Abstract-Two topographically similar regions located in the Upper Peninsula of Lake Michigan were analyzed and their seedling density of jack pine regeneration & mature jack pine density were determined. Trout Lake, which was burned forty years ago, served as the control/chronology comparison to the recent burn of two years ago at Sleeper Lake. Fire is needed for the establishment of jack pine seedlings. Each site was broken up into three zones. Each zone at Trout Lake displayed significant correlation to depth to bare mineral soil and seedling density. An inverse relationship was found between density of seedling establishment and ensuing mature tree density.

Key Words-Jack pine, Pinus banksiana, Wetland, Trout Lake, Sleeper Lake, Seedling, Regeneration, Fire, Forest, Depth to bare mineral soil, Organic layer, Mature, Density, Upland, Midland, Boreal.

INTRODUCTION

Pinus banksiana is a characteristic species of boreal forests (Li et al. 2009). These forests often experience various natural and artificial disturbances, such as wild fires and lumbering (Li et al. 2009). Although the jack pine and other boreal species can regenerate artificially following a disturbance, a successful natural revival is of immense importance (Li et al. 2009). North American jack pine stands are generally characterized by an even-aged structure resulting from high intensity fires (Smirnova et al. 2008). In the boreal biome, fire triggers a phase of fast nutrient cycling and tree regeneration (Li et al. 2009). This generally results in the recovery of a forest with basically the same properties as the pre-fire forests (Li et al. 2009). Serotiny, the capacity to retain seed in the plant canopy has evolved in many species under the selective pressures of fire (Gauthier et al. 1996). This feature is considered to be the main adaption of jack pine to the recurrence of fires, as it generally does not resprout in the absence of it (Gauthier et al. 1996). In the jack pine, the resin of serotinous cones melts only at or above 50 °C, so seed release mostly occurs after a fire (Gauthier et al. 1996).

Before Europeans came to North America and even before Native Americans inhabited this land, fire was a natural process that went unchecked and determined ecosystems structure and composition. It was not until the recent emphasis on fire prevention that jack pine's association with fire was investigated. The majority of American citizens associate fire with danger and fear; something that needs to be prevented at all costs. (Omi 2005) This prevention subsequently leads to a degradation and loss in biodiversity within ecosystems that depended on this natural disturbance (Arno and Alison 2002). Fire should be looked at as giving birth to and aiding in the success of certain ecosystems. Additionally, some species depend on jack pine as habitat for survival and reproduction, such as the Kirtland warbler (Barnes and Wagner 2004).

Studies have shown that jack pine germination rate decreases along a gradient fire occurrence and severity (Luc 1993). Furthermore, the proportion of *P. banksiana* seeds that produced seedlings surviving 13 months after sowing is .4% to 4.3% (Luc 1993). Thus, even though seeds can be released and germinate after a fire, their survival rate is remarkably low; a fire is needed for the mass dispersal of seeds. Moreover, there is data that supports the hypotheses that there is an increase in overall species diversity in newly established stands post disturbance; notably more than in the partial disturbance or no disturbance sites (Li et al. 1993).

Preserve the variety of forest structure types at the landscape scale is crucial for the protection of species (Lecomte et al. 2006). As noted earlier jack pine is a fire dependent species; without the incidence of wildfires or proscribed burns, jack pine will turn out to be dominated by *Picea mariana* and *Larix laricina* in wetlands

(Adamowicz 1985). Seed dispersal in the absence of fire will ensure the persistence of jack pine, but not its current significance (Adamowicz 1985).

Our study adds to the cannon of previous research by investigating seed establishment of jack pine to subsequent location and density of mature trees. While making observations of jack pine' arrival at Sleeper Lake, which burned 2 years, ago, we noted the mass extent of seed establishment in the wetlands. Yet, when compared to Trout Lake a site that was burned 40 years ago it was noticed that mature tree density was two fold as much in the uplands than it was in the wetlands. This study was performed to investigate the reason and relationships that the zones near wetlands, which have higher initial seed dispersal, lack mature tree density in comparison to the surrounding uplands.

We hypothesize that because seedling density is highest in the wetland zone and decreases as distance from the wetland increases, that the depth to the bare mineral soil is inversely related between seedling germination and mature tree density. Our independent variable was seedling establishment, which was operationalized by counting the seedlings along, transects. The dependent variable was mature tree density, which was operationalized by using a center point-quarter method. Lastly, our moderating variable, depth to bare mineral soil, was operationalized by taking soil core samples along our transect lines. There are variables other than the thickness of the organic layer that were not considered such as fire intensity, aerial seed banks, sun availability, etc. but we selected soil depth to focus on because it appeared to be the strongest moderator, as indicated by much of the literature. Jack pine seed in northern areas only germinates heavily following fire and most of the sprouts die except if the organic matter left on the soil is less than 1.3cm (Burns & Honkala 1990). These variables were gathered in three zones: wetland, midland, and upland. We used the two sites Sleeper and Trout Lake to compare the density of seeds two years after a fire (Sleeper lake) to the ensuing mature tree stand density relative to location 40 years after a fire (Trout lake) along with the data collection depth to bare mineral soil (thickness of organic layer).

METHODS AND MATERIALS

Study sites

Sleeper Lake is located in the Upper Peninsula of Northern Michigan. A fire occurred at this lake and around the surrounding region in August 2007. The fire burned about 20,000 acres in Luce County north of Newberry. Trout Lake provided a similar jack pine dominated landscape for analysis comparison; this site was burned 40 years ago (Adamowicz 1985).

Data collection

Data were initially collected along eleven transect lines: four in the wetland, three in the midland, and four in the upland. Only three transects were located in the midland due to the sharp transition from wetland to upland. The transect lines, which were 100 meters in length, ran parallel to the wetland. The distance between the wetland transect lines was set at 20 meters, while the distances between the lines in the midland and upland were set at 10 meters apart due to the limited site of the upland dune feature.

Depth to mineral soil was taken by measuring the thickness of the organic layer. These samples were taken using a random design system along the transect lines. To introduce distance randomness into our collection method a coin was flipped to decide the increments between sample points. At the beginning of each transect an initial soil sample was collected. Following the initial sample, a coin was flipped to determine whether the next point was 10 or 20 meters away. At each sample the coin was tossed to determine the distance to the next sampling site. This data was recorded on survey sheets created by our team.

At these distances along the transect line that were determined randomly and the point-center quarter method was used to determine mature tree density. The method is based on linear measurements, a form of plot-less sampling as apposed to an area measurement. A crucial rule to ensure proper calculation of tree density is to make sure that no tree is used or counted twice. The procedure of the point-center quarter method is as follows.

a) Locate the transects that were initially laid down
b) Locate the sample point determined by the coin toss
c) Each sampling location represents the center point of four imaginary lines.
d) Inside each individual quarter sampling will be taken on the nearest tree.
e) Record the distance from the center of origin to the tree.
f) Then record the tree height and diameter

To record seedling density count the number of seedlings in a 1x1 m^2 square sampling frame at the corner of each imaginary quarter that touches the center point.

Randomly selected trees were cored along with height to determine the productivity and age of the site. These measurements were averaged together to determine where the site fit in on a productivity site index of *P. banksiana*. This site index curve was utilized to compare Trout and Sleeper Lakes productivity and furthermore to analyze the difference in productivity between the zones at each site.

Statistical tests

Seedling Density

A *One-Way ANOVA* was utilized. After it was determined that there was normal distribution a *t test* was run comparing: upland vs. midland, midland vs. wetland, and wetland vs. upland.

Depth to bare mineral soil

There was normal distribution between for upland and midland however the distribution for the lowland had a ratio of 2 for *Kurtositis S.E. / Stat.* After a *Kruskal-Wallis Test* was performed, Non-parametric analyses through *Mann-Whitney Tests* were run comparing: upland vs. midland, midland vs. lowland, and lowland vs. upland.

Depth to bare mineral soil vs. seedling density

Seedling density and depth to bare mineral soil were both significantly correlated to slope position. So a linear regression of the two variables was performed.

Mature tree density

A general trend comparing the two sites by pairing matching zones was compiled for mature tree density. This is due to the nature of our collection method that did not allow us to run statistical tests (Further discussed in discussion section).

Carex pensylvanica

A *One-Way T Test* was run to compare the *Carex pensylvanica* densities on the uplands of both sites.

RESULTS

Seedling density at Sleeper Lake exhibited significant variance based on slope position; upland vs. wetland (P<.001, t=-5.577, df=158), upland vs. midland (P<.001, t=-5.009, df=138), midland vs. wetland (P<.002, t=-3.14, df= 138) (Figure 1). Depth to bare mineral soil also exhibited significant variance based on slope position (figure 1); upland vs. wetland (P<.001), upland vs. midland (P<.001), midland vs. upland (P<.001). Furthermore, seedling density exhibited a general trend based upon depth to bare mineral soil at Sleeper Lake (Figure 2). At each site mature tree density increased in a general trend from wetland to upland (Figure 3). *Carex pensylvanica* showed no significant difference of cover between sites (P=.328, t=.982, df=158).

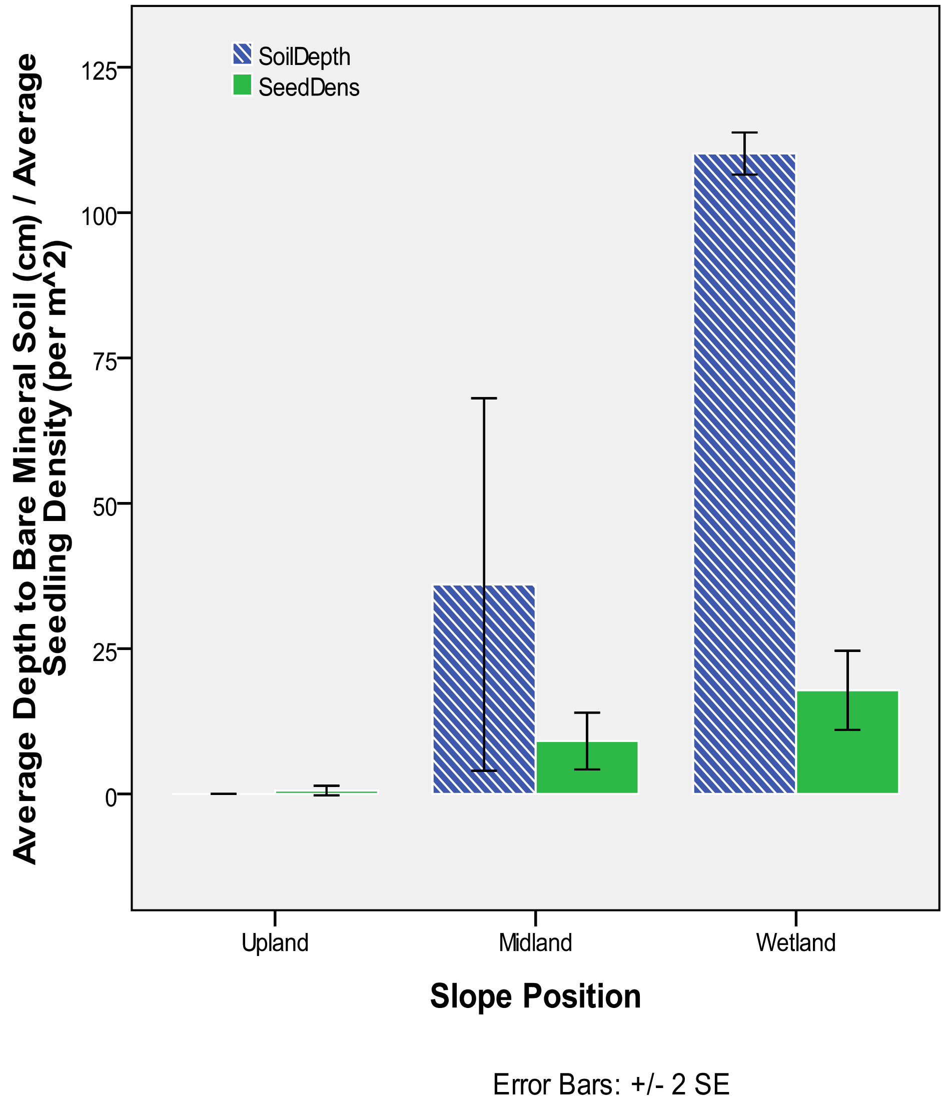

Fig. 1, A VISUAL REPRESENTATION OF SEEDLING DENSITY & DEPTH TO BARE MINERAL SOIL CATAGORIZED BY ZONE WITH STANDARD ERROR BARS[1]

[1] *Sample size for seedlings density was 80 for the upland, 60 for the midland, and 80 for the lowland. Sample size for depth to bare mineral soil was 12 for the upland, 8 for the midland and 12 for the lowland.*

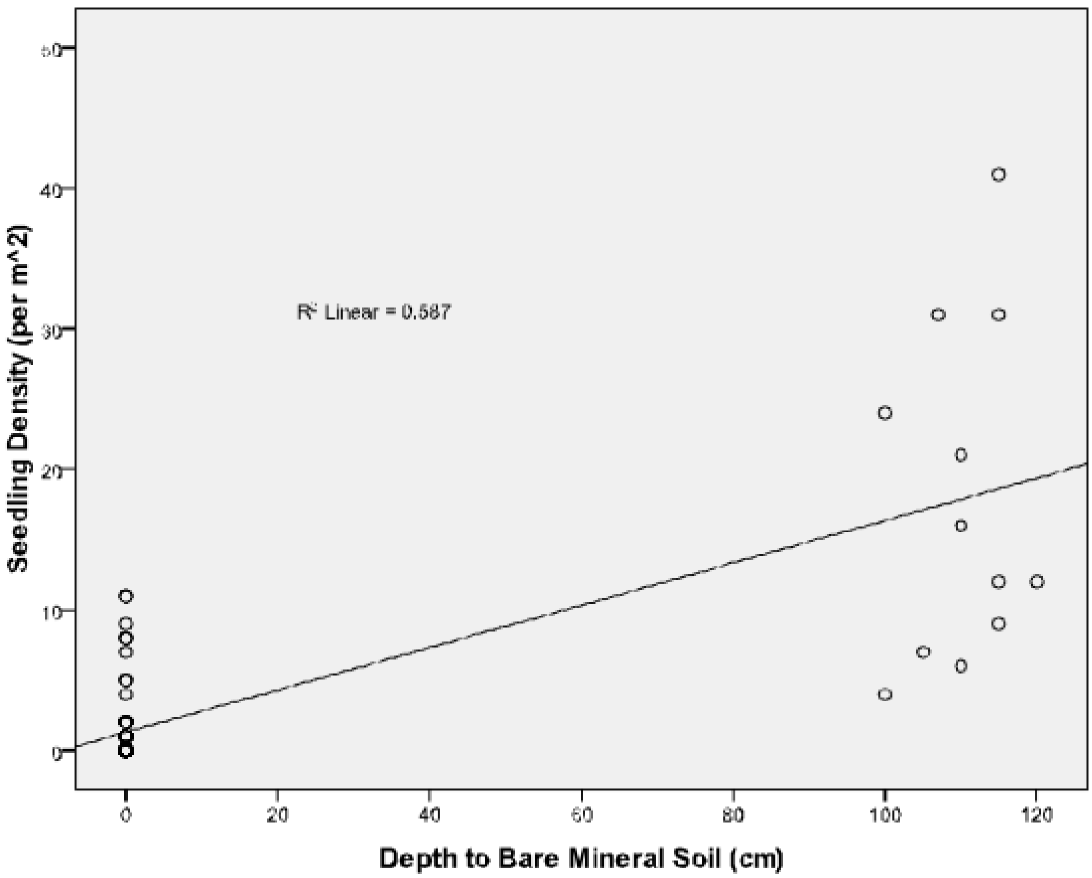

Fig. 2, LINEAR REGRESSION OF DEPTH TO BARE MINERAL SOIL VS. SEEDLING DENSITY

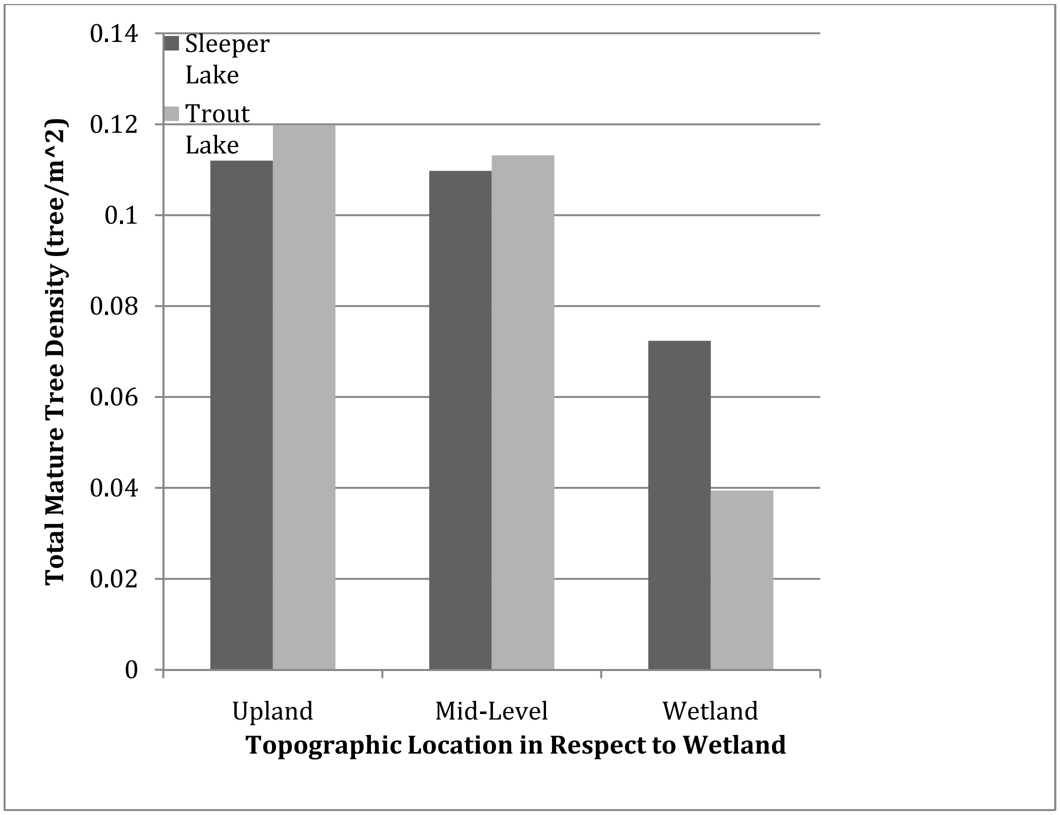

Fig. 3, MATURE TREE DENSITY AT SLEEPER AND TROUT LAKE, SEPERATED BY ZONE

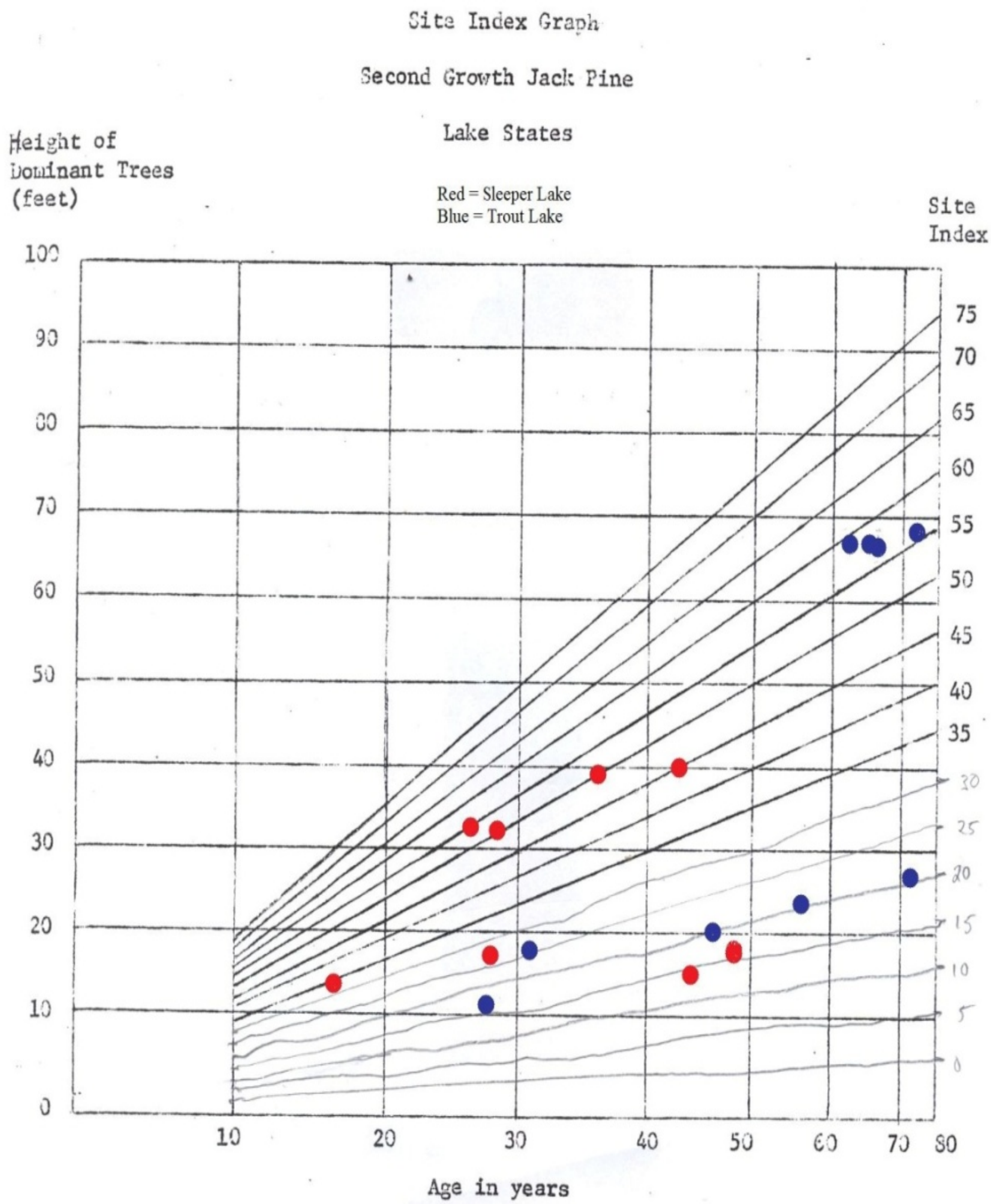

Fig. 4, SITE INDEX GRAPH OF SECOND GROWTH JACK PINE IN THE LAKE STATES WITH TROUT LAKE REPRESENTED BY (X) AND SLEEPER BY (CIRCLES)[2]

[2] *each zone had three trees cored and all wetland trees fell below site index curves*

Table 1, SITE INDEX OF STUDY SITES

Site	Elevation	Site Index
Sleeper Lake	Upland	47.50
Sleeper Lake	Midland	41.00
Sleeper Lake	Wetland	26.33
Trout Lake	Upland	58.67
Trout Lake	Midland	31.00
Trout Lake	Wetland	22.67

DISCUSSION

Results show that slope position significantly dictates both depth to bare mineral soil & seedling density after a fire. Because of this result depth to bare mineral soil dictated seedling density, however this only displayed a general trend. Yet, since there was a general trend of mature tree density by zone, some conclusions can be drawn from the data. The data show that mature trees are most likely to be found in the upland and that site index for individual zones shows that upland zones are around twice as productive as the wetland zones. However, this is where there was the lowest tree seedling density. Because, the seedling density was highest in the wetland; the same zone where every tree fell below all standard site index curves and where the depth to bare soil mineral depth was greatest, we considered to soil depth to be the moderating variable. Lastly, we included the percentage cover of *Carex pensyvanica*, based on the observation at Sleeper Lake where it seemed that this rhizomenous species could have been a third party variable influencing seedling density in the upland. However this was not the case; it had the similar establishment at Trout Lake, which was documented by the lack of significant correlation between the sites.

The literature on the jack pine revolves around the fact that seedlings will only survive in bare mineral soil of around 1cm or less. But, no literature was found about the initial establishment of the seeds and their survival rate for the first few years with regards to wetlands. According to our research jack pine seedlings establish in higher numbers in wetlands when depth to bare mineral soil is 100cm or greater. However, these seedlings may not persist and potentially face a severely high rate of mortality.

If this research were conducted again with modified methods, there would undoubtedly be stronger correlations and most likely highly significant data. First, only two zones should be sample: upland and wetland. The sharp transition between upland and wetland did not justify our sampling along this ecotone. In other words, this is why there was such a larger error bar on the midland soil sample plots. The transect that we laid out over this potential midland region were simply straddling upland or lowland and this is why the soil depth was 0 or 100cm with no measurements in-between that range. Furthermore, new sites could be located or even created with fire burns. If two sites were in the same location right next to each other there would have to me no site index comparison to make sure we were measuring similar factors.

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