Determination of UNDERC Forest History from Current Forest Structure

BIOS 35502: Practicum in Environmental Field Biology

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ABSTRACT

Recently uncovered archive documents revealed that the most recent logging occurred on the UNDERC property from 1955-1967, not prior to 1920 as had been thought. This study was undertaken to confirm the accuracy of the archive documents, to determine what areas the numerous unmapped cuts took place in, and to determine whether partial- or clearcutting was the primary technique used. Stand parameters such as diameter distribution and species composition were used. Trees in each stand were also cored to determine age and to look for tree ring size releases caused by post-cut growth increases. Sugar maple dominated (shade-tolerant hardwood – TH), aspen dominated (shade-intolerant hardwood – IH) and mixed (MI) stands were studied. Age and diameter distribution indicated that all stands studied had been cut more recently than the 1920s and supported the claims of the archive documents. For the most part, the unknown-history stands were similar in average diameter and species composition to the known-cut stands, meaning they were probably treated similarly. Diameter distribution, age, and species composition of the stands generally indicated that current TH stands were partially cut and current IH and MI stands were probably clearcut. Diameter distribution was not very helpful or consistent in determining this. The logging history of the study areas was determined fairly well, but the study was narrowly focused on only two of the numerous stand types on property.

INTRODUCTION

The history of the forests of the western Great Lakes over the last 130 years is largely related to human intervention, primarily motivated by commercial interests (Whitney 1987). Logging of the old-growth forest began in the 1870s, taking primarily white pine (*Pinus strobus*) close to rivers. Once white pine of harvestable size was decimated, logging efforts expanded between 1880-1920 to include all pine (*Pinus* spp.) and hardwood types (e.g. *Acer saccharum* [sugar maple], *Tsuga canadensis* [eastern hemlock], and *Tilia americana* [basswood]) in virtually all areas accessible via newly-created railroad routes (Whitney 1987, Peterson and Squiers 1995).

Heavy logging in northeastern Wisconsin began in the 1890s (Stearns and Likens 2002). By 1920, most of the profitable timber had been removed from this region (Sakai and Sulak 1985, Whitney 1987), and fires, first consuming the slash left from logging and later the small trees that grew in the exposed, dry soils, slowed the regrowth of the forests (Sakai and Sulak 1985, Whitney 1987, Peterson and Squiers 1995, Stearns and Likens 2002). Around 1920, technical advances and an increase in resources devoted to fire control allowed a second-growth forest to be established (Whitney 1987). Over the past 90 years, these young forests have been logged, using primarily more conservative selective-cut methods (Whitney 1987, Crow et al. 2002).

The forests of the University of Notre Dame Environmental Research Center (UNDERC) in Vilas County, Wisconsin and Gogebic County, Michigan have departed from this common history only since the late 1960s. In the winter of 2005-2006, the discovery of University archive documents put to rest any doubt that logging occurred from 1955-1967 or 1968. Based on calculations reliant on volume-to-weight conversions from Spelter (2002) and Lothner et al. (1974), archive documents indicate that ca. 85% of the timber removed from the property was aspen (*Populus tremuloides* [quaking aspen] and probably also *Populus grandidentata* [bigtooth aspen]), which was cut from 1955-1967. Sugar maple, yellow birch (*Betula alleghaniensis*), eastern hemlock, and white pine, cut in 1958, 1960, 1961, 1963, and 1964, accounted for the majority of the remaining harvesting activities (Marathon records of stumpage sales ca. 1967, Notre Dame Archives).

These documents are incomplete and appear contradictory. Furthermore, they only indicate the location of the 1955-1961 aspen logging sites (Figure 1), leaving the location of ca. 62% of the total aspen logging unknown (Marathon ca. 1967, Notre Dame Archives) and they do not clearly delineate the area of any of the non-aspen cutting. Those locations would constitute a substantial portion of the UNDERC property. The logging technique that was used, e.g. selective-cutting or clearcutting, is also not specified. The logging contract specified that healthy forest development was to be a priority of the cutting, but the agreement may not have been faithfully carried out (Committee on Institutional Cooperation report 1967, Notre Dame Archives).

At present, no other source of detailed information has been uncovered concerning the mid-20th-century history of the UNDERC forests. In recent years, only one very general survey of the composition of the forests (Underwood 2005) and one tree age study of limited scope (Mahon 2003) have been undertaken. There is no information available on forest stand characteristics such as stand age, stand diameter, and detailed stand composition.

The UNDERC property, like much of the northwestern Upper Peninsula, is a mosaic of forest types that are frequently lumped together under the name northern hardwoods (Barnes and Wagner 2004, Anne Chouinard, personal communication). The property includes numerous stands of swamp conifers (e.g. *Picea mariana* [black spruce], *Larix laricina* [tamarack]), mixed coniferous and deciduous forest, mixed hardwoods, sugar maple, and aspen, among others (Layer of UNDERC forest stand types and wetlands, created 2005; Francl, unpublished data).

Several factors make quaking and bigtooth aspen focal points of any study of UNDERC land use history. These trees were probably originally targeted by loggers for their value as pulpwood (Marathon records of stumpage sales ca. 1967, Notre Dame Archives, Barnes and Wagner 2004). After the logging had occurred, they would likely have been pioneer species in any clearcut areas of the forest due to their ability to generate root suckers, their high growth rate, and their affinity for sunny environments (Whitney 1987, Barnes and Wagner 2004).

The goal of this study was to assess the accuracy of the existing logging records and to attempt to fill in two gaps in those records – which areas of the property were logged during the 1962-1967 for which there is no location information, and what logging techniques were used in the 1955-1967 cutting.

I hypothesized that the archive records would be corroborated by the dbh (diameter at breast height) and age data of the stands that have been cut. In trees that predate the logging event, increased light resources should have caused a post-logging increase in growth that I would see in tree cores as a sudden increase in tree ring width (Canham 1985, Bebber et al. 2003). This increase should match up with the year of logging.

I also hypothesized that, because of their similar pre-1955 history, the as-yet unidentified areas of 1962-1967 logging should have been similar in present day average diameter species composition to the known and identified 1955-1961 areas if logging methods were unchanged throughout the entire logging period. I predicted that these parameters would not be significantly different between the known-cut and unknown-history stands.

Finally, I hypothesized that the diameter distribution and tree ages would indicate that partial cutting was the primary logging technique employed. I expected to find evidence of some clearcutting – this is the only way that the pure aspen stands on property could exist (Palik 2003). I predicted that the current stand diameter distribution in non-aspen stands would form a reverse-j shape. This distribution shape is characteristic of forest stands managed using an uneven-age (partial cut) system (Crow et al 2002). I also expected the cores of the largest trees in each stand to date at least to the ca. 1920 reestablishment period (these would be trees that were already in the canopy at the time of the most recent logging but were not chosen to be cut), and other canopy trees (those recruited into the canopy after the partial cuts) to date to the 20 years prior to the cut.

MATERIALS AND METHODS

Selection of Sample Stands

Survey stands were selected based on the clarity and consistency of the relevant logging records. An effort was also made to distribute the stands across the UNDERC property as much as possible in order to get a more complete picture of the logging events. A total of nine stands were sampled within the areas indicated as having been cut in the 1950s and 1960s – three shade-intolerant hardwoods (IH - largely aspen), three mixed hardwoods (MI), and three shade-tolerant hardwoods (TH - largely sugar maple). An additional nine stands of the same classification were sampled in areas of UNDERC that had no reliable records (Figure 1). The stands were selected using ArcView 3.3 (Environmental

Systems Research Institute, Redlands, California) data layers. Available layers included an UNDERC habitat layer (forest stand types and wetlands, created 2005; Francl, unpublished data; UTM NAD27, Zone 16N), and DOQQ (Digital Orthophoto Quarter Quadrangle) maps created from 1998 aerial photos (courtesy of USDA Forest Service).

Sampling of Stands

From a stand edge, I chose a random bearing and a random distance between 10 - 50 m to determine the start of the first transect. I set two additional transects parallel to the first, one 10 and one 20 m away from it. Each transect was 50 m long. This procedure was modified as necessary to fit the transects in the stand. I identified live canopy trees whose trunks were less than 5 m to one side of the transect and recorded their species and dbh. I cored three trees in each transect using an increment borer. In general, I selected healthy and large trees from each of the species that formed a substantial part of the forest canopy. In very uniform stands, once several cores had been taken from similar large, same-species trees, I cored small trees to get a more complete picture of the stand age.

General information regarding each stand was recorded, including dominant stand type (shade-tolerant hardwoods, shade-intolerant hardwoods, hardwood-softwood mix, or softwoods), percent canopy closure, and dominant and co-dominant species with relative abundances estimated based on transect composition and visual effort to determine if any substantial stand species were not included in the transects. Percent canopy closure was categorized (0-25%, 25-50%, 50-75%, or >75%) using visual estimation supplemented by a densiometer in “borderline” stands. Densiometer readings, when necessary, were taken in each cardinal direction at the start of each transect. The presence or absence of tree stumps of possible anthropogenic origin was noted. Where present, the approximate size and density of stumps was recorded.

I sanded the cores and aged them in the laboratory using a dissecting microscope, hand lens, and the naked eye as necessary. Each core was examined for growth releases, and, when one was found, the year was recorded. A release was defined as a 50% increase in ring length between consecutive years.

Statistical Analysis

In SYSTAT 11.0 (SYSTAT Software, Inc., Point Richmond, CA), the tree diameter in each stand was graphed and the distribution was fit to a negative exponent (reverse-j) regression and a normal distribution to determine if it was logged using apartial cut (Crow et al. 2002). In order to establish their similar history, Each stand of unknown history was compared to the combined known-cut stands of its type using a two-sample t-tests to test for difference in dbh of the dominant species of each stand, and to test for differences in percentage of each stand that was composed of shade-intolerant species.

RESULTS

Accuracy of 1955-1961 Archive Maps

Locations of study sites and “known-cut” areas are shown (Figure 1). Of the sites in “known-cut” areas, only site eight (TH) contained sugar maple of dbh >45 cm. This stand contained a substantial number of large, apparently sawn stumps. Six of the nine stands showed at least one credible release in the 1955-1967 period. Three of those six had more than one release in the same year. In three of the six, the release year was within one year of the cutting date indicated by archive maps. In all 18 stands surveyed, multiple cores appeared to show steady growth before, during, and after the 1955-1967 period with no sign of release. Only site 8 contained stumps.

General Results and Tree Coring Notes

The oldest tree cored in this study (a sugar maple) was aged to 1831. It was also the only tree that showed a release in the mid-1890s (approximately 1895). Twelve of 159 total trees cored were dated earlier than 1920. The largest number of current canopy trees was established in the 1940s and 1930s (Figure 2). This may represent the earliest time at which the post-logging, post-fire land was able to support the establishment of large numbers of new trees (Whitney 1987).

Calculations of relative species abundances in the stands surveyed caused some of them to be reassigned to different shade-tolerance stand types (TH, shade intolerant hardwood – IH, or intermediate/mixed tolerance hardwood – MI). Also, a distinction was made between MI dominated by sugar maple or quaking aspen and those dominated by red maple (*Acer rubrum*) due to the unique character of red maple-dominated stands observed in the field. As a result, the known-cut stands were comprised of three TH, two IH, three MI, and one red maple MI, and the unknown-history stands were comprised of four TH, four IH, and one red maple MI rather than the originally planned three of each type.

Comparison of Known- and Unknown-history Stands

Average dbh of dominant canopy species (Figure 3) and relative abundance of aspen in the canopy (Figure 4) were compared between each unknown-history stand and the combined known-history stands of its stand type using two-sample t-tests.

IH – Three of the four unknown IH stands showed significantly smaller average dbh than the known-cut IH stands (site 14: t=3.939, df=5.3, p=0.010, site 15: t=2.967, df=6.0, p=0.025, site 16: t=3.839, df=7.0, p=0.006). The fourth (site 10) showed a trend toward smaller dbh (t=1.498, df=6.1, p=0.184). Three of the four sites showed no significant difference in relative abundance of quaking aspen in the canopy (Table 1). One (site 16) had a significantly lower relative abundance of aspen (t=2.376, df=4.7, p=0.066), but this was due in large part to a higher abundance of shade-tolerant conifers (14.4% of sampled trees), not of late-successional hardwoods (7.1%).

MI (red maple) – The only unknown-history red maple MI stand (17) was not significantly different in mean dbh from the only known-history red maple MI stand (t=-1.283, df=3.8, p=0.272). A possible trend of lower aspen relative abundance in the unknown stand was found (t=1.903, df=2.6, p=0.165), but the sample size was very small.

TH – TH unknown site 11 had a significantly smaller mean dbh than the known-cut stands (t=5.431, df=9.0, p<0.001). That site also showed a strong trend toward a higher aspen canopy abundance (t=-1.814, df=9.5, p=0.101). Another unknown site (18) showed a strong trend toward smaller sugar maple dbh (t=1.901 df=6.7, p=0.101). This site and the two remaining unknown-history TH sites (12, 13) did not have enough aspen for a t-test to be performed on their aspen abundances. Eight of nine known-history TH transects contained no quaking aspen, so these three unknown TH sites are probably not significantly different from the known stands. Neither of the remaining two unknown TH sites had mean dbh significantly different from the known stands.

Logging Technique: Diameter Distributions and Stand Ages

The dbh distribution of each stand was fitted to an exponential curve. A good fit was characterized by a high Kolmogorov-Smirnov p-value: this indicates a low probability that the data and fit curve are significantly different (Figure 5). Only one of the three known-cut TH stands fit the curve well (site 8: K-S = 0.119, p = 0.635). Three of the four unknown TH stands fit the curve weakly (site 11: K-S = 0.144, p = 0.182, site 12: K-S = 0.193, p = 0.135, site 13: K-S = 0.167, p = 0.205). All of the known-cut MI stands fit to some degree (site 1: K-S = 0.170, p=0.158, site 3: K-S = 0.103, p=0.633, site 5: K-S = 0.131, p = 0.331, site 9: K-S = 0.108, p = 0.755). The unknown MI stand did not fit. Neither of the known-cut IH stands fit the curve. One of the four unknown IH stands fit the curve fairly well (site 2: K-S = 0.101, p = 0.476).

As with the distributions, of the three known-cut TH stands, only site 8 showed stand ages consistent with a partial cut, containing four trees older than 1920 (Table 1). All four unknown TH stands produced at least somewhat compatible tree ages, though site 18 only had one tree (1890) older than 1935, making it somewhat suspect. Of the other three, site 13, which had the best negative exponential curve fit, also had the most compatible tree ages – 7 of 9 were older than 1920. Only 7 trees older than 1930 were cored in the other 11 stands combined. Thus, they are not compatible with this idea of tree age in a mid-20th century partial cut.

DISCUSSION

The dearth of large trees in the stands indicated in the archives as cut means the last large scale disturbance in those stands probably cannot date as far back as 1920 - 1890s logging (Crow et al. 2002). The close correspondence between some measured tree releases and the cutting dates indicated by archive maps lends credibility to the accuracy of those maps. At the least, it seems safe to say that they can probably be trusted not to depict cutting that did not occur.

The 1831 sugar maple that was cored brings up an interesting possibility. Though it represents just one core, it is of relatively high quality and its release might suggest that the UNDERC property was logged in the mid-1890s, not long after the first logging operations moved into Northeastern Wisconsin and the Upper Peninsula. Further coring of known older stands (white pine and hemlock) at the southeast end of the property might confirm this suspicion.

History of Unknown UNDERC Stands

IH – These stands all have at least a trend toward smaller mean dbh than the known-cut IH stands. Thus, it is clear that they have been cut or otherwise entirely disturbed – the question in these cases is why they are smaller than the known-cut stands. It could simply be due to an environmental factor such as low soil nutrient levels, but it could be the result of a more recent disturbance, or of difficulty regenerating trees on the spot. Competing shrubs can substantially delay reestablishment of trees, sometimes causing regeneration to fail altogether (Dixon et al. 2006). This can happen for a variety of reasons (Iseman 1999, Balandier et al. 2006), many of which could be easily be different between two stand sites on the UNDERC property.

The date of logging in two of these four sites is evident from tree core releases– site 15 was probably cut in 1965, and site 10 was probably cut in 1962. Both of these dates correspond to years of unknown-location aspen logging on the UNDERC property. Site 10 is located northeast of Bogpot, near several areas of known 1955-1961 logging. Site 15 is located west of Tenderfoot creek, relatively far from any of the early logging. This might suggest that convenience was the prime mover in Marathon's aspen logging site selection, not a scientific or economic evaluation.

MI – The red maple (17) was almost certainly cut (or otherwise severely disturbed). Seven of the nine aged trees from the stand date to the 1940s. The two older trees (1920s) were probably passed over because they would probably not have been of merchantable size in the 1960s: they are currently only 21 and 25 cm dbh.

TH – Because all four of these stands have mean dbh less than or equal the combined known-cut stands, it is safe to say that they have also been logged more recently than 1920. The stand (11) with smaller mean diameter and a higher relative abundance of aspen in the canopy could potentially have been treated differently when it was cut. The term "partial cut" was often used in that time period to describe what was in fact simple high-grading – the removal of all trees over a certain size (Kelty and D'Amato 2005). This stand, relatively near the western edge of the Notre Dame property, away from most of the lakes, might have been cut more heavily due to its inconspicuous location. Of course, the discrepancy could be due to a natural event or the characteristics of the stand.

Two of the four unknown TH stands showed credible releases in more than one of their cores. The first, site 13, showed a release in 1962. This is not one of the years in which sugar maple and other tolerant hardwoods are recorded as having been harvested by Marathon. Normally, I would attribute this discrepancy to an imperfect core reading, but in this case one of the cores was a hemlock whose rings were very clear. It is unlikely that this core was misread. It is likely that this is an instance of either careless bookkeeping or undocumented cutting. The site does lie along the road to South Gate – there would be no easier place to surreptitiously extract lumber.

The other site (18) has a credible release in 1960. Archive records indicate that 1960 was one of three years in which basswood and ash were both cut. Site 18 contains both. This site is unusual that the largest trees (>30 cm dbh) are 53% basswood and white ash, while the site as a whole (dbh >10 cm) is only 11% those species. This is probably not the result of selective cutting of sugar maple (the dominant species), because several large basswood and white ash were cored and the oldest was 1940 – there is no evidence of large canopy basswood and white ash being passed over. This is probably an illustration of the higher growth rate of the two minor species – their subcanopy saplings were able to more rapidly exploit the canopy gaps opened by logging (Barnes and Wagner 2004).

Evidence of Logging Technique

Generally speaking, the negative exponential fit did not give consistent results that indicate partial cutting to have been the dominant method on the UNDERC property. That having been said, it is unlikely that multiple pure maple stands could have regenerated after a clearcut in an area obviously susceptible to colonization by shade-intolerant aspen. This incongruity in the three TH stands could be the result of several factors.

First, the fact that the UNDERC forests have been unmanaged for up to 40 years might have skewed the distribution, which was formulated for managed stands. This seems unlikely because old-growth and undisturbed stands, with natural treefall gaps and disturbances, also tend to take on a reverse-j diameter distribution (Crow et al. 2002, Lahde et al 2002). A stand that was transitioning between the two would probably show a similar distribution.

Second, the fact that only trees >10 cm dbh were recorded could have skewed the distribution results. This has been shown to happen in a related distribution curve that is theoretically negative exponential in uneven-age stands – the age distribution curve (Loewenstein et al. 2000). This possibility could be explored by determining the distribution of known uneven-age stands of similar composition, which could probably be located at the Ottawa National Forest.

Third, some degree of high-grading cut might have been performed, removing most of the handful of very large trees characteristic of the reverse-j uneven age diameter distribution. In addition to the large trees being absent from the distribution, their absence would mean that the forest would lose its main source of natural disturbance (treefall gaps). This would, on a longer time scale, reduce the small and medium-small diameter classes by eliminating the openings they use to establish and grow. The lack of subsequent logging to provide new gaps could have resulted in the atypical diameter distribution evident today. The observed TH stand ages could be explained in the same way. Older trees may not have been found because they, being the largest, were preferentially removed. A more intensive establishment date and diameter distribution study might be able to more conclusively explore the idea that high-grading or a similar method was practiced on property in the mid-20th century.

It now seems likely that the MI stands were either clearcut or very heavily partially cut. The absence of old trees is not consistent with a partial cut. Also, the substantial aspen presence (23% of the MI stands on average) probably indicates a very open post-cut forest floor. It is possible, however, that aspen was a part of the pre-cut MI stands, and that it could have grown rapidly from root suckers and re-entered the canopy in that way. The weak reverse-j fits do not provide much guidance.

The IH stands are almost certainly the result of clearcutting. An almost exclusively aspen stand could not have come about from any other logging technique. The lack of old trees in these stands and their general failure to fit the negative exponential distribution support this idea. The one stand that fit the distribution well defies my explanation.

Experimental Weaknesses and Direction of Future Research

The primary weakness of this study is its narrow focus. UNDERC, like most northern hardwood forests, is comprised of many different stand types. Aspen- and sugar maple-dominated stands may make up a substantial percentage of the property, but the majority of the property is comprised of stands with a more diverse mix of tree species. To get a complete picture of the logging history of the property, these sites must be examined. While very wet sites such as bogs dominated by black spruce and tamarack can be ignored because they are not likely places for a logging operation to try to harvest, all upland sites should be explored.

These methods and statistics of this study did not work very well with stands that could not be easily classified. The t-test known-unknown comparison method would be largely useless in a study that encompassed the full diversity of upland UNDERC forests – it would be impossible to classify enough stands in the same categories. Rigorous tree coring could be an alternative to this method. If a much larger number of trees in each stand were cored, and if the coring were done in a way that assured a representative sample, logging history and technique could probably be established reasonably well.

Another weakness in this study was the general difficulty of obtaining good tree core readings. This was due to two factors. First, many of the larger trees on property are experiencing heart rot or developing hollow centers, meaning they do not produce good, dateable cores. This could complicate a purely core-based experiment – if unhealthy trees are excluded, it might bias the forest sample. Second, it is simply very difficult to accurately read the cores. Ranges of ~3 years for a given event are not hard to provide, but specific years are anything but guaranteed.

The manner in which release years were determined may also have been a problem in this study. The typical method of determining release years relies on measuring the width of each tree ring using some combination of movable stage microscope and computer technology (Canham 1985, Bebber et al. 2003). The purely visual technique used in this study probably missed many less immediate and clear releases (Bebber et al. 2003). Also, releases and cuts may not always line up exactly– in white pine, it is common for releases not to appear until three or more years after a disturbance (Bebber et al. 2003).

Predictions for UNDERC Forests

The present-day UNDERC forest composition is still very much a result of the mid-20th century logging, which appears to have encompassed the majority of the upland areas of the property. As time goes on, the pure aspen stand will probably cease to exist on property except in future disturbed areas (i.e. windfalls). As the forest matures, sugar maple will increase in dominance. Large, old maple in some of the pure maple stands on property have already been creating natural treefall gaps for years. As time goes on and maple trees in what are currently mid- and early-successional forests become older, they will begin to die as well. In the long term, UNDERC should return to an old-growth style regeneration pattern, albeit with somewhat different species composition. Less dominant species such as yellow birch and white ash should find a lasting habitat in these canopy gaps.

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Table 1. Tree core results: Basic stand information, oldest three approximate establishment dates based on cores, and dates of releases. Number of cores with this date given in parenthesis.

Site #	Stand Type	Knwn./Unk.	Oldest Trees	Release? (# of cores)
1	MI	Known	1926, 1930, 1932	1957 (1)
2	TH	Known	1931, 1933, 1933	1956-7 (4)
3	MI(Red Maple)	Known	1933, 1939, 1941	1960 (1)
4	IH	Known	1944, 1945, 1960	None
5	MI	Known	1927, 1929, 1930	1959-60 (4)
6	TH	Known	1926, 1930, 1931	1961 (1)
7	IH	Known	1922, 1929, 1932	None
8	TH	Known	1831, 1897, 1905	1895 (1), 1959-60 (3)
9	MI	Known	1935, 1936, 1938	1954 or 60 (1)
10	IH	Unknown	1936, 1939, 1944	1962 (2)
11	TH	Unknown	1921, 1924, 1935	1962 (1)
12	TH	Unknown	1909, 1923, 1931	None
13	TH	Unknown	1883, 1887, 1891	1962-3 (2)
14	IH	Unknown	1940, 1961, 1963	None
15	IH	Unknown	1944, 1946, 1967	1965 (2)
16	IH	Unknown	1930, 1942, 1958	None
17	MI(Red Maple)	Unknown	1925, 1929, 1941	1954 (1)
18	TH	Unknown	1890, 1935, 1940	1960 (2)

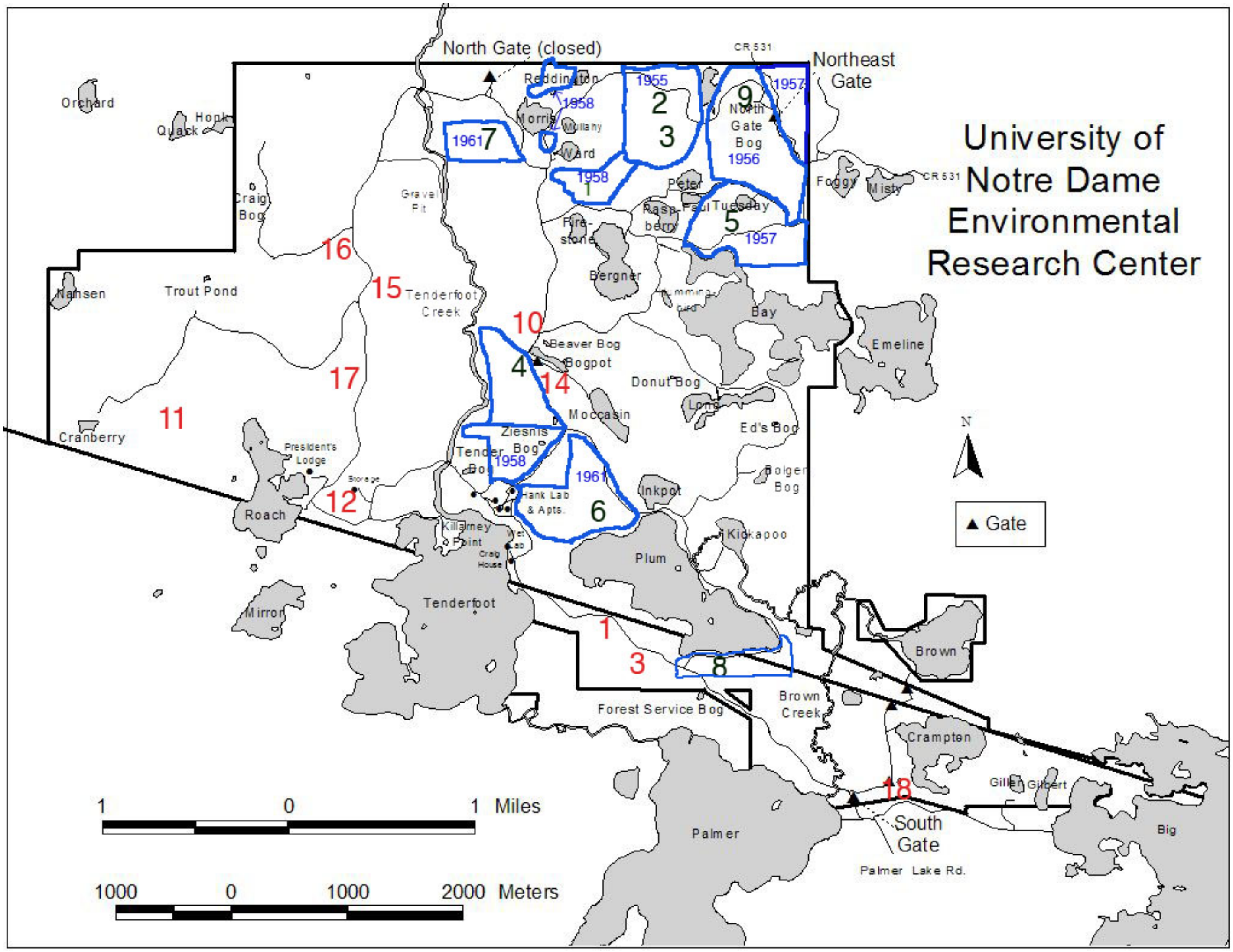

Figure 1. Map showing study sites and areas indicated as having been cut 1955-1961 by archive records. #1-9 are known-cut stands, #10-18 are unknown-history stands. Outlined areas are cuts marked on archive maps (with indicated year when provided).

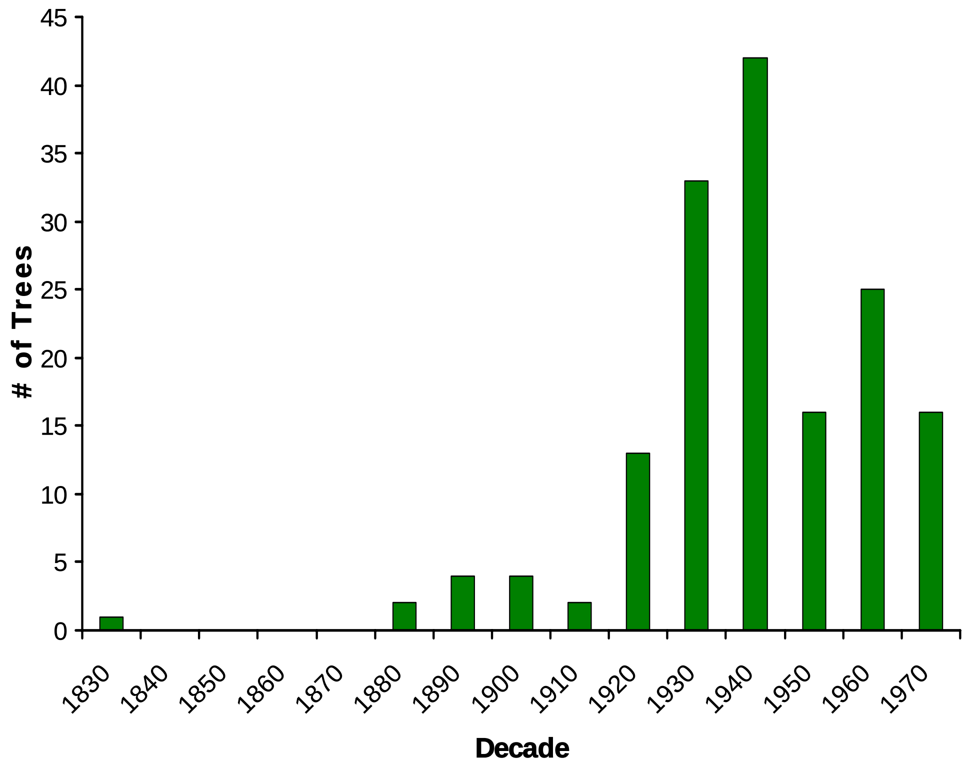

Figure 2. Distribution of approximate establishment dates of 159 trees from 18 stands on the UNDERC property.

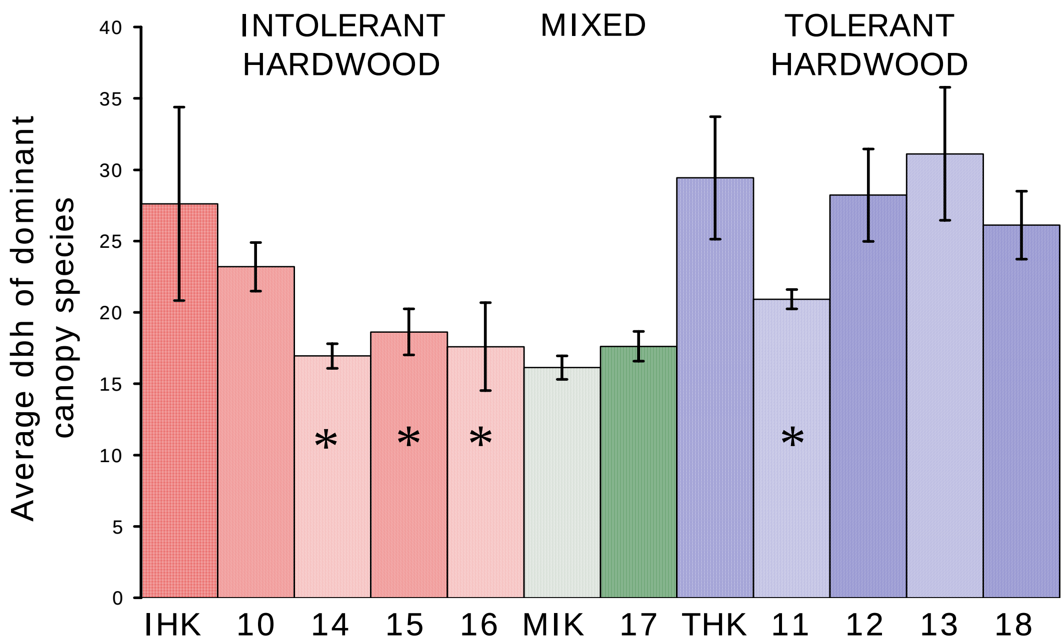

Figure 3. Average dbh of trees of dominant canopy species, dbh >10 cm. Checkered/dashed pattern bars represent combined average for all known-cut stands of that type (IH=diamonds, MI=dashes, TH=squares), each striped bar represents average for one unknown-history stand (IH stands=downward stripes, MI stand=vertical stripes, TH stands= upward stripes). Significant differences denoted with *****. Error bars are SD.

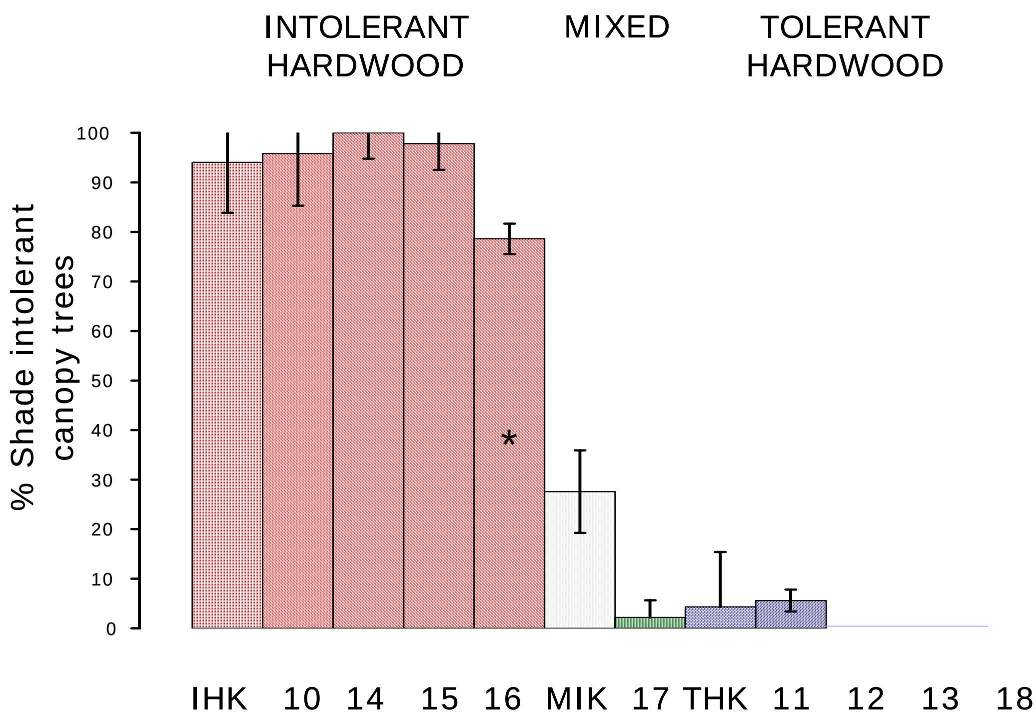

Figure 4. Average relative abundance of quaking aspen. Checkered/dashed pattern bars represent combined average for all known-cut stands of that type (IH=diamonds, MI=dashes, TH=squares), each striped bar represents average for one unknown-history stand (IH stands=downward stripes, MI stand=vertical stripes, TH stands= upward stripes). Significant differences denoted with *. Error bars are SD.

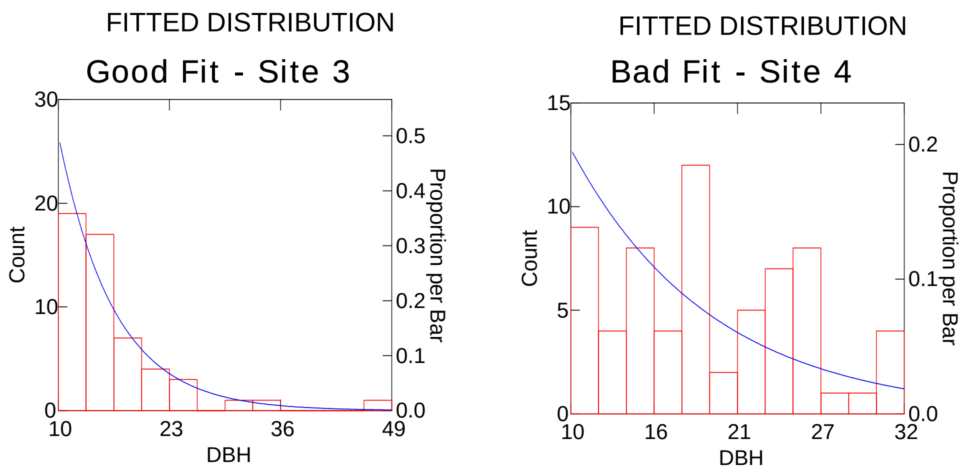

Figure 5. An example of a good fit to negative exponential diameter distribution curve (site 3: K-S=0.103, p=0.633) and a bad fit (site 4: K-S=0.191, p=0.017).