Characterization of the Photosynthetic Competitiveness of Autumn Olive (*Elaeagnus umbellata*)

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Abstract:

Autumn olive (*Elaeagnus umbellata*), a non-native invasive shrub in the United States, threatens to decrease biodiversity in natural areas throughout Southwestern Michigan. This study conducted at the ecological preserve at Pierce Cedar Creek Institute in Barry County, Michigan, sought to characterize the photosynthetic competitiveness of *E. umbellata* in comparison with several established native species. Photosynthesis rates of *E. umbellata* and native species were measured in both open meadow and forest under-story environments. In the meadow site, *E. umbellata* was found to fix carbon faster than any of the native species tested. In the forest site, the climax community species (*Quercus velutina* and *Acer saccharum*) accumulated carbon dioxide faster than *E. umbellata* at lower photosyntheticly active radiation (PAR) intensities (0-400 umol/m^2/sec), but *E. umbellata*'s photosynthesis rate surpassed all the native species evaluated at PAR intensities greater than 600 umol/m^2/sec. Black Cherry (*Prunus Serotina*) was the only native species in the under-story community found to have photosynthesis rates similar to those of *E. umbellata* at the higher radiation intensities. Finally, given that many areas exist that contain heavy infestations of mature *E. umbellata*, we evaluated the efficacy of glyphosate herbicide as a function of concentration on freshly cut stumps. While a low rate of re-growth occurred even at the highest glyphosate concentrations, a 20.5% solution was the optimum in this study. By knowing more about the physiological advantages of *E. umbellata*, managers of natural areas can effectively work to control *E. umbellata*, preventing it from reducing native species biodiversity in other areas of the United States where *E. umbellata* is found.

Introduction:

While *E. umbellata* is a nuisance to native plant species, it has some value for wildlife, but it may be sufficiently competitive to pose a significant challenge to native plant biodiversity. The native birds of Michigan eat the abundant berries in autumn and nest year-round in the thick, bushy growth of *E. umbellata*'s branches. Birds are also the primary seed dispersers. White-tailed deer and other herbivores will also browse the forage and fruits of this plant.

The biggest challenge surrounding invasive species is controlling them. The methods for controlling a non-native species are more costly ecologically than the presence of the invader itself. Artificially introducing a predator or herbivore that loves to snack on the invader could prove harmful to other native plants in the area if the herbivore is later found to be non-specific in its feeding habits. Control methods using broadcast treatments of herbicides can be expensive and unsafe to humans or environment. At the same time, and such control methods may simply not be efficacious.

The purpose of this research is to evaluate the risk *E. umbellata* poses to native biodiversity in temperate areas and to inform efforts to control this invasive shrub. Because *E. umbellata* is highly invasive, it challenges biodiversity by its continued existence here in the United States. *E. umbellata* is taking up space that would otherwise be available to native species. *E. umbellata* may also change the chemistry of the soil in which it grows (Funk *et al.* 1979). *E. umbellata* fixes nitrogen from the air, and deposits it in the soil by way of nitrogen-fixing bacteria living in root nodules.

The objectives of this study were to evaluate the photosynthetic capacity of *E. umbellata* in comparison with that of seven native species, and to evaluate the efficacy of glyphosate herbicide at a range of concentrations when painted on freshly cut stumps of mature E. umbellata plants. As evidenced by its strong presence in open areas and along forest edges, and its increasing presence in deep woods, *E. umbellata* is no slouch when it comes to growing in a variety of habitats. Characterization of the photosynthetic capacities of *E. umbellata* should shed light on the reasons behind the success of *E. umbellata* in Michigan's natural areas and provide some indication of the quantity of over-story that might be required to prevent its establishment. A second objective is to evaluate the effectiveness of glyphosate herbicide to control mature E. umbellata plants as an early step in a restoration process, enabling the eventual success of native species of trees and shrubs. Glyphosate is favored because of human and environmental safety, reasonable cost, and high level of efficacy. Based on its strong presence in meadows, and its infiltration of deep woods, we hypothesized that *E. umbellata* would exhibit higher net photosynthesis rates than the native species surveyed. Further, anecdotal evidence suggests that treatment of cut stumps with glyphosate at concentrations greater than 3% would be required to prevent re-growth.

Materials and Methods:

Description of the study area

Research was conducted at the Pierce Cedar Creek Institute (PCCI) in Barry County, Michigan. PCCI is an ecological preserve spanning 660 acres. The preserve hosts a variety of habitats including upland forest and old field. At the preserve, *E. umbellata* was found to be most abundant in sunny, open areas, like that of an old agricultural field. *E. umbellata* was also found to be infiltrating forest under-story environments in some areas of the preserve. One old field site and one forest under-story site were selected for study. The old field site had about 25% coverage of *E. umbellata*, whereas the forest under-story had about 50% coverage per acre (Travis & Wilterding, 2005). In the old field site, *E. umbellata* is the dominant woody species and is characterized by having many large and mature plants, while *Quercus velutina* is the dominant woody species in the forest site. While most of the plants were not as large in the forest as in the field site, *E. umbellata* represents a major component of the under-story in the forest site studied. *E. umbellata* plants in the meadow site are full shrubs reaching upwards of ten feet tall. In the forest site, there were small shrubs, some with berries on them already, indicating that they were about three years old.

Once the sites were selected, the native species were surveyed, and four individuals of each of four common native species were selected for gas exchange measurement at each site. The study was a split-plot completely randomized complete block design with five plant species as main treatments, leaf light intensity as sub-plots (either full sun exposure or shaded), and four replications.

Photosynthesis rates

Photosynthesis rates of *E. umbellata* shrubs were compared with those of shrubs and trees native and predominate to the area. Shrubs and trees were compared in two sites: an old field site, and a forest under-story. Wild Black Cherry (*Prunus serotina*), Black Walnut (*Juglans nigra*), Hawthorn (*Crataegus sp.*), and Gray Dogwood (*Cornus racemosa*) were the comparison species in the meadow site. Black Cherry (*P. serotina*), Sugar Maple (*Acer saccharum*), American Beech (*Fagus grandifolia*), and Black Oak (*Quercus velutina*) were the comparison species in the forest site.

Photosynthesis rates of the plants were measured using a PP Systems TPS-1 Portable Photosynthesis System. Photosynthesis, transpiration, and stomatal conductance measurements were taken on fully sunny days between the hours of 09:00 and 16:00 during the months of June and July in 2006. To compare photosynthetic rates at different light levels, measurements were taken on two fully illuminated and two shaded leaves on each plant. The mean was calculated from the measures of the two leaves of each light level for each plant. A quantum sensor on the TPS-1 cuvette was used to measure the natural light levels found in the field; no extra measures were taken to shade or illuminate the leaves.

Glyphosate Treatment on cut AO stumps

It was reported that glyphosate painted on freshly cut stumps at low concentrations was ineffective at killing another invasive shrub, common buckthorn (Moeller & Dornbos unpublished data). In this experiment, RoundUp Pro®, a trade name for glyphosate (41%) was used. In the open meadow site, mature *E. umbellata* shrubs were cut with a chainsaw, then one of five treatments (randomly selected) was applied to the stump. The five treatments included 0, 3, 20.5, 41%, and 20.5% glyphosate after a 30 minute delay after cutting. Stumps were checked for shoot re-growth 8 weeks after application, and will be re-checked in spring 2007.

Statistical Analysis

For both studies, the data were evaluated using general analysis of variance (Statistix 7.0).

Results:

Photosynthesis rates

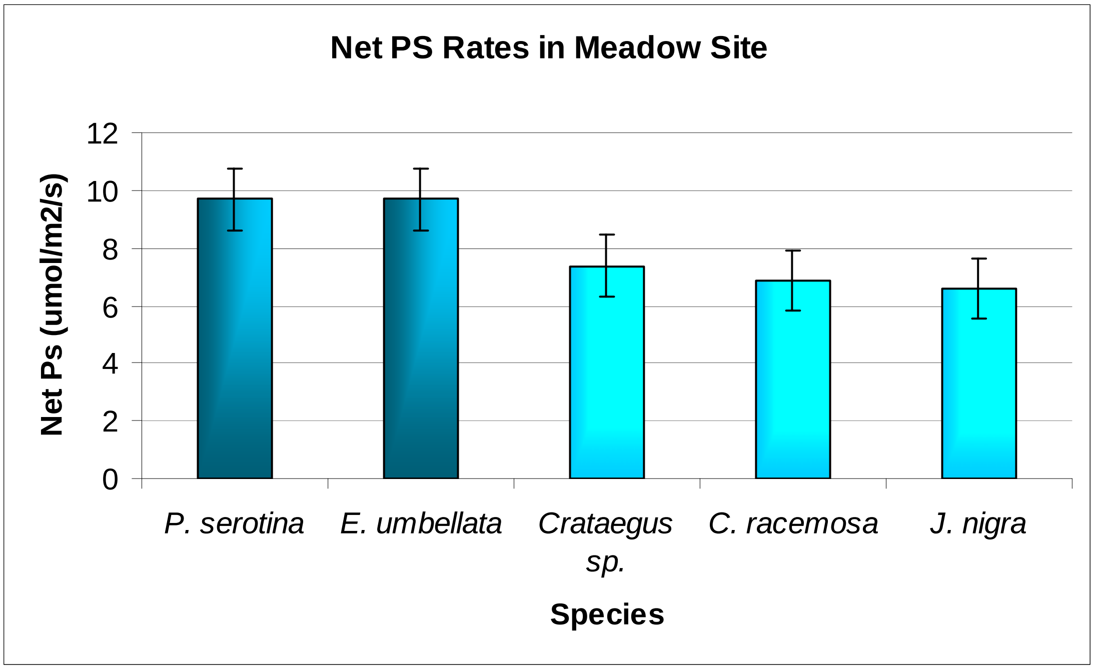

Figure 1: P>0.01. Error bars +/- One Standard Error

Figures 1 and 2 show the net photosynthesis rates in the meadow and forest sites respectively. In the meadow site, *E. umbellata* and *P. serotina* had comparable photosynthesis rates at 9.7 umol CO_2/m^2/sec. *Crataegus sp.*, *C. racemosa*, and *J. nigra* exhibited net photosynthesis rates comparable to one another around 7.0 umol/m^2/sec and below that of *E. umbellata*. A statistically significant difference was observed between the net photosynthesis rates of the species in the meadow site.

In the forest site, although net photosynthesis rates were substantially lower than in the field location, *E. umbellata* exhibited faster carbon fixation rates (1.3 umol CO_2/m^2/s) than that of any of the other four species measured. *P. serotina* and *Q. velutina* had the highest net photosynthesis rates of the native species evaluated at 0.2 umol CO_2/m2/sec. There were no statistically significant differences in photosynthesis rate among the species in the forest site. However, it appears there is a meaningful trend of faster photosynthesis rates on the part of *E. umbellata*.

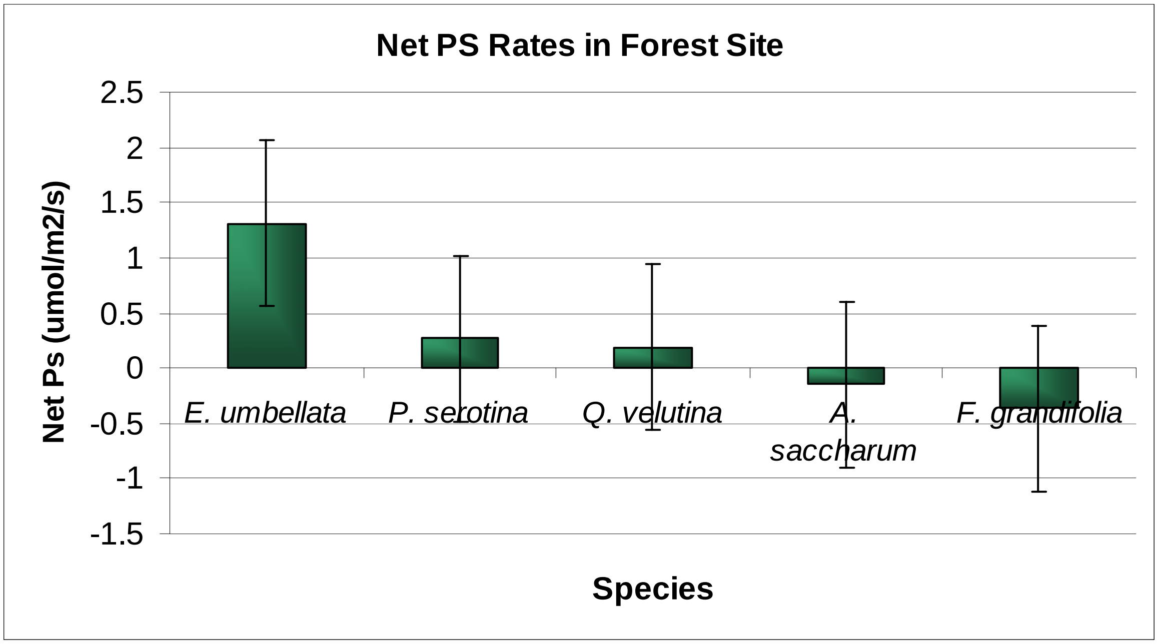

Figure 2: P=0.085 Error bars +/- One Standard Error

The power curves of the regression plots in Figures 3 and 4 characterize the net photosynthesis rate of the different species across a wide range of photosynthetically active radiation (PAR) intensities.

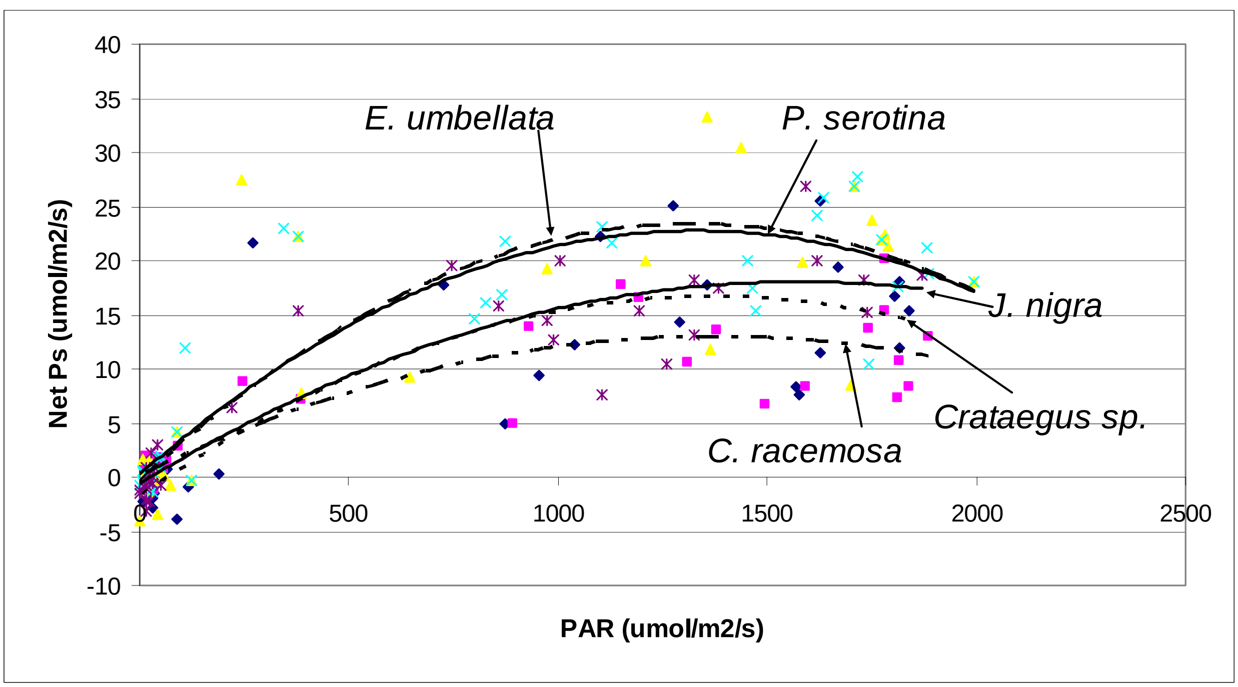

Figure 3: Net photosynthesis rates of five plant species as a function of PAR intensity in meadow site (field community).

In the meadow site, *E. umbellata* and *P. serotina* showed comparable photosynthesis rates across the PAR spectrum (Fig. 3). At the very low PAR intensities, *E. umbellata* (0.1 umol/m2/sec), and *P. serotina* (0.5 umol/m2/sec), while exhibiting faster net photosynthesis rates at higher light intensities, fix carbon more slowly than *C. racemosa* (0.7 umol/m2/sec). These data suggest that while *E. umbellata* has a significant competitive advantage in moderate to high light intensities to all but *P. serotina*, it may be inferior in environments where low levels of light are able to penetrate the leaf canopy.

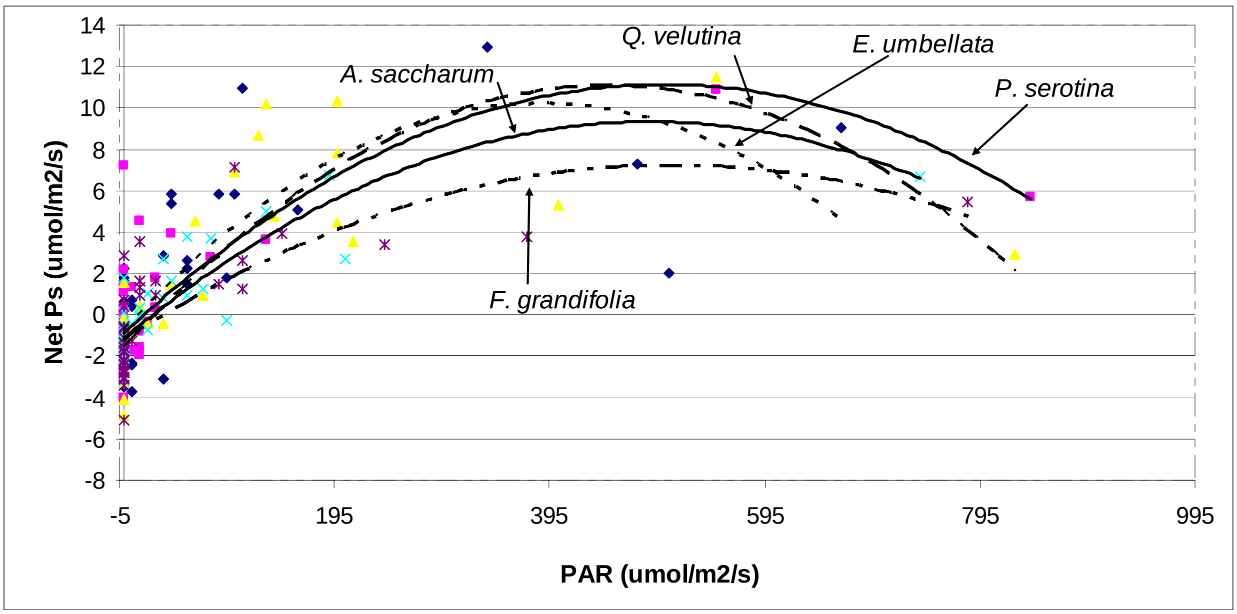

Figure 4: Net photosynthesis rates of five plant species as a function of PAR intensity in forest site (forest community).

In the forest site, in the low to middle radiation levels (0-400 umol/m2/sec), *E. umbellata* fixed carbon at a faster rate than the other species measured, as evidenced in Figure 2. *E. umbellata* and *P. serotina* had photosynthesis rates similar to one another, but *E. umbellata* was faster, similar to the field experience of Figure 3.

Glyphosate treatment of cut stumps

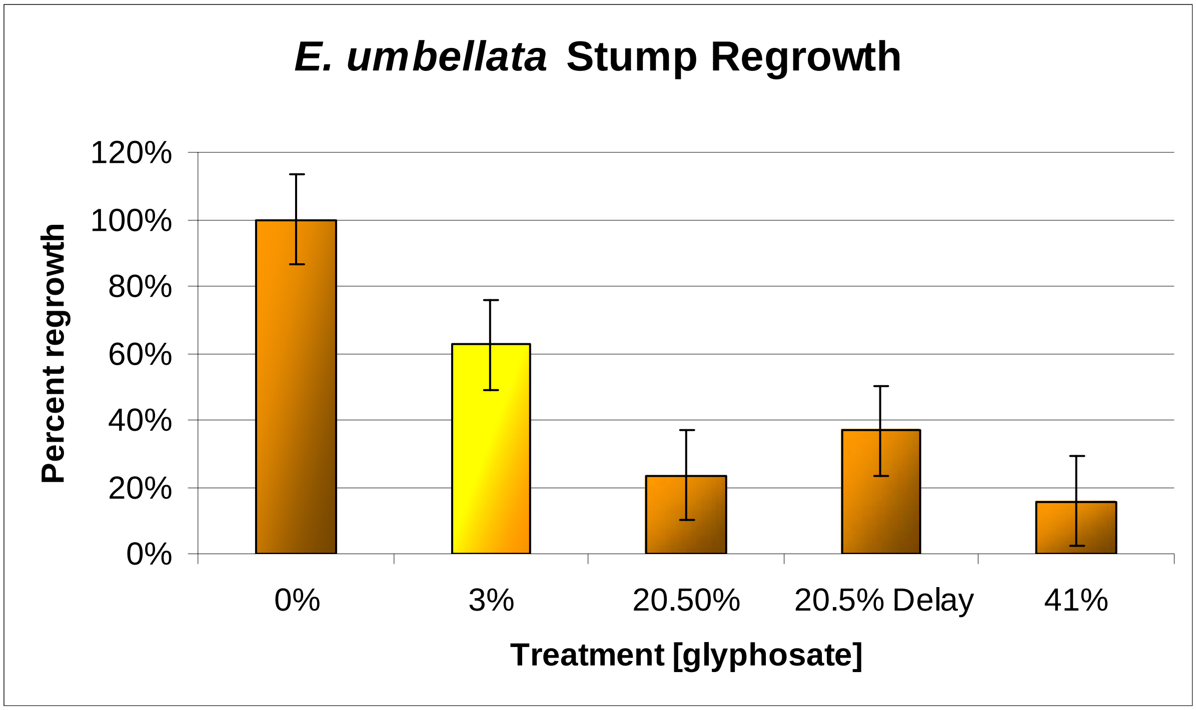

Figure 5: P>0.01 Error bars +/- One Standard Error

Eight weeks after glyphosate application, stumps were checked for re-growth. As the concentration of glyphosate increased, the frequency of re-growth declined (Figure 5). All untreated stumps exhibited re-growth in this test period, and three percent glyphosate exhibited 63% re-growth. Differences among 20.5%, 41%, and 20.5% after a 30-minute treatment delay were insignificant, ranging from 16 to 25%.

To further quantify the amount of re-growth, stumps were rated based on the extent of re-growth: stumps with 1-10 new shoots were given a rating of 1, 11-20 new shoots were given a rating of 2, and 21 or more new shoots were given a rating of 3. In contrast to the results of Figure 5, 41% and 20.5% glyphosate treatments produced an average re-growth rating of 0.2 and 0.4 respectively, as seen in Figure 6. The 20.5% delay treatment, however, produced an average rating of 0.7, suggesting that while a significantly different number of stumps did not express re-growth those that did produced fairly vigorous growth. Accordingly, it seems expedient to use 20.5% glyphosate while taking precaution to avoid significant time delays between cutting and treatment. Such a delay apparently interferes with the absorption of glyphosates active ingredient, thus reducing its efficacy.

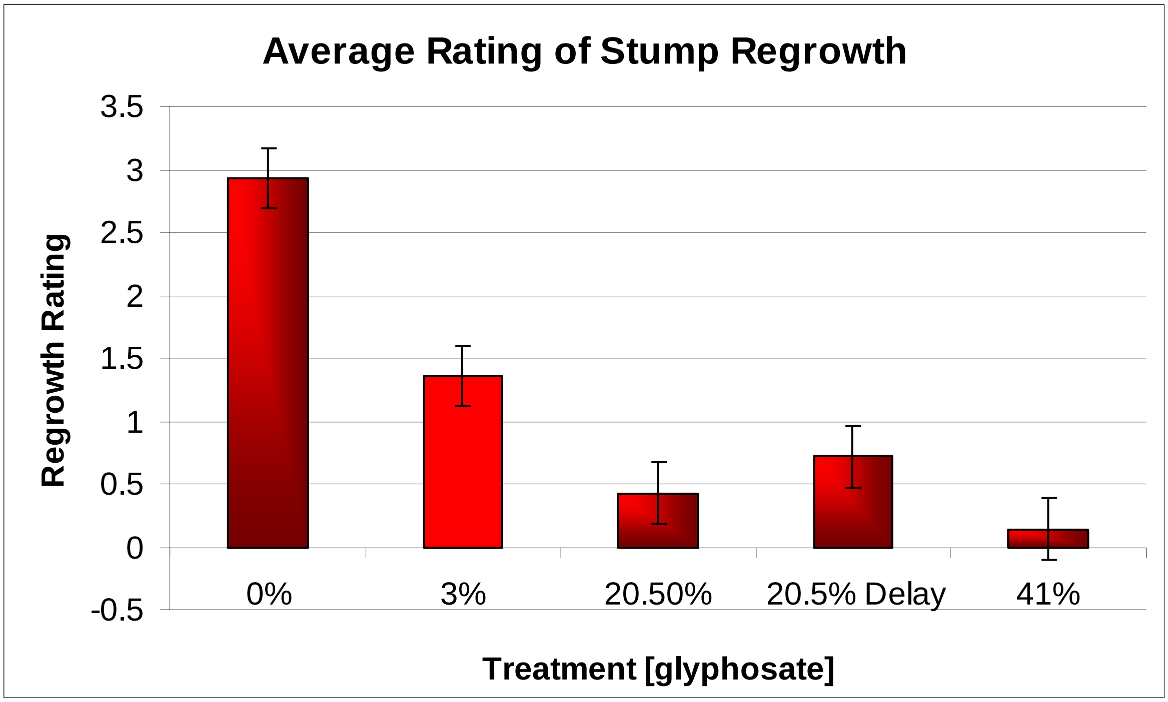

Figure 6: P>0.01 Error bars +/- One Standard Error

Discussion:

Early succession species like *P. serotina* grow well in open, sunny areas. Unfortunately, *P. serotina* was the only native species having net photosynthesis rates that could match those of *E. umbellata.* At the beginning of the research period, *Crataegus sp.* showed promise as a photosynthetic competitor to *E. umbellata*. However, most of the leaves were shriveled or had fallen off the *Crataegus sp.* shrubs after six weeks of research due to a cedar rust infestation in the meadow site *Crataegus sp.* community. Before the infestation ran its course, photosynthesis rates of illuminated leaves on *Crataegus sp.* were similar to those of *E. umbellata*. If *Crataegus sp.* did not experience this fungal infestation, it most likely would have experienced faster photosynthesis rates, thus making it a closer competitor for *E. umbellata*. This is just one example of the different effects of a natural control on native and non-native species.

As trees in the mature canopy of the forest site start dying, *E. umbellata* would potentially prevent germination and growth of native species seedlings. *E. umbellata*'s ability to proliferate in a concentrated area could induce intense competition for water and light resources may restrict growth of native seedlings (this would be a great lead-in to comparing water and light use efficiencies of AO and natives…maybe in another draft).

Attesting to the shaded nature of the forest under-story, few data were collected at the higher radiation levels (401-800 umol/m2/sec). The absence of highly illuminated leaves made it difficult to assess carbon fixation rates accurately at higher radiation levels in the forest community. (The main question I wonder about ... can we assess more accurately the ps rate of different species at very low PAR levels? Is AO slower there as in meadow, as we might logically expect? These curves don't really show us ... probably need to eval in a different way with the database.).

E. umbellata could fill open gaps in the forest canopy, thus reducing the amount of radiation available to native seedlings. In the forest under-story, *E. umbellata* was found in the more illuminated areas (PAR 800 umol/m2/sec and above), but there was no statistical difference between the amount of radiation reaching *E. umbellata* plants and the other species. It has been suggested that *E. umbellata* cannot be characterized as a shade-intolerant species (Sanford *et al.* 2003). This is consistent with our findings as *E. umbellata* has the fastest net photosynthesis rate of the species studied in the forest site. According to Yates *et al.*, *E. umbellata* was more likely to invade forest interiors than the invasive species *Rosa multiflora* and *Lonicera japonica* because it can tolerate light shade (Yates *et. al*, 2004).

Whatever the physiological advantage of invasive non-natives, the threat of invasion is constant. In a survey of woody invasive exotics in Northeastern United States, the non-native species *Acer platanoides, Ligustrum vulgare,* and *Lonicera morrowii* demonstrated the ability to occupy a large portion of the space in at least some forests between the years of 1938 and 1999 (Hunter & Mattice, 2002). *E. umbellata* has already shown invasive potential in the forest site, and especially in the meadow site.

Glyphosate treatment

Natural controls for *E. umbellata* do not exist in Michigan. Over the course of ten weeks of research, *E. umbellata* shrubs in the meadow and forest sites experienced minimal to no herbivory. *E. umbellata* is a typical non-native shrub because it experiences little to no competition from other species, and little to no predation. Since natural controls do not exist, human intervention is required to control rapidly expanding *E. umbellata* populations.

A benefit of using glyphosate to treat invasive species is the fact that glyphosate is biodegradable, thus minimizing the amount of damage to the environment. Glyphosate is generally non-toxic to animals and humans (Cornell University). Glyphosate is available to the general public in low concentrations (3.0%) in most supermarkets. This concentration was tested in our experiment, and it was found to be mostly ineffective at preventing re-growth.

The data suggest that a modest time delay between cutting and treatment should not reduce the efficacy of the glyphosate treatment. It appears that there may be a significant benefit of using at least a 20.5% solution of glyphosate for *E. umbellata* treatment. The statistical analysis suggests that higher concentrations will likely not provide improved control. However, in a practical sense, the 41% glyphosate treatment prevented re-growth better than the other treatments. The stumps treated with 41% glyphosate exhibited scarce, sickly re-growth, whereas the 20.5% treatment re-growth was fuller and greener. In spring of 2007, stumps will be checked again for re-growth. A possibility exists that the stumps treated with 41% glyphosate will show as much re-growth as the 20.5% treatment.

Soil Nitrogen Content

In hopes of further characterizing *E. umbellata's* competitive advantage, an analysis of the soil nitrogen content surrounding *E. umbellata* shrubs in differing habitats was planned. Soil samples were collected and plant-available nitrate and ammonia were extracted from the samples. Unfortunately, an effective method for analyzing the soil extractions has not been available at Calvin College as of yet. The soil samples and soil extractions will be preserved at Calvin College for future analysis.

Conclusions:

Through its rapid photosynthesis rates, *E. umbellata* is a threat to native biodiversity in (the Midwestern United States/ temperate climates/ other?). Few native species of trees and shrubs in this study could compete with its rapid photosynthesis rate. By cutting and treating freshly cut *E. umbellata* stumps with glyphosate herbicides in varying concentrations, we sought to prevent shoot re-growth. The strongest concentration exhibits the best control of *E. umbellata* in the weeks following herbicide application. Further evaluation of other characteristics influencing the success of *E. umbellata* in temperate habitats would lead to better understanding of both the needs of native plant life, and the *E. umbellata* advantage has over those needs.

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