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The effect of active and passive restoration strategies on the species composition of a hardwood forest

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Abstract

Less than 10% of Minnesota's hardwood forests remain after heavy logging in the 19th and early 20th centuries. In order to ensure that this ecosystem continues to be a part of Minnesota's natural history, forest managers have begun practicing active and passive restoration. The composition of a remnant forest, planted forest, and an adjacent old-field in the St. Olaf College Natural Lands, was analyzed to understand the effect of active and passive restoration on the composition of the forests. Forest composition data was collected using quadrat and point-quarter methods. Mature trees were measured for their DBH and distance from the point, to calculate importance values. Soil data was collected and analyzed for percent moisture, organic matter, and bulk density. Data indicated that red oak and white oak were important in all forests, but were more abundant as mature trees than as seedlings or saplings. The composition of the planted forest was statistically different ($p<0.05$) than the remnant for mature tree composition and different than both remnant and old-field forests in sapling composition. The planted forest had higher diversity for seedlings and saplings, while the remnant had the highest for mature trees. Soil data indicated that the planted forest had lower percent moisture and percent organic matter than the remnant and old-field forest plots. These results indicate that the forest composition for planted and old-field forests will change toward compositions similar to the remnant forest.

Introduction:

Minnesota forests were heavily logged in the late 19th century through the early 20th century, reducing native hardwood forests to a mere 3.6% of the forest cover in Minnesota (Survival of Old-Growth Forests, MNDNR). Beginning in the late 1960's, scientists and environmentalists began restoring forests around the United States. As part of restoration efforts scientists and conservationists have begun managing the remnant forests statewide and planting diverse forests where old forests once grew. In addition, many plots of agricultural land that had been abandoned by their owners have undergone revegetation of forest plants, without the help of foresters. Scientists have become increasingly interested in the composition of these passively reforested plots and the seed source of these trees. Determining whether remnant or planted forests are the source of these seeds can help scientists understand seed production and dispersal patterns, as well as assess the success of restoration projects.

Active restoration is the most widely used management technique regarding forest restoration. Actively restored forests are typically planted from saplings or seeds, burned, weeded, or thinned in order to influence the composition for the new forest (Morrison and Lindell 2010). Ecological forest planting has become a widely used form of forest restoration and has been cited as producing the highest biodiversity in restored forests (Munro et al. 2009). Many restoration projects either plant a variety of seedlings or use the direct seed approach. When planting seeds, grass is grown over an old agricultural field for several years. Following this, hundreds of seedlings of a variety of different species are planted throughout the plot. For the direct seed approach, areas to be planted are disced and an herbicide is applied to kill any remaining crops or weedy species. Then large seeds are broadcast over the area, followed by lighter seeds which are broadcast and dragged slightly (Direct seeding of native hardwood trees, MNDNR). Some managers prefer the direct seed approach because it produces higher quality timber, ensures that the plants that grow are well suited to the environment, and provides a more natural appearance. Other managers may choose to plant seedlings and saplings instead of seeds. This strategy requires less site preparation, is more successful in areas with tree populations, and has a lower initial cost than the direct seeding approach (Direct seeding of native hardwood trees, MNDNR). Planting a wide variety of trees with these methods ensures future biodiversity of the site, while reducing volunteer vegetation that could inhibit tree seedling growth (Baer and Groninger 2004).

While active reforestation remains the preferred means of restoration among researchers and foresters, passive restoration occurs throughout the state in many abandoned fields. Passive restoration does not require direct management of the composition of the forest, but instead involves management of environmental stressors that inhibit succession (Morrison and Lindell 2010). Passive restoration has been found to occur in tracts of land that have not been disturbed for long periods of time. While all types of trees can grow in this type of restoration, there needs to be a seed source nearby (Battaglia et al. 2002). However, even if there is a nearby seed source, some tree species still have difficulty reproducing. While light seeded trees, such as aspen, use the wind to carry their seeds to the open fields and easily reproduce, trees with heavy seeds, such as walnut, are rarely found in passively restored areas, unless their seeds were carried by animals (Battaglia et al. 2008). Smaller-seeded trees have an additional advantage in that they can more easily germinate in open conditions whereas larger-seeds may need herbaceous cover in order to germinate. In addition, larger seeds have added disadvantages of needing open spaces to germinate and are more likely to be predated by animals (Desteven 1991).

The size of a patch of old field near a forest also affects the degree of succession. Small patches are more sensitive to disturbance and therefore have low seedling survival rates. The sensitivity and high rate of disturbance in small patches undergoing old-field succession leads to greater heterogeneity in species composition than large patch areas (Cook et al. 2005). However, if a small patch is found next to an established forest, it may have an increased ability to successfully undergo old-field succession (Connell and Slayter 1977). While this may increase the ability of a small plot to be populated by trees, larger plots still have an advantage because of temporal and community stability (Cook et al. 2005). In addition to being able to easily disperse seeds in the old-field, mature forests that are adjacent to old-fields provide mycorrhizal infection that promotes nutrient uptake and growth of young trees (Dickie et al. 2007).

The loss of hardwood forest has caused issues for plants and animals that depend on those ecosystems for food and habitat. Forest managers are currently working to restore this precious habitat before it is lost. Understanding the benefits of active and passive restoration techniques would provide managers with information that could optimize their restoration capacity and lead to a decrease costs associated with restoration. St. Olaf's Natural Lands contain a remnant forest, along with passively and actively restored forest land. The purpose of this study is to examine the effect of management strategies on the composition of their respective forests as well as infer the possible origins of the seeds that germinated in the passively restored woodland.

Methods:

Forest Composition

50 meter transects were laid in the Ytterboe remnant forest, planted forest, and unplanted successional field, all of which were in the St. Olaf Natural Lands (N 44° 27' 30.4", W 93° 11' 5.3"). Sampling methods were conducted in keeping with the methods outlined in *Field and laboratory methods for general ecology* by Brower et al, 1998. Point-quarter sampling along a transect was used to collect species composition for mature trees. Mature trees were defined as trees with diameters at breast height (DBH) of 13 cm or greater. Each tree was identified, measured for distance from the point, and the diameter was measured at breast height. At each of the random sample points, a one meter squared rectangular plot was laid down and the number of seedlings of different species in the plot was recorded (seedlings were defined as being less than 0.5 m tall). At the same point, a ten meter squared rectangular plot was laid down and the number of saplings of different species in the plot was recorded (saplings were defined as being taller than 0.5 m and having less than a 13 cm DBH). This was conducted at 8 points in the unplanted successional forest, 8 in the planted forest, and 8 in Ytterboe forest (with the exception of point-quarter data in Ytterboe which was collected at 10 points instead of 8).

Soil

Two locations in each forest plot were analyzed for soil characteristics. For each site, one soil core was taken and placed in pre-weighed tins. Soil cores were weighed and placed in a drying oven for 48 hours. The percent moisture and bulk density were calculated for each sample. Portions of the dried soil were placed in a pre-weighed crucible and put in the muffle furnace at 500°C for four hours. After four hours, samples were allowed to cool and were weighed. Using this data, the percentage of organic matter was calculated for each sample.

Data Analysis

Mature tree data was compiled and the importance values were calculated for each species present in the plot, using the equation:

Importance Value = Relative Density + Relative Frequency + Relative Coverage (Brower et al. 1998)

$$Relative\ Density = \frac{Number\ of\ individuals\ in\ a\ given\ species}{Total\ number\ of\ individuals\ counted}$$

$$Relative\ Frequency = \frac{Number\ of\ individuals\ in\ a\ given\ species}{Total\ number\ of\ points\ sampled}$$

$$Relative\ Coverage = \frac{Total\ basal\ area\ for\ a\ given\ species}{Total\ basal\ area\ for\ all\ species}$$

A contingency table was made in R commander version 2.15.2(Chambers et al. 2012) to determine if there was a difference between the mature tree compositions of the three forests, as well as just between the planted and unplanted plots, using a Pearson's Chi-Squared and p-value test. Mature trees in all three forests were also compared to mature tree composition of Norway Valley, using data collected by the St. Olaf College Field Ecology 371 class from the fall of 2012, using the same contingency table analyses. The DBH for red oak and white oak were compared between all three sites using ANOVA analyses.

Relative density values were also used to calculate mature trees per hectare. Quadrat data was used to calculate the number of seedling and saplings per hectare. Shannon and Simpson diversity indices were calculated using the Community Diversity Calculator (Farris 2012). The diversity of seedlings, saplings, and mature trees were compared between the forest types using a pairwise comparison of the Simpson index. In addition, the diversity within each plot was compared for all three life stages using pairwise test of the Simpson index.

Soil data was analyzed for difference between plots for percent soil moisture, bulk density, and percent organic matter using ANOVA analyses.

Results:

Mature Trees

Species composition data showed that red oak (IV=99.5), white oak (IV=84), and bur oak (IV=72.5) had the highest importance values in the unplanted plot. The species with the highest importance values in the planted plots were white oak (IV=88.89), green ash (IV=63.05), bigtooth aspen (IV=56.51), and bur oak (IV=44.9). The species with the highest importance values in Ytterboe forest were sugar maple (IV=102.2), red oak (IV=86.76), and to a lesser extent bitternut hickory (IV=22.9) and white oak (IV=22.39). Contingency table analysis of common species in all three forests yielded a chi-squared value of 22.14 and a p-value of 0.00114. In addition, contingency table analysis of just the unplanted and planted forests yielded a chi-squared of 15.626 and a p-value of 0.003564. Along with this, contingency tables showed that the composition for the three forest plots was significantly different from Norway Valley (chi-squared=56.4497, p-value=2.30e-9). ANOVA analyses comparing red oak and white oak DBH showed no significant difference in diameter between unplanted and planted, but both were different from Ytterboe (Table 1).

Stand Table

While the mature tree stage in the unplanted and planted plots were dominated by red oak, white oak, and bur oak (as well as green ash in the planted plot), Ytterboe forest was dominated by sugar maple, red oak, and bitternut hickory. In contrast with the mature tree composition, the unplanted plot was dominated by bitternut hickory and green ash in the seedling stage. The sapling stage was dominated by green ash, bitternut hickory, red oak, and prickly ash. However, prickly ash was found in only one quadrat. In contrast, the seedling composition in the planted forest was dominated by basswood, green ash, and white oak; whereas the sapling composition was dominated by butternut, sugar maple, and green ash. Finally, the seedling stage in Ytterboe forest was dominated by sugar maple, green ash, and basswood. The sapling stage was dominated by sugar maple and ironwood (Table 2).

Diversity

Diversity indices comparing the diversity of the unplanted, planted, and Ytterboe forests at all three growth stages showed no difference in diversity at the seedling stage. However, the planted forest had a higher diversity than the unplanted and Ytterboe forests at the sapling stage. In addition, the planted forest had a significantly lower diversity at the mature stage, while Ytterboe had a significantly higher diversity and the unplanted plot was not different from either forest plot (Table 3).

In comparison, diversity indices comparing the growth stages within each forest showed slight differences in diversity over the different growth stages. The unplanted plot had no difference in diversity between the seedling, sapling, and mature tree stages. Planted and Ytterboe both had significantly lower diversities at the sapling stage, while the diversity at the seedling and mature tree stage were not statistically different (Table 4).

Soil

Soli characteristic data showed a general trend of higher average percent moisture and organic matter, as well as lower soil bulk density, in the Ytterboe site. In addition, the data showed a general trend of lower average percent moisture and organic matter, as well as higher bulk density, in the planted forest. However, ANOVA analyses indicated that these differences were not statistically significantly different from one another (Table 5).

Discussion:

Mature Trees

Species composition data showed that the only species that while no species had high importance values in all three forests, both red oak and white oak had medium to high importance values all forests (medium importance is defined in this study as an IV of 15-35, high importance is above 35). Red oak was important in unplanted and Ytterboe, but was relatively unimportant in the planted plot. Conversely, white oak was important in the unplanted and planted, but was relatively less important in Ytterboe. In addition to having varying degrees of importance between the sites, different species were important in each site. In Ytterboe, sugar maple was the most important. In the planted forest, bigtooth aspen, green ash and bur oak were also high in importance. In the unplanted plot also had a high importance value for bur oak, with IV=72.4. These dissimilarities in importance values reflect a difference in the general composition of all three forests.

The difference in the most important species, as well as the general composition, is most likely due to the different restoration strategies, as well as the age of the forest. Ytterboe forest is a remnant forest; therefore the trees are much older and provide greater canopy cover than the unplanted and planted plots. This canopy provides the shade that is necessary for some tree species, such as sugar maple and basswood (Baker 1949). In addition, Ytterboe forest has been highly disturbed due to the construction of cross country trails and other gap inducing disturbances. Therefore sugar maples are more likely to be found in this forest because of their affinity toward gaps in mature forests (Connell and Slayter 1977). The planted forest is much younger than Ytterboe forest and therefore does not provide the shade necessary for sugar maple and other shade tolerant species to survive. While some of the mature trees are shade tolerant, such as basswood, they were planted there as saplings by restoration ecologists and therefore do not follow the normal trend of successional forests (i.e. shade intolerant species grow first, followed by shade tolerant species that fill in the gaps in the canopy). However, all of the important species were in the intermediate and intolerant range of shade tolerance, which is expected because of the smaller canopy cover due to the age of the forest (Connell and Slayter 1977). Similarly, the unplanted plot only had shade intolerant species, which is characteristic of an old-field succession forest (Battaglia, Minchin, Pritchett 2002).

The abundance of mature oaks, especially white oak and bur oak, in the unplanted plots is somewhat surprising because acorns from oaks are not dispersed far from their parent tree unless they are carried by animals. Therefore the parent trees would most likely be nearby, but Ytterboe forest did not show an abundance of white oak or bur oak. However, studies have shown that old-field sites have an increased survival rate of oaks, if they are adjacent to a remnant forest. This is because the oak seedlings are inoculated with mycorrizal fungi from the adjacent forest, assisting them in the uptake of nutrients which increases their survivorship and gives them a competitive advantage over the pre-existing grasses (Dickie et al. 2007). Therefore, acorns from the limited number of mature white oak and bur oak would be able to successfully germinate and grow (although no bur oak were found in the Ytterboe study sites, it is possible that the random sampling simply did not come across the mature, seed producing individuals). In addition, contingency table analyses indicated that the composition of the three forests was statistically different than Norway Valley, another nearby forest remnant which is dominated by sugar maple and basswood. Therefore, the oak seeds did not originate from Norway Valley, leaving the Ytterboe-Hoyme forest as the only viable option for seed production.

Seedlings and Saplings

While oak trees were the most important trees found in all three forest sites, the composition of seedling and saplings showed higher abundances of different species. In the unplanted plot, bitternut hickory and green ash were abundant at both the seedling and sapling stages. These species are both categorized as having intermediate tolerance to shade (Baker 1949). Oak, bitternut hickory, and green ash are typical early successional forest trees, which grow in nutrient deficient soils, such as those used in conventional agriculture (FORSite 2012, Dickerson 2002). Simpson diversity indices showed that the diversity of the seedling, sapling, and mature trees were not different from one another. However, this may be due to small abundances of individuals of the species found in the seedling and sapling stages, rather than the richness. Saplings had a much higher species richness than mature trees and seedlings, but the evenness may have caused the diversity levels to be not significantly different than the other age classes. Therefore, while the diversity is not different across the age classes, the richness indicates that the forest may be changing and has the potential to become more diverse in the future.

While the mature trees in the planted and unplanted forests are around the same age, as determined by ANOVA comparisons of the DBH for red oak and white oak, their seedling and sapling compositions are very different. Green ash is prominent in the seedling stage, as well as abundant in the sapling stage along with butternut. This indicates that the forest is still young enough to provide the open canopy needed for green ash and butternut to survive. However, basswood is also dominant in the seedling stage and sugar maple is in higher abundance in the sapling stage. These species grow well in shade, indicating that gaps in the canopy are beginning to close (Baker 1949). These results indicate that the forest structure is beginning to change because of the increased shade due to the reduction of gaps in the canopy. Simpson diversity indices support this conclusion because of increased diversity of seedlings and saplings, as compared to mature tree diversity. The higher diversity at younger growth stages, coupled with the difference in dominant species, indicates that the forest is rapidly changing. Although it is not certain, the structure may begin to change to be more similar to Ytterboe forest because of the proximity to seed producing trees.

While the composition of the unplanted and planted plots at the different growth stages indicates that the forest composition will likely change in the future, this may not be the case in Ytterboe forest. Sugar maple is abundant in both the seedling and sapling stages. While green ash and basswood are also abundant at the seedling stage and ironwood is abundant at the sapling stage, the sugar maple's ability to quickly grow and inhabit gaps in the canopy may help it out compete the other species (Connell and Slayter 1977). Although basswood and ironwood are shade tolerant species, green ash is not (Baker 1949). Green ash may be abundant in the seedling stage because of disturbance from the cross country trail going through the forest, in addition to the heavy foot traffic leading to Ytterboe Hall. These disturbances may increase the amount of light the ground layer receives and allow intermediate shade tolerant species to grow in the younger layers of the forest. Human foot traffic would lead to the reduction in abundance of younger life stages, but may have more of an effect on the sapling stage. As students move through the forest, they may have to push branches away in order to get through the forest, which could potentially cause damage to the tree. This difference in abundant species at different growth stages is supported with pairwise comparison of the Simpson diversity index that show that the seedling stage has a much higher diversity than the sapling stage.

Comparison of Diversity between Forests

While there was variation in diversity and species with higher abundance within each plot, there were also significant differences between the diversity of the forests sites. A comparison of the seedling diversity showed no difference between the unplanted, planted, and Ytterboe forests. However, the planted forest had significantly higher sapling diversity and significantly lower mature tree diversity. This could be due to a variety of factors including induced competition for resources in the first generation of trees. A diverse group of saplings were planted in transects in 1991 (St. Olaf College 1999). It is possible that the location of the planted saplings did not have enough resources or nutrients for the individuals to survive. Trees growing in the unplanted plot grow where there are resources, but when managers plant trees they may not place them resource levels are high and individual saplings may not survive (Finnegan et al. 2012). As new seeds enter the forest, they may germinate where the plant has enough resources to grow, leading to a higher diversity in younger growth stages.

Soil

Soil analyses showed that although the soils from the different forest plots had varying levels of moisture, organic matter and bulk density, they were not significantly different from one another. This indicates that the variation in forest composition is most likely not due to any underlying soil characteristics, but to the plants themselves. However, in order to draw any firm conclusions further studies on soil chemical characteristics must be conducted.

Passive and Active Restoration

Passive restoration led to a more diverse group of mature trees in the first generation of the forest, as compared to the actively restored forest. While these differences in mature tree diversity are not significant and more studies must be conducted to draw any conclusions, the trend indicates that there may be a relationship between these two variables. Passive restoration may produce a more diverse first generation of forest, but further studies must be conducted in order to draw conclusions.

Conclusions

Comparisons of importance values of mature trees in the unplanted, planted, and Ytterboe forests showed that oaks were important in all three forests. However, the forest compositions of the three plots were significantly different from one another. The high abundance of oak species in the unplanted plot, along with the significant difference in composition between these three forests and Norway Valley, suggest that the unplanted plot is populated with the offspring of trees in the Ytterboe forest. Species composition data for the seedling, sapling, and mature tree stages indicate that the unplanted and planted forests are changing. The proximity to Ytterboe forest along with the changing composition of the forest indicates that all three forests will eventually become similar to Ytterboe forest and each other. While passive restoration yielded higher diversity of mature trees than active restoration, active restoration will likely facilitate higher levels of diversity by providing different shade treatments to the plot, allowing a more diverse group of trees to populate the area. Passive and active restoration strategies must be taken into account when designing management strategies.

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Sample	Wet Weight (g)	Dry Weight (g)	Percent Moisture	Organic before	Organic After
A remnant	68.94	59.26	16.33	7.17	6.83
B remnant	66.24	52.27	26.73	6.68	6.05
A planted	88.24	77.12	14.42	6.81	6.53
B planted	73.55	65.38	12.50	6.52	6.27
A unplanted	71.81	61.26	17.22	6.74	6.41
B unplanted	84.18	70.52	19.37	4.81	4.54

Organic Matter	Percent Organic Matter	Bulk Density
0.34	4.742	1.232879725
0.63	9.431	1.087455673
0.28	4.112	1.604449618
0.25	3.834	1.360203787
0.33	4.896	1.274488895
0.27	5.613	1.467139355

Table1. Importance values of mature trees in Ytterboe forest and an adjacent planted forest and unplanted, successional forest in the St. Olaf Natural Lands. Importance values were calculated by summing the relative density, relative frequency, and relative coverage. Data for all species with individuals all forest type were compiled and a contingency table was used in a Pearson's Chi-squared test to show statistical difference between the forest composition of the three forests (X-squared = 22.1441, df = 6, p-value = 0.00114). In order to establish if there was a difference between the unplanted and planted forests contingency table calculated in the same manner without the data on the Ytterboe forest (X-squared = 15.626, df = 4, p-value = 0.003564).

Species	**Relative Frequency**			**Relative Density**			**Relative Coverage**			**Importance Value**		
	Unplanted	**Planted**	**Ytterboe**	**Unplanted**	**Planted**	**Ytterboe**	**Unplanted**	**Planted**	**Ytterboe**	**Unplanted**	**Planted**	**Ytterboe**
American Elm	0.00	0.00	7.14	0.00	0.00	5.13	0.00	4.40	0.756	0.0	4.40	13.03
Basswood	0.00	5.56	3.57	0.00	3.13	2.56	0.00	10.7	0.481	0.0	19.38	6.62
Bigtooth Aspen	10.0	5.56	3.57	6.45	3.13	5.13	6.00	47.8	0.784	22.4	56.51	9.48
Bitternut Hickory	0.00	0.00	10.7	0.00	0.00	10.3	0.00	2.40	1.92	0.0	2.40	22.90
Bur Oak	25.0	11.1	0.00	25.8	6.25	0.00	21.6	27.5	0.00	72.4	44.90	0.00
Green Ash	10.0	27.8	3.57	6.45	28.1	2.56	5.12	7.15	1.32	21.6	63.05	7.46
Hackberry	0.00	0.00	3.57	0.00	0.00	2.56	0.00	0.00	0.892	0.0	0.00	7.03
Ironwood	0.00	0.00	7.14	0.00	0.00	7.69	0.00	0.00	0.910	0.0	0.00	15.75
Red Maple	0.00	0.00	3.57	0.00	0.00	2.56	0.00	0.00	0.308	0.0	0.00	6.44
Red Oak	30.0	11.1	28.6	35.5	9.38	28.2	34.0	0.00	30.0	99.5	20.49	86.76
Sugar Maple	0.00	0.00	21.4	0.00	0.00	28.2	0.00	0.00	52.5	0.0	0.00	102.2
White Oak	25.0	38.9	7.14	25.8	50.0	5.13	33.2	0.00	10.1	84.0	88.89	22.39

Table 2. Number of seedlings, saplings, and mature trees of a particular species per hectare of forest.

Species	Seedlings			Saplings			Mature Trees		
	Unplanted	**Planted**	**Ytterboe**	**Unplanted**	**Planted**	**Ytterboe**	**Unplanted**	**Planted**	**Ytterboe**
American Elm	0	1250	0	0	0	0	0	0	20.78
Basswood	0	2500	3000	250	1000	500	0	8.786	10.39
Bigtooth Aspen	0	0	2000	250	125	400	17.76	8.786	20.78
Bitternut Hickory	3750	0	1000	375	750	0	0	0	41.56
Black Walnut	0	1250	0	0	125	0	0	0	0
Bur Oak	1250	0	0	125	875	0	71.04	17.57	0
Butternut				0	1375	0	0	0	0
Cherry	0	0	2000	250	0	200	0	0	0
Green Ash	3750	2500	5000	1875	1125	200	17.76	79.07	10.39
Hackberry	0	0	0	0	0	200	0	0	10.39
Ironwood	0	0	2000	125	250	2000	0	0	31.17
Prickly Ash	1250	0	1000	3375	1125	0	0	0	0
Red Maple	0	0	0	0	0	0	0	0	10.39
Red Oak	0	0	2000	375	0	100	97.69	26.36	114.3
Red Pine	0	0	0	0	125	0	0	0	0
Sugar Maple	0	0	7000	0	1250	4200	0	0	114.3
White Oak	0	2500	0	125	375	0	71.04	140.6	20.78

Table 3. Simpson diversity indices of unplanted, planted, and Ytterboe forests at the seedling, sapling, and mature tree stages. A pairwise comparison of the Simpson diversity indices showed differences between plots in the same growth stages with significance at p-value <0.05. Differences are shown using different letters within each major group.

Growth Stage	Plot	Richness	Simpson (DS)	Variance of DS	Pairwise Comparison of DS
Seedling	Unplanted	4	0.79	0.0059	A
	Planted	5	0.89	0.0025	A
	Ytterboe	9	0.87	0.0012	A
Sapling	Unplanted	10	0.71	0.0023	B
	Planted	12	0.89	0.0001	C
	Ytterboe	8	0.64	0.0021	B
Mature tree	Unplanted	5	0.76	0.0010	DE
	Planted	6	0.68	0.0038	D
	Ytterboe	11	0.84	0.0013	E

Table 4. Simpson diversity indices of seedling, sapling, and mature trees in the unplanted, planted, and Ytterboe forests. A pairwise comparison of the Simpson diversity indices showed differences between growth stages within a plot with significance at p-value <0.05. Differences are shown using different letters within each major group.

Plot	Growth stage	Richness	Simpson (DS)	Variance of DS	Pairwise Comparison of DS
Unplanted	Seedling	4	0.79	0.005859	A
	Sapling	11	0.72	0.002230	A
	Mature tree	5	0.76	0.001041	A
Planted	Seedling	5	0.89	0.001465	B
	Sapling	12	0.89	0.000090	B
	Mature tree	6	0.68	0.003777	C
Ytterboe	Seedling	10	0.88	0.001137	D
	Sapling	8	0.64	0.002078	E
	Mature tree	11	0.84	0.001258	D

Table 5. Average percent moisture, percent organic matter, and soil bulk density for soil samples taken in an unplanted, planted, and Ytterboe remnant forest. ANOVA analyses showed no statistically significant difference between the sites for all soil characteristics ($p>0.05$).

Site	Percent Moisture	Percent Organic Matter	Soil Bulk Density (g/cm^3)
Remnant	21.53	7.09	1.16
Planted	13.46	3.97	1.48
Unplanted	18.30	5.25	1.37