# Carleton Arboretum Study

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## INTRODUCTION

Carleton College's Arboretum ("the Arb") was created in the 1920's by the college. The 'Upper Arb' spans east of Highway 19 while the 'Lower Arb' stretches west of the highway into the floodplains of the Cannon River. Containing a total of 360 hectares of land neighboring Carleton's campus, the Arb is widely used by students, faculty and Northfield residents alike. Numerous courses, from biology to art, make extensive use of the Arb's resources and beauty. The Arb also serves as a State Game Refuge and conservation for a diverse variety of species. Finally, the Arb provides recreational use where visitors hike, walk, run, ski, fish, and (on occasion) hunt.

To best maintain and maximize the educational, conservational, and recreational value of the Arb, managers are working to increase its biodiversity through ongoing restoration projects. Underdeveloped areas, in particular, are a focus of these projects. In the Upper Arb, most plantings have focused on the restoration of the Alumni Field (H3-4, I3-4)[1]. Removed from agriculture since 1986, plantings of a diverse variety of species of trees have occurred in Alumni Field in 1994, 1995, and 1997 to help return the land to forest.

In order to determine the success of and need for additional restoration projects in Alumni Field, it is necessary to have a current understanding of the density and biodiversity of the field's tree community. Using a combination of Simple Random Sample (SRS) and Cluster Sample techniques, this study aims to estimate the total number of (living) trees in the field, the proportions of different species, and thus the relative success rate of the restoration projects.

## METHODOLOGY

### Sample Design

Our survey studies trees in Alumni Field, an area which has been the attention of recent restoration efforts. This field is approximately 12.5 acres, estimated using Google Earth technology.[2] Our survey is based on the analysis of a simple random sample of plots within the field, and the actual plot division is discussed below. For total tree counts, SRS techniques are used with plots as the sampling units and as elements. However, when we determine proportions for tree characteristics, the sampling design is a one-stage cluster sampling method. In this second case, the population elements are the individual trees within the field, and our sampling units are plots of the field. More efficient sampling was achieved by recording data by cluster rather than by element.

[1] See Appendix A1 for the Official Carleton Arboretum Map
[2] See Appendix A1 for the Google Earth Image

**Plots (Sampling Frame)**
We chose to divide our plots into 6-foot wide North-to-South transects covering the length of Alumni Field. This was desirable because the arm-span of a typical researcher is approximately 6 feet and plots running the length of the field are easy to locate. With the help of GIS Specialist Wei-Hsu Fu, we were able to overlay transects onto a high resolution Google Earth satellite image. With this sampling frame we found $N = 150$ plots. From this we selected a SRS of $n = 30$ plots from a table of random numbers, uniformly distributed from 1 to 1000. Values larger than 150 were ignored; and we continued down the list of random numbers until 30 unique plot indices were chosen. We chose a sample size of $n = 30$ because it allows us to use the central limit theorem in our analysis and therefore minimizes possible selection bias.

To lay out our transects, the point of origin was set at the Northeast corner of the field. GPS units were considered to locate plots, but they are only precise to 7 meters. In order to preserve our desired plot width, we instead opted to mark our plots using a compass and tape measure. Despite the additional time required, we believe the 6-foot transects minimize potential measurement error in the form of double counting or under counting, since the elements in wider transects would be more difficult to observe.

**Variables**
Our data is based on field observations of a sample of plots in Alumni Field. For each plot, we recorded total counts for each variable of interest. The number of trees per plot for each species is the only quantitative variable for this study. Species type, however, is a categorical variable. When recording the tree species, trees are divided into paired, alternate, and needle categories. These broad tree characteristics are more obvious than actual species identification. All conifer trees fall into the needle category, and deciduous trees are classified as paired or alternate according to the arrangements of the twigs, leaves, and buds. Our second categorical variable is whether or not the tree was protected. A tree is considered protected if it has a plastic or metal tree sleeve. The status regarding whether or not a tree was dead was also recorded as our third categorical variable. Rough height estimates were included as categorical variables as well, observed as below the knees, below the waist, below the shoulders, or above the shoulders.[3]

**Dates of Data Collection**
Data was collected during the 2nd week of May, 2008.

[3] See Appendix A2 for field identification notes and the sample data collection sheet – note, we did not record the region indicator despite its appearance on our data collection sheet

## RESULTS[4]

Unbiased SRS estimates of total trees in Alumni Field were calculated. The total tree population for Alumni Field is 4,235 (SE 332.3075), and the tree density is estimated at 337.7605 (SE 26.5030) trees per acre, using the estimated field acreage of 12.5385. Total populations of paired and alternate trees are 1005 (SE 178.2849) and 3215 (SE 242.46010), respectively. This results in a near 76% majority for the alternate trees (see Table 1 for confidence intervals). Estimated totals over species can be found in the appendix.[5]

**Table 1: Total Estimates of Tree Population in Alumni Field**

| Variable | Total | Std. Error | Lower Bound | Upper Bound |
|---|---|---|---|---|
| Total Trees | 4235 | 332.3075 | 3555.3550 | 4914.6450 |
| Alternate Arrangement | 3215 | 242.4601 | 2719.1130 | 3710.8870 |
| Paired Arrangement | 1005 | 178.2849 | 640.3664 | 1369.6340 |

Note: Totals estimated with SRS survey technique. All estimates are unbiased

In Alumni Field, oak varieties are the most abundant tree species, accounting for 70% of the total and 92% of the alternate types. White, Red, and Bur Oak species were observed within the field, with 44.1% of the oak population as Red Oak and 46.5% as Bur Oak (see Tables 2 and 3). Figures 1 and 2 show a graphical representation of the distribution of tree species.

**Table 2: Ratio Estimates of Total Trees in Alumni Field by Species and Arrangment**

| Variable | Proportion | Std. Error | Lower Bound | Upper Bound |
|---|---|---|---|---|
| Alternate Arrangement | 0.7591 | 0.0317 | 0.6943 | 0.8240 |
| Paired Arrangement | 0.2373 | 0.0318 | 0.1723 | 0.3023 |
| Oak | 0.6978 | 0.0315 | 0.6333 | 0.7622 |
| Bur | 0.3247 | 0.0512 | 0.2199 | 0.4295 |
| Red | 0.3081 | 0.0545 | 0.1966 | 0.4197 |
| White | 0.0649 | 0.0208 | 0.0224 | 0.1074 |

Note: Ratios estimated with cluster sampling All estimates are biased

[4] See Appendix A4 for Stata Output
[5] See Appendix A3 for estimated totals over species.

| Table 3: Ratio Estimates of Oak Trees in Alumni Field by Species | | | | |
|---|---|---|---|---|
| **Variable** | **Proportion** | **Std. Error** | **Lower Bound** | **Upper Bound** |
| Bur | 0.4653 | 0.0676 | 0.3270 | 0.6036 |
| Red | 0.4416 | 0.0744 | 0.2894 | 0.5939 |
| White | 0.0931 | 0.0313 | 0.0290 | 0.1571 |

Note: Ratios estimated with cluster sampling All estimates are biased

**Figure 1: Proportion of Trees by Type**

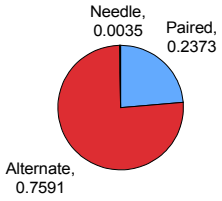



**Figure 2: Proportion of Oaks by Type**

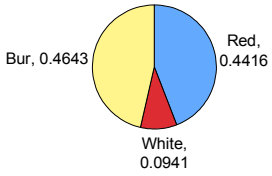
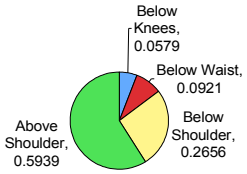



**Figure 3: Proportion of Trees by Height**




*Note, the total of the proportions for Figure 3 is not equal to 1 due to observation errors

In order to determine the success rate of tree plantings, we observed variables regarding tree status. Approximately 51.59% (SE 3.37%) of the trees in Alumni Field were found to be protected. We also concluded that 3% (SE 0.64%) of the trees were dead. Based on the analysis an estimated 5.8% (SE 1.1%) of the trees are below the knees in height. Mature trees constitute the largest proportion of trees in the field: 59.38% (SE 3.58%) of the trees are above the shoulder in height (see Table 4 and Figure 3).

| Table 4: Ratio Estimates of Total Tree Population in Alumni Field by Status | | | | |
|---|---|---|---|---|
| **Variable** | **Proportion** | **Std. Error** | **Lower Bound** | **Upper Bound** |
| Protected | 0.5159 | 0.0337 | 0.4470 | 0.5849 |
| Dead | 0.0307 | 0.0064 | 0.0175 | 0.0439 |
| Above Shoulder | 0.5939 | 0.0358 | 0.5206 | 0.6671 |
| Below Knees | 0.0579 | 0.0112 | 0.0350 | 0.0807 |

Note: Ratios estimated with cluster sampling All estimates are biased

## DISCUSSION

In our study, we conclude that the Alumni Field currently contains about 4,235 trees of various species. Given that we have information for planting of 3,365 established trees and 2,015 seedlings[6], there is no information demonstrating a failure of the attempted restoration. However, it may be inaccurate to conclude that restoration has been a complete success as the true quantity of plantings is unknown. We *can* conclude that the current density of the field is approximately 337.76 trees per acre. Whether or not this is a sufficient density for the field to be left to grow on its own is up to the Arb managers.

All three primary purposes that the Arb serves (education, conservation, and recreation) benefit from biodiversity both among the Arb and within tree field communities. Thus it is important to look at how well the Alumni Field is doing in terms of biodiversity. Our results show that over three-fourths of the trees in Alumni Field are of the alternate leaf and stem arrangement. This may at first imply relatively low diversity. However, eight out of the thirteen species observed in our sample were of the alternate arrangement. In order to gain a better understanding of overall biodiversity, trees were broken down into specie categories. From such analysis we concluded that nearly 70% of all the trees were Oak, consisting mostly of Bur Oak and Red Oak. Estimates of Bur Oak and Red Oak were both over 1300, indicating that they strongly dominate the tree community. The next most prominent tree specie in the field was Box Elder, with only an estimated total of 695. Of the rest of the trees observed, no single specie was found to have more than 300 trees.

In order to restore Alumni Field to a diverse community, future plantings should limit the input of additional Bur Oaks and Red Oaks, as these species have already demonstrated the establishment of a secure community. Two scenarios can help explain the abundance of Red and Bur Oak. Either these Oaks take particularly well to the physical conditions present in Alumni Field, or an abundance of them were planted. Due to incomplete records and inadequate time to study conditions in Alumni Field, our analysis is limited to estimating current populations rather than explaining the mechanisms behind these estimations.

The final part of our analysis examined the status of trees in Alumni Field. A relatively low mortality rate of 3% was found, implying that trees are fairing well overall. Small trees, of height no greater than two feet, were found to be nearly 6% of the total tree population. If small trees are indicators of 'new' trees, or tree community growth rates, there is a net growth of around 3%. Still, a majority of all trees are well established older trees at least 5 feet in height, implying that older trees dominate the field. The final status variable measured was whether or not a tree was protected by a sleeve. A slight majority of all trees in Alumni Field were estimated to be protected. While not all trees planted in the field (as opposed to those which came in on their own) were protected, this estimate may provide Arb managers with a better sense of how quickly the density of the field may increase.

[6] Information on tree plantings may be incomplete. Part of the need for this study was due to the possible incomplete information regarding prior plantings.

While our study was fairly rigorous, there are a few possible sources of bias that may affect our estimates. One possible source of bias may be caused by errors in tree identification (observation error). Many of the trees did not have leaves or other distinguishing features at the time of observation, making identification difficult. A second source of bias may be that our transects were not sampled in a true N-S line. If we systematically avoided or counted trees that were outside of a specific transect, our estimates may be biased. However, we used the technology available to us to minimize this and any resulting noise should be random. Additionally, more thorough analysis could be completed if we had complete information regarding the planting of trees in Alumni Field. A true success rate is impossible to estimate without knowing the number of trees planted, as well as if any trees existed in the field prior to restoration. A future study with more complete information could improve our ability to comment of the success of the plantings. For instance, if the general location of plantings by species was known, a stratified sample could produce more efficient estimates. Spatial analysis and more advanced sampling techniques could also control for variations attributed to natural clusters of trees.

## CONCLUSION

Our study finds no evidence to argue that the restoration efforts in Alumni field have been unsuccessful. However, without more detailed planting records we cannot confirm the success of the planting. We can say that Alumni Field currently contains about 4,235 trees of various species with an approximate density of 337.76 trees per acre. In addition, we conclude that the biodiversity is limited in the field, with nearly 70% of all the trees being Oak. Again, a relatively low mortality rate of 3% was found and trees less than 2 feet tall constitute nearly 6% of the tree population. As in the case of many natural ecosystems, trees were clustered in different regions of the field. Therefore, future studies could be improved by performing a pre-sample to determine strata of nearly homogeneous tree stands. Stratified estimates or spatial analysis may be more precise by reducing the variation; moreover, this would lead to better identification of sparsely populated strata in need of additional plantings. In the meantime, the determination of whether additional restoration projects are needed in Alumni Field is left to the discretion of the Arb Directors.