Master's Thesis

Forest biodiversity value and the structural characteristics of forests and polypore species

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In Finland, there is currently no systematic monitoring network for saproxylic species. Monitoring would give important information about saproxylic species of which about 300 species are threatened. Carrying out the monitoring as reliably as possible is important, because the results of the monitoring affect, for example, conservation decisions. Majority of Finnish forests are in commersial use, so monitoring should also be targeted to these areas in addition to protected areas. Given the large extent of the managed forest cover in the landscape, there is a clear need for a protocol for targeting the monitoring effort within managed forests. The national forest conservation value analyses using Zonation software are potentially such an approach. In my thesis I studied if they can be used to allocate monitoring effort. When choosing the study sites, I used the forest biodiversity value (FBV) derived from national conservation value analyses using Zonation software. There is no certainty about the reliability of the data and I studied how the real characteristics of the forest and its polypore species correspond to the FBV of the area. In addition, I studied how different aspects of forest structure affect the polypore communities in the area. According to the results, as the FBV increased, the diversity of deadwood, the volume of living trees and the number of polypore species increased. The volume of deadwood also seemed to increase as the FBV increased, altough the result was not significant. The FBV is therefore a reliable tool for allocating monitoring efforts to forests of different value.

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Suomessa ei tällä hetkellä ole lahopuulajiston systemaattista seurantaverkostoa. Seuranta antaisi tärkeää tietoa lahopuulajistosta, joista noin 300 lajia on Suomessa uhanalaisia. Seurannan toteuttaminen mahdollisimman luotettavasti on tärkeää, sillä seurantojen tulokset vaikuttavat esimerkiksi suojelupäätöksiin. Suomen metsistä 95 % on talousmetsää, joten seurantoja kannattaa kohdentaa myös näille alueille suojelualueiden lisäksi. Zonation-ohjelmalla tehdyt valtakunnalliset metsien suojeluarvoanalyysit ovat mahdollisesti hyvä keino seurantaresurssien kohdentamiseen. Tutkimusalueita valitessa käytin Zonation-ohjelmalla tehdyistä kansallisista suojeluarvoanalyyseista saatua metsien monimuotoisuusarvoa. Aineiston luotettavuudesta ei ole täyttä varmuutta, ja gradussani tutkin, kuinka metsän todelliset rakennepiirteet ja sen kääpälajisto vastaa alueen monimuotoisuusarvoa. Lisäksi tutkin, kuinka erilaiset ympäristömuuttujat vaikuttavat alueen kääpäyhteisöihin. Tulosten mukaan monimuotoisuusarvon noustessa metsän lahopuun monimuotoisuus, elävän puuston tilavuus ja kääpälajiston määrä lisääntyi. Myös lahopuun määrä näytti lisääntyvän monimuotoisuusarvon noustessa, vaikka tulos ei ollutkaan merkitsevä. Monimuotoisuusarvoa voidaan siis luotettavasti käyttää seurannan kohdentamisessa erilaisiin metsiin.

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TERMS AND ABBREVIATIONS

Terms

Saproxylic	Species dependent on the availability of deadwood

Abbreviations

AIC	Akaike's information criterion
DBH	Diameter at breast height
DDI	Deadwood diversity index
FBV	Forest biodiversity value

1 INTRODUCTION

1.1 Monitoring of species

Global biodiversity is declining fast (IPBES 2019). To estimate endangerment of species and reasons causing it, we need spatial and temporal information about population and community dynamics of species. To get that information, we need long-term monitoring of species (Yoccoz et al. 2001, Legge et al. 2018). To be successful, monitoring of species should be globally uniform and cost-efficient (Henry et al. 2008). Monitoring helps in conservation management and improves its effectiveness (Nichols & Williams 2006). For example, with monitoring information we can allocate the protection to the species that could otherwise become extinct (Martin et al. 2007).

Results of monitoring can be used in decision making, and therefore results should be reliable. Halme et al. (2019) states that specifically the monitoring of threatened species needs a lot of planning and investments to be reliable. If the decision making is based on erroneous information, also the decisions might lead to unwanted results. Monitoring should be carried out so that possible sources of errors are taken into account (Yoccoz et al. 2001). The biggest challenge in long-term monitoring is to ensure adequate sampling with limited time and money. Funding should be enough to cover the costs of monitoring for a long time (Field et al. 2007). If money is not enough to ensure significant results, all the monitoring effort would be useless.

When planning the monitoring, the spatial aspects are important to consider. It is often difficult to generalize results of one monitoring site to the whole area as the regional variation of species can be remarkable (Yoccoz et al. 2001, Abrego et al. 2016). That's why choosing the study sites needs to be done well. The sites may be randomly or systematically selected. For example, the Breeding Bird Survey in the United Kingdom utilizes the stratified random sampling design (Wright et al. 2014), while a 6 km long bird monitoring transects in Finland are systematically located 25 km from each other and they cover the whole Finland (Finnish Museum of Natural History 2024). Finnish national forest inventories are done with systematic cluster sampling (Korhonen et al. 2020). To get unbiased data, sites are not usually selected based on already existing data on occurrence of a species, because this could lead to biased information. However, this technique is sometimes used in studies that for example survey the impact of human-induced disturbances by surveying sites with known records of species to be studied (Mackenzie & Royle 2005).

In this master's thesis I focus on improving the methods for spatial implementation of the monitoring of species living in deadwood. Monitoring of deadwood species is important, because with monitoring we get information of reasons why so many deadwood species are threatened. Also, with the information from monitoring, protection of deadwood species could be done more effectively. At the moment, there is no long-term deadwood monitoring in Finland, and the study methods need improvement. Also, biodiversity strategy of European Union encourages to improve monitoring of species by saying that monitoring of old forests in Europe should be improved (European commission 2021).

1.2 Forest structural features as biodiversity indicators

Forest structure means the distribution and configuration of different plant species and individual tree sizes in the forest (Hui et al. 2019). Traditionally, forest structure is created by natural sources such as succession, fire and other disturbances (Spies 1998). Nowadays, forest structure is increasingly modified by forest management (Hansen et al. 1991). Forest structure-based indicators can be used to identify the biological value of the forest (Saarinen et al. 2018). Indicators are usually related to living trees and deadwood in the forest (Lombardi et al. 2015).

1.2.1 Living trees

Stand structural diversity, which is related to the structural diversity of living trees, can be used to estimate the biodiversity in an area (Staudhammer & LeMay 2001). Also, old deciduous- and conifer trees are important structural features in forest (Syrjänen et al. 2016). In Finland, especially old pines and aspens are important structural features in old-growth forests (Siitonen et al. 2000). In the old-growth forest, there are many different tree species and age classes (Franklin & Spies 1984). Also, there are a lot of different sized trees. That is why the volume of living trees can often be lower in old-growth forests compared to matured managed forests (Burrascano et al. 2008). However, forest canopy can act as a buffer helping species to cope with extreme climate and temperatures (De Frenne et al. 2019). Closed forest canopy is important for example to many northern saproxylic beetle species (Goßmann et al. 2024). Also, Eurasian goshawk (*Accipiter gentilis*) which is near threatened in Finland, favors relatively closed forest canopy (Hayward & Escano 1989, Lehikoinen et al. 2019). However, for some saproxylic species, forest with closed canopy cover is not a suitable habitat. For example, many beetle species associated with old oaks prefer sun-exposed habitats and warm microclimate (Ranius & Jansson 2000). So, biodiversity in the forest does not necessarily increase when the volume of living trees and canopy cover increase. Therefore, the volume of living trees does not indicate the biological value of the forest (Siitonen et al. 2000, Burrascano et al. 2008). However, the information from living trees have been successfully used to count deadwood potential for the forests, when the information about deadwood is not available (Pohjanmies et al. 2019, Mikkonen et al. 2020, Repo et al. 2020).

1.2.2 Deadwood

One of the most important structural features for forest biodiversity is the volume and quality of deadwood in the forest (Kriteerityöryhmä 2003, Syrjänen et al. 2016). Especially forests which have a lot of coarse deadwood, made up of different tree species and in different stages of decay, are the most important for conservation of saproxylic species in Finland (Kriteerityöryhmä 2003).

Deadwood is a vital habitat for many species, and many of the boreal ecosystems are dependent on deadwood (Jonsell et al. 1998, Stokland et al. 2012 & Thorn et al. 2020). In Finland there are about 5000 species dependent on deadwood, from which about 300 are threatened e.g., because of fragmentation, destruction, and intensive ways of forest management (Siitonen 2001, Grove 2002). Deadwood can be used as biodiversity indicator due to high number of species that are dependent on it (Stokland et al. 2004). The decrease of deadwood is the second most serious cause of losing the forest species (Kotiranta et al. 2019).

Majority (90–95%) of Finnish forest is managed forest, which has less deadwood compared to unmanaged forests (Rouvinen & Kouki 2002). Therefore, large volume of deadwood is mainly found from unmanaged forest areas, that are minority of Finnish forests (Kotiranta et al. 2019, Rouvinen & Kouki 2002). In old and unmanaged boreal forests, volume of deadwood is usually 40–120 m^3/ha (Tonteri & Siitonen 2001). In Southern Finland the volume of deadwood in managed forests is on average 3.9 m^3/ha and in Northern Finland 4.8 m^3/ha (Korhonen et al. 2020).

The total volume of deadwood in Finnish forests has remained nearly the same for 20 years according to the national forest inventory (NFI) 9 and 12 but the number of certain types of deadwood, such as fallen "kelo" trees in dry heath forests, are still decreasing (Kotiranta et al. 2019). Saproxylic species refers to a species dependent on deadwood at some point during their life (Stokland et al. 2012). The threshold level for below which many saproxylic species are not able to survive, is estimated to be around 20–40 m^3/ha (Junninen & Komonen 2011).

Deadwood diversity means the number of different deadwood types (Larrieu et al. 2019). One deadwood type has specific diameter, decay stage, tree species and deadwood position (downed, standing or stump) (Stokland et al. 2012, Bouget et al. 2013). Deadwood diversity has reduced in European forests due to forest management (Bouget et al. 2013). Deadwood diversity is important for saproxylic species, because habitat heterogeneity increases species richness (Stein et al. 2014).

1.2.3 Saproxylic fungi and polypores

The biggest group of saproxylic species is fungi that produce visible fruit bodies (Siitonen 2001). Fungi have a big role in communities of deadwood; they for example rot wood, are habitats for other species and are food for some species (Stokland et al. 2012). Wood-inhabiting fungi can be used as indicators for deadwood associated biodiversity (Christensen et al. 2004). For example, the presence of polypore species *Fomitopsis rosea* indicates that the forest has a long developmental history and is therefore near natural state (Kotiranta & Niemelä 1996).

Polypores are a morphological group of Basidiomycetes. Fruitbodies of polypores can be either perennial or annual. Polypores usually have spore-producing poroid structures on the underside of their fruitbodies (Väisänen et al. 1992). Most polypores share the same ecology; they decay living or dead trees and recycle nutrients (Niemelä et al. 2016). In Finland, there are about 250 polypore species (Kotiranta et al. 2019, Niemelä et al. 2016). Over 40% of Finnish polypores are red listed and 19% of them are threatened (Kotiranta et al. 2019). Polypores have an important role in the boreal forests as pathogens of living trees and decomposers of deadwood. When decomposing the deadwood, polypores create microhabitats for other species living in deadwood (Kotiranta & Niemelä 1996, Penttilä et al. 2004).

For many of the 46 polypore species that are threatened, decrease of suitable deadwood is one reason to their endangerment. Also, the reduction of old trees in old forests has the same effect (Kotiranta et al. 2019). Especially polypores that require a prior presence of certain polypore species are threatened; for example, *Antrodiella citrinella* lives in a log which *Fomitopsis pinicola* has rotted first (Kotiranta & Niemelä 1996). Polypores are often used as indicators for forest value. Niemelä et al. (2016) made a list of polypore species that indicate the forest to be old-growth forest. If there are enough of these species in the area, the area can be called as old-growth forest.

1.3 Site selection for monitoring

As the majority of Finnish forests are managed, deadwood monitoring should also be targeted at these areas in addition to the protected areas. The purpose of my master's thesis was to test how monitoring of saproxylic species could be spatially organized for forests with different ecological values. I tested the selection of monitoring sites using forest biodiversity value (FBV) derived from a national-scale conservation prioritization analysis (Mikkonen et al. 2023). When doing the spatial planning of monitoring, it would cost less to select monitoring areas with FBV compared to finding suitable monitoring sites with field inventories. This data by Mikkonen et al. (2018 & 2023) has not been validated before in the field. Therefore, the aim was to test how well the FBV correlates with the actual structural features of the forest and polypore species richness that I identified in the field.

1.4 Research questions and hypotheses

1. How do different structural features of the forest and its polypore species correspond to the forest biodiversity value (FBV) of the area?

I hypothesized that measured structural features of the forest and polypore species richness are positively correlated with FBV. FBV is created with the help of variables that are known to be correlated with forest value and biodiversity (Mikkonen et al. 2018). Therefore, also FBV was expected to be correlated with indicators of forest value. Volume of living trees was expected to correlate positively with FBV, because deadwood potential is calculated with the information from living trees (Mikkonen et al. 2020). Deadwood potential is used in calculating the FBV.

2. How do different structural features affect the area's polypore communities?

Polypores are dependent on volume and quality of deadwood (Bader et al. 1995, Penttilä et al. 2004, Hottola & Siitonen 2008, Hämäläinen et al. 2018), so these variables were expected to be positively correlated with the number of polypore species. Polypore species richness is also shown to be positively correlated with the volume of living trees (Sippola et al. 2004). Therefore, I assumed that also the volume of living trees per hectare would be positively correlated with the species richness of polypores.

2 MATERIALS AND METHODS

This master's thesis was implemented as part of the "DEADMON – A protocol for long-term monitoring of saproxylic species" research consortium of the University of Jyväskylä, the University of Turku and Finnish Museum of Natural History. It aims to develop monitoring methods for deadwood species and their habitats that are comprehensive, transparent, as affordable as possible and based on research. The consortium is funded by Finnish Ministry of Environment.

Jenna Purhonen, Timo Kosonen and Pedro Cardoso supervised me in this master's thesis. I did polypore inventories and Jenna Purhonen did deadwood measurements in the field. We both did relascope and hypsometer measurements. Field assistants Vanja Rimpiläinen and Michael Pipinis-Troupakis helped with deadwood inventory and measurements with hypsometer and relascope. I did fieldwork in Autumn 2023.

2.1 Materials

2.1.1 Study areas and site selection

Jenna Purhonen and Timo Kosonen selected three permanent study areas for the data collection for the DEAMON-project within the areas owned by Metsähallitus. The first area was in Kittilä, Kolari and Muonio near and within Pallas-Yllästunturi national park located in the Northern boreal zone (Ahti et al. 1968). The second area was in Kuhmo near and within Ulvinsalo strict nature reserve located in the Middle boreal zone. The third area was in Padasjoki and

Hämeenlinna near and within Evo national hiking area located in Southern boreal zone. In this thesis, I will call the areas as “North”, “Middle” and “South” (Figure 1).

I selected the study sites for this master’s thesis using Report of Zonation-analysis from previous study by Mikkonen et al. (2018). In that study the main idea was to produce maps of nature values in forested habitats of Finland. This was done to help identify suitable sites for the METSO program.

Zonation-analyses gives 96x96 m raster pixel a priority value that describes the biodiversity of forests. The higher the value in the data, the more valuable the forest is according to the analysis. Pixels in the material (Mikkonen et al. 2018) get values between 0 and 1. The most valuable raster pixels for biodiversity are presented in red on the priority map, and the least valuable in blue.

In my site selection I used the third Zonation analysis version of the publication (Mikkonen et al. 2018) where the modeled deadwood potential, measures that weaken forest biodiversity, and the connectivity between forests were taken into account. I used the third analysis, because the fourth, fifth and sixth versions included occurrence information on forest species, that I sampled as well. Also, occurrence information was not systematically collected with the same effort from conservation and commercial forests.

For selecting the study sites, I divided maps of the study areas into squares of 1 km x 1 km, and I selected the sites randomly from these squares (Figure 1). To do that, I used a random generator to take a number between zero and the number of squares in an area. Then I went as many squares forward on the map as the number indicated. From every area, I selected two study sites with high FBV and two study sites with low FBV. One of the high FBV sites was in a commercial forest and another in a protected forest. At total, I selected 12 study sites from three different areas (Appendix 1).

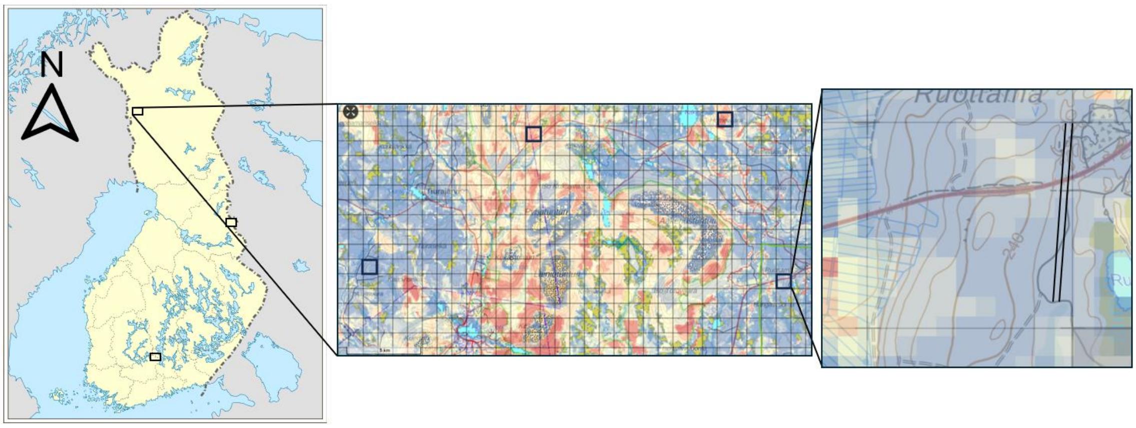

Figure 1. On the left: Locations of study areas in Finland. On the middle: Selected 1 km x 1 km study sites in North. On the right: Transect 2 (low FBV) in North. Picture sources: Oona Räisänen (Mysid), Public domain, Wikimedia Commons. Paikkatietoikkuna 10/2024: High biodiversity value forests 2018 (Zonation), Suomen Ympäristökeskus, CC BY 4.0. Tilastoruudukko 1 km x 1 km, Tilastokeskus. Maastokartta, Maanmittauslaitos.

The study sites had to fulfill the following criteria: could not be a top of a fell, a peatland, a sandpit, a very drained forest, a waterbody or built area. Also, the area consisted almost exclusively of red (high FBV) or blue (low FBV) 96 x 96 m pixels on the map depending on the situation (Figure 1). Sites also needed to be located at the highest 500 meters from a road and must not be located right next to another selected sampling study site. If the randomly selected study did not fulfill the above-mentioned terms, I selected the nearest suitable study site to the randomly selected study site.

I started one 25 meter wide transect from the study site corner closest to the road (Figure 1). I selected the direction of a transect randomly using a random generator so that the direction was inside the chosen 1 km x 1 km study site. Prior to the fieldwork, I draw the transect borders to Tracker App (Natlink Oy 2020), which is an openly available map app for smartphones. I used the Tracker App and GPS to estimate the transect borders in the field.

From the transects I collected field data including standing tree-, deadwood- and polypore inventory data.

2.1.2 Fieldwork

I determined the length of the transects by the first and the last examined log in the transect. I inventoried the polypores from eight fallen deadwood logs per transect. The distance between these logs was at least 50 meters, but in many cases, it was more, because I did not find the next log right after each 50 meters. If after 50 meters there were many possible deadwood logs that I could inventory, I always chose the nearest deadwood to me. Doing so, I avoided situations where I would always choose certain kinds of deadwood logs to survey. I excluded logs that were of decay stage five or completely covered by bryophytes.

I identified the polypores to the species level in the field always when possible. If the identification was not possible, I took samples from the polypore fruitbody using a knife. I dried the samples and identified them later in the laboratory with a 1000 times magnifying light-microscope. I did the identification using Niemelä et al. (2016) as a reference. From the deadwood logs where I inventoried polypores, I also recorded the coordinates, tree species, diameter of a wood from base, breast height and the top, decay stage, height, direction of the top (°), bark coverage, moss coverage, lichen coverage, ground touching (m) and falling type.

From every deadwood in the transect that had diameter over 10 cm at breast height, I recorded coordinates, tree species, diameter at breast height (DBH), decay stage and type of deadwood (standing, fallen etc). For determining the decay stage, I used instructions from Renvall (1995), where value 1 is almost undecayed wood and value 5 means almost decayed wood. I did a deadwood inventory to know the volume and the diversity of deadwood in the transects.

I did the inventory of living trees in the transects using relascope to estimate the volume of trees per hectare by every tree species. I did relascope measurements every 100 meters in the transect. In addition to relascope measurements, I measured the average height of trees with hypsometer by tree species in relascope points. I also measured height and DBH for living trees from different diameter classes to help in predicting the heights of deadwood logs using only their diameter.

2.2 Methods

2.2.1 Prosessing of the data

I calculated an average FBV for each transect. For this I recorded the FBV (Mikkonen et al. 2018) corresponding to each deadwood log on the transects from open spatial data platform Paikkatietoikkuna (Maanmittauslaitos 2023) using the coordinates of each log.

I used the information of heights and diameters of random trees measured in the field to get the predicted height of all the deadwood pieces using DBH. I calculated equations of the relationships between tree height and DBH for every tree species in all the areas (North, Middle, South). I used R Studio (Posit Team 2024, R Core Team 2023) to make line equations for all tree species in all three areas. In some cases, I combined many tree species into the same equation, because there were too few trees to make the equation using only one tree species. For example, in many cases I combined the broadleaved trees into one equation. Also, in the data there were trees that I identified as conifers, usually because they were too decayed to identify the species. For them, I made equations using spruces and pines. Some species were so decayed that I identified them as "deadwood". For class "deadwood" I calculated the equation utilizing all tree species. In the equation for broadleaved trees in North I removed two very wide and short outliers from the data, because they caused a negative relationship between the diameter and height. Using these line equations, I made predictions of tree heights for all the deadwood logs using DBH. Many logs in the data were in two or more pieces. For them, I assumed the height of the standing part of the tree in the field. To get the height of the other half, I subtracted the height of a standing part from the estimated total height.

After these steps some diameters of deadwood pieces were still missing. That is because they were treetops of which diameter was not measured in the field. Their diameter was predicted using their predicted heights and the line equations discussed before.

For deadwood pieces that were in one part, I assumed the volume of a tree using the volume equation for circle cone:

$$V = \frac{1}{3}\pi r^2 h, \qquad (1)$$

where V is volume of a tree, r is radius of a tree and h is tree height). For most deadwood logs on the ground that were not treetops, and were only part of the tree, I measured the diameters of both ends in the field. I did this to calculate the volume of a tree. However, I only measured diameter from one of the ends for some of these kinds of trees. For them, I assumed that diameter of a tree decreases 1 cm per 1 meter of a tree to calculate the diameter of the missing end

(Siitonen et al. 2023). To get a volume for these kinds of dead trees, I used volume equation for truncated circular cone:

$$V = \left(\frac{\pi h}{3}\right)(r_1^2 + r_1 r_2 + r_2^2), \qquad (2)$$

where r_1 is bigger radius of a tree, r_2 smaller radius of a tree, and h is tree height.

To estimate the diversity of deadwood, I used Siitonen index (Shannon 1948, Siitonen et al. 2000, Markkanen & Halme 2012) as a basis for calculating the Deadwood diversity index (DDI):

$$H = -\sum \left(\frac{n}{N}\right) ln \left(\frac{n}{N}\right) \qquad (3)$$

where H is Shannon index and n is proportion of deadwood pieces in one deadwood type and N is number of all deadwood pieces in a transect (Gardener 2014). The index that I made was calculated as Shannon index, because Shannon index usually emphasizes rarity (Nagendra 2002). I wanted to emphasize rarity, because probably the most important logs for biodiversity and conservation are logs that are not frequent. The idea of the DDI is, that every new deadwood type (fallen or standing tree), diameter class (0-10 cm, 10-20 cm…60-70 cm), tree species (11 classes) and decay stage (1, 1b, 2, 3, 4 or 5) increase the index value. When calculating the DDI, I put all the deadwood pieces that were not identified to their species in the category "deadwood". I calculated the index for every transect using deadwood data from the first 393 meters of each transect. I did this because the transects were of different lengths and the shortest transect was 393 meters long.

I determined the average height of the forest stand in relascope points with hypsometer measurements. I measured the basal area per hectare of the trees with relascope every 100 meters. I recorded the volume of living trees per hectare with the information of the average height of the forest stand in relascope points and the basal area per hectare of the trees using relascope table. Using this data, I calculated the average volume of living trees per hectare for each transect.

2.2.2 Statistical analyses

I used R Studio for all statistical analyses (Posit Team 2024, R Core Team 2023). The limit of statistical significance was 0.05. I selected suitable data distribution using Akaike's information criterion (AIC) values. AIC value tells how well the data fits with the distribution (Mazerolle 2006). The lower the AIC value is, the better the distribution fits to the data. I checked the AIC values of negative binomial, Poisson, gamma and gaussian distributions. I checked the limitations of distributions for every analysis using command "simulateResiduals" of DHARMa package in R (Hartig 2022). DHARMa command shows the fulfillment of the assumptions using residuals.

2.2.1.1 Biodiversity value (FBV) compared to forest dynamics and polypore species richness

I used separate generalized linear mixed models (GLMM) to study the relationship between the following transect level response variables and FBV as an explanatory variable (Mikkonen et al. 2018); 1) DDI, 2) the volume of deadwood per hectare, 3) the volume of living trees per hectare and 4) number of polypores per transect. In the first three models I expected data to be gaussian distributed and in the fourth Poisson distributed.

In addition, I modelled polypore species richness with the FBV and the average volume of the polypore inventory logs. This was done because the volume of deadwood is shown to be positively correlated with polypore species richness (Renvall 1995, Sippola et al. 2004). I expected data to be Poisson distributed. In every model, random variable was the location of the transect (North, Middle or South), because the transects were nested within certain study locations.

2.2.1.2 Species richness of polypores in relation to structural features of forest

I used separate models to study the relationship between species richness of polypores as a response variable and the following explanatory variables; 1) DDI, 2) the volume of deadwood per hectare and 3) the volume of living trees per hectare. In every analysis, also the average volume of inventoried logs was another explanatory variable. In all the analyses I expected data to be Poisson distributed.

2.2.1.3 Community analysis

I used community composition analysis (NMDS, Nonmetric Multidimensional Scaling) to study the polypore community differences between transects. In the analysis I used command "metaMDS" with Bray-Curtis distance in "vegan" package in R (Oksanen et al. 2022, R Core Team 2023). I used polypore abundance data for the analysis.

I studied with a permutation test how FBV (High or low FBV) and study area (North, Middle or South) explain the differences in community composition. For this I used the "envfit" command in "vegan" package (Oksanen et al. 2022).

3 RESULTS

I conducted the deadwood inventory for 1480 deadwood pieces from 12 transects. On average there were 123 deadwood pieces per transect (SD=71.4). I inventoried polypores from 96 downed deadwood logs in the 12 different transects and found 115 occurrences from 37 different species. On average there were 1.24 polypore species per inventoried deadwood (SD=1.47). One of them is a threatened species *Skeletocutis stellae*. I also found *Amylocystis lapponica,* *Fomitopsis rosea, Meruliopsis albostraminea* and *Skeletocutis brevispora* which are near threatened (Kotiranta et al. 2019). The most abundant polypore species in the data were *Fomitopsis pinicola*, *Antrodia sinuosa* and *Trichaptum abietinum* (Appendix 2).

On average there were 6.83 polypore species per transect (SD=3.60). The most species rich transect was transect 9 with 14 species and the least species rich transect 8 with one species (Table 1).

TABLE 1 Relevant numbers in all transects. High FBV transects are 1,4,5,6,9 and 10. Low FBV areas are transects 2,3,7,8,11 and 12. FBV is forest biodiversity value, DDI deadwood diversity index, "deadwood" volume of deadwood per hectare, "trees" volume of living trees per hectare and "polypore species" number of polypore species in a transect.

Transect	FBV	DDI	Deadwood (m^3/ha)	Trees (m^3/ha)	Polypore species	Site area
1	0.963	3.605	30.144	158.75	6	North
2	0.363	2.462	4.990	75.944	5	North
3	0.252	2.310	19.961	73.929	5	North
4	0.967	3.606	20.643	113.5	7	North
5	0.991	3.855	55.878	208.6	12	Middle
6	0.992	2.959	13.689	121.5	5	Middle
7	0.227	3.510	16.980	29	7	Middle
8	0.327	2.806	12.257	89.833	1	Middle
9	0.997	3.509	62.113	380.5	14	South
10	0.962	2.665	5.168	254.04	3	South
11	0.657	2.672	2.470	201.25	6	South
12	0.446	3.135	18.788	81.583	11	South

3.1 How were structural characteristics of the forest and polypore species correlated with FBV?

The DDI increased as the FBV increased (Figure 2, Table 2). The volume of living trees per hectare increased as the FBV of the area increased (Figure 2, Table 2).

FBV was not significantly correlated with the volume of deadwood in a hectare (Table 2). FBV still seemed to have some correlation with the volume of deadwood, even though the effect was not proven to be significant (Figure 2).

FBV was significantly and positively correlated with species richness of polypores (Table 3), when volume of inventoried trees was another explanatory variable in addition to FBV. When volume of inventoried trees was not considered, the correlation was not significant (Table 3).

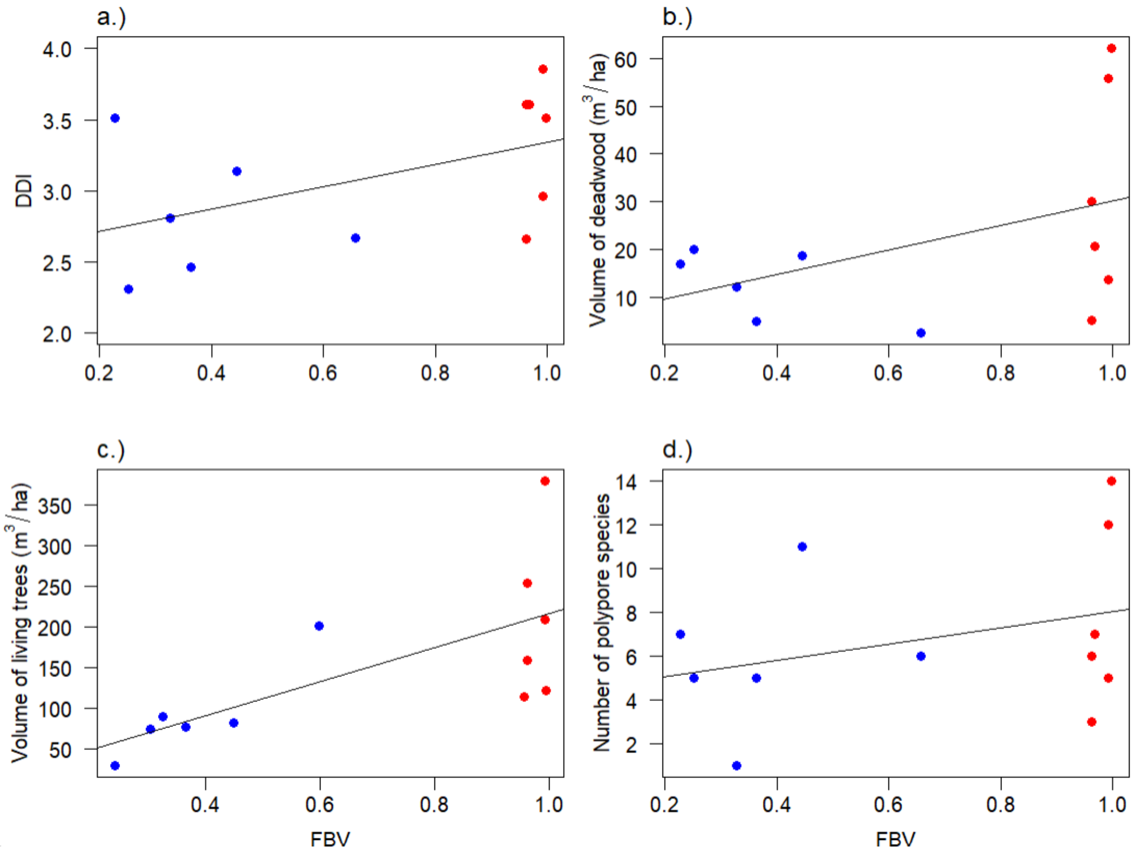

Figure 2. The correlations between explanatory variable average biodiversity value (FBV) and response variables a.) DDI, b.) Volume of deadwood (m^3/ha), c.) Volume of living trees (m^3/ha) and d.) Number of polypore species. Every circle symbolizes one transect. Red circles symbolize sites with high FBV, and blue circles with low FBV.

TABLE 2. Test statistics in the analyses where forest biodiversity value (FBV) is explanatory variable. Response variables are Deadwood diversity index (DDI), volume of deadwood per hectare (deadwood) and volume of living trees per hectare (trees). I used models to study the relationship between structural features of forests and FBV. T value belongs to Gaussian distribution and Z value to Poisson distribution.

Response	Explanatory	Estimate	SD	T/Z value	*p* value
DDI	FBV	0.262	0.130	2.013	0.044
Deadwood	FBV	1.621	1.179	1.374	0.169
Trees	FBV	1.628	0.350	4.651	<0.001

TABLE 3 Test statistics in the analyses where number of polypore species (polypore) is included as response variable. "Log volume" is average volume of polypore inventoried logs. FBV is forest biodiversity value, DDI deadwood diversity index, "Deadwood" volume of deadwood per hectare and "Trees" volume of living trees per hectare.

Response	Explanatory	Estimate	SD	Z value	*p* value
Polypore	FBV	0.555	0.361	1.538	0.124
Polypore	FBV	0.921	0.386	2.386	0.017
	Log volume	2.132	0.769	2.774	0.006
Polypore	DDI	0.670	0.285	2.350	0.019
	Log volume	0.449	0.840	0.534	0.593
Polypore	Deadwood	0.018	0.005	3.204	0.001
	Log volume	0.751	0.805	0.933	0.351
Polypore	Trees	0.002	0.001	2.472	0.013
	Log volume	1.663	0.713	2.331	0.020

3.2 How polypore species richness was correlated with the structural characteristics of forests?

When DDI increased, the number of polypores in transect increased (Figure 3, Table 3). Also, the number of polypore species increased when the volume of deadwood increased. The number of polypore species was positively correlated with average volume of living trees per hectare (Figure 3, Table 3).

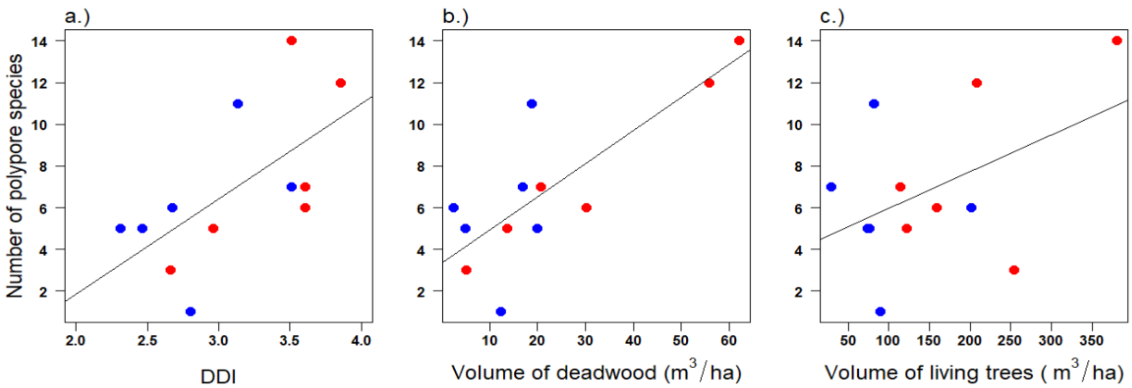

Figure 3. The correlations between explanatory variables a.) DDI, b.) Volume of deadwood (m^3/ha), c.) Volume of living trees (m^3/ha) and response variable Number of polypore species. Every circle symbolizes one transect. Red circles symbolize sites with high FBV, and blue circles with low FBV.

3.3 Did polypore communities differ between high and low FBV forests?

FBV (r^2=0.063, p=0.513) and study area (r^2=0.173, p=0.473) did not affect significantly to polypore community. The composition of communities in the transects is relatively randomized (Figure 4).

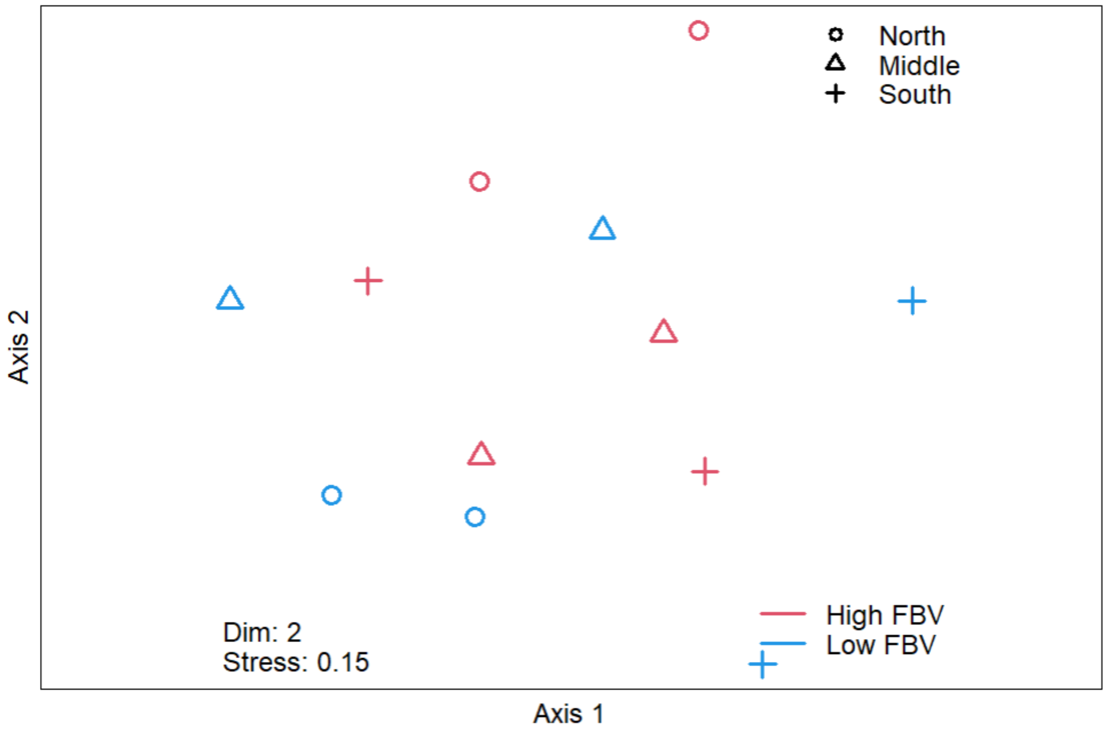

Figure 4. Non-metric multidimensional scaling of the polypore communities found from transects in different FBV values and site areas. The number of dimensions and stress are reported on the bottom of the figure.

4 DISCUSSION

4.1 Structural characteristics of forests and FBV

This study was the first validation of using the forest biodiversity values (FBV) provided by Mikkonen et al. (2018 & 2023) in allocating monitoring resources spatially to forests with different biodiversity. I found that the FBV reliably reflects several relevant structural features of forests and the diversity of polypore communities.

In line with my hypotheses, FBV was positively correlated with DDI. Deadwood potential is one of the layers in Zonation analysis of FBV (Mikkonen et al. 2020). When volume of deadwood increases, also the diversity of deadwood can be expected to grow (Müller & Bütler 2010). So, I expected that the diversity of deadwood would increase, when deadwood potential of the area increases. The positive correlation between FBV and DDI indicated that FBV (Mikkonen et al. 2023) is a useful tool to estimate the current diversity of deadwood in the Finnish forests.

However, the FBV of the forest was not shown to be significantly correlated with the volume of deadwood per hectare. In FBV analyses (Mikkonen et al. 2018) deadwood is taken into account as deadwood potential that is calculated using information from living trees (Mikkonen et al. 2020). That is because there are no comprehensive deadwood data that covers the whole Finland. It is therefore understandable that the volume of deadwood now in the area could not be deduced using FBV. In the future it might work if the deadwood potential turns into real deadwood in the area.

FBV was positively and significantly correlated with the volume of living trees per hectare (Table 2). This is very logical as deadwood potential (Mikkonen et al. 2020), which is the first layer in the FBV Zonation analysis, is calculated with the information from living trees (Mikkonen et al. 2018 & 2023). This finding also confirms the reliability of my results as if the volume of living trees and FBV did not have a positive correlation, something would have gone wrong in the analyses of this study.

4.2 Polypores and FBV

The number of polypore species per transect did not correlate with FBV when the volume of polypore logs was not considered in the analysis. This is reasonable, as the number of study transects was quite small, and therefore coincidence may have had a big role in shaping the results. For example, transect 7 with low FBV happened to have a lot of deadwood, because a lot of retention trees had fallen straight to the transect. Therefore, there were many polypore species, even though the transect had low FBV. Also, in addition to deadwood of ordinary tree species, transect 12 with a low FBV happened to have a lot of deadwood of *Abies* and *Larix* that do not naturally grow in Finland. That is why the deadwood in transect 12 was exceptionally diverse compared to other low FBV transect. In transect 12 I found 11 polypore species. The most species rich transect (Transect 9, Kotinen in South) had 14 species and the least species rich (Transect 8, Painattilehto in Middle) 1 species. Different tree species can host different polypore species because of their different chemical qualities (Stokland et al. 2012), and this can affect the results. Also, the diameter of a tree affects the species richness of polypores (Renvall 1995, Sippola et al. 2004). That's why I made another analysis where the volume of inventoried deadwood logs was taken account in the analysis as another explanatory variable. In this case, the correlation between the number of polypore species and FBV was significant and positive. Therefore, it seems that the higher the FBV is, the better the forest is for polypores.

The study area or FBV did not affect the community composition of polypores (Figure 4). I had only 12 transects in this thesis, and it is a really small number for comparison. If there were more transects, the results could have been clearer. However, only one of the six findings of red-listed polypores in this thesis was from low FBV area. That was *Meruliopsis albostraminea* that I found from transect 2 (Ruottama, Kittilä). Most of the red-listed polypore findings were from protected areas Kotinen in Hämeenlinna or Ulvinsalo in Kuhmo. So, even though communities did not seem to differ between low and high FBV areas, more red-listed species were found in high FBV areas.

4.3 Structural characteristics of forests and species richness of polypores

As found previously by for example Bader et al. (1995) and Penttilä et al (2004), the number of polypore species was positively correlated with the volume of deadwood in the area. The result was logical, because the higher the volume of deadwood is, the more species can fit in. Also, deadwood diversity probably increases with the increasing volume of deadwood (Hottola & Siitonen 2008). Different saproxylic species favor different deadwood types (Junninen & Komonen 2011), so in the forest with more deadwood types, also the species richness should be higher.

Deadwood diversity is found to be positively correlated with species richness of saproxylic species (Hottola & Siitonen 2008, Hämäläinen et al. 2018). Also, in this study species richness of polypores in a transect increased when DDI increased. That is probably because habitat heterogeneity usually increases with species richness (Stein et al. 2014). For saproxylic species, increase of different deadwood types means increase of habitat heterogeneity (Hämäläinen et al. 2018).

The number of polypore species was correlated with the volume of living trees per hectare in my study. Sippola et al. (2004) found a similar pattern, but they also included living trees in their study. Thus 15 % of the found polypore species inhabited living trees. As I did not include living trees in the polypore inventories, my finding may result indirectly from the fact that when the volume of living trees increases, also the volume of dead wood usually increases (Sippola et al. 1998). Generally, the volume of living trees does not always indicate high overall biodiversity, even though it might benefit some species (Hayward & Escano 1989, Goßmann et al. 2024). This is because the volume of living trees can be higher in mature managed forests than in protected old-growth forests (Siitonen et al. 2000, Burrascano et al. 2008).

4.4 Error sources and self-reflection

Possible error sources in my study included, for example possible misidentifications of polypores. However, I have probably been able to at least distinguish the species from each other. When studying the species richness of polypores, this is enough. Also, I verified some difficult species to identify with species specialists. Mistakes during digitization have probably been small. If there were big mistakes, I would have noticed them while plotting the results.

As the number of polypore inventoried trees was low, coincidence plays a big role. For example, when doing the polypore inventory, it was random, which tree species inventoried tree was. Different tree species can host different species (Junninen & Komonen 2011, Stokland et al. 2012), so this has affected the results.

When doing the polypore survey in the study areas of North and Middle, there were very low number of annual polypores. For example, I did not find any annual *Postia* species from these areas. In the South I found four *Postia* species. The survey in the North and Middle might have been too early for annual polypore fruitbodies to emerge. This has affected the number of species in transects in Middle and North. However, when comparing the high and low biodiversity transects, this should not affect much to the results. That is because there were same number of high and low biodiversity transects in every study area (South, Middle and North).

Different forest types can have naturally different volume of deadwood and living wood (Christensen et al. 2005, Oettel et al. 2020). Also, the diversity of deadwood varies between forest types (Oettel et al. 2020). However, for species richness of polypores, forest fertility type should not affect much because of their strong dependence on deadwood (Sippola et al. 2004). Polypore species richness can be high even in poorer forest site types (Sippola et al. 2004). The transects of this study were in forests with different forest types. This is because I did not take into account the forest type in the site selection. Despite this, the forest types were relatively evenly distributed in areas of low and high FBV. Therefore, forest types should not cause systematic error to my results.

In this study I only surveyed deadwood logs that were over 10 cm in diameter, to limit the variation in the quality of the inventoried logs between the transects. To have a comprehensive picture of all deadwood species in the area, also the trees with small diameter should be taken into account (Juutilainen et al. 2011). However, polypore species that favor small-diameter trees, can usually grow also on large trees (Junninen & Komonen 2011).

In the low FBV areas in my study, there was on average 12.6 m^3 deadwood in a hectare. This is quite much compared to 3.9–4.8 m^3/ha, which is the average volume of deadwood in Finnish commercial forests (Korhonen et al. 2020). The objective of a new forest strategy in Finland is to have on average at least 10 m^3 of deadwood in Finnish forests in the future (Maa- ja metsätalousministeriö 2022). In my study transects, all the forests that had low FBV, were Metsähallitus multi-use forests. That is simply because our project had permission to collect samples there. It is possible that these forests don´t represent the typical commercial forest in Finland, as recreational and importance of biodiversity is also recognized in multi-use forests in addition to economic value (Kaukonen et al. 2024). Therefore, in Metsähallitus multi-use forests there can be more deadwood compared to typical commercial forests, and it may affect the results.

4.5 Remote sensing in monitoring allocation

Traditional field inventories of deadwood and related biodiversity are reliable but need a lot of resources. For this reason, it is good to think about alternative methods of site selection for monitoring. In addition to FBV, also remote sensing methods could be used for this.

Remote sensing methods are already widely used in predicting the structure and volume of living trees (Holopainen et al. 2014). Especially information about living trees in Northern Finland was gained with remote sensing techniques for the calculations of deadwood potential and FBV (Mikkonen et al. 2018). Estimating the volume and diversity of deadwood using remote sensing is fairly new (Yrttimaa et al. 2019). With remote sensing techniques, especially large-diameter logs can be found quite reliably. Yrttimaa et al. (2019) found on average 68 % of downed deadwood logs using terrestrial laser scanning methods. Saarinen et al. (2018) found that unmanned aerial vehicles can be used in monitoring different biodiversity indicators (Volume of deadwood, structural heterogeneity, number of deciduous trees, volume and number of each tree species and successional stage). The diversity of polypore species was positively correlated with some of these variables in my thesis and also in many other studies (Bader et al. 1995, Penttilä et al. 2004, Sippola et al. 2004, Hottola & Siitonen 2008, Hämäläinen et al. 2018). Thus, with the help of only the volume and diversity of deadwood and the volume of living trees, it could be possible to select forests with differing deadwood and polypore diversity for monitoring. Remote sensing has a lot of potential in monitoring planning, and the techniques can improve to be more accurate in the near future.

5 CONCLUSIONS

FBV can be used reliably in selecting sites with different forest quality for monitoring of saproxylic species, here validated with deadwood and polypore species diversity. This was also important validation for using the FBV in its original purpose of planning forest conservation networks. When planning the monitoring network at a larger spatial scale, the sites should cover as many different habitat types as possible to include all biodiversity over the landscape. FBV analyses emphasize rare habitat types, but it still should be verified that all habitats are represented in the monitoring sites. Detailed spatial habitat type information is still largely lacking outside of the protected areas. This kind of data would be highly crucial for planning the spatial configuration of monitoring network alongside the utilization of FBV. The present deadwood volume of a site cannot be reliably deduced using FBV. To ensure that also the sites with very low volume of deadwood would be included into the monitoring network, the volume of deadwood could be deduced using remote sensing methods. Considering monitoring network planning, the comparison of the overall benefits and disadvantages between the remote sensing methods and FBV was outside of the scope of my thesis, but it would be useful to study in the future.

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Veera Silenius

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APPENDIX 1. TRANSECT LOCATIONS

Transect	Start (WGS84, degrees)	End (WGS84, degrees)	Length (m)
1	N 67.727069 E 24.256776	N 67.728783 E 24.245970	495.6
2	N 67.652608 E 24.665550	N 67.645164 E 24.665509	830.2
3	N 67. 650300 E 23.982438	N 67.644876 E 23.984187	609.4
4	N 67.749840 E 24.561883	N 67.749450 E 24.550400	487.3
5	N 63.997576 E 30.333175	N 63.999462 E 30.325778	418.6
6	N 63.923361 E 30.130666	N 63.926549 E 30.121223	583.9
7	N 63.998931 E 30.374417	N 64.001698 E 30.367950	441.9
8	N 63.981009 E 30.269925	N 63.979255 E 30.279122	491.0
9	N 61.239439 E 25.062346	N 61.239626 E 25.055034	393.2
10	N 61.195876 E 25.158047	N 61.193204 E 25.152225	432.0
11	N 61.194520 E 25.026624	N 61.197826 E 25.016379	662.7
12	N 61.249012 E 25.132989	N 61.248175 E 25.123889	497.3

APPENDIX 2. POLYPORES IN DIFFERENT TRANSECTS

	1	2	3	4	5	6	7	8	9	10	11	12	Total
Amylocystis lapponica					**2**								**2**
Antrodia serialis					**1**				**3**				**4**
Antrodia sinuosa	**1**				**1**		**1**		**3**		**1**	**1**	**8**
Antrodia xantha	**2**											**1**	**3**
Butyrea luteoalba					**1**								**1**
Canopora subfuscoflavida											**1**		**1**
Cerrena unicolor				**2**									**2**
Fomes fomentarius	**1**			**3**						**1**		**1**	**6**
Fomitopsis pinicola			**1**		**1**	**1**			**5**		**1**	**1**	**10**
Fomitopsis rosea				**1**	**2**								**3**
Gloeophyllum sepiarium				**2**	**1**	**2**	**1**						**6**
Gloeoporus dichrous												**1**	**1**
Inonotus obliquus												**1**	**1**
Ischnoderma benzoinum											**1**		**1**
Meruliopis albostraminea		**1**											**1**
Meruliopsis taxicola									**1**				**1**
Osteina undosa									**1**				**1**
Oxyporus corticola							**1**						**1**
Phellinus abietis	**1**				**1**								**2**
Phellinus ferrugineofuscus				**1**	**1**				**1**				**3**
Phellinus laevigatus				**1**								**1**	**2**
Phellinus nigricans							**1**						**1**
Phellinus viticola			**1**		**2**		**1**		**2**				**6**

Piptoporus betulinus		**1**		**1**			**1**						**3**
Postia caesia coll.									**2**			**1**	**3**
Postia calvenda									**1**		**1**		**2**
Postia guttulata									**1**				**1**
Postia hibernica												**1**	**1**
Rhodonia placenta			**1**								**1**		**2**
Skeletocutis biguttulata		**1**			**2**				**1**	**1**			**5**
Skeletocutis carneogrisea						**1**						**1**	**2**
Skeletocutis brevispora									**1**				**1**
Skeletocutis papyracea												**1**	**1**
Skeletocutis stellae									**1**				**1**
Trametes sp.	**1**												**1**
Trichaptum abietinum	**1**	**2**	**1**		**1**	**2**	**1**	**1**	**2**	**1**			**12**
Trichaptum fuscoviolaceum		**4**	**3**			**1**							**8**
Total	**7**	**9**	**7**	**11**	**16**	**7**	**7**	**1**	**25**	**3**	**6**	**11**	**110**