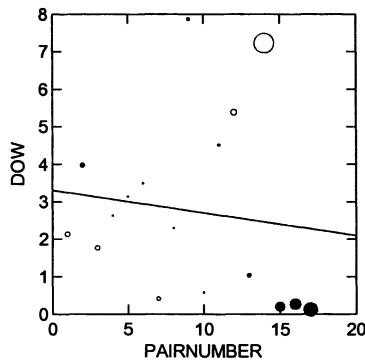
Addendum A:

DISTRIBUTION MODELS:

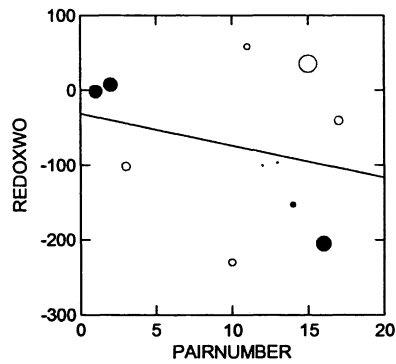
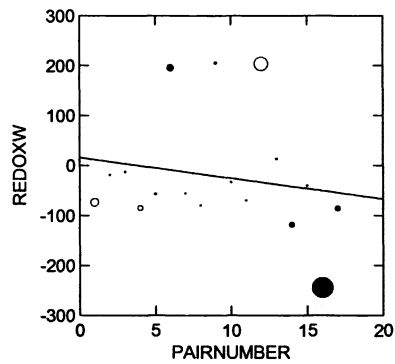
Water pH increases moving downstream



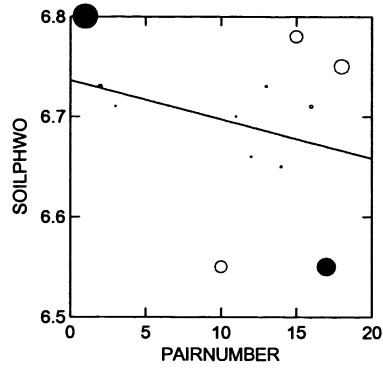
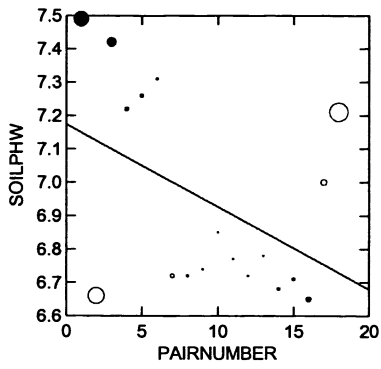
Dissolved oxygen increases moving downstream



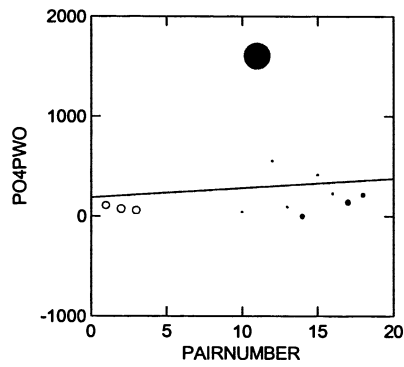
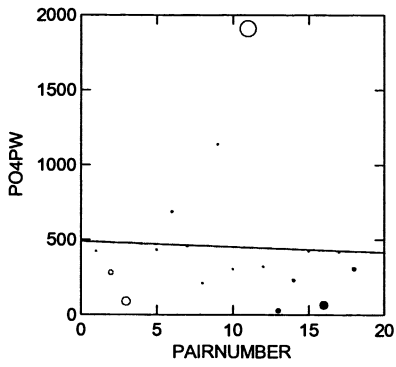
Redox potential increases moving downstream



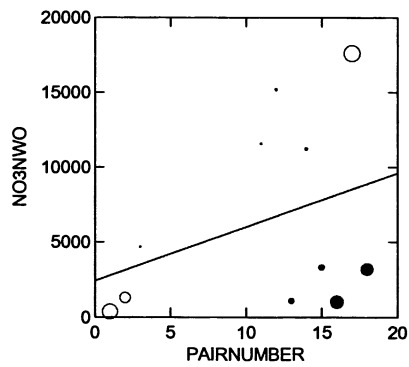
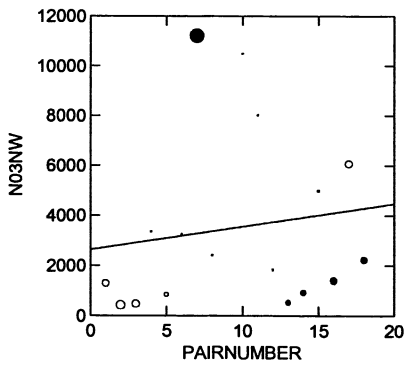
Soil pH increases moving downstream



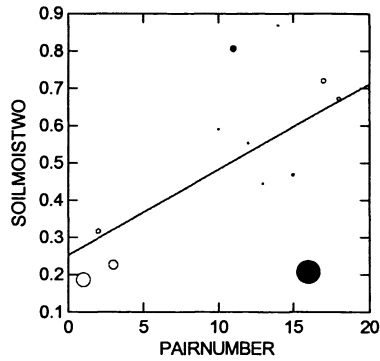
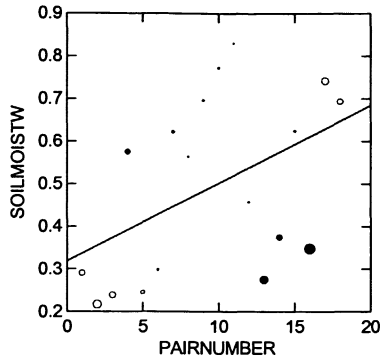
Phosphate concentrations only slightly vary along the creek



Nitrate concentrations decrease moving downstream

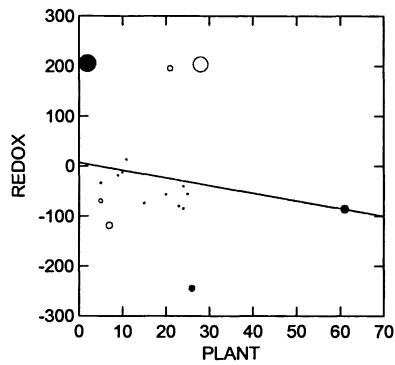


Soil moisture decreases moving downstream

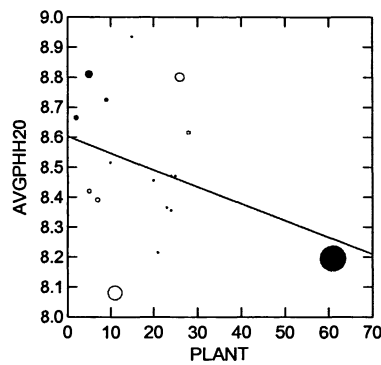


ABUNDANCE MODELS:

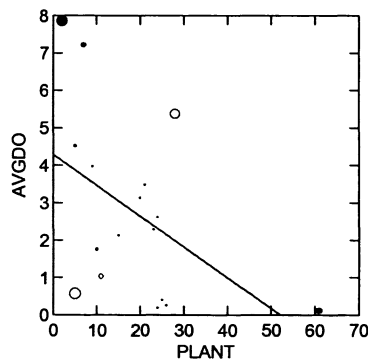
Redox potential decreases with plant density



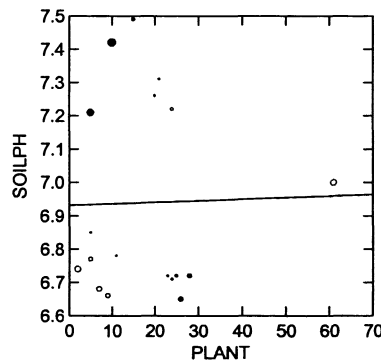
Water pH decreases with plant density



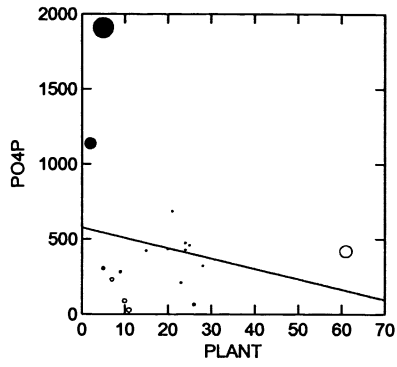
Dissolved oxygen levels decrease with plant density



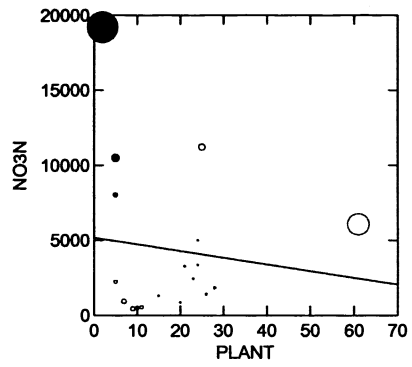
Soil pH slightly increases with plant density



Phosphate levels decrease with plant density



Nitrate levels decrease with plant density



Soil moisture increases with plant density

