The effect of forest management strategies on forest health on the Utrecht Heuvelrug

Research Report 1A

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Introduction

Global climate change causes changes in weather patterns and increases extremes, which threatens the stability and growth of forests (Katz & Brown, 1992). It is, therefore, important to assess the health and biodiversity of natural areas for effective management (Park et al., 2014). One of the largest natural conservation and recreation areas in the Netherlands is the Utrecht Heuvelrug, administered by National Park Utrecht Heuvelrug (NPUH) in collaboration with other organizations such as Staatsbosbeheer (Lecture 2 RIP, 2021). The Utrecht Heuvelrug is a biodiversity rich area, however, due to changes in weather conditions the health of these areas is endangered.

To manage this National Park, NPUH and Staatsbosbeheer employed three different methods of forest management: multifunctional forest, nature forest, and forest reserve management (Staatsbosbeheer, 2015). Multifunctional forest management entails a prominent level of human interference, as the area serves for recreation, logging, and nature conservation. Nature forest involves trees harvesting to promote regeneration. In forest reserve regions, the approach includes little to no human interference.

Since the effect is unclear, studies are critical to ensuring effective protection and well-being of the Utrecht Heuvelrug. Changing weather patterns are already threatening several tree species. To assess the health of the forest, three indicators will be used: woody plant species richness, the Shannon-Wiener index for trees, and Diameter at Breast Height (DBH). Species richness includes the number of species per area (Rousseau & Van Hecke, 1999). The Shannon-Wiener index is a biodiversity index that uses species richness but also accounts for relative abundance (Spellerberg & Fedor, 2003). DBH measurement can partly determine the trees age variance and further indicates the health of the plot through its regeneration rate (Clark, 2017)

To demonstrate the influence of different forest management methods on forest health, three separate locations within the Utrecht Heuvelrug will be examined. In these locations, forest health will be assessed by determining woody plant species diversity and the DBH of key species. This data will also construct an overview of the forest structure. The research question is: how do the three different management strategies influence forest health? To create a more holistic view on the health of the forest, the following sub-questions shall be answered:

- What effect do different forest management strategies have on the species richness of woody plants?
- What effect do different forest management strategies have on the Shannon-Wiener index of tree species?
- What effect do different forest management strategies have on the DBH of six key species?

The hypothesis is that there is a significant difference in forest health between the three different forest areas. For the species richness and Shannon-Wiener index, it is expected that biodiversity is highest in the forest reserve area, and lowest in multifunctional forest. The same principle applies to the DBH distribution, which is expected to be the healthiest in the forest reserve and least in multifunctional forest. The null hypothesis for the first two sub-questions is that there is no significant difference between the forest management types.

Literature review

Forest management

Forest management is the constitution of legal administrative activities, planning and implementing practices based on multiple aspects throughout silvicultural, protection, and forest regulation (Ministry of Forests and Range (Canada), March 2008). Sustainable forest management (SFM) can be described as the long-term use and protection of forests with the goal of preserving and improving multiple forest values through human interference. It provides valuable environmental services such as carbon sequestration, biodiversity restoration, and water supply security (FAO, 2020). Consequently, SFM calls for a balance between the need for natural resources and the forest's vitality. Sustainable forest management strategies are often limited to ensuring the sustainability of wood production and other forestry products (Rainforest Alliance, 2016). Their reach, on the other hand, include socioeconomic, cultural, and environmental forest values equally. Despite human interference of maintaining and enhancing, this does not mean forests will not be subjected to degradation (Earth Eclipse, 2017). Forests will still be affected by outside influences and as such SFM cannot fully control the sustainability of the forest.

Forest currently covers approximately 10% of the land surface in the Netherlands, this corresponds to around 360.000 hectares. The main forest functions in the Netherlands include wood production, soil and water protection, biodiversity conservation, social services, and additional functions such as biomass and carbon sequestration (Van der Maaten-Theunissen & Schuck, 2013). In 2017, the Dutch government updated the Dutch Nature Conservancy Act (Natuurbeschermingwet) to protect several plant and animal species living in the wild.

Forest health

Each stage in a forest's life provides a niche for a different group of animals. In natural forests these stages happen at the same time in a mosaic like pattern (Remmert, 1991). In the innovation phase that trees are mostly absent, being replaced by shrubs and herbs, this provides food for smaller herbivores. During the aggradation phase trees start growing, and during the biostatic phases those provide a stable environment for plants and animals, such as for birds to nest in or lichens and moss to grow on. And finally, during the degradation phase the trees that die provide a living space for small animals and food for scavengers and detritivores (Whittaker, 1972).

A forests health can be measured in numerous ways. One indicator is species diversity. Common ways to measure species diversity are species richness and the Shannon-Wiener index (Rousseau & Van Hecke, 1999). Species richness shows the number distinct species live in a certain area, without their proportions (Gotelli & Colwell, 2011; Keylock, 2005; Zhang et al., 2012). The Shannon-Wiener index uses species richness but accounts for relative abundance (Spellerberg & Fedor, 2003). In this research, species richness and the Shannon-Wiener index are the indicators for biodiversity. Biodiversity provides a safety net because fungal diseases spread more slowly (Pautasso et al. 2005) and pests are less harmful when diversity is high (Guyot et al. 2016). Diameter at Breast Height (DBH) can be used to measure forest health as the different stages of a forest’s life, which corresponds to different diameters.

This research paper will focus on woody plant species diversity. The DBH will be measured for six tree species, of which four are vulnerable species, namely: Norway spruce, inland oak (European oak), Douglas fir, Japanese larch. The spruce is highly vulnerable to drought, which has become more common in the Utrecht Heuvelrug due to climate change.

Forest management plan

Woody plant species are (mainly) managed through silvicultural operation, which commonly include plantation, pruning, thinning, and felling (WFF Nepal, 2020). The process in a plantation is different for each species depending on the site, its value for the market and community and the appropriate environmental needs that need to be met. Trees can be felled to harvest wood, but care must be taken as it negatively impacts forest health.

The first part of forest management plan is the forest assessment, analyzed using both socio-economic and technical aspects, this report is primarily targeted at the technical aspects. The species diversity and forest structures will be used to determine which the advantages and disadvantages of each forest management system.

Research gaps

The forest management strategies that exist in the Utrecht Heuvelrug, nature forests, forest reserves and multifunctional forests, and their effects on forests are not well researched. The Utrecht Heuvelrug makes up more than a third of the Dutch forests (139.000 hectares) alone and as such there is a need for more research.

Methods

Study area and design

Data was collected at three different locations in the Utrecht Heuvelrug: in a multifunctional forest, in a nature forest, and in a forest reserve. The locations are shown below in a map. Thirty locations were chosen, then divided further into 10 locations per management area (Figure 1). Ten plots of each strategy were used, which each had their own dominant tree species which corresponds to the key species. From the thirty plots in total, one proved to be inaccessible in the field, resulting in data being collected in 29 plots.

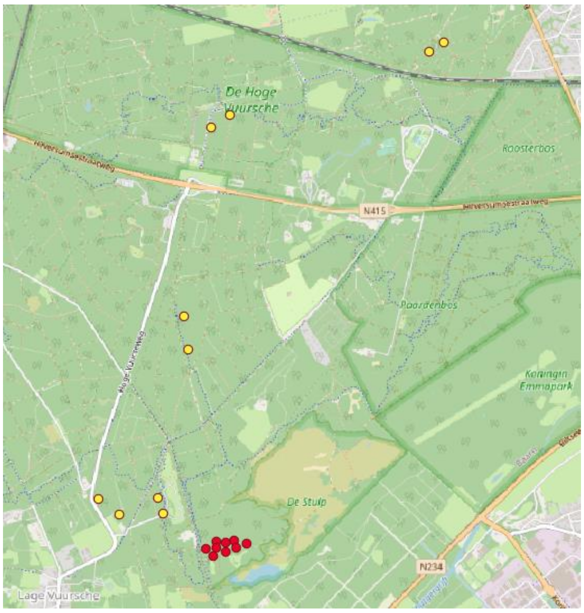

Figure 1a: Map with multifunctional forest and nature forest locations. Yellow dots represent multifunctional forest areas, red dots indicate nature forest areas.

Figure 1b: Forest reserve locations. Blue dots indicate forest reserves.

Plots were chosen over transects because it was easier to keep track of and mark as well as several similar studies also chose to work with plots (Clerkx & Broekmeyer, 1997; Paquette & Messier, 2011; Čugunovs et al., 2017; Sano, 1997; Shumi, 2019). The plots were located along the transect of group 1B (looking into bird biodiversity) to ensure integration. The plots were 20 by 20 meters, as this is a size that contains enough individuals to count and measure but was also doable within a reasonable timeframe, as this was tested prior to the data collection by doing a pilot in a nearby (similar) forest.

Data collection

Data was collected to gather information on woody plant species richness, tree diversity (indicated by the Shannon-Wiener index) and forest structure (indicated by DBH).

The woody plant species richness was measured by counting all woody plant species presented in a plot, included both tree and shrub species. It was only noted down whether a certain species was there instead of individual numbers. Trees were identified using a personalised printed tree key which included the key tree species (Annex 5). Shrubs and unknown trees were identified using the PlantNet app.

To collect necessary data to calculate the Shannon-Wiener index, i.e., species and number of individuals; we focused on only the tree species. In contrast to the woody plant species richness, the number of individuals per species were counted as well.

The structure of the forest was assessed by measuring the diameter at breast height (DBH) of trees on the Utrecht Heuvelrug. This was done by measuring, at a height of 130 centimetres (Roman & Henning, 2020) from the ground, the circumference of trees with a diameter larger than 5 centimetres (Shumi et al., 2019). Then, the diameter was calculated by dividing the circumference by the number pi (π). Six key species were selected for this process, namely Inland/European oak (*Quercus robur*), Norway spruce (*Picea abies*), European beech (*Fagus sylvatica*), Douglas fir (*Pseudotsuga menziesii*), Scots pine (*Pinus sylvestris*), and Japanese larch (*Larix kaempferi*). These were selected based on two criteria. The first criterion was commonness. Beech and Scots pine were chosen because these are species representative of the forest, and it is important that the trees selected can be found in every plot measured. Second, the Japanese larch, Douglas fir, Inland oak and Norway spruce species have been mentioned to be vulnerable species in the Utrecht Heuvelrug (Staatsbosbeheer, 2021). These trees, which are typical for the area, have been suffering from illness and stunted growth. Considering these trees are also common, they are vital for the health of the forest.

The collected measurements of these trees were then divided into ten size classes. This classification was based on a paper by Clerkx & Broekmeyer (1997) which also investigated DBH distribution in a specific area of the Utrecht Heuvelrug.

Table 1: DBH classification

DBH class	1	2	3	4	5	6	7	8	9	10
Diameter in centimetres	5.1-10	10.1-15	15.1-20	20.1-25	25.1-30	30.1-35	35.1-40	40.1-45	45.1-50	>50.1

Data analysis

Species richness was calculated by counting the woody plant species per plot.

Following many other studies into biodiversity (Gao et al., 2014; Kooch et al., 2012; Thom & Seidl, 2016) this study used the Shannon-Wiener index to calculate biodiversity. The Shannon-Wiener formula is as follows (Spellerberg & Fedor, 2003):

$$H' = -\sum_{s=1}^{s} P_i \log P_i \quad \text{and} \quad P_i = \frac{N_i}{N_{tot}}$$

In which:

s = species number

N_i = total number of individuals of species i

N_{tot} = total number of individuals of all species

P_i = proportion of all individuals that belong to species i

After the woody plant species richness and Shannon-Wiener index for trees were calculated for the different plots, they were compared to assess woody plant species diversity under different management strategies. First, graphs with the mean and standard deviation per management strategy were created. Then, statistical tests were done in SPSS to determine if the differences found were significant. Because both datasets were not normally distributed (Annex 4) and three groups were compared, the Kruskal-Wallis test was used. The dependent variables in these tests were the species richness and the Shannon-Wiener index and the independent variable was the forest management strategy. If the p-values (probability that results are caused by chance) were equal to or below 0,05, the differences were significant, and the null-hypothesis could be rejected. To determine which management types differed significantly, the Dunn-Bonferroni post-hoc test was used. This test does pairwise comparisons for the dependent variables for which the Kruskal-Wallis test is significant.

For the DBH data, histograms were used to analyse the distribution across the different DBH classes. A histogram was made for inland oak, Norway spruce, beech, Douglas fir, Scots pine, and Japanese larch with rows for each management strategy. Afterwards they were divided into rows based on management type.

The obtained histograms were compared to discover trends of tree regeneration, as characterised by the number of trees in the lower classes relative to the number of trees in the upper classes (Kuuluvainen & Kalliola, 1998), as well as other trends in the data. Possible distributions include an inverted J-shape, indicating a managed forest from which timber is recruited while it is also steadily regenerating, and a broken inverted J-shape, indicating selective timber cutting (Gebrehiwot & Hundera, 2014).

Results

Out of the 30 plots that were chosen, 29 were feasible to be measured. The DBH of 381 living trees was measured in 29 plots for an average of 13,1 (± 8,3) trees per plot. In the nature forest, eight dead Japanese larch were found, with a DBH ranging between 30 to 70cm. The largest tree measured was a Japanese larch in a forest reserve with a circumference of 213 cm and a DBH of 67,8 cm. The tree species that was measured most was the Japanese larch with 132 individuals, and the least measured was Sessile oak with three individuals. The average woody plant species richness across the plots was 6,14 (± 2,9). The plot with the highest woody plant species richness had 13 species and was in a multifunctional forest. The plot with the lowest species richness was also located in a multifunctional forest and had two woody plant species.

Species richness

Species richness differed between the three forest management types. It was highest for the nature forest (mean ± SD: 7,78 ± 2,64), followed by the multifunctional forest (mean ± SD: 6,60 ± 3,31) and then the forest reserve (mean ± SD: 4,20 ± 1,40; Figure 2). The standard deviation was relatively large in all the management types. Still, from this graph it could be derived that the forest reserve has the lowest species richness, and the nature forest has the highest.

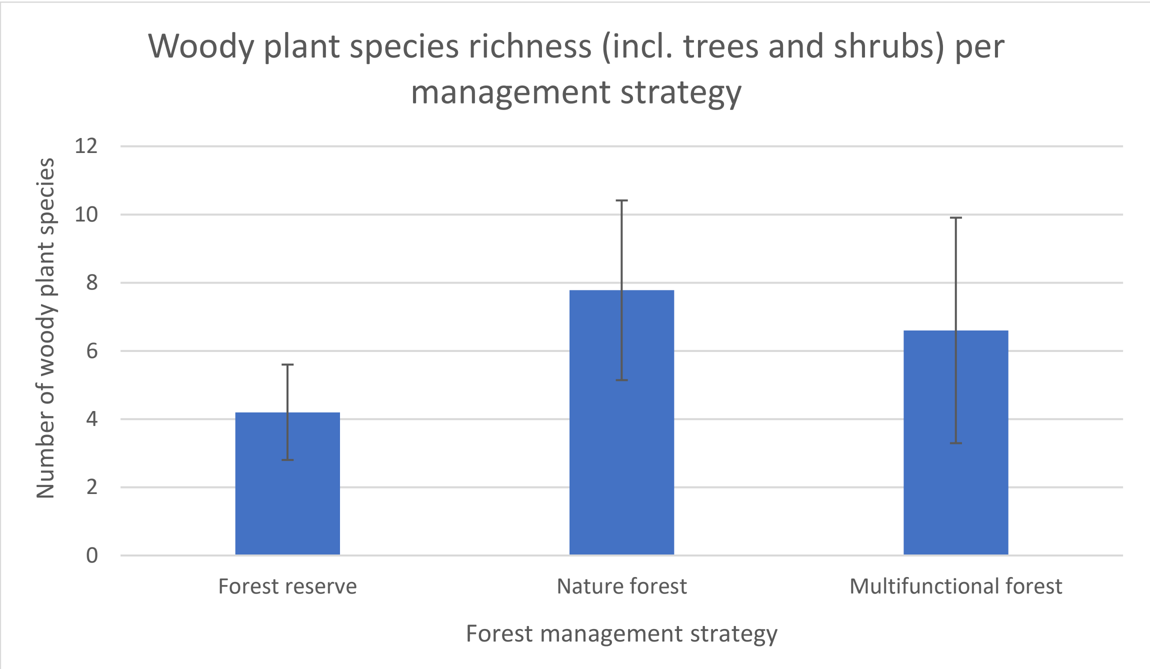

Figure 2: woody plant species richness per management strategy

The Kruskal-Wallis test showed that the p-value is 0,021 (Table 2), which means that the difference is significant (lower than 0,05). There is thus a significant difference between the forest management types.

Table 2: output Kruskal-Wallis test for woody plant species richness

Kruskal-Wallis Test

Ranks

	Forest management type	N	Mean Rank
Species richness incl. shrubs	Forest reserve	10	9,40
	Nature forest	9	20,06
	Multifunctional forest	10	16,05
	Total	29	

Test Statistics[a,b]

	Species richness incl. shrubs
Kruskal-Wallis H	7,771
df	2
Asymp. Sig.	,021

a. Kruskal Wallis Test

b. Grouping Variable: Forest management type

The Dunn-Bonferroni post-hoc test revealed that only the difference between the forest reserve and nature forest is significant (p-value = 0,018) (Table 3). This means that a nature forest management strategy results in higher woody plant species richness than a forest reserve approach.

Table 3: output Dunn-Bonferroni test for woody plant species richness

Pairwise Comparisons of Forest management type

Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.[a]
Forest reserve-Multifunctional forest	-6,650	3,778	-1,760	,078	,235
Forest reserve-Nature forest	-10,656	3,882	-2,745	,006	,018
Multifunctional forest-Nature forest	4,006	3,882	1,032	,302	,906

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is ,05.

a. Significance values have been adjusted by the Bonferroni correction for multiple tests.

Shannon-Wiener index

The results for the Shannon-Wiener index also differed across the forest management strategies. The nature forest had the highest Shannon-Wiener index (mean ± SD: 0,65 ± 0,14), followed by the multifunctional forest (mean ± SD: 0,49 ± 0,26) and then the forest reserve (mean ± SD: 0,43 ± 0,11; Figure 3). Again, the standard deviations were relatively large, mainly for the multifunctional forest.

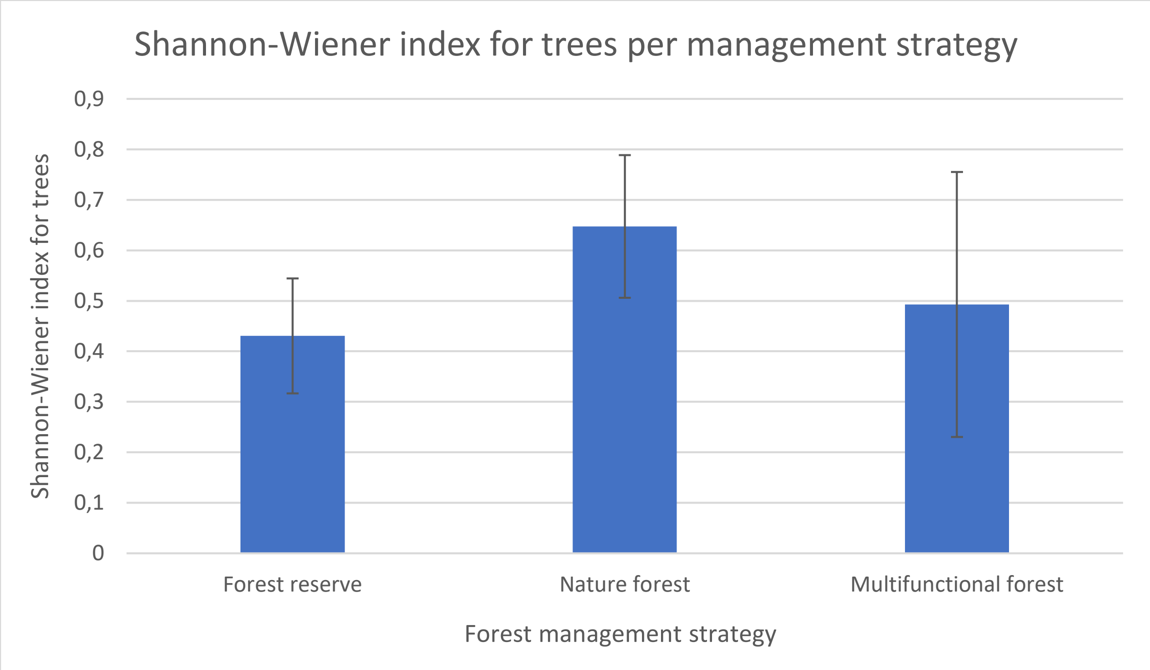

Figure 3: Shannon-Wiener index for trees per management strategy

The Kruskal-Wallis test showed that the p-value is 0,048 (Table 4), which means that the differences between the management strategies are significant.

Table 4: output Kruskal-Wallis test for Shannon-Wiener index

Kruskal-Wallis Test

Ranks

	Management type	N	Mean Rank
Shannon-Wiener index	Forest reserve	10	10,90
	Nature forest	9	20,44
	Multifunctional forest	10	14,20
	Total	29	

Test Statistics[a,b]

	Shannon-Wiener index
Kruskal-Wallis H	6,087
df	2
Asymp. Sig.	,048

a. Kruskal Wallis Test

b. Grouping Variable: Management type

The Dunn-Bonferroni post-hoc test revealed that only the difference between the forest reserve and the nature forest is significant (p-value = 0,044) (Table 5). This means that the nature forest management strategy results in a higher Shannon-Wiener index for trees than the forest reserve approach.

Table 5: output Dunn-Bonferroni test for Shannon-Wiener index

Pairwise Comparisons of Management type

Sample 1-Sample 2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj. Sig.[a]
Forest reserve-Multifunctional forest	-3,300	3,808	-,867	,386	1,000
Forest reserve-Nature forest	-9,544	3,912	-2,440	,015	,044
Multifunctional forest-Nature forest	6,244	3,912	1,596	,110	,331

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is ,05.

a. Significance values have been adjusted by the Bonferroni correction for multiple tests.

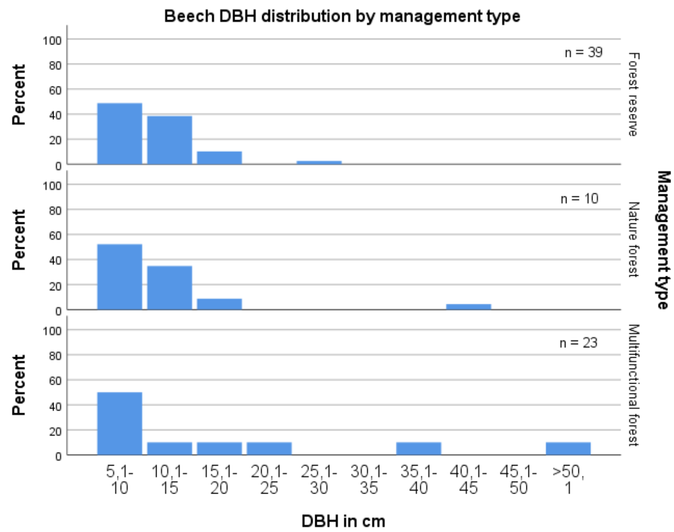

Figure 4a: Beech

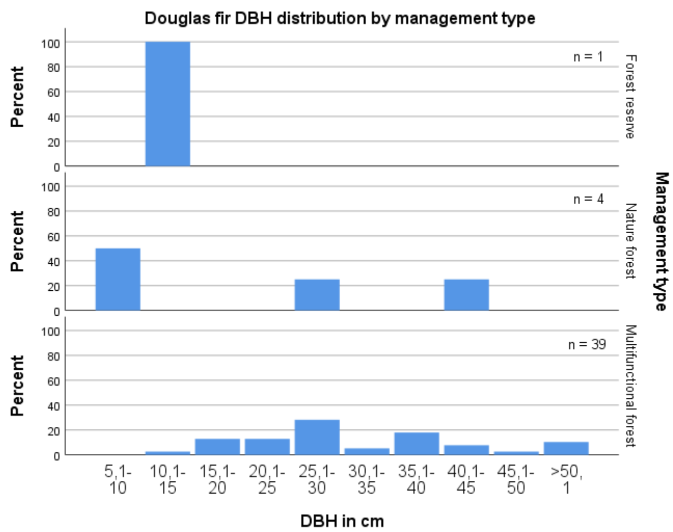

Figure 4b: Douglas fir

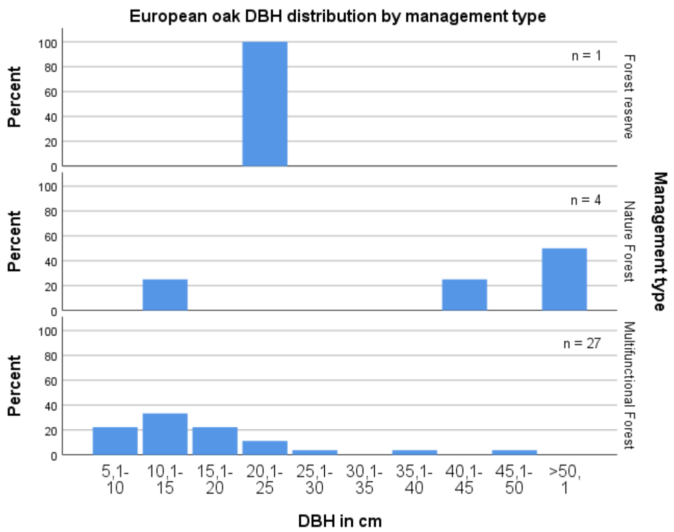

Figure 4c: European oak

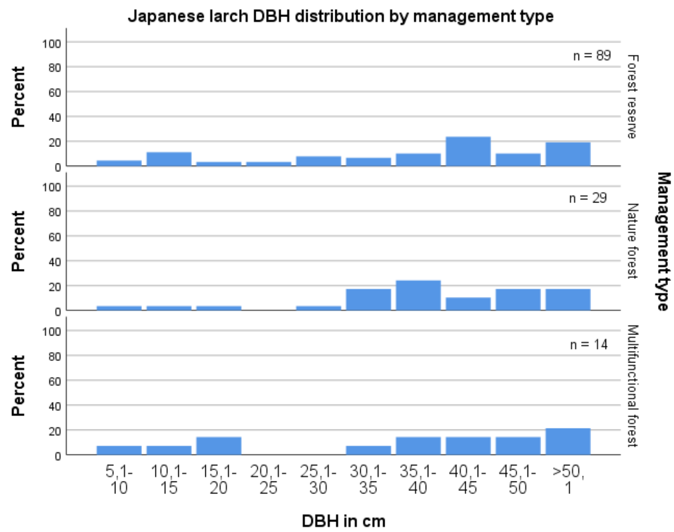

Figure 4d: Japanese larch

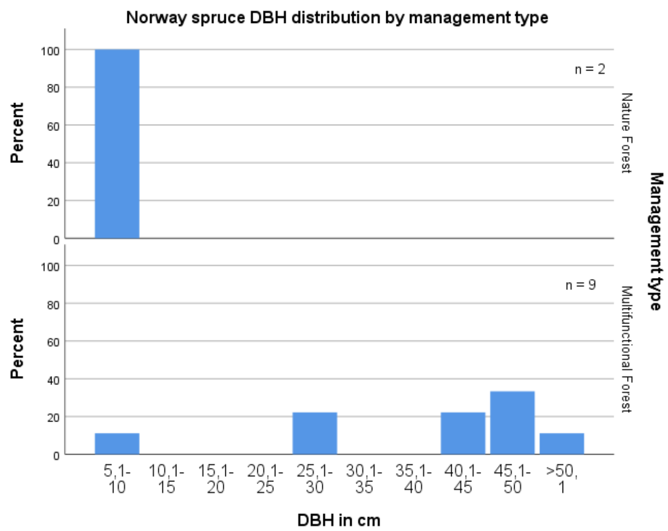

Figure 4e: Norway spruce

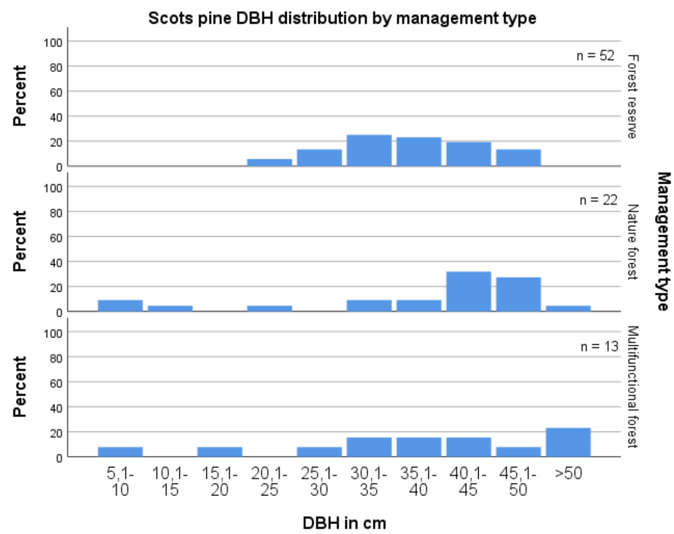

Figure 4f: Scots pine

The DBH measurements were put into SPSS where they were assigned a DBH size class based upon the classes, as discussed in the methods section.

Beech (Figure 4a) followed an inverted J-shape in forests of all three management types, few of the trees were recorded with a high DBH. The multifunctional forests had comparatively the oldest trees with the forest reserve having the fewest. Douglas fir (Figure 4b) was normally distributed in the multifunctional forests, having many individuals close to the middle range, falling off towards the edges and was randomly distributed in forest reserves and nature forests. The multifunctional forests had no trees with a small DBH and a relatively high percentage of trees with a high DBH.

European oak (Figure 4c) followed an inverted J-shape in multifunctional forests, having a high number of individuals with a low DBH, but few with a high DBH, but had a random distribution in forest reserves and nature forests. There was a large amount of Japanese larch (Figure 4d) with the forest reserves having 89 individuals. It has a distribution close to a J shape in all three management types, with few individuals of low DBH and a relatively high number of individuals with a high DBH. Multifunctional forests had no individuals with a DBH between 20,1 to 30 cm.

Norway Spruce (Figure 4e) was only found in nature forests and multifunctional forests, having no individuals in nature reserves. It had a random distribution in both management types. Scots pine (Figure 4f) was normally distributed in forest reserves and had a J shaped distribution in nature forests and multifunctional forests. There were no trees with low DBH in the forest reserves, and few in the nature forests and multifunctional forests.

Discussion

The goal of this research was to determine how three different management strategies influence forest health on the UH. The indicators of forest health that were used in this research were woody plant species richness, the Shannon-Wiener index for tree species, and the DBH of six key species.

The research question was: how do the three different management strategies influence forest health? The sub-questions were focused on three chosen indicators of forest health:

- What effect do different forest management strategies have on the species richness of woody plants?
- What effect do different forest management strategies have on the Shannon-Wiener index of tree species?
- What effect do different forest management strategies have on the DBH of six key species?

Species richness

The results
show that the nature forest management strategy leads to significantly higher woody plant species richness than a forest reserve approach (Figure 2; Table 3). Since this means that there is a significant difference between the forest management strategies, the null hypothesis can be rejected. However, the alternative hypothesis cannot be accepted either, because it predicted that the species richness would be highest in the forest reserve and lowest in the multifunctional forest, which is not the case.

These results are in line with biodiversity theories. The most important theory explaining the findings is the 'intermediate disturbance theory', which states that biodiversity is highest if there is a (intermediate) level of disturbance occurring (Davis, 2013). Excessive disturbance leads to few species being able to survive in the harsh conditions, but too little disturbance does not facilitate a large variety of species (Molino, 2001). This could be applied to the findings of this research. As forest reserves were 'left alone' and little to no human interference took place, there was too little disturbance to increase species richness. In nature forests, the forests are managed to optimise forest health, which appears to create a level of disturbance that leads to more species richness than the forest reserve management strategy. The multifunctional forests, although not significantly different from the other forest management strategies, showed a trend to have a species richness higher than a forest reserve but lower than a nature forest. This could be because there might be too much disturbance, which results in reduced species richness compared to nature forests.

Shannon-Wiener index

The results of the Shannon-Wiener index for trees are similar to those of the woody plant species richness. The nature forest management strategy leads to a significantly higher Shannon-Wiener index than the forest reserve (Figure 3; Table 5). This means that both the null hypothesis and the alternative hypothesis can be rejected, since the prediction was that the forest reserve would have the highest Shannon-Wiener index for trees. Like the results for species richness, these findings can also be explained with the intermediate disturbance hypothesis. The level of disturbance in the forest reserve seems too low to result in higher Shannon-Wiener indices, while in a nature forest the level of disturbance seems more optimal for biodiversity.

A striking factor influencing the Shannon-Wiener index was that multiple dead Japanese larch were found in several plots, along with living individuals of the same species. Within this study, the cause was not identified. It is interesting since the Japanese larch is one of the vulnerable species on the UH (Staatsbosbeheer, 2021).

DBH

The distributions of beech trees in all areas were showing signs of regeneration. In the multifunctional forest, there is a gap in sizes 25,1 to 35 cm, which is almost the same size class as the one missing in Japanese larch distribution, as well as sizes 40,1 to 50 cm. This could point to selective logging of certain size classes. However, the sample size might be too small to make any meaningful conclusions. Moreover, the forest reserve and nature forest showed even larger gaps in their distributions. Since the largest number of younger trees was concentrated in the forest reserve, it could be concluded that this area has the healthiest beech tree distribution, but the lack of older trees could also mean that the forest is too dense, and trees cannot develop fully. Research by Trotsiuk et al. (2012) into virgin beech forests in Ukraine showed a bimodal distribution, peaking around 8 cm and then a smaller peak at 56 cm. Compared to the nature forest distribution from this research, there is also a peak around 8 cm, but the 56 cm peak is missing.

Douglas fir showed a bell-shaped distribution in the multifunctional area, missing trees in the lower size classes. This might point towards low regeneration and intensive competition with surrounding trees (Gebrehiwot & Hundera, 2014). The other areas measured only five trees, making it difficult to compare the distributions.

The distribution of European oaks relatively had the largest number of younger trees in the multifunctional area, however, there were only five trees to compare this distribution to in the other forest areas. Consequently, no real conclusion can be made. Two of the plots in which oaks were measured were dominated by Scots pine trees. Previous research into this type of forest shows that the oaks in these forests had a mean DBH of 17.8 cm (Jakubowski & Dobroczyński, 2021), which is not too far from the oaks in Scots pine dominated areas measured in this study (24.83 cm & 12.41 cm).

The Japanese larch trees relatively had many older trees, meaning that there might not be a lot of regeneration. Moreover, the distribution in the multifunctional forest area showed a gap in sizes of 20,1 to 30 cm. This could point towards potential tree harvesting of that size (Gebrehiwot & Hundera, 2014), but could also be due to the small sample size (n=14) and high bucket amount (n=10). Therefore, the Japanese larch histogram (Figure 4d) of the nature forest shows the healthier distribution, as it shows the most signs of undisturbed regeneration.

Norway spruce was only found in nature forests, with two trees in the lowest category, and in the multifunctional forest, with a sample size of nine and a relatively substantial number of larger trees. Because of these low sample sizes, it is difficult to conclude anything, although it could be said that the multifunctional forest does not show many signs of regeneration.

The Scots pine distribution is bell-shaped in forest reserve areas, with no trees in the lower categories. Like the Douglas firs in the multi-functional forest area, this could mean that there is intense competition as well as low regeneration. In the other two areas, there are also not that many smaller trees, meaning that in all the areas the Scots pine was measured, there is almost no regeneration.

These results seem to be inconclusive. Not only are the sample sizes for some species in certain areas too low to compare the management strategies, the species that could be compared all point towards a different strategy. This also makes it difficult to compare the results from our research to previous research. Lastly, the hypothesis stating that the distribution is the healthiest in the forest reserve and the least multifunctional reserve, can be rejected. However, it is difficult to come to any other conclusion using this data.

Limitations

The most important limitation is that the measured plots were too close together. This leads to pseudoreplication: statistical tests are done with samples that are not independent of each other (Hurlbert, 1984; Heffner et al., 1996). The differences that were found in this research might not have been significant if the plots (samples) were further away from each other. It could be that factors other than forest management strategy influenced the woody plants of the specific areas that were measured. For example, all forest reserve plots were located within an area of less than one square kilometre.

Another limitation is the amount of data that was gathered. In this research only some aspects of biodiversity and one aspect of forest structure were investigated. In addition, there was only one independent variable. Other factors were not considered, which possibly influenced the outcomes. Other variables such as soil properties, water level and climate conditions could have caused the differences. Certain areas may be compatible with the growth of more tree species regardless of its management strategies. Another problem could be that invasive species were not considered in the biodiversity indices. This might have led to certain areas being seen as biodiverse and healthy, while invasive species were outcompeting the native species. However, this was not within the scope of this research.

Furthermore, the researchers may not have sufficient knowledge to identify the woody plant species. This would have caused mistakes in the measurements, which influenced the analysis. However, minor misidentifications might not have a huge impact on the species richness and Shannon-Wiener index data.

Finally, there were some practical limitations, such as one plot being inaccessible, quantities of small trees that were too large to count manually and mistaking dead trees for alive ones. However, these factors will not have resulted in major differences in the analysis.

Conclusion

Key results

In this research, forest health was indicated by woody plant species richness, the Shannon-Wiener index for trees, and the DBH distribution. The aim was to determine how three different forest management - forest reserve, nature forest, and multifunctional forest - affect forest health.

Woody plant species richness and the Shannon-Wiener index were significantly higher in the nature forests than in the forest reserve. Considering these are both indicators of biodiversity, it can be concluded that in this case, the nature forest management strategy leads to a higher woody plant biodiversity, and the forest reserve strategy leads to a lower woody plant biodiversity.

The DBH results are more open for interpretation since no statistical tests were done for analysis. When comparing the distributions of the six key species, large variation in the number of trees per species and forest area made it difficult to conclude anything. However, it could be said that no management strategy is able to facilitate regeneration of all key species.

Answering the research question, the nature forest management strategy leads to the most biodiverse forest considering species richness and Shannon-Wiener index, and the forest reserve strategy then in turn leads to the least biodiverse forest. This could have consequences on the forest health; however, it is not a given that more biodiversity means a healthier forest. Drawing a conclusion from the DBH data is much more difficult. The forest management strategies do not result in DBH distributions that differ much. Thus, cannot be concluded that one forest management strategy leads to healthier forests than the others. The results of this research only show that a nature forest approach leads to higher woody plant biodiversity than the other management strategies.

Future research

Although the results of this research suggest that the nature forest approach leads to the healthiest forests, this might not be the total picture. As discussed in the limitations, other factors could have influenced the outcomes. In addition, there was too little data to analyse and draw conclusions about the DBH distributions. That is why for future research, it is important to conduct a more elaborate research, with plots further away from each other, accounting for invasive species, and more plots so the data is richer. In addition, the cause of death of the Japanese larch trees could be investigated. Moreover, when investigating regeneration, gathering data on the number of saplings and seedlings relative to the number of older trees might lead to more conclusive results.

Policy recommendations

From these findings it can be concluded that if the aim of Staatsbosbeheer is to increase woody plant diversity on the UH a successful management strategy is the nature forest approach. However, when it comes to regeneration it is not clear which management strategy yields the best results. A recommendation for policy would be paying more attention to forest regeneration across all forest types.

Relevance and integration possibilities

The overarching research question of topic 1: Sustainable Forest Management is: *What are the challenges and opportunities for the management of forests on the Utrecht Heuvelrug?*

Forests provide an array of ecosystem services, such as timber production, carbon storage, and recreation (Van der Maaten-Theunissen & Schuck, 2013). Different management strategies prioritise different ecosystem services (Lecture 2 RIP, 2021). To determine which management strategy is appropriate for a certain area it is important to understand the trade-offs between these ecosystem services.

Our research is essential, since it tells how different management strategies affect biodiversity and the forest structure of the Utrecht Heuvelrug. Nature forest management lead to the highest species richness and biodiversity and forest reserve management the lowest, on the Heuvelrug. Multifunctional and nature forests provide DBH distributions with younger trees, showing the most signs of regeneration.

Still, forest health is not the only aspect of the ecosystem that needs to be considered when making trade-offs. That is why it is important to work together with the other groups within our research topic. Group 1B, which studied bird and mammal diversity, can help us assess the state of the forests in terms of biodiversity. Their results will possibly correlate with our results, since different kinds of trees attract different kinds of birds, so in an area with more woody plant diversity there will probably be more bird diversity too. Group 1C assessed how effective different strategies are in eradicating invasive species, which helps in identifying ways to maintain biodiversity. Moreover, a lot of black cherry trees were found in our plots, which is one of the invasive species this group is looking into (Topic descriptions RIP, 2021). Group 1D, which studied biomass production, quantified the function of the forest in terms of CO2 capture. Groups 1E and 1F looked at the perceptions of residents and foresters on the forests, which results in information about other ecosystem services such as recreation or beauty. Together, these research projects provide information about ecosystem services, enabling us to draw conclusions about the trade-offs in forest management on the Utrecht Heuvelrug. For example, relationships between woody plant diversity and animal diversity could be defined. There could potentially be a link between the types of trees and the types and amounts of birds. Invasive species affect the health of the forest, and the damage done by these species can be assessed and lessened with the right management. Lastly, healthy forests also attract recreation, however, recreation can disturb the forest.

Within this research topic, an interdisciplinary approach is necessary: ‘management’ implies the involvement of social structures and policies, while the managed areas are forests, which are seen as the natural environment. There is thus a need for natural sciences to determine the state of the forest components under different management strategies. In turn, the extent to which different ecosystem services are valued and trade-offs are made are a social matter. Therefore, forest management needs research on the topic of both natural sciences (forest health) and social sciences.

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Annex

Annex 1: species richness data

Management type	**Plot number**	**Main tree species in area**	**Species richness incl. shrubs**	**Species richness excl. shrubs (used to calculate Shannon-Wiener index)**
Forest reserve	1	Scot pine	3	2
Forest reserve	2	Scot pine	4	4
Forest reserve	3	Scots pine	5	3
Forest reserve	4	Scots pine	4	3
Forest reserve	5	Scots pine	7	6
Forest reserve	6	Japanese larch	6	5
Forest reserve	7	Japanese larch	3	3
Forest reserve	8	Japanese larch	4	4
Forest reserve	9	Japanese larch	3	3
Forest reserve	10	Japanese larch	3	3
Nature forest	11	Japanese larch	11	8
Nature forest	12	Japanese larch	8	6
Nature forest	13	Japanese larch	5	4
Nature forest	14	Japanese larch	3	3
Nature forest	15	Japanese larch	10	8
Nature forest	16	Scots pine	8	7
Nature forest	18	Scots pine	10	9
Nature forest	19	Scots pine	9	9
Nature forest	20	Scots pine	6	6
Multifunctional forest	21	Scots pine	8	6
Multifunctional forest	29	Scots pine	9	8
Multifunctional forest	31	Douglas fir	13	11
Multifunctional forest	34	Inland oak	9	6
Multifunctional forest	39	Inland oak	3	3
Multifunctional forest	40	Japanese larch	4	4
Multifunctional forest	42	Douglas fir	2	2
Multifunctional forest	45	Inland oak	5	5
Multifunctional forest	49	Douglas fir	6	6
Multifunctional forest	50	Japanese larch	7	6

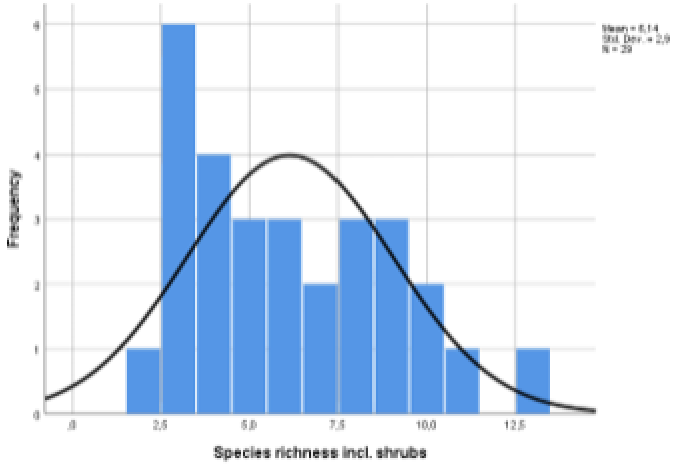
Annex 2: Shannon-Wiener index data

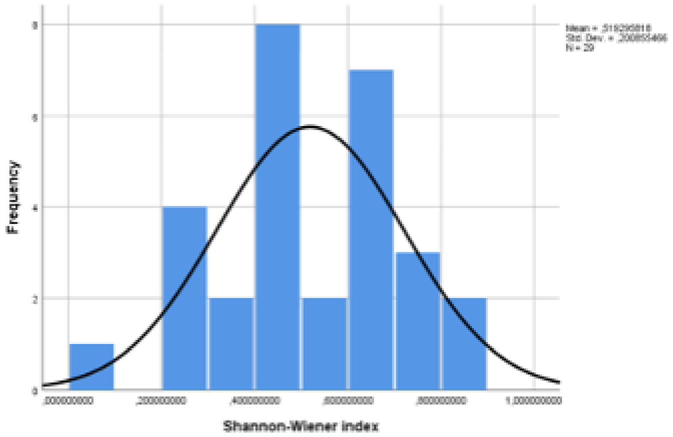
Management type	Plot number	Main tree species in area	Shannon-Wiener index
Forest reserve	1	Scots pine	0,296583222
Forest reserve	2	Scots pine	0,530326433
Forest reserve	3	Scots pine	0,421947761
Forest reserve	4	Scots pine	0,409864962
Forest reserve	5	Scots pine	0,649790972
Forest reserve	6	Japanese Larch	0,477627779
Forest reserve	7	Japanese Larch	0,421262284
Forest reserve	8	Japanese Larch	0,495246982
Forest reserve	9	Japanese Larch	0,313908726
Forest reserve	10	Japanese Larch	0,288777606
Nature forest	11	Japanese larch	0,811661083
Nature forest	12	Japanese larch	0,694532967
Nature forest	13	Japanese larch	0,431575402
Nature forest	14	Japanese larch	0,436527842
Nature forest	15	Japanese larch	0,586554365
Nature forest	16	Scots pine	0,61930909
Nature forest	18	Scots pine	0,761013567
Nature forest	19	Scots pine	0,786960776
Nature forest	20	Scots pine	0,698133
Multifunctional forest	21	Scots pine	0,634780438
Multifunctional forest	29	Scots pine	0,787943744
Multifunctional forest	31	Douglas fir	0,860627707
Multifunctional forest	34	Inland oak	0,640047389
Multifunctional forest	39	Inland oak	0,079257462
Multifunctional forest	40	Japanese Larch	0,30561915
Multifunctional forest	42	Douglas fir	0,251853959
Multifunctional forest	45	Inland oak	0,448369597
Multifunctional forest	49	Douglas fir	0,25081102
Multifunctional forest	50	Japanese Larch	0,668663431

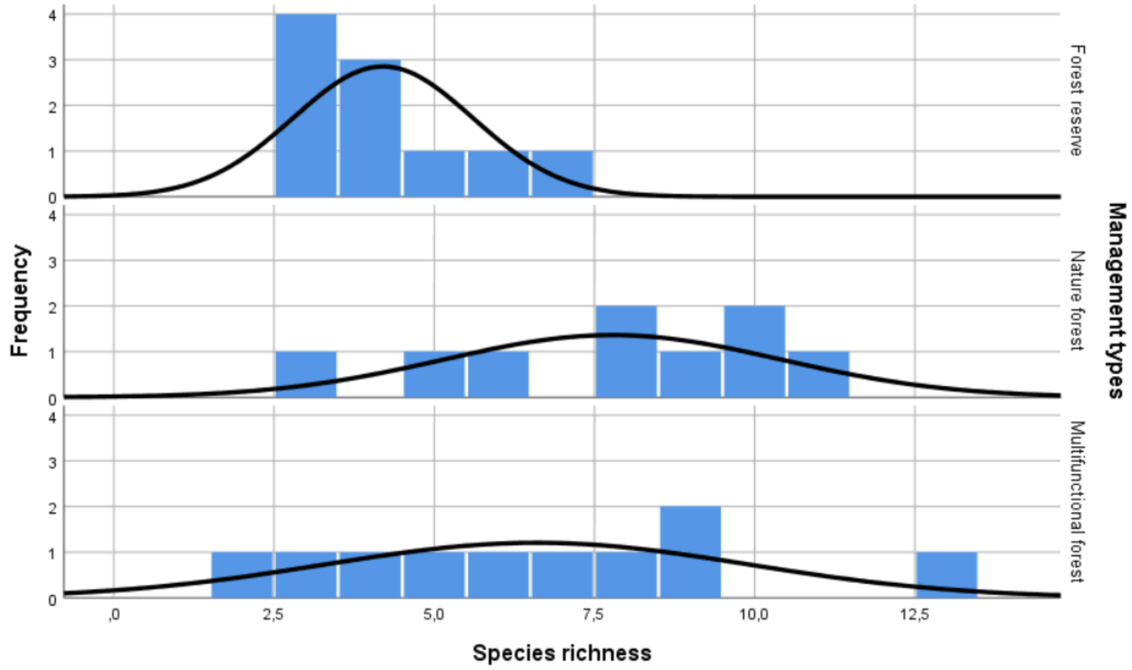
Annex 3: DBH data

DBH data.xlsx

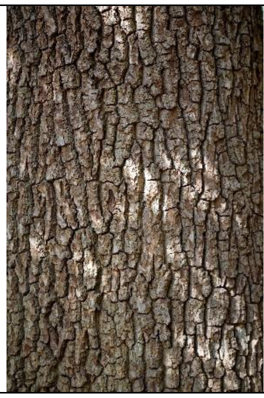
Annex 4: Normal distribution graphs

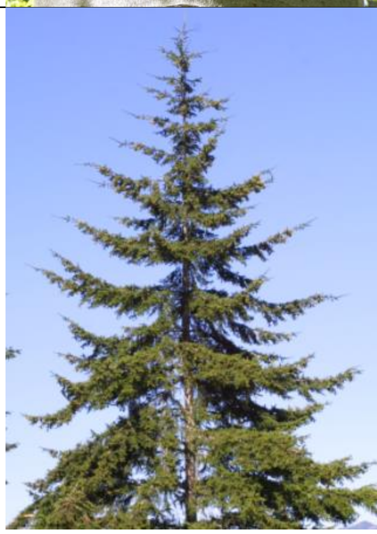






Annex 5: tree key

Tree type	Leaves	Full tree or bark
Sessile oak **(*Quercus petraea)***	 More/ deeper slit	
European oak or **English oak** **(*Quercus robur)***	 Less slit	

Japanese larch	 Bark: 	
Beech		
Douglas fir		

Norway spruce		
Scots pine