Habitat Selection of the Great Spotted Woodpecker

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1. Abstract

Background: Habitat selection involves finding species-specific conditions and resources. When the necessary requirements cannot be met because of changes within the environment, species can become constrained in their habitat choice. Anthropogenic influence such as forest disturbance, management and introduction of exotic tree species complicate habitat selection of wild animal species.

Aim: Analyze how and to what level different forest attributes influence habitat selection of the Great Spotted Woodpecker.

Organisms: Great Spotted Woodpecker (*Dendrocopos major*)

Place of research: Forest area in De Bilt, the Netherlands.

Methods: Observations of presence by using the transect method on existing forest paths during the breeding season. After presence was observed 45 presence plots were randomly selected and linked to 45 randomly selected absence plots of 10 meters^2 to an adjoining forest grid. Information on the number of trees, the condition of the tree (alive/dead), the size of the trees (DBH in centimeters), the origin of the trees (native/exotic) and the forest openness (total basal area in meters^2) was obtained for all 90 plots. A logistic regression analysis allowed predicting habitat selection and testing hypotheses on the relationship between forest attributes and the presence of the Great Spotted Woodpecker. Group differences were explored for the variables included in the hypotheses.

Principal findings: The percentage of native trees and the number of dead trees were most important in predicting habitat selection for the Great Spotted Woodpecker. The forest openness was higher in plots without the woodpeckers. In habitats selected the number of dead trees was higher, tree size was larger, and the number of different tree species was higher, compared to plots without Great Spotted Woodpeckers.

Conclusion: Predicting habitat selection for the Great Spotted Woodpecker can best be based on the percentage of native trees and the number of dead trees. Furthermore, the density of the forest together with forest variety have a positive effect on selecting a habitat.

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2. Introduction

Forest birds choose their habitat based on various resources and conditions such as food availability, nesting sites and shelter (Stirnemann et al., 2015). The different resources and conditions available in various habitats might cause selection pressure, impact survival and reproduction success (Kristan III et al., 2007). Anthropogenic activities complicate habitat selection by fragmenting nature areas and decreasing habitat quality (Kang, 2015; Stirnemann et al., 2015). In this case, the options for the best suitable habitat become constrained. The habitat of forest birds is affected by human interference such as the introduction of exotic species and intensive management, both of which are evident in the Netherlands (Dieler, 2017; Vogelbescherming Nederland, n.d.). Knowledge of which habitats contain sufficient resources allows forest managers to conserve and protect these habitats. This research aims to analyze the influence of different forest attributes on habitat selection during the breeding season in order to contribute to conservation of forest-dwelling animals.

Decision making

Species' individual access to resources can be influenced by anthropogenic activities. Resources are discontinuous and limited, and whether an individual can benefit from the resources is important for their survival (Wiens, 1976). Considering there is never one perfect area, optimal decision theory (ODT) can help to get insights into foraging behavior in differing environments. ODT includes assumptions about the compromises that animals make. Habitat ecologists assume that foraging animals are indeed optimal decision makers and that they contemplate the pros and cons of their surroundings to access the best resources (Kamil & Roitblat, 1985). The ongoing decision-making results in non-random use of patches, determined by species-specific preference and habitat quality (Johnson et al., 2007; Wiens, 1976).

Habitat quality in the Netherlands

Anthropogenic activities influence the resources available within the habitat. Insectivorous birds are dependent on the abundance of invertebrates on forest substrates like trees. The enemy release theory (ERT) states that the number of invertebrates on native species is higher compared to exotic species (Keane & Crawley, 2002). According to the ERT, the introduction of exotic tree species in the forest can have a negative effect on the number of invertebrates, thus compromising the food availability for insectivorous birds. The Dutch Forest Inventory showed that the percentage of exotic broadleaved tree species in Dutch forests has increased from 0.5% (measured between 2012-2013) to 0.8% (measured between 2017-2022) (Schelhaas et al., 2022). The Netherlands is a good example of a country with forest areas that are patchy in structure and composition and are managed intensively. Less than 10 percent of the Netherlands is forested, of which none is primary forest. Secondary forest was planted during the second half of the 20th century. These forests consist mainly of coniferous trees of which most species are exotic (Grashof-Bokdam, 1997). Some forest birds are able to keep their numbers stable despite living in habitats with compromised resources, like the Dutch forests containing exotic tree species and young secondary forest. This study is conducted in a forest in the Netherlands, in order to see which choices are made in the selection of habitat.

Habitat selection of the Great Spotted Woodpecker

The GSW can acquire habitats within a human-dominated environment, which might explain why these specific species woodpeckers (family Picidae) are the most common in Europe (BirdLife species factsheet, n.d.; Vogelbescherming Nederland, n.d.). The number of Great Spotted Woodpeckers (GSW hereafter) has been stable for decades in the Netherlands, a densely populated country with relatively young and partially exotic trees (van Kleunen et al., 2017; Vogelbescherming Nederland, n.d.). However, changes within the habitat can influence even the GSW, the most abundant and least specialized woodpecker species (Mikusiński et al., 2001). Woodpecker species in Europe are associated with large deciduous trees and dead wood (Angelstam, 1990). Disturbance of habitats containing forest attributes needed by fragmentation is known to negatively affect the GSW (Virkkala, 2006). Within large patches (>120 hectares) the clutch size plus the number of fledglings are higher and breeding phenology is better compared to smaller forest patches (Mazgajski & Rejt, 2006). Large trees, snags and logs provide shelters, nesting sites and food (Mikusiński, 2006). These substrates are important requirements for habitat selection of the GSW for nesting and foraging.

Nesting requirements

The GSW is a hole breeder, and therefore suitable habitat for the cavitation of trees is required for their survival. Woodpeckers make a trade-off between wood quality: hardwood provides nest security and softwood costs less energy to excavate (Kosiński et al., 2018). The wood quality is species dependent and can be influenced by process of decay and fungi growth (Barrientos, 2010). Older stands of spruce trees and deciduous trees are most often used as nesting sites and limited availability of those trees can constrain nest sites (Hansson, 1992, Rolstad et al., 1995). The size of the tree also matters because large trees have stable temperatures in the excavation (Wiebe, 2001). The importance of vegetation surrounding the nesting tree is debated. Some research suggests that surrounding trees can provide protection against predation and therefore make attractive habitats for nesting (Giese & Gutbert, 2003; Wiebe, 2001). Trees with a DBH 15-20 centimeter larger than the mean DBH of the plot are selected as nesting trees (Basile, 2020; Stański et al., 2023). In order to protect the nesting tree, the trees surrounding the nesting tree have to have a substantially large size as well. Contrary, other studies suggest surrounding vegetation hardly influences nest-site selection (Kosiński & Winiecki, 2004). In this research the range in DBH is measured, but no individual nesting trees are incorporated in the analysis. With knowing what the GSW requires for nesting this study can assess to which extend these substrates, combined with the required foraging opportunities, are important in deciding which habitats are suitable.

Foraging requirements

The GSW is a generalist, insectivorous feeder and uses a large range of the habitat for foraging (Rolstad et al., 1995). Research conducted in Poland showed that the tree composition used by the woodpeckers consist of more than half of pine trees (*Pinus*), followed by birch (*Betula*) and to a lesser extend aspen (*Populus tremula*), alder (*Alnus*) and spruce (*Picae*) (Vikberg, 1982). The GSW forages mostly on standing trees, laying trees and vegetation on the ground, of which the latter is predominantly used during the breeding season (Stański et al., 2023). The trees are exploited at deeper levels of the wood to feed on beetles and beetle larvae in dead wood, aphids in the canopy of deciduous trees, or on ants (Angelstam & Mikusiński, 1994; Kosiński et al., 2018). In areas with large seasonal differences, the diet can shift from invertebrates in summer to seeds of conifer trees during cold winters (Rolstad et al., 1995). During spring and summer, trees might also be used to drink mineral and sugar rich sap (Moraal, 2023). Elm *(Ulmus glabra*), red oak (*Quercus rubra*), sessile oak (*Quercus petraea*), lime (*Tilia*) and maple (*Acer platanoides*) are known to be used to obtain the sap from. The GSW can reach the xylem and phloem juices by creating small drinking holes (Moraal, 2023). The GSW does not show a specific preference for dead wood to forage on, but does prefer older and wet vegetation types due to insect prey groups (Kosiński et al., 2018; Rolstad et al., 1995). Different foraging substrates throughout the year make up the varied diet of the GSW.

Woodpecker as umbrella species

Woodpecker species are considered as important species to indicate biodiversity and function as umbrella species (Martin & Eadie, 1999; Mikusiński, 2006). The removal of required substrates for foraging and nesting, such as old and dead wood, can impact other members of forest communities (Martin & Eadie, 1999). Through the creation of cavities, woodpeckers change the forest and create suitable habitats for secondary nesting birds – some of which, such as the hoopoe *(Upupa epops*), are red list species in the Netherlands (Giese & Cuthbert, 2003; Kikkert, 2013; Mikusiński, 2006). A positive relationship between the number of GSW and the number of other forest bird species has been found in Poland (Mikusiński et al. 2001). In addition, some mammals like bats use tree cavities as cover or dens (De Zoogdiervereniging, 2023, Giese & Cuthbert, 2003; Kotowska et al., 2020). Conservation of the GSW and other woodpecker species can therefore contribute to the protection of species under the umbrella (Mikusiński et al., 2001, Onodi et al., 2021).

Research aim

The degradation of habitats by anthropogenic activities complicates the selection of habitats (Kang, 2015; Stirnemann et al., 2015). Only few studies have assessed how fine-scale heterogeneity in habitat influences the GSW specifically, especially during the late breeding season when they require most food to feed their offspring (Stirnemann et al., 2015). There has been research on habitat requirements, but little is known about which forest attributes are best in predicting habitat selection for the GSW. More insight on which forest attributes influence habitat selection can help to improve forest conservation of fragmented and human-dominated areas. Furthermore, knowledge gained from this research will contribute to sustainable conservation concerning silvicultural treatments, anthropogenic disturbances, possibly conserving specific tree species and management practices like the removal of dead wood. These conservation measurements can benefit the GSW and other forest-dwelling species.

In this research the main research question on which forest attributes are best at predicting habitat selection of the GSW is assessed, including nine variables (Appendix B). Furthermore, three hypotheses on the relationships between the presence of the GSW and its environment were tested (Figure 1).

The first hypothesis concentrates on foraging behavior: GSW are dependent on the presence of invertebrates to forage on, and the ratio between native and exotic species might be important for habitat selection due to foraging opportunities on native trees (Keane & Crawley, 2002). For this reason, I categorized the trees into native and exotic species, and predicted that **(1)** a high percentage of native tree species positively affects the presence of the GSW.

Anthropogenic activities might also impact the presence of the GSW. With the removal of vegetation, there are fewer suitable habitats for invertebrates (Dix et al., 1995). The forest disturbance is measured by calculating the openness of the habitat within the forest (i.e. measuring the DBH and counting the number of trees allowed to calculate the total basal area). I predicted that **(2)** forest disturbances due to man-made openings like roads, buildings and open (agricultural) fields in the forest area negatively affect the presence of the GSW.

The third hypothesis is based on the influence of forest variety. The forest variety includes the tree size variety. The number of tree species is included as a variable because a variety in tree species causes a variety in size and provides the GSW with a variety of resources. The third variable making up forest structure is the number of dead trees. Dead trees are important for foraging as well as for cavitation of nesting sites (Kosiński et al., 2018). Forest variety is indicated in this research by the tree size variety, the tree species variety and the number of dead trees. I predicted that **(3)** a higher forest variety positively affects the presence of the GSW.

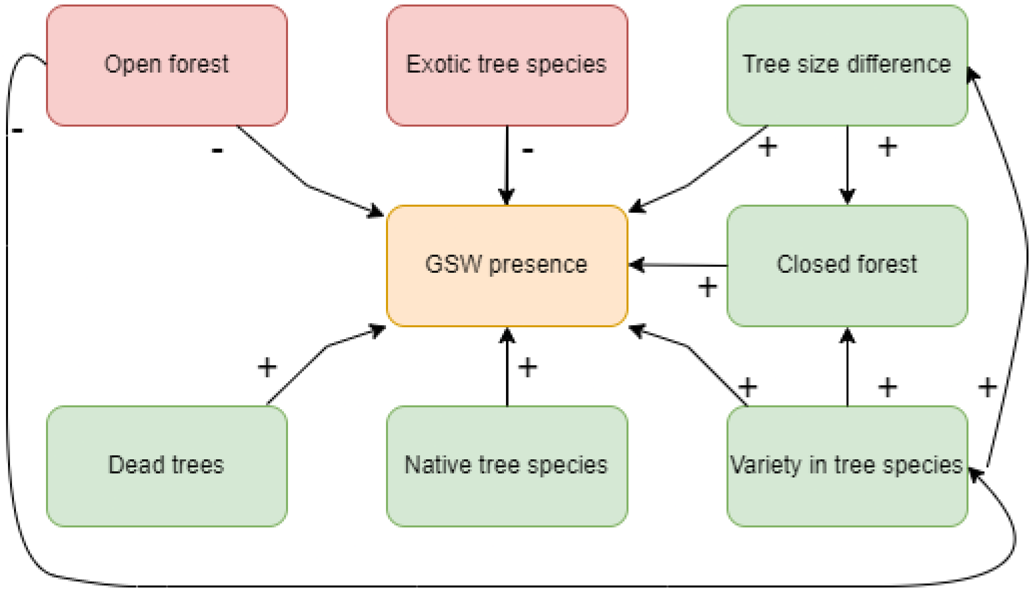


Figure 1 Expected effects of different forest attributes. Green indicates a predicted positive effect on the presence of GSW. Red indicates a predicted negative effect on the presence of GSW.

3. Methods

The GSW was selected for this study because they are common, function as indicator species and are recognizable because of their conspicuous appearance and their loud calling and drumming. The GSW has a relatively small territory with a mean of 17.8 hectare (Kosiński & Winiecki, 2004). This maximized my chance of collecting enough present-data in the study area. The dependence of the GSW on forest areas (Angelstam, 1990; Angelstam & Mikusiński, 1994; Mikusiński, 2006), in combination with their ability to sustain themselves within human-dominated landscapes, made them the ideal species for studying habitat selection in a forested area. Between hatching and fledging of the offspring, GSW are most actively searching for food, therefore I conducted the research during that period of time.

3.1 Study area

I carried out this explorative study in a temperate forest near De Bilt (central Netherlands), in an area located in the province of Utrecht (Figure 2). The study area is around 150 hectares and is part of a bigger nature area of 378 hectares, managed by Utrechts Landschap. In 1965 this land was sold to Utrecht Landschap by a private owner (Berents, 2023). I chose this particular study area because it was easily accessible, and includes a variety of habitats within a relatively small area. This meant that I was able to collect data on all habitats within the available timeframe of the fieldwork. Within 100 meters, the forest structure can change from a completely open field to dense forest. The heterogenous study area consists of closed, open, deciduous, and coniferous forest, together with old lanes, open park structures, a sculpture garden and openings created for houses and a water purification facility. In this research I refer to forest openings or forest disturbance when there is no vegetation for more than 20 meter^2. All the forest openings in the study area bigger than 20 meters^2 are man-made: roads, buildings or recreational purposes. A road accessible by cars runs through the complete forest area and forms the eastern boundary of the study area. Right next to the study area are small roads, another nature area, and villages on the northern and western side. The southern side of the study area holds a couple of houses that overlook the provincial road. The climate is temperate and warm. In the driest month (April) there is still rain, with an annual rainfall around 827 millimeters. The average annual temperature in this area is 10.6 Celsius (Utrecht climate: Temperature Utrecht & Weather By Month - Climate-Data.org, n.d.).

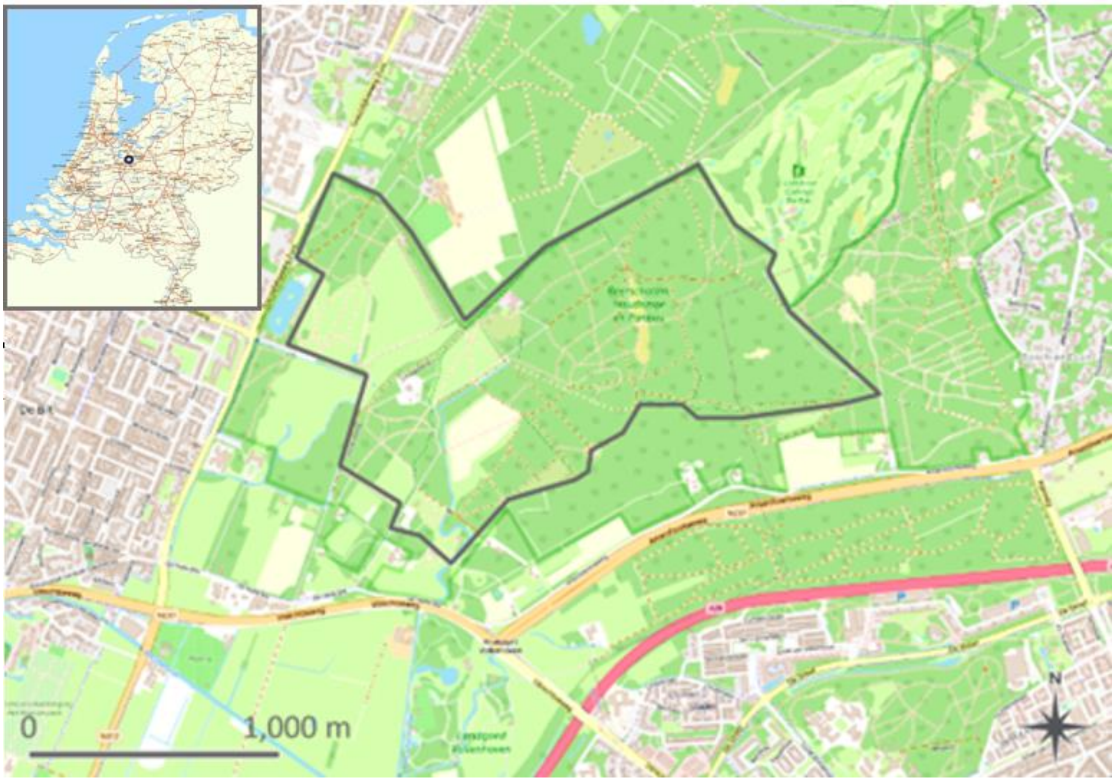


Figure 2 Study area located in De Bilt, central Netherlands.

The forest contains a variety of tree patches, with several dominant tree species (Appendix C). The most abundant tree species were the rowan (*Sorbus aucuparia*), Scots pine, black cherry *(Prunus serotina*), silver birch (*Betula pendula*), common oak (*Quercus robur),* beech (*Fagus sylvatica*) and alder buckthorn (*Frangula alnus*).

3.2 Data collection

To answer the main research question and test the three different hypotheses about habitat selection of the GSW during the breeding season, this research was conducted in two phases of observational fieldwork.

3.2.1 Part one: occurrence data

The first part of the fieldwork started in the second half of April 2023, just after the hatching period. It ended when the juveniles were most likely to have fledged (second half of May). During this period I counted the number of birds seen and heard between sunrise and noon, using the transect method by walking at a slow walking pace and carefully listening and observing (Emlen, 1977). I mapped five transects of lengths around 5 kilometers, together covering all existing forest paths in the whole study area (Figure 3). Because of restrictions by Utrecht Landschap during the breeding season I could only walk on existing forest paths during the first part of the fieldwork. Per weekday I randomly selected a transect to observe the GSW, avoiding days with rainfall or heavy winds. The phone application iObs allowed me to collect the observation in the field. This app is made for citizen data collection on flora and fauna (iObs, n.d.). I gathered the coordinates with the GSW present in Microsoft Excel file and mapped it with QGIS 3.28. In addition to the occurrences of the GSW, I noted striking observations like the presence of groups of dogs and other human disturbances.

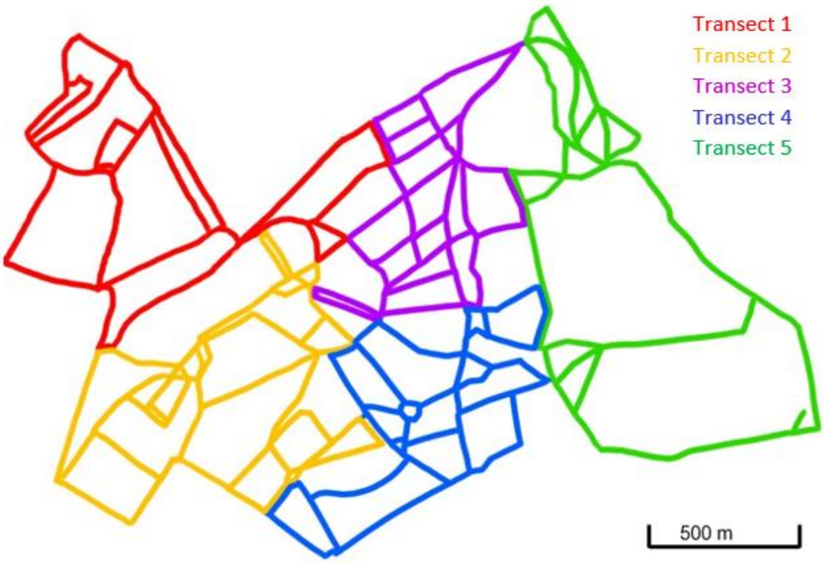


Figure 3 Five different transects following existing paths in the study area.

3.2.2 Part two: habitat assessment

The second part of the fieldwork I conducted was from the second half of June until the first week of July. During this fieldwork I collected data on vegetation. The rasterization of the map allowed for grids of 100 meters by 100 meters, which either had occurrence data or were chosen randomly as a grid without GSW present (Appendix D). I chose 100 meters² as the grid size because of practical reasons like accessibility of the data points and the gradual changes within the forest. Occurrence data conducted in part 1 allowed me to make a binary categorization of each grid between GSW present or absent. Within the grids, I created fine-scale plots of 10 by 10 meters. To investigate the variation of forest attributes, I randomly chose 45 grids with GSW present (present plot) compared those to 45 adjoining grids were the GSW was absent (absent plot). In case the selected present plot was surrounded by merely grids including present plots, I randomly selected the closest absent plot available. The plot size was based on research stating that heterogeneity on a scale of tens of meters is an important determinant of animal composition and occurrence (Benton et al., 2003). For each absent and present plot, I measured three parameters, with which other values could be calculated. I identified tree species to establish the percentage of native and exotic species within a plot (Temperature Species – Tree Database. (n.d.). With the use of circumference tape I measured the DBH of each tree in the absent plots and present plots. The number of trees in each plot allowed me to calculate the basal area. The total basal area is the total amount of the area that is occupied by tree stems, and I used this measurement as a variable of forest openness.

3.3 Data analysis

For the data analysis of this study I used QGIS 3.38 and R version 4.2. During the fieldwork I collected eleven logistic independent variables (Appendix B) and one continuous dependent variable (GSW absent or present). I measured the influence of the independent variables on the dependent variable using a logistic regression (1 = GSW present, 0 = GSW absent). I compared different models based on AIC-values to find the best predictive model. To test the three hypothesis I used logistic regressions to analyze the relationship between the dependent and independent variables. I tested group differences with either the Wilcoxon rank-sum test in case of non-parametric data and by using a t-test for normally distributed data.

4. Results

4.1 Model selection

To predict the habitat selection of the GSW, I compared forest characteristics of presence grids and absence grids, using binary logistic regression. High VIF values indicating collinearity and performing a PCA showed me that some variables were highly correlated (Appendix E). Model 1 and model 2 performed in a similar way according to AIC values (Table 1). I choose model 1 as the best model for predicting habitat selection. Model 1 includes four independent variables, which are scaled for logistic regression analysis: the percentage of native species (logistic regression, $z_{85} = 3.332$, $p < 0.001$), the number of dead trees (logistic regression, , $z_{85} = 2.537$, $p = 0.011$), the range in DBH of the trees (logistic regression, $z_{85} = 1.774$, $p = 0.076$) and the number of different tree species (logistic regression, $z_{85} = 1.659$, $p = 0.097$) (Appendix F). The effect size of the number of dead trees is largest. The probability occurrence of GSW increases when the percentage of native tree species within a plot increases (Figure 4a). Furthermore, there was a positive significant relation between the number of dead trees and the presence of the GSW (Figure 4b). Lastly, the range in DBH (Figure 4c) and the number of different tree species (Figure 4d) show a positive trend in relation to the occurrence probability of the GSW.

Table 1 AIC values for two different models

Model	Independent variables included in model	AIC	ΔAIC
1	DeadWood + TreeSpecies + NativePer + RangeDBH	96.53	-1.69
2	DeadWood + TreeSpecies + NativePer + MeanDBH + RangeDBH	98.22	

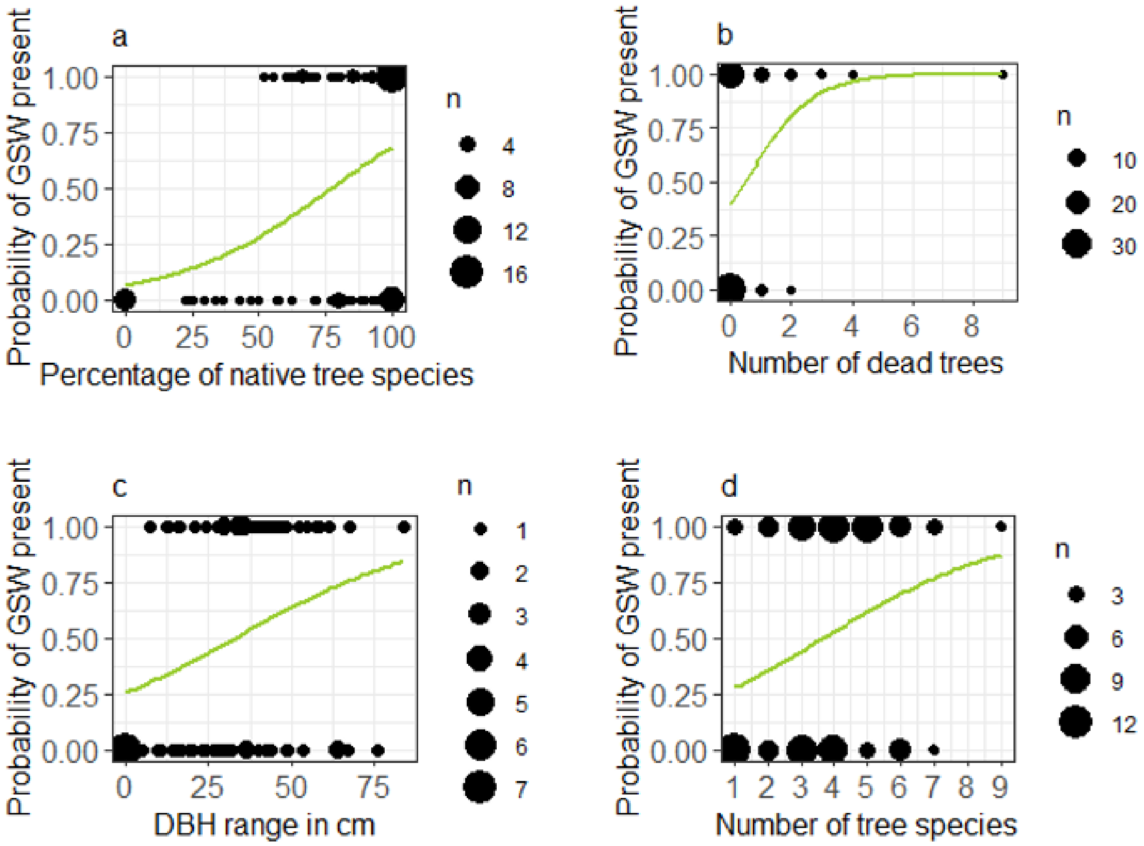


Figure 4 Relationships between independent variables and the probability of GSW included in model 1. Sample size is indicated with n. a) The percentage of native tree species in relation to the probability of GSW present (p < 0.001). b) Number of dead trees in relation to the probability of GSW present (p = 0.011). c) DBH range in centimeters in relation of the probability of GSW (p = 0.076). d) Number of tree species in relation to the probability of GSW present (p = 0.097).

Apart from looking at which environmental variables were most important for predicting habitat selection, I tested three hypotheses to gain more knowledge on the relationship between habitat selected by the GSW and the presence of native tree species (§ 3.1), forest openness (§ 3.2) and forest variety (§ 3.3).

4.2 Hypothesis 1: The effect of native tree species

The percentage of native trees was an important variable determining habitat selection. With the increase of the percentage of native tree species, the probability of GSW occurrence increased (Figure 4a, logistic regression, $z_{85} = 3.332$, $p < 0.001$). Absent plots had significantly fewer native trees than present plots (Figure 5, Wilcoxon rank-sum test, $W_{88} = 1380.5$, $p = 0.0026$).

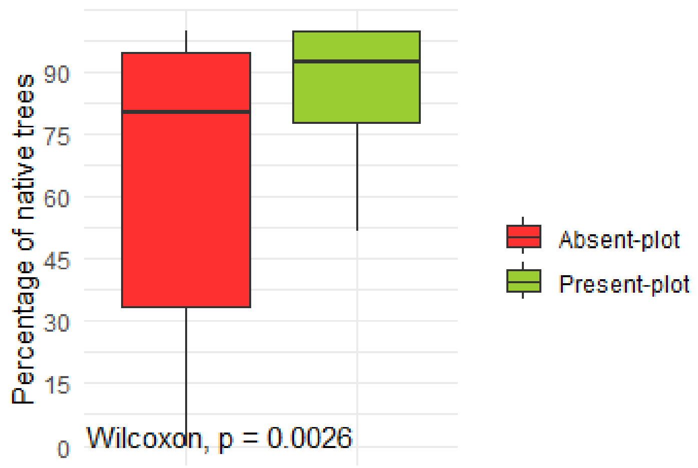
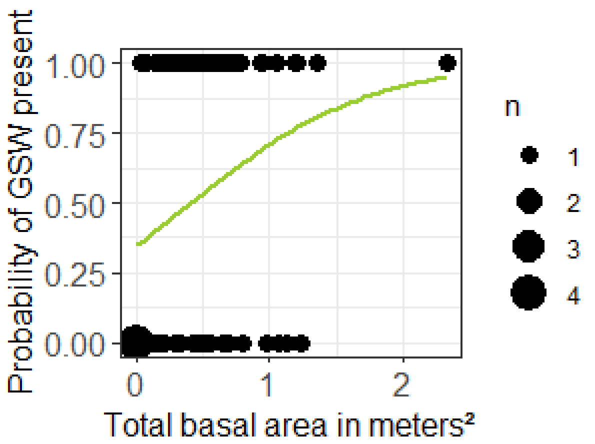


Figure 5 Boxplot showing the difference in the percentage of native trees between absent plots and present plots

4.3 Hypothesis 2: The effect of forest openness

Using a binomial logistic regression for solely the total basal area, revealed a positive significant effect of the total basal area on the occurrence probability of the GSW (Figure 6, logistic regression, $z_{85} = 2.311$, $p = 0.0208$). The total basal area was higher in present plots compared to absent plots (Figure 7, Wilcoxon test, $W_{88} = 1349$, $p < 0.01$).



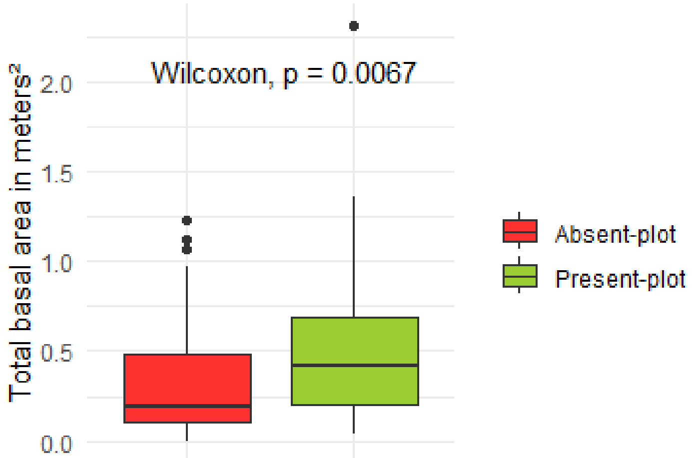


Figure 6 Total basal area in meters² relation to the probability of GSW. Sample size is indicated with n.

Figure 7 Boxplot showing the difference total basal area in meters between absent plots and present plots.

4.4 Hypothesis 3: The effect of forest variety

Forest variety is an important attribute in habitat selection for the GSW. Forest variety was characterized by the number of dead trees; the number of tree species; and the range in DBH. Dead trees had a strong positive effect on the probability of GSW being present in a plot (logistic regression, $z_{85=}$ 2.537, p = 0.01). The positive relation between the two other variables was weaker: tree species (logistic regression, z_{85}= 1.659, p = 0.097) and the range in DBH (logistic regression, $z_{85=}$ 1.774, p = 0.0761) (Appendix F).

The patterns in the logistic regression were confirmed when comparing absent plots and present plots for the three different variables chosen as indicators for forest variety. Present plots have more dead trees (Figure 8a, Wilcoxon rank-sum test, W_{88} = 1329.5, p = 0.0016). More different tree species are present in present plots (Figure 8b, Wilcoxon rank-sum test, W_{88} = 1353.5, p = 0.0053). Finally, the range in DBH was higher in present plots (Figure 8c, t-test, t_{89} = 15.793, p = 0.007).

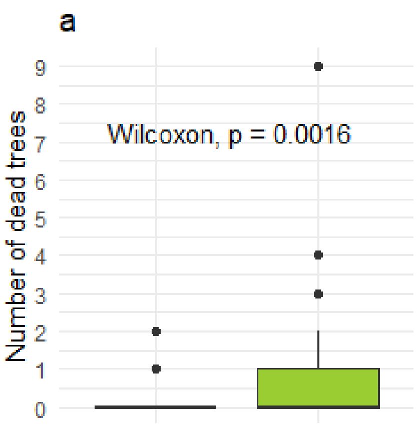


Figure 8a Boxplot showing the difference in the number of dead trees between absent plots and present plots.

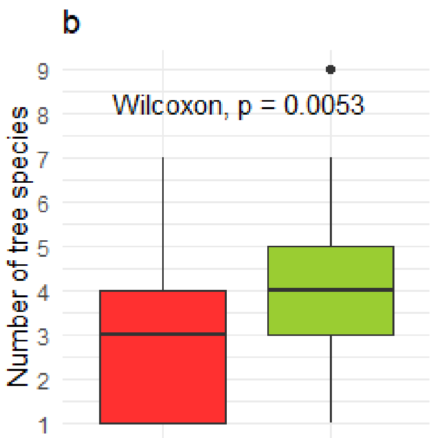


Figure 8b Boxplot showing the difference in the number of tree species between absent grids and present grids.

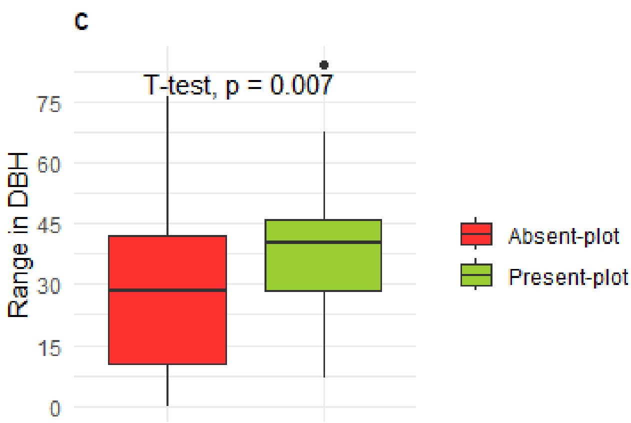


Figure 8c Boxplot showing the difference in the number of tree species between absent grids and present grids.

5.Discussion

The GSW is considered a generalist forest bird, yet they show a marked habitat selection (Barrientos, 2010). Here, I researched which forest attributes are best at predicting habitat selection. Furthermore, I researched the relationship between various forest attributes to gain insight into the effect of different forest attributes on the habitat selection by the GSW. I measured various forest components and compared between absent plots and present plots.

5.1 Predicting habitat selection

Habitats including dead wood are most likely to be chosen by the GSW. Together with the percentage of native trees, habitat selection can be best predicted. Forest management should conserve native trees and decaying and dead trees to keep up the stable numbers in areas such as the Netherlands (Thorn et al., 2020). The knowledge gained in this research on the value dead wood and native trees contributes to effective management in areas where GSW communities are unstable or absent.
As mentioned in the results, the model without the mean tree size was excluded in the final model. Forest plots with the same average tree size showed a completely different forest structure in the study area. Therefore, the tree size difference was chosen as indicator for tree size in the final model.

The explanation of the importance of native trees and dead wood can be found in the following paragraphs discussing the hypotheses.

5.2 Hypotheses 1: The effect of native tree species

As expected, native tree species had a positive impact on the presence of GSW (Figure 4a, Figure 5) with the percentage of native trees ranging from 52 to 100 percent in the present patches. Native trees are expected to have a higher abundance of invertebrates (Kennedy & Southwood, 1984). A higher abundance of feed has been associated with a higher forest bird abundance, especially insectivorous birds (Burghardt et al., 2009). With more abundant foraging opportunities close by, the GSW prefers nesting in native trees over non-native trees (Barrientos, 2010; Rolstad et al., 1995). Access to suitable resources for foraging and nesting explains the preferences for habitats with a high percentage of native trees.

5.3 Hypotheses 2: The effect of forest openness

The hypothesis that the forest openness negatively affects the presence of the woodpeckers was accepted. More dense forest patches are more likely to be chosen as habitat by the GSW than forest openings (figure 6). Furthermore, there were significant differences in the total basal area between absent plots and present plots (Figure 7). This outcome matches earlier findings on a long-term study in Poland in which the basal area of habitats selected for nesting is significant larger than in random sites (Kosiński & Winiecki, 2006).

The existence of a threshold can help to understand the effect of forest density. Within this research I never observed a GSW when there were no trees. The minimum number of trees in a present plot was 4, with a total basal area of 0.1360 meter^2. A threshold for forest openness can explain to what level suitable forage and nesting attributes must be present for the GSW to select certain habitats.

5.4 Hypotheses 3: The effect of forest variety

The GSW prefers habitats with a greater forest variety: higher number of dead trees, tree species and the size range. When comparing present and absent plots the number of dead trees proved to be the most important factor: absent plots contained fewer dead trees compared to present plots (Figure 8a). The number of tree species and the range in DBH showed significant differences between absent plots and present plots as well (Figure 8bc).

The multiple resources dead wood and large trees provide can explain habitat selection based on these variables. A higher variety in tree species and more tree size-classes leads to higher bird abundance (Poulsen, 2002). The importance of dead wood within the habitat can be explained by decrease of the wood density with age. Nesting is preferred in softer wood, which can be an effect of decaying wood (Kosiński, 2018). Another aspect of nesting can explain the relationship between the size range and the woodpecker presence. Large trees are attractive for nesting since the temperature within the excavation deviates less and provides most shelter for the GSW and their offspring (Wiebe, 2001). Besides the explanation for habitat selection for nesting, foraging can also contribute in explaining the importance of forest variety. With increasing age, and hence increasing DBH, trees become more important as foraging substrates because of the increasing sensitivity to injury (Vuidot et al., 2011). Consequently, these injured trees are colonized by invertebrates that the GSW forages on. The invertebrates are excavated from beneath the rotting bark (Cramp, 1985). Even when a forest is perceived as unsuitable because of the low number of native deciduous trees to excavate, habitats can still be suitable because of the retention of dead trees (Barrientos, 2010). For nesting as well as for foraging the tree condition, the variety in tree size and tree species are indicators for habitat selection.

5.5 Conclusion

Here, I demonstrated that the number of dead trees and the percentage of native trees were the most important predictors for the presence of the Great Spotted Woodpecker in a managed forest. Forest variety was important in relation to the habitat selection of the GSW, notably the number dead trees and the variety in tree size. Forest disturbances because of man-made openings created in the forest showed to have an effect on habitat selection as well. Knowledge on fine scale heterogeneity of different forest attributes contributes to conservation of suitable habitats and the species' access to resources. To keep to numbers of GSW in the Netherlands stable and improve potential habitats, forest management focused on the conservation of decaying and native tree species is essential. Large decaying and dead trees that are also native, deserve special attention. These trees create crucial resources and conditions for the GSW for foraging and nesting. Foraging and nesting resources are essential for habitat selection of the GSW and potentially for other woodpeckers species, which all help to create suitable habitats for a variety of forest-dwelling animals.

5.6 Recommendations

5.6.1. Sustainable conservation

No urgent management changes in this area are necessary on the short term since the GSW numbers are stable (van Kleunen et al., 2017; Vogelbescherming Nederland, n.d.). Long term conservation measurements advisably focus on the conservation of native tree species. Especially large, native trees can function as nesting and foraging sites, even more so when they are conserved while slowly decaying and dying. Because of the importance of native trees and dead wood, monitoring of regeneration of those trees is recommended. Regeneration can become a problem for some tree species important to the GSW because of climate change. New insights of ongoing research on climate smart forestry can help chose future proof trees, with extra attention to woodpeckers' preference for tree species. Admixtures of tree species can possibly mitigate vulnerabilities of individual tree species and at the same time provide a variety of different food resources for woodpeckers (Bowditch et al., 2020).

5.6.2. Further research

Research period

The admixture of tree species can also help provide a greater variety in foraging opportunities for the GSW, especially when combined with research on habitat selection throughout the year. The period in which habitat selection is researched influences the results because foraging behavior differs between seasons. My research was conducted in spring because I was interested in habitat selection during the breeding season. In this period, native nesting birds with an insectivorous diet are most abundant around native trees because of their dependence on insect populations to feed their offspring (Dickinson, 1999). Because GSW's foraging behavior differs throughout the year when seasonal differences are present (Rolstad et al., 1995), researching their habitat selection in different seasons potentially results in different outcomes. For example, research on foraging behavior of the GSW over two seasons in Poland showed that food resources change over time (Stański et al., 2023). During the colder months, the GSW are expected to reside more in pine forest where they forage on pine seeds (Myczko & Benkman, 2011). Before April, the contribution of drinking sugar-rich sap might also influence their choice of habitat, however the importance of this largely unknown for the GSW (Moraal, 2023). Having a variety of tree species can supply the woodpeckers with different food sources throughout the year. Little information is available on the effect of mixtures of tree species on woodpeckers. Knowledge on suitable forest composition can help forest managers with conserving woodpeckers by protecting the different resources required by the GSW in all seasons, now and for the future.

Research design

During the second part of the fieldwork, 45 of the plots with GSW observations were randomly selected as present plots. Forty-five grids without GSW observations were chosen adjoining present plots. For the second hypothesis in which I looked at the effect of forest openings on the GSW presence, it is important to note the consequences of the research design chosen in this study. For studying forest openings further, I advise to look into a possible edge-effect in which the woodpecker avoids habitats surrounding openings. Furthermore, researching a threshold for forest openness, can give more insight into the effect of forest openings as well. In this study the absent plots are chosen adjoining present plots in order to look at fine-scale heterogeneity of the forest attributes. As such, interactions between the plots could not be excluded. For research on an edge effect or a threshold in forest openness in relation to the GSW, I advise to randomly select the absent plots out of all plots without GSW observations. A second option for doing more research on the effect of forest openings is with measuring GSW abundance around forest patches with different vegetation density. The research design I used was useful in this study, because I assessed the relationship between forest openings and the GSW presence and compared the absent plots and present plots. Further research on forest openness would provide us with practical knowledge on forest structure required by the GSW. I expect a potential threshold and an edge effect to be the lowest for the generalist GSW compared to other woodpecker species.

Conservation of other woodpecker species

For further research I advise to expand research on the use of resources for a greater variety of woodpeckers, in addition to the GSW. During the fieldwork, a fellow woodpecker enthusiast informed me about the rare occurrence of the black woodpecker (*Dryocopus martius)* and the green spotted woodpecker (*Picus viridis)* in the study area. Habitat quality for those woodpeckers can, together for those of the GSW, be improved by conserving patches with large beech and oak trees . For the black woodpecker it is necessary that some patches are rarely or never accessed by visitors that potentially disturb them (Vogelbescherming Nederland, n.d.). From a human point of view the accessibility of the forest is important, since well-being is higher when people have access to public green spaces (Methorst et al., 2021). This point of view was really apparent when meeting forest visitors during the fieldwork and hearing about their appreciation of the forest. Visitors mostly used the forest paths and the forest openings, which were all man-made with mostly recreational purposes. In this research I focused on the indirect, physical forest disturbances. Direct forest disturbance by visitors could provide complementary information to the overall effect of anthropogenic activity on woodpeckers. To do so, intensive and year-round fieldwork is advised incorporating the movement of visitors on different moments of the day and the influence on the presence and absence of the GSW and other woodpecker species. Woodpeckers in general are considered umbrella species and different species of woodpeckers such as the already observed black woodpecker and green woodpecker, can create a more attractive habitat for secondary nesters. Species like the tawny owl *(Strix aluco)* and the beech marter (*Martes foina)* use the larger sized holes as shelter and to breed in (Vogelbescherming Nederland, n.d.). Together with the conservation and protection of the habitat selection the GSW, even those more specialized and protected woodpecker species can be conserved with the right management.

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Appendix A Abbreviations

AIC
Akaike information criterion

DBH
Diameter at breast height

ERT
Enemy release theory

GSW
Great Spotted Woodpecker

ODT
Optimal decision theory

PCA
Principal Component Analysis

Appendix B Dataset index

Table 3 Dataset index

Column	Entry	Value	Unit	Remark
A	Plot	Numerical	-	Plot number within study site
B	PresAbs	Numerical	-	Presence of absent of the GSW within grid
C	**TreesTot**	**Numerical**	**Count**	**The total number of trees within a plot**
D	**Deadwood**	**Numerical**	**Count**	**The number of dead trees within a plot**
E	**TreeSpecies**	**Numerical**	**Count**	**The number of tree species within a plot**
F	**NativeNum**	**Numerical**	**Count**	**The number of native trees within a plot**
G	**NativePer**	**Numerical**	**Percentage**	**Percentage of native trees within a plot**
H	**TotalDBH**	**Numerical**	**Centimeters**	**The DBH cumulutative of all trees within a plot**
I	**MeanDBH**	**Numerical**	**Centimeters**	**The DBH cumulutative of all trees divided by the total number of trees within a plot**
J	MinDBH	Numerical	Centimeters	The lowest DBH value within a plot
K	MaxDBH	Numerical	Centimeters	The highest DBH value within a plot
L	**RangeDBH**	**Numerical**	**Centimeters**	**The difference between the MaxBSAm and MinBSAm**
M	**TotalBSAm**	**Numerical**	**Meters ^{2}**	**(Total DBH / 2) ^{2} * π**

* Variables in bolt are included the final regression model for predicting habitat selection.

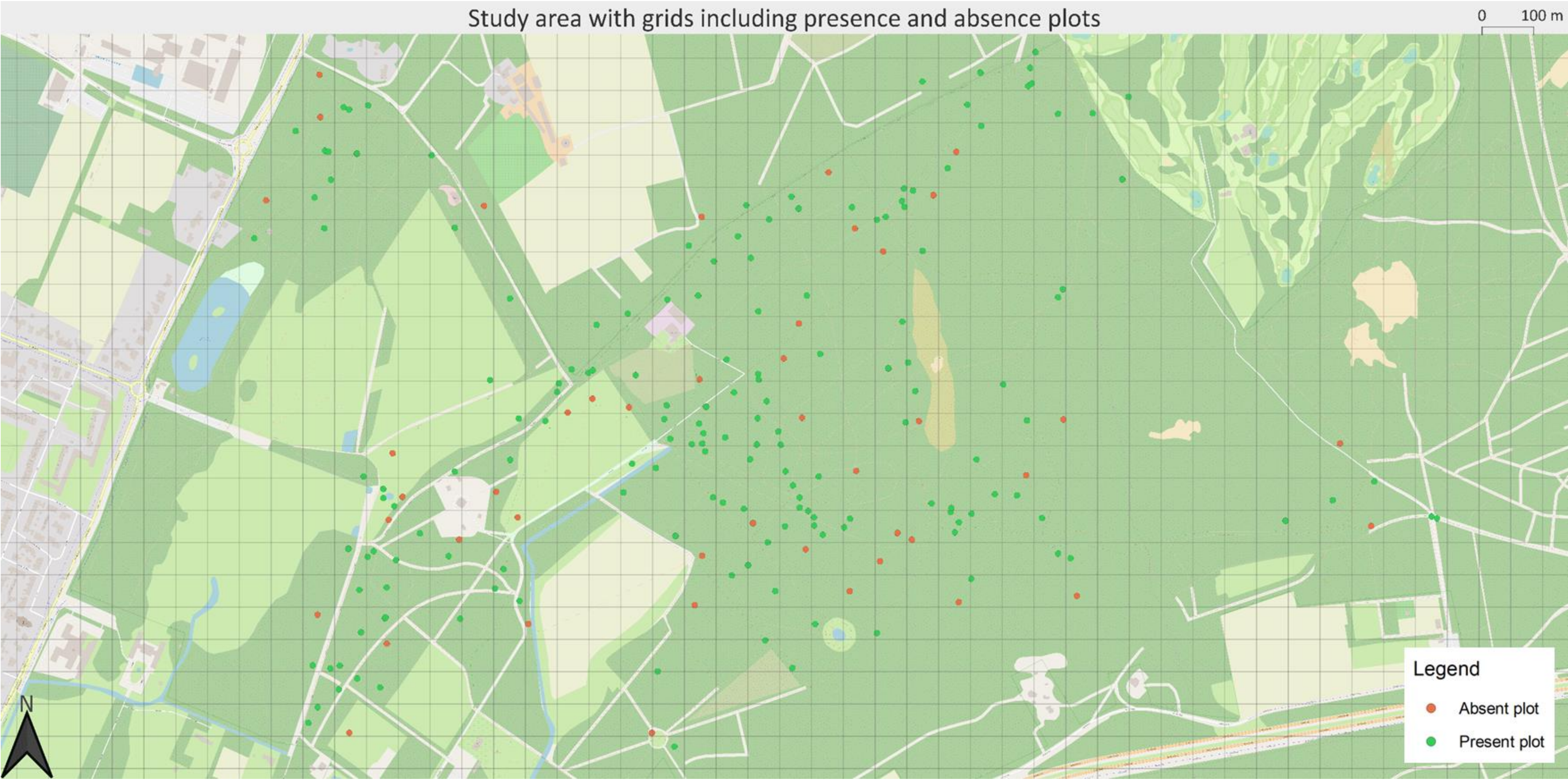
* Grey variables are the independent variables included in PCA.

Appendix C Tree species composition

Table 2 Tree species composition in study area

Tree species	Percentage
Sorbus aucuparia	25.37
Pinus sylvestris	18.4
Prunus serotina	13.15
Betula pendula	10.41
Quercus robur	9.48
Fagus sylvatica	8.23
Frangula alnus	3.55
Larix	2.68
Acer pseudoplatanus	1.56
Picea abies	1.56
Quercus rubra	1.56
Abies picea	0.62
Ilex aquifolium	0.56
Pseudotsuga menziesii	0.50
Unknown standing	0.50
Pinus nigra	0.37
Sambucus nigra	0.37
Robinia pseudoacacia	0.31
Tilia Cordata	0.25
Unknown	0.25
Abies alba	0.06
Amelanchier canadensis	0.06
Corylus avelana	0.06
Picea sitchensis	0.06
Pine unknown	0.06
Tsuga heterophylla	0.06
	100%

Appendix D Study area including presence and absence plots



Appendix E PCA

Table 4 Summary PCA

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10
Standard deviation	1.95860	1.50425	1.04802	0.98530	0.94950	0.72364	0.53406	0.28709	0.19772	0.00000
Proportion of Variance	0.38361	0.22628	0.10983	0.09708	0.09016	0.05237	0.02852	0.00824	0.00391	0
Cumulative Proportion	0.38361	0.60989	0.71972	0.81681	0.90696	0.95933	0.98785	0.99609	1	1

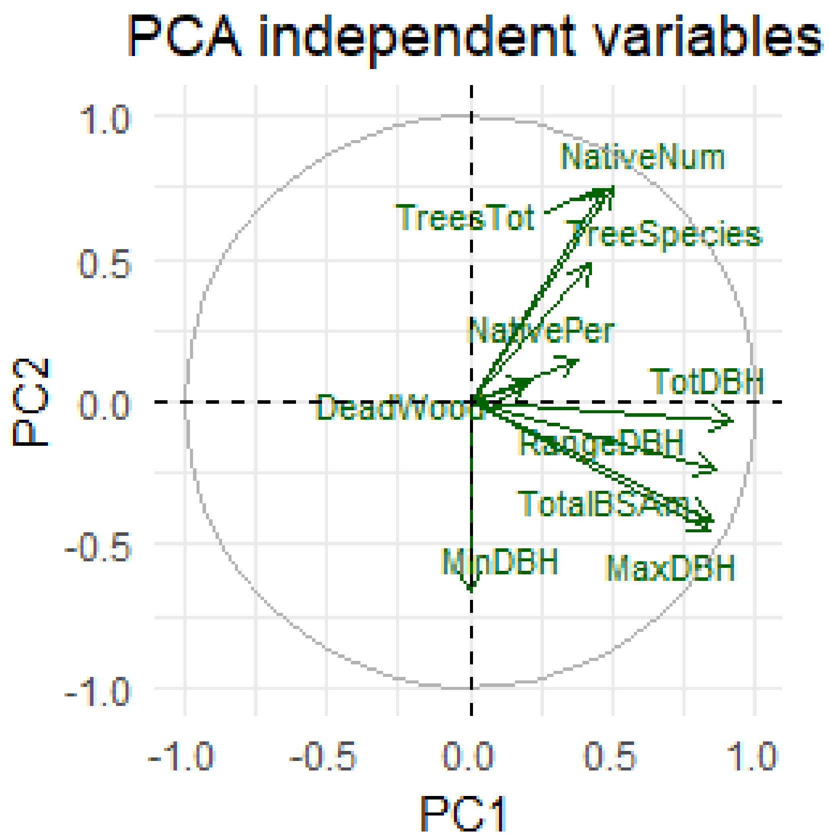


Figure 9 Visualization of a PCA

Appendix F Output logistic regression

Table 5 Summary logistic regression for variables included in the final model

Variables	**Estimate**	**Std. Error**	**z value**	**Pr(>|z|)**
PresAbs	0.5404	0.4409	1.226	0.220345
scale(DeadWood)	6.0280	2.3758	2.537	0.011173*
scale(TreeSpecies)	0.5204	0.3137	1.659	0.09711 .
scale(NativePer)	1.4033	0.4211	3.332	0.000861***
scale(RangeDBH)	0.5544	0.3125	1.774	0.07603 .