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An Ecological Investigation into a Remnant Oak Savanna in Southern Minnesota

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AN ECOLOGICAL INVESTIGATION INTO A REMNANT OAK SAVANA IN SOUTHERN MINNESOTA

by

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Abstract:

A small forested plot in Northfield, MN was examined to determine if it is a remnant oak savanna and to gather baseline data to assess the area's present successional status. The canopy of the 90m X 90m test site was dominated by old growth Quercus macrocarpa (bur oaks). The plot was divided into periphery and interior according to the size of surrounding shade-tolerant saplings, and radiation levels in both areas were measured over three days. The height of each oak's lowest living lateral branch was recorded along with the number of dead branches below it. Spatial dispersion, coverage, and the map location of each old growth oak were also determined. A soil pit was dug in the remnant and a nearby late-successional forest plot. Nitrates, percent organic matter, and pH were compared between the remnant and the comparison plot. There were significant differences in radiation levels, lowest living lateral branches, and number of dead limbs below the lowest living branch between interior and periphery oaks. Results suggest that each shade-intolerant Quercus macrocarpa is being overtaken from its base up, as growing invasive species reduce its light. Dispersion tests revealed a slight tendency toward a contagious pattern in the oaks, especially in the southern corner of the plot. The oak coverage estimate was less than 70% and, therefore, within the classification range of an oak savanna ecosystem as defined by the state of Minnesota. The oaks' narrow diameter range suggests that most of the oaks were established during the same time period. Although soil tests did not reflect prairie conditions within the remnant, its lower organic levels could have resulted from compacting of the soil by grazing and a rapid adjustment of soil properties to closed canopy conditions. Overall results suggest that the study plot is a remnant oak savanna undergoing rapid invasion of late-successional species.

Introduction:

Settlement has greatly reduced the amount of oak savanna existing today in the United States. Marschner's map of Minnesota (1974) indicates that around 1,829,750 hectares of oak savanna existed prior to settlement. Oak savannas once covered 11 to 13 million hectares of the midwest (Abrams 1992). Fire-breaks formed by transportation networks caused rapid fire cessation. Within twenty to forty years of settlement, oak savanna virtually disappeared. In 1985, an investigation found only 113 sites totaling 2,067 hectares of relatively high-quality oak savanna remaining in the midwest (Nuzzo 1986). This is approximately 0.02% of the original extent. All but around 161,000 m^2 of these remaining savannas were found on sandy, rocky, or similarly dry substrates, and none were intact, high-quality deep soil mesic savanna areas.

Savanna has become the general name in many European languages for a plant community in which trees are so sparsely dispersed that grasses and other herbaceous vegetation are allowed to become the actual dominants of the community (Curtis 1959). It is an intermediate ecosystem between forest and prairie. Although tropical savannas are largely independent of climate, temperate savannas are best developed in the climatic belt separating forests from grasslands. This intermediate community between forests and grasslands parallels the intermediate climate.

Oak savannas with an intact ground layer are thought to be the rarest plant communities in Minnesota and Wisconsin (Curtis 1959). Almost all of them have been converted to farm land or forests. An early study of oak savannas by Bray examined 59 stands in southwestern Wisconsin (Bray 1955). One of Bray's major difficulties was finding stands in their pre-settlement condition. The oak openings changed quickly to closed oak forest in the absence of fire. The oak forest can, therefore, be considered a community intermediate between prairie and a closed canopy forest. Hannah Dunevitz of the Minnesota Natural Heritage Program estimates that between 0.08% and 0.10% of the original amount of class C or better exists today (ranking system evaluates the quality and condition of natural communities: A-highest, D-lowest; Dunevitz 1995). Remaining savanna remnants are most likely not representative of their presettlement ecosystems. They survived because most existed on marginal soil (sandy or rocky) or within rough topography, which was not favored for development.

Historically oak savannas were not recognized as a viable ecosystem but, rather, an intermediate between two others--prairie and hardwood forest. This makes an investigation into its historical and even present extent very difficult due to the massive amount of subjective vocabulary used in its description. Early surveyors, settlers and explorers used such terms as barrens, oak openings, scrub prairie, brush prairie, brush savanna, open woodland, scattered timber, meadow, prairie, and oak scrub (Curtis 1959, Nuzzo 1986, Dyksterhuis 1957). Even General Land Office surveyors lacked a standardized terminology, using the same term to describe many vegetation types or using different terms for the same community.

These accounts were given by laymen, while no detailed scientific studies exist.

Such confusion has led to a number of classifications systems for midwest oak savanna. Curtis described a savanna as having more than one oak per acre with not more than 50% coverage (Curtis 1959). Missouri accepts coverage of 10 to 50%, while Ohio may consider a stand of 100% coverage to be savanna (Nuzzo 1986). Coverage alone is insufficient in classifying savanna. Understory vegetation must also be characterized. Minnesota's Department of Natural Resources considers both oak woodland and savanna to have 10 to 70% coverage (Minnesota Natural Heritage Program 1993). Oak woodland is classified as dense brush with less than 30% open grassland, while savanna is the opposite. The *Midwest Oak Ecosystem Recovery Plan* does not focus as much on the floor matrix nor does it combine woodlands and savanna under one coverage definition (Leach and Ross 1995). It considers savanna to have 10 to 25% tree cover, while woodland has 25 to 60% coverage. This system has no specific guidelines for the floor matrix because the groundlayer species are thought to be determined by the canopy structure. To restore and inventory existing savannas it is essential to develop a consistent criteria for distinctions between prairie, savanna, woodland, and forest.

Remembering his boyhood in Columbia County Wisconsin, John Muir described the encroachment process. "As soon as the oak openings in our neighborhood were settled, and the farmers had prevented running grassfires, the grubs grew up into trees, and formed tall thickets so dense that it was difficult to walk through them and every trace of the sunny 'opening' had vanished" (Curtis 1959). For restoration of these lost ecosystems to be successful, we must first understand the unique local conditions that maintain each savanna. Savanna ecology differs greatly from site to site according to varied topography, soil and vegetation types, and microclimate. Some major factors which determine the location of savanna ecosystems include the rate and intensity of fire (to control outside competition), soils, climate, number of oaks in an area, and the amount of light they need.

Oak savanna originated in the most recent glaciation. A rapid retreat of the Laurentian ice sheet occurred 10,000 years ago marking the beginning of the Holocene. This resulted in a major change in climate across the Midwest. The impact of the Arctic airstream was reduced, allowing more influence from the dry Pacific and warm tropical Atlantic airstream. The Holocene saw a reduction in precipitation and an increased windiness, allowing the prairie border to move east about 8700 years before present (1950). The prairie took up a large portion of the Midwest (Bradbury et al. 1993). The last 10,000 years has shown continual climatic change, constantly shifting the prairie-forest border where savannas exist (Whitney 1994, Jacobson and Grimm 1986). The border shifts according to the relative importance of the Arctic, Pacific, and Gulf air masses. Fire-history analyses indicate that changing climate also reveals changing fire regimes (Clark 1990, Bradbury et al. 1993). The past 4,000 years terminated the prairie period and established modern climatic and environmental regimes.

Midwestern soils reflect these climatic changes. Although soil formation depends a great deal on local conditions (specific vegetation types and their microclimates), a general comparison can be made between prairie and forest soils. Humid temperate deciduous-coniferous forests and deciduous forest regions are associated with alfisols. Such soil is formed through podzolization, accumulating clay in the B horizon, while the shallow A horizon is darkened by well mixed organic matter (Fuller and Anderson 1993, Smith 1996, Birkeland 1984). The forest floor is covered by a layer of litter called the O horizon. Forest floors often show greater leaching than prairies, causing the soil to become more acidic (Birkeland 1984, Bailey et al. 1964). Hydrogen ions from rainfall displace nutrient cations connected to clay or humus, such as Ca^{2+}, Mg^{2+}, K^{+}, and Na^{+}. Semihumid grassland regions are associated with mollisol. This soil develops from a process called calcification. The dense root systems of prairie species extend many feet below the surface forming a much larger A horizon of humus and mineral soil that is high in nitrogen (Smith 1996). These roots are a major organic input for prairies, whereas the main forest input is litterfall (Birkeland 1984). The amount of prairie rainfall is insufficient to remove calcium and magnesium carbonates.

Two of the most important factors influencing oak savannas are fire and radiation. These two aspects are highly interrelated. Fire allows for the existence of prairie species while not harming the large, fire tolerant bur oaks. Prairie fires burn much cooler and quicker than forest fires (Pierce 1996). Such frequent, low intensity fires maintain the savanna ecosystem. These constantly changing ecosystems are dependent on the range of frequencies and intensities of disturbances. The specific disturbance regime can determine recruitment of species, biodiversity, and structure of the ecosystem. Such regimes vary vastly from site to site (White 1986, Tester 1989, Pierce 1996, Davis 1995). A universal regime for prescribed burning does not exist. Local conditions such as topography allow great variation among savannas. Initial stand structure, in particular larger size classes, imposes some limitation to the extent to which groundfires can open up a stand. Conversely, stand structures are shaped by fire histories (Taylor 1990).

As settlement stopped fires, radiation levels within the oak savannas greatly decreased with the invasion of fire-intolerant species. Invading species (such as sugar maple and basswood) were also shade-tolerant. This shade-tolerance allowed them to outcompete the shade-intolerant oaks for radiation. Due to their fire dependent nature, oak savannas are less well understood than most plant communities of the Midwest. If we are to attempt to restore these rare ecosystems, we must learn how radiation and fire (frequency and intensity) create and maintain the oak savanna.

Oak savanna extends from the southeastern corner of the state northwestwardly to the opposite corner (Figure 1). The narrow savanna band separates the conifer and hardwood forests of the northeast from the tallgrass prairies of the southwest. The "Big Woods" section of Minnesota's Maple-Basswood Forest region is surrounded by oak forest and oak savanna. It is dominated by late-successional, shade-tolerant species. The savanna band encircling the Big Woods and the interrupted forest belt west of the Big Woods are both bur oak (Quercus macrocarpa) savanna (Figure 1).

This study is an ecological assessment of an 8100 m^2 (0.81 ha) forested plot near Northfield, MN, which is likely to be an oak savanna remnant. Almost all of the old growth trees are bur oak, while the younger seedlings and saplings are those of a late-successional, maple-basswood forest (basswood, buckthorn, green ash, ironwood, black cherry and elm). The purpose of my study was to determine whether the study site could be considered an oak savanna remnant and to gather baseline data to assess the area's present successional status. I tested whether radiation levels differed between the periphery and interior of the savanna plot. All old growth Quercus macrocarpa (bur oaks) within the remnant were tested to determine whether the height of each lowest living branch and the number of dead limbs below it differed between the interior and the periphery of the forest. Each of the twenty four old growth oaks in the study plot was mapped, and their spatial distribution was assessed, along with an estimate of their total coverage. Soil tests of nitrate levels, organic matter, and pH were conducted and compared to a nearby forested plot of similar topography (Block 5, #18A; Figure 2). Neither the test plot nor the comparison site had a recorded history of vegetation. However, old growth trees within the comparison site were late-successional species (sugar maple, basswood, elm), allowing it to be used as a late-successional forest comparison to the possible early forest succession, remnant savanna plot (Bailey et. al 1964).

Methods:

The study plot is in southern Minnesota. It is in the southeast corner of the northeast quarter of section 2 within the Bridgewater township of Rice county. The land is owned by St. Olaf College (Block 5, #19; Figure 2). I walked the study plot to determine which oaks were in the periphery of the forest and which made up the center of the canopy. While this process was partly subjective without exact parameters to separate interior from periphery, there was a definite difference between the two portions of the forest (Figure 3). The periphery oaks were surrounded by young buckthorn, elm, green ash, and black cherry saplings which reached no higher than the oak's lowest branch (Figure 3A). The interior oaks were completely surrounded by much larger saplings (Figure 3B). I took circumference measurements of the ten largest periphery saplings and averaged them (15.5 cm) as another guideline for oaks on the periphery. Saplings larger than the averaged circumference were considered part of the interior. Smaller individuals were part of the periphery. These young invading saplings on the periphery had not yet begun to directly compete with the oaks for radiation, leaving large portions of the bur oaks open to the sun.

In September, two LI-COR L1-1000 data loggers were used to record photosynthetically active radiation (400-700 nm) every hour over a three day period. One data logger was placed in the center of the forest, and the other was placed under an oak at the edge of the forest in an area which was representative of the periphery coverage. In addition, a hand held LI-COR L1-189 photometer was used in the open field outside the study plot to record ambient radiation at two or three points during each of the three days. These measurements were used to model the amount of radiation each oak would have received during the three days if fire had kept the larger invasive trees out of the area.

Each of the old growth bur oaks was measured for decay of lower branches. I took a measurement from the ground to the lowest living branch of each oak. I also recorded the number of dead branches below the lowest living branch.

In February a compass was used to establish the perimeter of the oak savanna plot. The dispersion pattern of the oaks was analyzed to determine whether the old growth individuals were uniformly, randomly, or contagiously spaced. Once the corners were staked, compass readings and 50 meter tapes were used to place a grid over the 8100 m^2 area. The grid was composed of 36 cells. Each cell was 15m X 15m. I recorded the number of old growth oaks within each cell. The cells were then enlarged to 30m X 15m to test their dispersion on a different scale. This second grid was made-up of 18 cells.

Using the northeast and northwest sides of the perimeter as a set of axes, I plotted x and y distance coordinates for each bur oak.

The distance from each oak to both axes was measured following perpendicular compass readings. All twenty four bur oaks within the study plot were then mapped to indicate their relative positions. While taking the distance measurements, each bur oak was tagged, a measurement of diameter was taken, and the longest branch on the west side of each oak was measured and recorded. This number was used to roughly estimate the total coverage of the oaks. Other old growth species were not included due to their small coverage contribution (three individuals). The branch measurement was used as a radius in πr^2 for circular area, and all bur oak coverage areas were added to obtain a general coverage value.

In April, comparison soil tests for the remnant savanna plot and the late-successional forest plot were completed as composite samples. A pit was dug in both plots to determine the depth of the A horizon. Five samples sites were randomly chosen in both plots. A soil sample was taken in the A horizon from 15-30 cm below the surface at each of the five sites per plot. The five samples within each plot were combined to form a composite sample representative of the site. Moisture was removed from the composite samples from both plots by allowing them to air dry for three days. Three samples from both composites were used to test nitrates, pH, and organic matter. An average value for each composite sample was then computed for all three test parameters. The amount of nitrates in the composite samples was determined using a model DR/3000 Hach spectrophotometer (Hach 1988). The pH was determined by adding deionized water, filtering the solution, and using an electronic pH meter. Organic matter was determined for both composite samples by heating the oven dried sample for 30 minutes at 850 degrees with a muffle furnace (Brewer and McCann 1982). Soil samples were taken using the same sampling scheme on 3 different days. Organic matter, nitrates, and pH were then compared between both plots.

An analysis of variance was performed (using Statview 4.5) to compare the mean height of the lowest living lateral branch, the mean number of dead branches below that branch, and the mean level of radiation in the interior and periphery of the test site. Light measurements in the periphery and interior were graphed over each of the three days using Statview. Each recorded ambient light measurement taken by the hand held sensor was also added to the radiation graphs for a third level of comparison. The dispersion data for both cell scales were analyzed by a chi-square goodness of fit test and by Morisita's index of dispersion (Brower et. al 1990). The two grid scales were compared for each test. The oaks were mapped using Cricket Graph III. An analysis of variance test was performed to compare pH, percent organic matter, and nitrates for the savanna remnant and the comparison plot.

Results:

A comparison of mean radiation levels in the interior of the forest and in the periphery showed that radiation levels were significantly higher within the periphery of the forest (Table 1). The mean radiation within the periphery was 125 um/m^2/sec greater than the mean radiation within the interior ($P < 0.001$).

When graphed, I found that all the daytime radiation readings over all three days varied according to location within the savanna plot (Figures 4-6). During daytime hours, the ambient radiation recordings were consistently higher than the periphery and the interior readings. The periphery daytime readings were consistently higher than the interior readings. The readings for ambient, periphery and interior radiation during the second and third day were similar in shape and degree of variation. The peak radiation readings for all three locations over all three days was just after 1:00 p.m.

The lowest living, lateral branch height and the number of dead branches below it varied between periphery and interior oaks. The lower branches of the interior oaks were higher above the ground, and the oaks had a greater number of dead branches below the lowest living branch. On average, the lowest living, lateral branches within the interior were 1.183 m ($P < 0.010$) higher than those within the periphery (Table 1). The average number of dead branches below the lowest lateral branch within the interior was 1.909 greater than those within the periphery ($P < 0.05$, Table 1).

The dispersion analysis using Morisita's index found that the distribution of oaks was not significantly different from random

(Table 3). The Morisita index values of 1.174 and 1.435 indicated that the oaks do have a slight tendency toward clumping. The chi-square goodness of fit analysis showed a similar pattern (Table 2), however, the 225 m^2 plot size was significantly different from random.

The map of the oaks (Figure 7) visually indicated no strong areas of clumping within the savanna plot, although a very slight clustering seems to appear in the southern corner. The summed coverages for all 24 old growth oaks was 5848.6 m^2. Therefore, the coverage estimate for the old growth bur oaks was 72.2% of the plot. More than 70% of the bur oaks were within the 40-60 cm diameter class (Figure 8).

There was significant variation in soil characteristics between the savanna remnant and the forested comparison plot (Table 4). The remnant had higher pH values but less nitrates and organic matter. On average the comparison plot had 0.35% more organic matter ($p = 0.006$), 0.761 ppm more nitrates ($p = 0.0027$), and a pH 0.356 lower than the remnant. The A horizon of the savanna remnant was also 19 cm thinner than that of the comparison plot (Figure 9).

Discussion:

This study indicates that it is likely the study plot is a remnant oak savanna. The canopy is almost exclusively composed of bur oak. Spatial dispersion and total coverage tests reflect the conditions associated with savanna. In addition, the baseline data collected for the plot indicate the area is in a transitional phase of succession. Radiation levels and the decay of lower limbs suggest that the early-successional bur oaks within the savanna are slowly being overtaken as late-successional species invade.

The radiation readings in the representative periphery area were significantly higher than in the interior of the canopy (Figures 4-6, Table 1). The periphery readings were not once below or even equal to the interior readings for the daytime hours over all three days. The similar pattern in the graphs of the second (Figure 5) and third day (Figure 6) reflect similar weather patterns over those two days. While September 27 was mostly cloudy (Figure 4), September 28 (Figure 5) and 29 (Figure 6) were mostly sunny. It is usual for the sun's radiation to peak at around 1:00 p.m. this time of year, which is what I found.

Bur oaks are an early-successional species (Bailey et al. 1964). They have low or intermediate tolerance to shade (Abrams, 1992). A recent study by M. K. Owens (juniper vs. oak in a semiarid savanna) demonstrated the competitive edge of one of the many shade tolerant invaders (Owens, 1996). A reduced leaf area and a different leaf area distribution coupled with lower leaf gas exchange rates explained the lower overall competitive potential of the oak.

The lower branches of the oaks are dying off as radiation within the understory decreases with the continued growth of shade-tolerant seedlings and saplings. As the larger invading species (basswood, black cherry, ash, elm, and buckthorn) cut out more light in the interior of the remnant savanna, it is logical that the height from the ground to the lowest living branch should increase as indicated by my results (Table 1). The lower interior radiation readings reflect this process, as invading species cut out more light within the interior of the forest. Degradation is further represented by the significantly higher number of dead lower branches of the interior oaks in comparison to the periphery oaks (Table 1).

With much greater radiation in the periphery of the savanna remnant, the lowest lateral branches of the bur oaks on the edge of the forest did not die off. The measurements from the ground to the lowest living branch were, therefore, shorter than for the periphery oaks (Table 1). The young invading species on the periphery were not yet large enough to take away radiation at the oaks' bases.

These results suggest that although a few oak savanna remnants do exist, they are not permanent structures. The massive oaks are slowly dying from the ground up as settlement deprives them of the previous conditions which allowed them to thrive. The shade-tolerant seedlings and saplings (basswood, ash, elm, etc.) indicate a late-successional transition. If these invaders continue to enter the area, the present oak canopy will be replaced by late-successional species. Any new oak seedlings will not mature with the shade-tolerant competitors entering the area uninhibited. On the other hand, such results also reveal the possibility of saving these large oaks before they are shadowed over.

The dispersion results show that the 24 bur oaks are generally distributed at random or slightly clumped. The dispersion was not significantly different from random in 3 of the 4 tests using chi-square goodness of fit analysis and Morisita's index. The goodness of fit test for the 36 cell grid was the only dispersion significantly different from random. Although this test does not determine if such a dispersion was uniform or contagious, the Morisita's index indicated a slight tendency toward a contagious pattern. The map of my test site (Figure 7) reveals the southern corner to be the probable source of the clumping tendency indicated in my data.

Dispersion of oaks within savannas tend to show variation, rather than strict randomness. Aggregation is the rule. The trees are usually arranged in isolated patches, groves, or as irregular peninsulas composed of widely spaced trees projecting from a dense forest into the open prairie (Bray 1955, Curtis 1959). Although the study plot is small, it is logical that on a larger scale the oaks randomly associated in this plot could collectively be considered one clumping within a larger area of savanna. Bur oaks are scattered in groves of 1 to 2 hectares (Natural Heritage Program 1993). My study site totals only 0.81 hectares. If it was part of a larger savanna, the plot could, therefore, be considered a single grove of randomly associated oaks within a larger contagious dispersion of groves. While in this case there are no oaks in the immediate area outside my test plot, this does not mean none ever existed. Three of the four adjacent regions to this study plot are developed. Any large bur oaks in these regions would have been cut down. The fourth side is cut by a nearby stream (Figure 2). Even though I could not have tested a larger area, it is likely that the savanna stretched beyond my study plot, as the contagious tendencies in my data suggest.

Considering the large variety of oak savanna classification systems and the confusion within them, it was important to make a clear decision on which guide to follow. I used the Minnesota Department of Natural Resources' classification system because of its input from a large savanna database collected by the Natural Heritage Program and due to its comprehensive account of the prairie matrix (the dominant savanna community) in combination with canopy structure (Minnesota Natural Heritage Program 1993). This classification scheme considers savanna to exist within 10% to 70% canopy coverage. Although my estimate was slightly above this range (72.2%), the actual canopy coverage within my study site is almost certainly within the range. I estimated only bur oak coverage. However, only three individuals of other species were large enough to contribute to the upper canopy and not accounted for. The calculation was intentionally an upper limit to avoid over-estimating the value. The *longest* limb on the west side of each tree was measured to estimate a circular area of coverage. The coverage, however, did not extend to this distance all the way around each trunk. In addition, this estimate did not account for overlap from tree to tree. As the map of the site indicates (Figure 7), there is a large amount of overlap within the small plot, especially in the southern corner.

One characteristic not mentioned in the Department of Natural Resources' classification scheme is the relative age of bur oaks within the savanna stand. My study used diameter as an indirect indication of age. Early accounts and studies are in general agreement that all trees in a particular stand are of the same size and age (Curtis, 1959). The bur oak diameter measurements in the remnant plot reflect this characteristic. Seventeen of 24 oaks (>70%) were between 50 to 70 cm (Figure 8). The others were all in nearby size classes, and none greater than 74.9 cm nor less than 38.3 cm.

The soil comparison of the savanna remnant and the late-successional forest plot (Table 4) reveals that the remnant plot does not reflect prairie soil conditions. It actually has a lower percentage of organic matter (Table 4) and a thinner A horizon (Figure 9) than the comparison plot. The dense prairie root systems result in a higher percentage of organic matter and generally increased nitrates in the A horizon (Birkeland 1984, Smith 1996, Bailey et al. 1964). Most nitrogen in forested sites is usually found in the O horizon due to large amounts of surface litter (Ovington 1953). Much of the forest's organic matter is also concentrated in this surface litter (Birkeland 1984). The only indication of prairie characteristics in the soil of the remnant plot was its pH which was significantly higher than in the comparison plot (Table 4). This may reflect greater leaching in the comparison plot, which is typical of late-successional forest sites (Fuller and Anderson 1993).

These results, however, are not surprising. It is possible that the current soil might not give any indication of recent environmental change. Soils change quickly with changing ecosystems. Nitrogen and pH tend to change most rapidly as environmental conditions are altered. Although organic matter can persist for longer periods of time, its change to new steady-state values can be rapid if its turnover rate is rapid. The grassland areas of the humid midcontinent are examples of such high turnover rates (Birkeland 1984). The larger shade-tolerant saplings of the remnant's interior indicate the area has been forested for a number of years. Tree cores of both the oaks and the interior saplings could give a good indication of the age discrepancy between them. Such direct age assessment of tree species is an important reason for further study of the area. If a prairie did exist during the lifetime of the larger oaks, it is likely that much of the organic matter has already decomposed under the area's current closed canopy. In addition the remnant plot has extremely level topography and would have been an optimal grazing area prior to St. Olaf's ownership of the land. The comparison plot has more rolling topography and areas of standing water, making grazing more hazardous. The remnant plot could have been grazed more heavily, thus quickly compacting the prairie soils and reducing the *A* Horizon.

There are many aspects (other than radiation, spatial dispersion, coverage, and soil characteristics) of oak savannas which need to be researched to better define remnant savannas and to better apply restoration techniques. For example, climate and more in-depth soil studies in an area of probable remnants will help determine whether the area was once a savanna or, if not, whether one could exist under the area's current condition. Although the prairie is the dominant savanna community, it no longer exists within the darker understory of remnants. Other soil analyses, such as lake cores and pollen tests, can be effective in determining if prairie previously existed in the area and how long ago. Different tree densities could also be studied to determine the number of large oaks which allow prairie to thrive below. The density per acre is believed to be variable for savannas (Curtis 1959). The upper limit for oak density is most likely site specific depending upon fire characteristics and the topography of the area.

Fire and radiation are intimately related aspects of the oak savanna ecosystem. Fire is a dominant factor in the survival of both prairie and oak species. Periodic fires prohibit fire-intolerant tree species from growing to sapling height, as they are in my test sight. Fires, therefore, maintain the levels of photosynthetic radiation required by the open-grown, shade-intolerant oaks in the savanna. Savanna species are favored by increasing light intensity (White 1983, Nuzzo 1986). Relative to other hardwoods, oaks are also favored by fire due to their sprouting ability, thick bark, resistance to rotting after scarring, and the suitability of fire-created seedbeds for acorn germination (Abrams, 1992). In 1989 a study conducted on nine portions of oak savanna in east central Minnesota showed that prescribed burning not only aids in oak survival but increases the cover of true prairie grasses and true prairie forbs (Tester, 1989).

Although it is evident that fire plays a critical role in the savanna ecosystem, the specific nature of such fires is largely speculative and site specific. Different size burning areas and burn intensities could be studied to learn how to most effectively manage a restored area with the loss of free ranging fires. White (1986) found that grasses and forbs had higher average frequency values in prescribed burn plots than in the control plot and that burning reduced the oak overstory by killing mainly the smaller diameter oaks. More intense burns killed the larger oaks. With these data, he suggests that pretreatment community structure and composition influenced the burns he studied. One may predict the effects of fire by knowing what plant species are present and how each reacts to fire. White's study also suggested that the type of fire needed for oak savanna restoration may be very different from the type of fire required to maintain an oak savanna. Another study investigated how fire frequency shaped the structure of a Quercus velutina savanna (Nuzzo, 1986). Frequent, low intensity fires rarely killed overstory trees, while high intensity, infrequent fires killed large trees but stimulated dense sprouting, resembling more of a thicket. More frequent, high intensity fires would most likely avoid the thicket growth. White's and Nuzzo's studies together suggest that frequent fires of high intensity are required for restoration of an oak savanna, while frequent, low intensity fires should follow for maintenance.

The results of my study reveal that, without such fire regimes, the oaks do not have enough radiation within the interior of a late-successional forest to survive. The lowest living branch of each oak is higher above the ground in the interior and has more dead limbs below it. The oaks of the interior slowly lose their lower branches as the invading shade-tolerant species get larger and cut out more light.

My study also indicates the high probability that this area was once an oak savanna. Although the prairie matrix has long been overrun, spatially and structurally the trees within the small plot still have the features of a savanna. These features are becoming less and less evident. As a remnant, the site is presently an oak forest with only subtle indications that it was once a savanna. There is also strong evidence that it is quickly progressing beyond an oak ecosystem to a late-successional maple-basswood forest.

Although the large bur oaks still remain in oak forests as savanna remnants, they are dying out. While valuable maple/basswood species may move in (basswood, black cherry, maples, etc.), they are not as valuable as the last remains of the prairie-forest ecotone that previously dominated the midwest (White, 1986). This places much ecological concern on such areas due to the limited time frame we have to restore them. While many of Minnesota's native ecosystems have been leveled due to farming and industry, the remaining oak savanna remnants still retain part of their infrastructure--the massive bur oaks. There is still time save these old growth trees, and regenerate what's left of a now rare ecosystem.

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Table 1: A Comparison of Mean (±Std. Dev.) Radiation, Height, and Number of Dead Branches between the Interior and Periphery of the Oak Savanna Remnant

Character	Number Sampled	Interior	Periphery	p-value
Radiation (um/m^2/sec)	68 (interior) 67 (periphery)	6.8 (±11.1)	131.8 (±273.6)	0.0003
Height of Lowest Branch (m)	13 (interior) 11 (periphery)	4.0 (±1.1)	2.8 (±0.4)	0.0023
Number of Dead Branches (per oak)	13 (interior) 11 (periphery)	3.0 (±2.1)	1.1 (±1.8)	0.0317

Table 2: Chi-square Goodness of Fit Comparison for Old Growth Oak Dispersion in Remnant Savanna Using Two Grid Scales

	450 m^2 Plots	225 m^2 Plots
Degrees of Freedom	2	1
Chi-square Value	3.31	*6.85
Critical Value (=0.05)	5.991	3.841

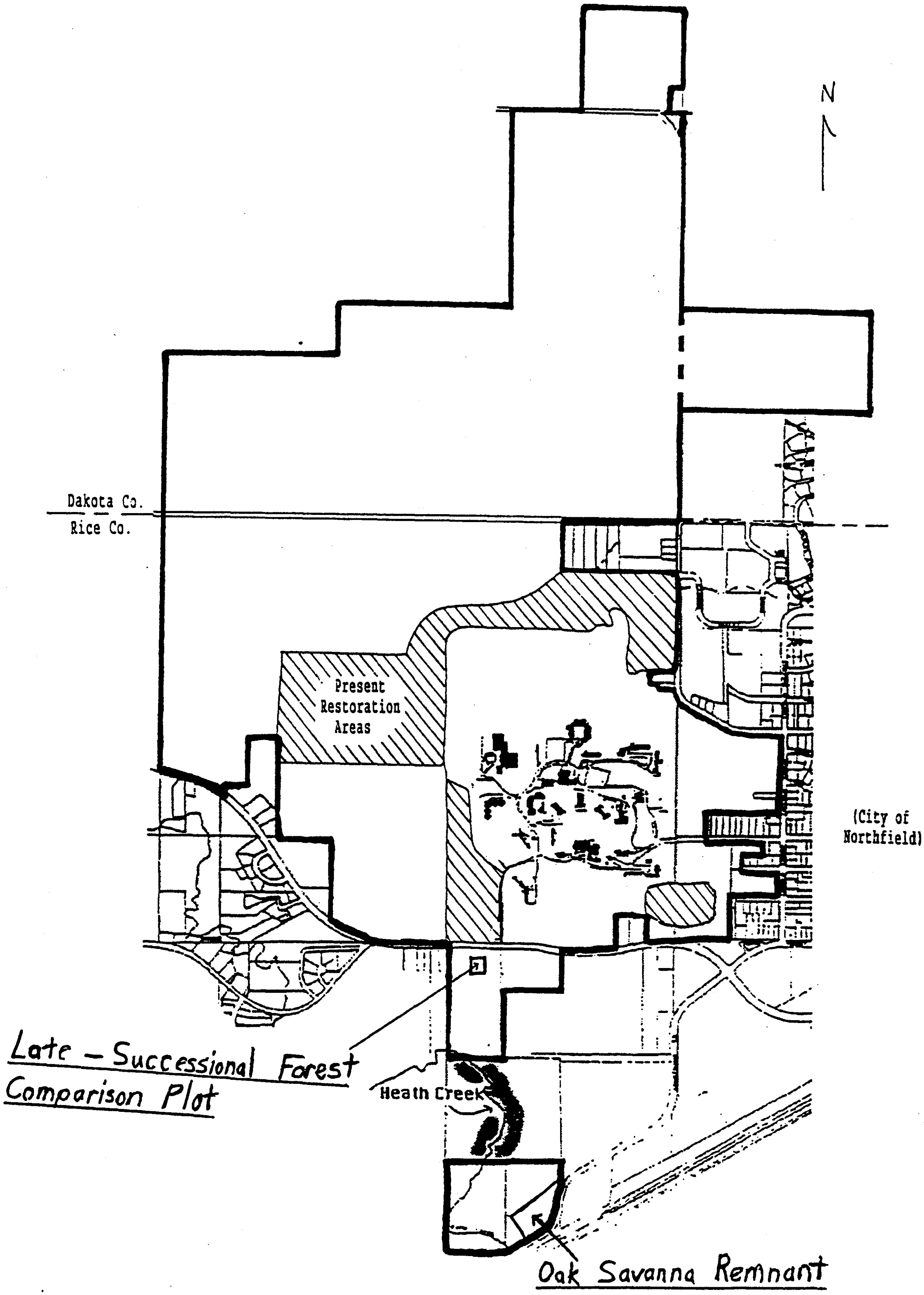
Table 3: Morisita's Index Analysis for Old Growth Oak Dispersion in Remnant Savanna Using Two Grid Scales

	450 m^2 Plots	225 m^2 Plots
Morisita Index	1.174	1.435
Chi-square Value	21	45
Degrees of Freedom	17	35
Critical Value (=0.05)	27.6	49.8

Table 4: A Comparison of Mean (± Std. Dev.) Soil Characteristics for the Savanna Remnant (n = 3) and a Forested Comparison Plot (n = 3)

	pH	Percent Organic Matter	Nitrates (ppm)
Savanna Remnant	6.879(±0.155)	2.751(±0.115)	3.304(±0.530)
Comparison Plot	6.523(±0.085)	3.100(±0.310)	4.065(±0.365)
p-value	<0.0001	0.006	0.0027

Figure 2: St. Olaf College Land Holdings Indicating Location of Oak Savanna Remnant and Comparison Plot



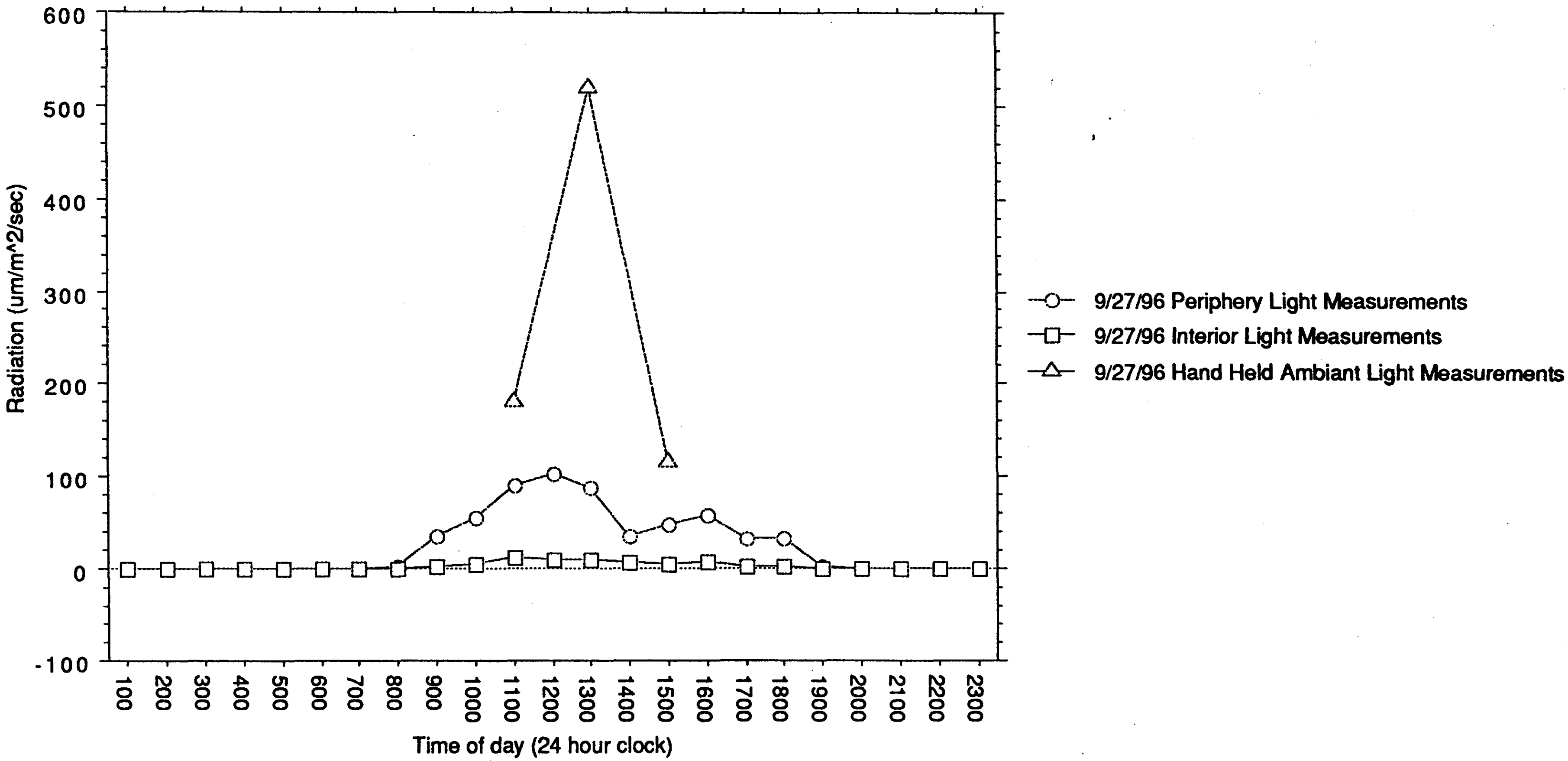


Figure 4: A Comparison of Ambiant, Periphery, and Interior Radiation Measurements of the Oak Savanna

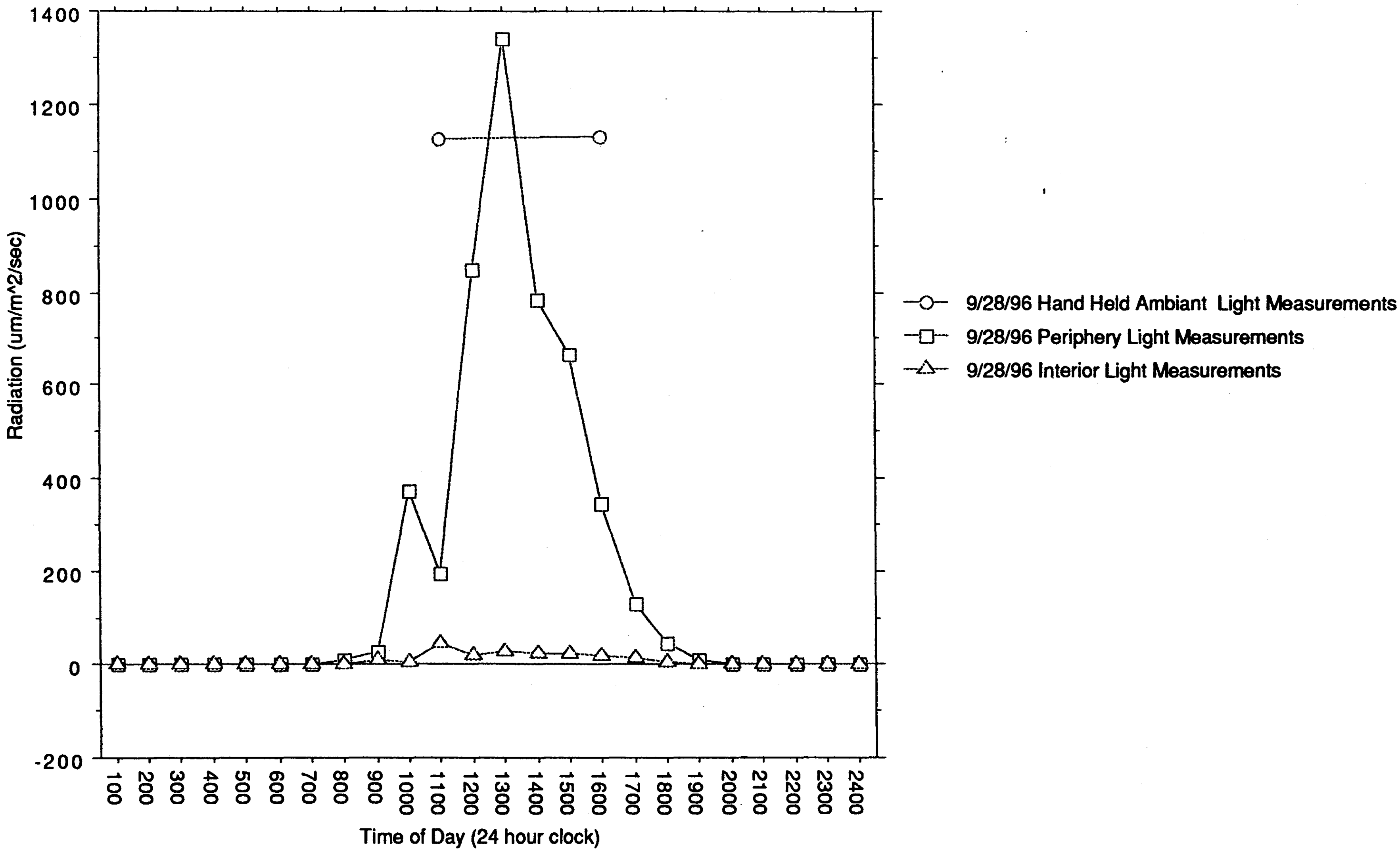


Figure 5: A Comparison of Ambiant, Periphery, and Interior Radiation Measurments of the Oak Savanna

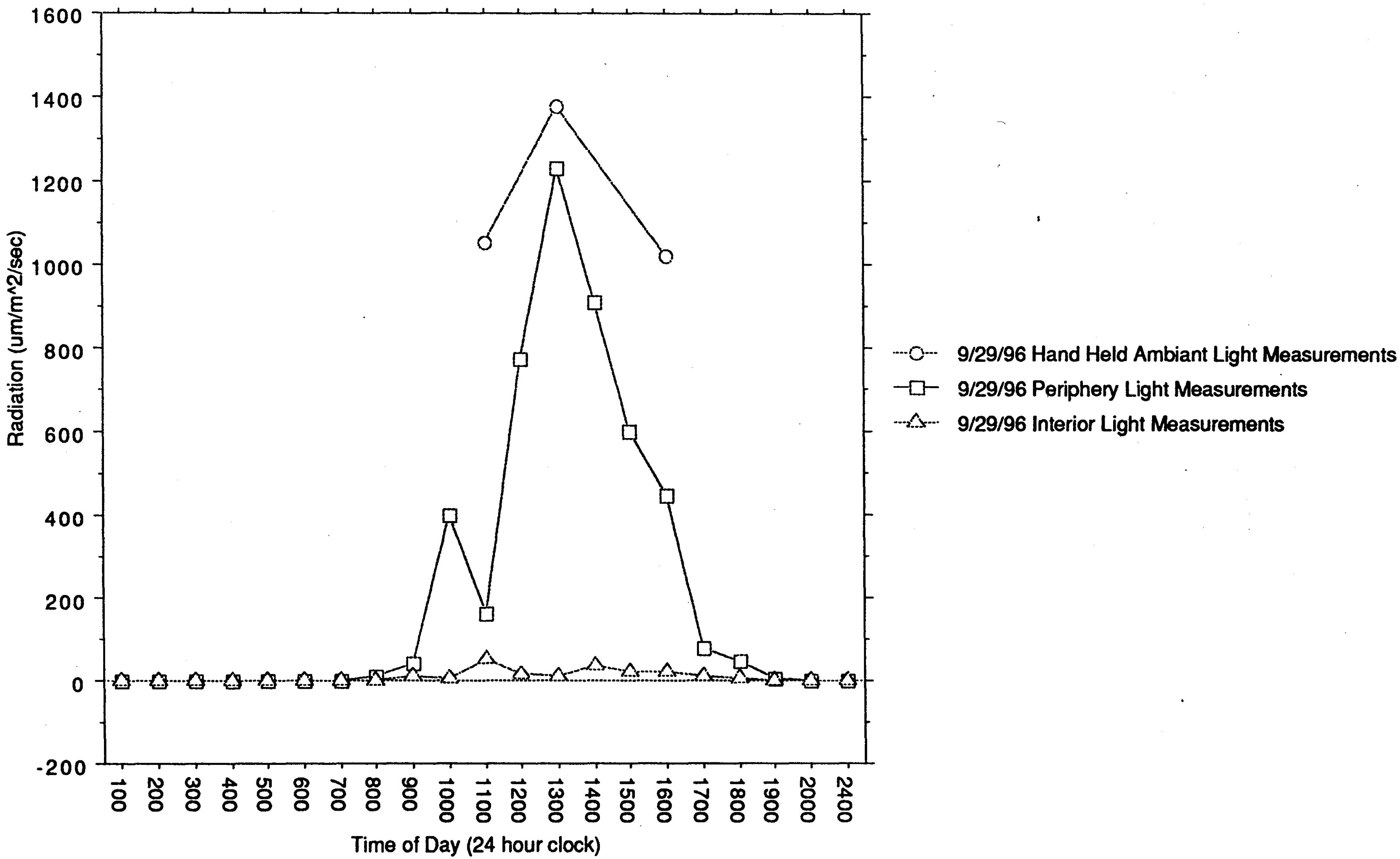


Figure 6: A Comparison of Ambiant, Periphery, and Interior Radiation Measurements of the Oak Savanna

Figure 7: Location of Bur Oak (<u>Quercus macrocarpa</u>) within St. Olaf College Oak Savanna Remnant

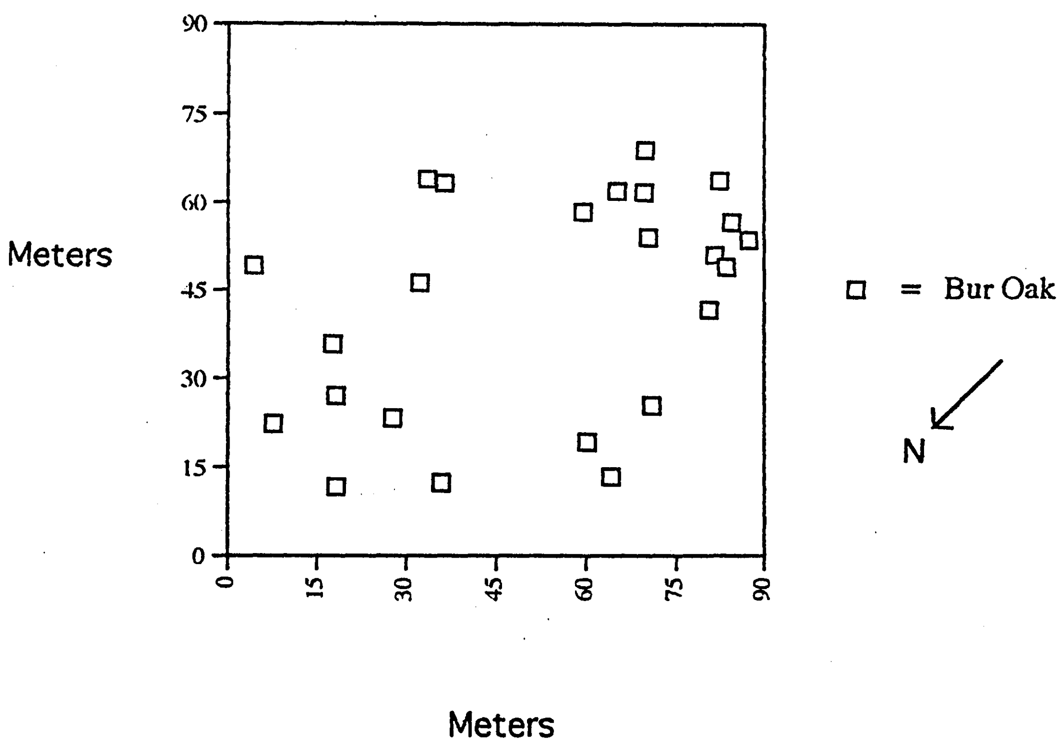


Figure 8: Comparison of Bur Oak Diameters within the Remnant Savanna