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Master Thesis

Forest dynamics of the natural forest reserve Schiffwald

submitted by

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This Master Thesis was written at the

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Affidavit

I hereby declare that I have authored this master thesis independently, and that I have not used any assistance other than that which is permitted. The work contained herein is my own except where explicitly stated otherwise. All ideas taken in wording or in basic content from unpublished sources or from published literature are duly identified and cited, and the precise references included.

I further declare that this master thesis has not been submitted, in whole or in part, in the same or a similar form, to any other educational institution as part of the requirements for an academic degree.

I hereby confirm that I am familiar with the standards of Scientific Integrity and with the guidelines of Good Scientific Practice, and that this work fully complies with these standards and guidelines.

Vienna, 23.06.2022 Ajdin STARCEVIC *(manu propria)*

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Abstract

Changes in forest characteristics, primarily influenced by natural disturbances, characterize forest dynamics. Natural forest reserves (NFR) provide a unique chance to study natural forest dynamics since they are unaffected by human management. In this regard, 45 sample plots with a 9.77-meter fixed radius were resampled in the NFR *Schiffwald* in 2021 to examine forest dynamics over the previous 12 years. The NFR *Schiffwald* is located on the northern slopes of the *Hochschwab* massif between 960 and 1500 meters above sea level and, and with 692 hectares, one of the largest NFRs in Austria. To assess the current state of the NFR a descriptive analysis of the growing stock, diameter and height distribution, natural regeneration, and deadwood volumes was required. Besides this, a comparison with the data from the last inventory cycle from 2009 was undertaken to examine the natural forest dynamics. In 2021, the growing stock was 284.90±155.03 m^3/ha, which was 16.81 m^3/ha less than in 2009. In 2021, the volume of deadwood increased by 14.68 m^3/ha and averaged at 71.62 m^3/ha. In 2021, around 80% of the deadwood was categorized as standing deadwood, while 60% of the deadwood was in the early stages of decomposition. Due to the limited amount of advanced and heavily decomposed deadwood, natural regeneration in 2021 was considerably lower than in 2009. Due to a higher vulnerability of Norway spruce to natural disturbances, the heterogeneity of various development stages could increase in the decades to come. To determine the actual causes of tree morality and to continuously study the future dynamics of forests, additional research is needed.

Zusammenfassung

Veränderungen der Waldmerkmale, die in erster Linie durch natürliche Störungen beeinflusst werden, kennzeichnen die Walddynamik. Naturwaldreservate (NFR) bieten eine einzigartige Möglichkeit, die natürliche Walddynamik zu untersuchen, da sie von menschlicher Bewirtschaftung unbeeinflusst sind. In diesem Zusammenhang wurden im NFR Schiffwald im Jahr 2021 45 Probeflächen mit einem festen Radius von 9.77 Metern neu beprobt, um die Walddynamik der letzten 12 Jahre zu untersuchen. Das NFR Schiffwald liegt an den Nordhängen des Hochschwabmassivs zwischen 960 und 1500 Metern Seehöhe und ist mit 692 Hektar eines der größten NFRs in Österreich. Zur Beurteilung des aktuellen Zustandes des NFR war eine deskriptive Analyse des Bestandes, der Durchmesser- und Höhenverteilung, der Naturverjüngung und der Totholzmengen erforderlich. Außerdem wurde ein Vergleich mit den Daten des letzten Inventurzyklus aus dem Jahr 2009 vorgenommen, um die natürliche Walddynamik zu untersuchen. Im Jahr 2021 betrug der Vorrat 284.90±155.03 m^3/ha, das sind 16,81 m^3/ha weniger als im Jahr 2009. Das Totholzvolumen nahm im Jahr 2021 um 14,68 m^3/ha zu und betrug im Durchschnitt 71,62 m^3/ha. Etwa 80 % des Totholzes war stehendes Totholz, während sich 60 % des Totholzes im Jahr 2021 in den frühen Stadien der Zersetzung befanden. Aufgrund der begrenzten Menge an fortgeschrittenem und stark zersetztem Totholz war die natürliche Verjüngung im Jahr 2021 deutlich geringer als im Jahr 2009. Durch die höhere Anfälligkeit der Fichte für natürliche Störungen könnte die Heterogenität der unterschiedlichen Entwicklungsphasen im Reservat in den kommenden Jahrzehnten zunehmen. Für die kontinuierliche Beschreibung der Ursachen der Mortalität und der künftigen Dynamik der Wälder ist die Fortsetzung des Monitorings erforderlich.

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Abbreviations

Abbreviation	Meaning
°C	Degrees Celsius
BA	Basal area
BAF	Basal area factor
BF	Blow up factor
BFW	*Bundesforschungszentrum für Wald*
cm	Centimeter
DBH	Diameter at breast height
dm	Decimeter
E	East
ELENA	*Empfehlungen für die Naturverjüngung von Gebirgswaldern*
ff	Form factor
km^3	Cubic kilometer
m	Meter
m.a.s.l.	Meter above sea level
m^2	Square meters
m^3	Cubic meters
MDM	Medium diameter
mm	Milimeter
N	North
n/ha	Number per hectare
NFR	Natural forest reserve
ZAMG	*Zentral Anstalt für Meteorologie und Geodynamik*

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1. Introduction

Changes in forest attributes such as growing stock, species composition, and mortality, which are primarily influenced by natural disturbances at various spatial and temporal scales, characterize forest dynamics in general (Frelich 2016). Natural disturbances affect the forest's structure, biodiversity, species composition, nutrient cycle, and carbon storage, particularly in unmanaged forests (Panayotov 2015, Oliver 1996, Foster et al. 1998, Bradford et al. 2013). Regeneration is one of the most crucial phases of forest dynamics, and natural disturbances have a substantial effect on it (Filion 1998, Fraver 2008). Insights into how these changes occur can be used as a basis for designing close-to-nature forest management approaches.

Due to centuries of human land use and management, the lack of virgin forests in Europe makes it difficult to study natural forest dynamics (Parviainen 2005, Kulakowski and Bebi 2004). This is especially true for subalpine Norway spruce forests in Central Europe, where larger areas of unmanaged forests are uncommon, and it is difficult to distinguish between natural and human impacts due to a long history of human management (Motta et al. 2002). As the Norway spruce is the dominant tree species in subalpine European conifer forests (Caudulo et al., 2016) and as its susceptibility to disturbances increases with global climate change (Bugmann et al., 2014), it is becoming increasingly important to study the forest dynamics of these forests to improve their resilience. In this context, natural forest reserves provide a unique and significant opportunity to research forest dynamics because they are not managed by humans.

The Austrian "Natural Forest Reserves Program" was initiated in 1995 in order to conserve the most significant forest types in Austria and to investigate the forest dynamics of these forests, as well as the effects of natural disturbances (Frank and Müller, 2003). One of the primary objectives was not to preserve certain forest conditions, but rather to allow forest dynamics to develop without interference (Frank and Koch 1999). As a result of less extensive management in the past, the majority of Natural Forest Reserves (NFRs) cannot be termed virgin forest remains (Vacik et al. 2017). Nonetheless, the impact on these forests throughout history was negligible due to their inaccessibility and poor agricultural soil conditions.

In 2008, the University of Natural Resources and Life Sciences, Vienna, in collaboration with the Austrian Federal Forests, launched the research project ELENA (*Empfehlungen für die Naturverjüngung von Gebirgswaldern*) to investigate some of the issues mentioned above. The purpose of the project is to investigate the dynamics of natural forests and the effect of deadwood on biodiversity and natural regeneration (Vacik et al. 2010). In order to accomplish this, permanent sampling plots were established in six natural forest reserves in Austria: *Goldeck, Laaser Berg, Krimpenbachkessel, Schiffwald, Hutterwald,* and *Kronenwettgrube.*

Few studies, except the ELENA project (Ruprecht et al. 2013) have investigated forest dynamics of strictly unmanaged Norway spruce subalpine forests in Austria. Norway spruce mortality is expected to significantly increase in the future, both in Austria and across Europe due to increase of climate-induced challenges, such as bark-beetle outbreaks, and decrease of suitable climatic conditions (Jandl 2020, Čermák et al. 2021, Northdurft 2013). This becomes more important when taking into account that Norway spruce covers around 50% of production forests in Austria (Russ, 2019). Understanding natural forest dynamics, under the current climate change, is required to design close-to-nature management approaches that will boost the future resilience of Norway spruce forests in Europe.

This master's thesis was conducted within the ELENA project. The purpose of the thesis was to assess the natural forest dynamics of the NFR *Schiffwald* and to estimate the implications of stopping human interventions. In 2021, a remeasurement of the permanent sampling plots was performed. Forest attributes such as growing stock, species composition, natural regeneration, and deadwood volumes were studied and compared to the 2009 inventory cycle to determine the changes that have happened over the previous 12 years.

1.1 Research questions

The aim of the thesis was to answer the following research questions:

- What is the current state of the NFR *Schiffwald* in regards to the growing stock, species composition, natural regeneration and deadwood volume?
- How did the aboveground living and dead woody biomass and the natural regeneration change over time ?
- Does a change of the tree species composition influence the share of tree species in the natural regeneration?
- Is the diameter distribution of the deadwood changing over time due to increased mortality or decreased competition ?

2.Materials and methods

2.1 Site description

2.1.1 Location

The NFR *Schiffwald* is situated several kilometres south (47°36'N, 15°00'E) from the municipality of *Wildalpen* in the Austrian state of *Styria*. It is located on the northern slopes of the *Hochschwab* mountains, and with its 692 ha of area, it represents one of the biggest natural forest reserves in Austria. Vertically, the NFR is situated between 960 and 1500 m.a.s.l., with the main plateau of the NFR being in the range of 1250-1350 m.a.s.l. (Steiner & Schweinzer, 2012).

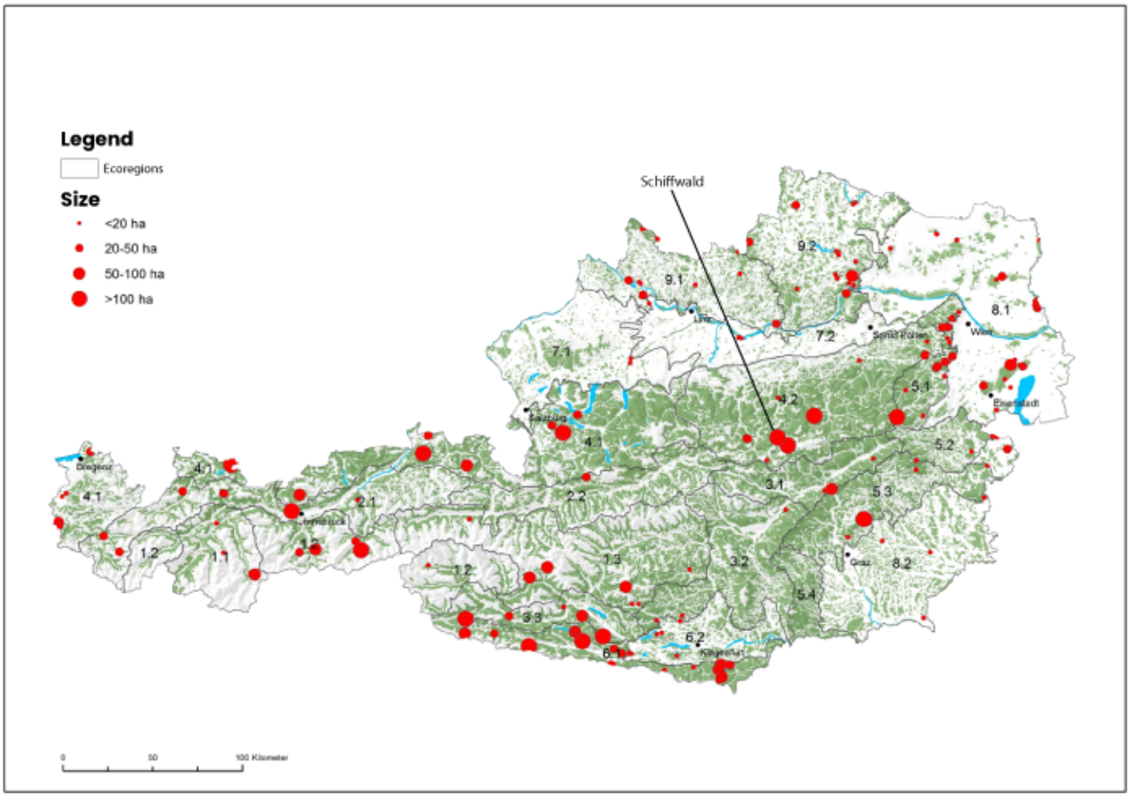

Figure 1. Map of natural forest reserves in Austria, modified from BFW (2021)

The NFR *Schiffwald* was founded in December 1999 as a result of a contract between the owner, the municipality of Vienna, and the Austrian Republic. The forest is part of the Vienna municipality's spring protection area (Steiner & Schweinzer, 2012). As a result of this, as well as the enormous area it covers, the NFR *Schiffwald* already had a close-to-nature vegetation (Prskawetz, 1999).

The NFR *Schiffwald* covers the middle montane, upper montane and subalpine vegetation zones in the forest ecoregion *eastern north Alps* (4.2) (Killian et al., 1993). The forest stands of the NFR are made up of the following potential natural forest associations (Willner & Grabherr, 2007):

- *Saxifrago rotundifoliae-Fagetum* Zukrigl 1989 s.l. (Willner & Grabherr, 2007)
- *Adenostylo glabrae-Piceetum* Zukrigl 1973 (Willner & Grabherr, 2007)
- *Rhodothamno-Laricetum* Willner et Zukrigl 1999 (Willner & Grabherr, 2007)
- *Erico-Pinetum prostratae* Zöttl 1951 (Willner & Grabherr, 2007)
- *Rhododendro hirsuti-Pinetum prostratae* Zöttl 1951 (Willner & Grabherr, 2007)

Around 11 percent of the NFR is covered with mixed spruce-fir-beech forests (Prskawetz, 1999). *Adenostyle glabrae-Piceetum* is the most prevalent forest type, accounting for 35 percent of the total area. Dwarf pine covers 45 percent of the NFR, with the remainder of the area made up of windthrow zones, screes, crevice communities, and meadows (Steiner & Schweinzer, 2012).

Norway spruce (*Picea abies* (L.) Karst.), European larch (*Larix decidua* Mill.), European beech (*Fagus sylvatica* L.), and Dwarf pine (*Pinus mugo* Turra) are the predominant tree species (*Pinus mugo* Turra). Parts of the reserve are interspersed with Sycamore maple (*Acer pseudoplatanus* L.), Silver fir (Abies alba Mill.), Silver birch (Betula pendula L.), and Mountain ash (Sorbus aucuparia L.).

2.1.2 Climate

As the reserve is located at the northern slopes of the *Hochschwab* massif, an alpine climate dominates which is characterized by heavy snow winters and rainy summers. The snow can pile up several meters with redeposition done by mostly south-east directed winds (Plan & Decker 2006). Long-lasting snow coverage can shorten the vegetation period while also putting mechanical pressure on trees and regeneration. This might have an impact on the vegetational cover (Steiner & Schweinzer, 2012).

Climate data for the NFR Schiffwald were interpolated from meteorological stations in *Schöckl* (1443 m.a.s.l.) and *Präbichl* (1215 m.a.s.l.) (ZAMG-*Zentral Anstalt für Meteorologie und Geodynamik*, 2008-2021). A linear relationship between climatic parameters (temperature and precipitation) and elevation was assumed to determine the values for the NFR Schiffwald. The data were calculated using a mean elevation of 1300 m.a.s.l. for the NFR's main plateau, an annual temperature of 7.1 °C, and 1115 mm of precipitation. As seen in Fig. 2, precipitation levels peak throughout the growing season, from May to August, indicating that there are no significant drought periods in the NFR. January has the coldest average temperature of -2.6°C, while July has the warmest average temperature of 17.2°C.

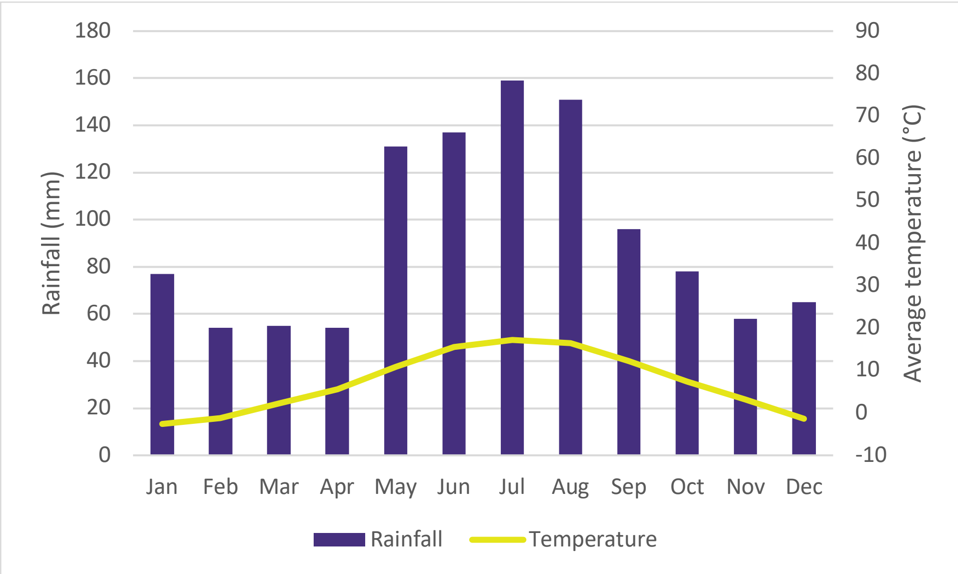

Figure 2. Climate diagram of NFR *Schiffwald* with average monthly temperature and precipitation sums (2008-2021), interpolated from the meteorological stations *Schöckl* (1443 m.a.s.l.) and *Präbichl* (1215 m.a.s.l.)

2.1.3 Geology

The NFR is situated near a landslide that occured around 5,900 to 5,700 years ago (Van Husen & Fritsch, 2007). A new basin was produced during a mass movement of around 4-6 km^3, and it is marked by an extremely uneven topography with numerous hills and depressions (Steiner & Schweinzer, 2012).

Calcareous rock dominates in terms of area, with dolomite transitions (Pavlik & Van Husen 2010). Because they were formed by a landslide, the soils are young and deficient in fine soil. As a result, rendzines are dominant over the soil landscape. Mixed soils, on the other hand, can be found in limited areas as well (Köck et al. 1996).

2.1.4 Forest associations and vegetation

The NFR Schiffwald is important for the municipality of Vienna because it is a spring protection area. As a result, much research has been done on the NFR's vegetation, particularly in terms of mapping the dominant forest associations (Lackner 1994, Vacik 1994, Köck et al. 1996, Prskawetz and Exner 1999, Muncina et al, 1993). Fischer et al. 2015 and Frahm and Frey 1992 were used to nominate the vascular plants and mosses.

Aside from Norway spruce, which is the dominating tree species in the NFR, dwarf pine covers a large area. Along with this, spruce-fir-beech and larch stands can be found. Additionally screes, ridges, and meadows can be found throughout the NFR Schiffwald.

Helleboro nigri-Fagetum **Zukrigl 1973 (according to Wallnöfer et al. 1993)**
This forest association is primarily found in the northern half of the NFR, but it can also be found intermittently throughout the reserve. The dominating tree species is the beech, which is mostly found in the second forest story and just occasionally in the first. We also find spruce, sycamore, and fir as secondary species, in addition to beech. Plant vegetation is characterized by groups of basophile and acidophile plants that correlate to soil parameters. *Calamagrostis varia, Adenostyles alpina, Valeriana tripteris, Carex digitata, Rubus saxatilis*, and *Tortella tortuosa*. *Ctenidium molluscum* are the most prevalent basophile plants. *Vaccinium myrtillus, Lycopodium annotinum, Vaccinium vitis-idaea, Homogyne alpina,Vaccinium vitis-idaea* and *Majanthemum bifolium* are the most common species found in acidic environments.

***Asplenio-Piceetum* Kuoch 1954**

Because it is formed by landslides over hard limestone, this association is characterized by a small-scale mosaic of sites (Wallnöffer 1993). The trees here are mostly present on the small hills. *Adenostyles alpina, Calamagrostis varia, Oxalis acetosella, Lycopodium annotinum, Vaccinium myrtillus*, and *Valeriana tripteris* are some of the most common species. *Tortilla tortuosa* and *Ctenidium molluscum* are two common mosses. Plants like *Asplenium viride* and *Valeriana saxatilis* are also common due to the large amount of rocks.

***Adenostylo alliariae-Abietetum* Kuoch 1954**

This association is characterized by fresh to humid site conditions. As a result of this, The herb species are largely moisture indicators and forbs. *Adenostyles alliariae, Crepis paludosa, Hypericum maculatum, Luzula luzulina, Veratrum album, Viola biflora*, and *Saxifraga rotundifolia* are the most prevalent species. Poorly water supplied places might exist in close proximity due to the fact that relief can alter in a very small space and that there are variable snow accumulations. Due to the high proportion of rocks, plants such as Asplenium viride and Valeriana saxatilis are also common.

***Adenostylo glabrae-Piceetum* M. Wraber ex Zukrigl 1973**

A moderate to unfavorable water supply characterizes this association.

The soils, at the same time, have a large proportion of skeleton. *Betonica alopecuros, Buphthalmum salicifolium, Calamagrostis varia, Carduus defloratus, Polygala chamaebuxus,* and *Sesleria albicans* can withstand dry environments and are indicators of a high presence of limestone. High skeletal content in the soil is indicated by *Adenostyles alpine* and *Gymnocaripum robertianum*. As a result of the unfavorable decomposition rates, moder humus pockets lead to a grouping of acidophilic and basophilic synusia.

***Laricetum deciduae* Bojko 1931**

The larch stands were allocated to this association based on Wallnöfer's syntaxonomy (1973). This association is mostly restricted to the reserve's north and north-western slopes. Aside from the larch, secondary species such as birch and spruce can be found. Dwarf pine is very common in the shrub layer. This association is highly rich in herbaceous species due to the high amount of light that penetrates to the forest floor. *Carex ferruginea, Calamagrostis varia, and Rhododendron hirsutum* are the most common species. Numerous tall perennials and moisture indicators, such as *Adenostyles alliariae*, *Saxifraga rotundifolia, Geranium sylvaticum, Veratrum album, Deschampsia cespitosa, Crepis paludosa,* and *Chaerophyllum hirsutum,* can be found due to the abundance of snow and the shady locations. Shallow and poor soils are present here and this we can conclude due to theoccurrence of Sesleria albicans, Scabiosa lucida and Leucanthemum atratum. Because of the presence of Sesleria albicans, Scabiosa lucida, and Leucanthemum atratum, we can assume that the sites are shallow and poor in fine soils.

Erico-Pinion mugo **Leibundgut 1948**

The dwarf pine dominates large portions of the NFR. This species prefers to live in dry areas where other trees can't compete with it. In locations where there is a lot of snow and frost, the dwarf pine has an advantage. Herbaceous species thrive here due to the amount of light, strong wind protection, and favorable substrate qualities. The mosaic-like interlocking of acidophilic and basiphilic synusia is caused by small-scale changes in soil conditions. Within this category, Prskawetz and Exner (1999) distinguished the following associations:

Lycopodio annotini-Pinetum uncinatae **Starlinger 1992**

These stands are dense, more stepped stands with well-developed dwarf pine, spruce, and juniper layers. The *Lycopodio annotini-Pinetum* is particularly notable for its *Sphagnum quinquefarium* dominated moss layer. This formation of a thick, permanently damp humus layer that is prone to sliding. *Lycopodium annotinum, Calamagrostis villosa*, *Calluna vulgaris, Maianthemum bifolium*, and *Oxalis acetosella* predominate the herbaceous layer. *Maianthemum bifolium* and *Oxalis acetosela* are primarily found in submontane and montane climax forests. The *Lycopodio annotini-Pinetum* shares with the later *Erica herbacea*, *Rhododendron hirsutum, Sorbus chamae-mespiuls*, and *Sesleria varia*. These calcareous plants likely obtain the majority of their base requirements from dolomite detritus in the subsoil.

Additionally two other forest associations can be found in the NFR *Schiffwald: Vaccinio myrtilli-Pinetum montane* Morton 1927 and *Erico carneae-Pinetum prostratae* Zöttl 1951

2.2 Sampling design

In order to collect data, the sampling was carried out on a grid of 63 permanent plots that had previously been created for the research project ELENA in 2008. Due to difficulties in identifying all of the plots in 2021, a total of 55 plots were resampled (Figure 3). In all, 10 plots were sampled using angle count sampling, whereas the remaining 45 plots were sampled as fixed radius plots.

There were 17 plots that were situated in the north-eastern part of the reserve, which were established in an *Adenostylo alliariae-Abietetum* forest community. These plots are 100 m apart in the north-south and east-west orientation. The remaining plots are more widely spaced apart, where the horizontal and vertical distance between plots is 200 meters and the diagonal one 142,42 meters. These plots were established in an *Asplenio-Piceetum* forest community. The area of the plots is 300 square meters (radius of 9,77). The sampling design followed an already established sampling method developed for the ELENA project (Vacik et al., 2010). For the data collection sampling was done on five different levels:

1. Fixed radius plot – location survey
2. Fixed radius plot – living trees
3. Fixed radius plot – standing and lying deadwood
4. Angle count sampling
5. Natural regeneration

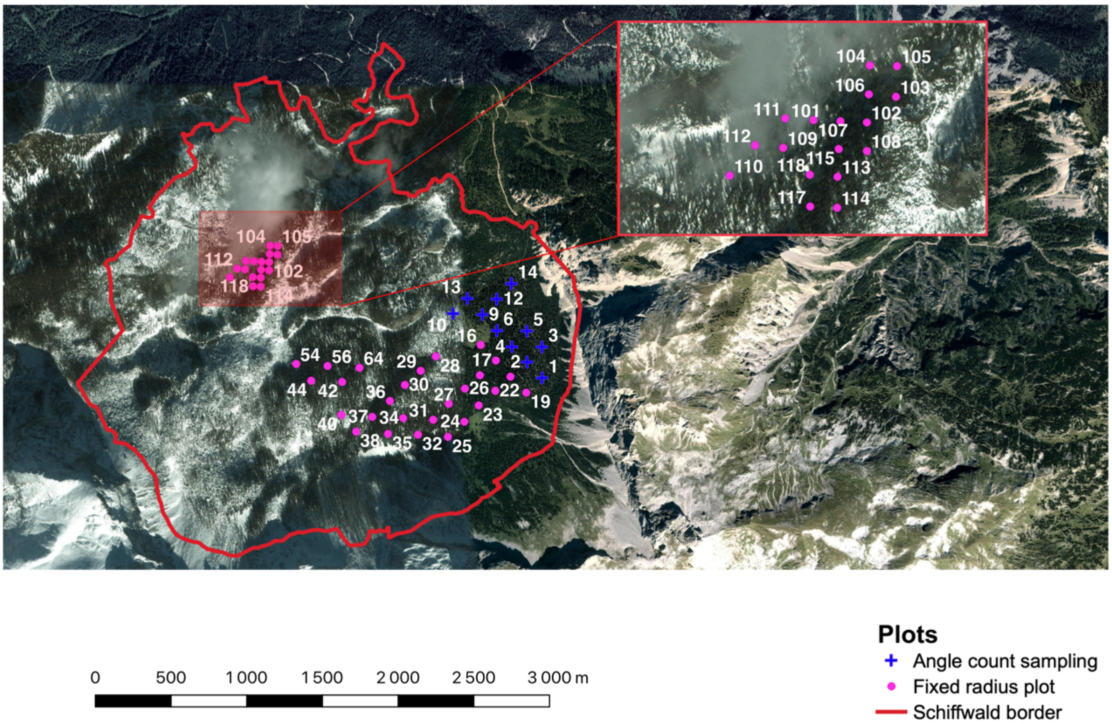

Figure 3. Sampling design of the inventory conducted in 2021

2.2.1 Fixed radius plot – location survey

For the location survey several characteristics have been assessed on the plots:

- Description of the location – general and verbal description of the area of the plot, for example indicating certain characteristics that would make locating the plots easier
- Elevation in meters
- Exposition in Gon
- Slope gradient in percentage
- Vertical structure – the coverage degree for the different layers was estimated in percentage. All together four layers were differentiated: trees, shrubs, herbs and mosses. The mosses represent all rootless plants, and the herbs layer all non-woody vascular as well as woody plants up to 30 cm of height. The shrub layer was assumed between 3 and 5 meters, and the tree layer was further divided into three sublayers.
- Other remarks

Due to the fact that the site attributes have been documented during the 2008 sampling a reassessment of them has not been done in 2021, except for the vertical structure.

2.2.2 Fixed radius plot – living trees

Trees taller than 1,30 m were documented on the whole 300 m^2 plots. Data on following attributes were collected:

- Position – the azimuth and distance from the centre pole
- Height - in decimetres by using height measurement device Vertex
- Diameter -measured in centimetres by using a tape measure at 1,30 meters
- Height of the first living branch - measured in decimetres by using a Vertex
- Species
- Damages
- Fructification
- Other remarks

2.2.3 Fixed radius plot – standing and lying deadwood

Both standing and lying deadwood was documented on the whole area of the plots. For standing deadwood that had a DBH larger than 5 cm, following attributes were assessed:

- Position – the azimuth and distance from the centre pole
- Height - in decimetres by using height measurement device Vertex
- Diameter -measured in centimetres by using a tape measure at 1,30 meters
- Species
- Deadwood type (see Table 1)
- Decomposition stage (see Table 2)
- Debarking intensity (see Table 3)
- Cause of death (see Table 4)

- Time of death – assessed how long ago the tree has died based on the visual condition of the individual deadwood. Several classes for grouping were used: 0-4 years, 5-9 years, 10-14 years, 15-19 years, 20-24 years, 25-29 years.
- Other remarks

Table 1. Type of deadwood, according to the ELENA sampling manual

Code	Deadwood type
1	Tree with crown: with remaining leaves or needles
2	Tree with crown: with fine branches
3	Tree with crown: with coarse branches
4	Trees without crown: stem
5	Root plate
6	Sticks
7	Tree or part of a tree: DBH measurable
8	Tree part: DBH not measurable

Table 2. Deadwood decomposition stage, according to the ELENA sampling manual

Code	Decomposition stage	Bark characteristics	Wood characteristics
A	Freshly dead	Bark still firmly attached to wood	Solid
B	Starting decomposition	Bark starting to fall off	Solid
C	Advanced decomposition	Bark partially fallen off	Not solid
D	Heavily decomposed, decayed	Bark mostly fallen off	Soft, recognizable wood structure
E	Humus, no recognizable wood structure		

Table 3. Deadwood debarking intensity, according to the ELENA sampling manual

Code	Debarking intensity
1	Stem fully covered with bark: 75-100 percent
2	Stem half covered with bark: 50-75 percent
3	Stem quarterly covered with bark: 25-50 percent
4	Bark not present: 0-25 percent

Table 4. Deadwood cause of death, according to the ELENA sampling manual

Code	Cause
1	Anthropogenic
2	Windthrow
3	Snow break
4	Competition
5	Age related
6	Bark beetles
7	Other

Lying deadwood was also documented on the total plot area. Similar attributes were assessed for lying deadwood with a ≥ 10 cm DBH:

- Position – the azimuth and distance of the closest point from the centre pole
- Length – horizontal length in centimetres by using a tape measure
- Diameter - measured in centimetres by using a tape measure at the middle point of the deadwood
- Species
- Deadwood type (see Table 1)
- Decomposition stage (see Table 2)
- Debarking intensity (see Table 3)

- Cause of death (see Table 4)
- Time of death – assessed how long ago the tree has died based on the visual condition of the individual deadwood. Several classes for grouping were used: 0-4 years, 5-9 years, 10-14 years, 15-19 years, 20-24 years, 25-29 years.
- Fungus fruiting bodies – number
- Vegetation cover – assessed in percentage, separate for mosses and vascular plants.
- Other remarks

For lying deadwood <10 cm the total prevalence on the forest floor was assessed on the whole plot according to Figure 4. All together there were five different categories: very low to no deadwood, low occurrence, average occurrence, high occurrence, and especially high occurrence

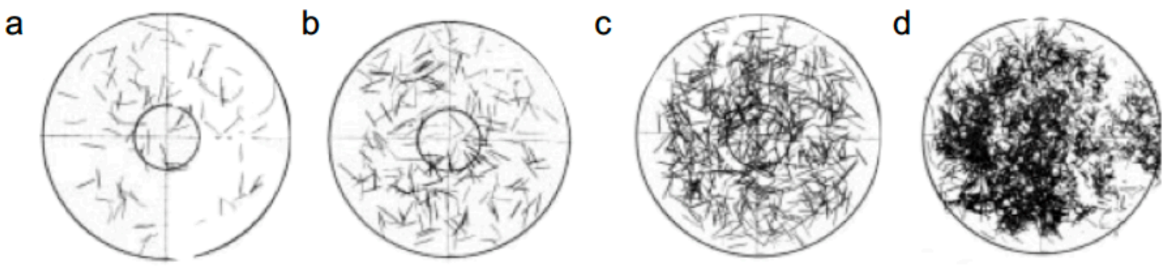

Figure 4. Prevalence of lying deadwood <10 cm on the forest floor; a) 1-3 % b) 4-10 %, c) 11-50 %, d) >50 % (Vacik et al., 2010)

2.2.4 Angle count sampling

All together 10 plots were sampled by using the angle count sampling method. A basal area factor (BAF) of 4 was used for this purpose. For trees that were previously measured in the fixed radius plots and that fall inside the BAF of 4 the data was copied. For trees that were not measured previously in the fixed radius plot and that were considered as *inside*, following attributes were documented:

- Diameter at breast height – in centimetres
- Height – in decimetres
- Height of first living branch – in decimetres

- Species
- Other remarks

2.2.5 Natural regeneration

Sublots for regeneration sampling were placed in each of the four major expositions, with the midpoint being 5 meters from the plot's centre. The sublots were separated into two categories: category A, which is 0.25 m^2 in size, and category B, with an area of 1 m^2 in size (Figure 5). All trees that were below 1,30 m were considered as regeneration. All together the natural regeneration was grouped in four different classes:

- Seedlings – counted separately for each species in each of the category A subplots
- Sapplings until 15 cm – on both sublot categories, age (1-year-old, 2-year-old, or older) and species were recorded
- Regeneration 15-30 cm - documented on both types of sublots, together with the species, root collar diameter, and growth during the previous 5 years. Grazing effect, damages, and microhabitat were also assessed.
- Regeneration 30-130 cm – documented on the whole plot area, attributes as species, root collar diameter, height, increment during the previous 5 years, and vitality were all reported. In addition, the influence of grazing, damages, and microhabitat were evaluated alongside information about the quadrant (i.e.. S1, S2, S3, S4). This regeneration category was also marked by using a marking tape.

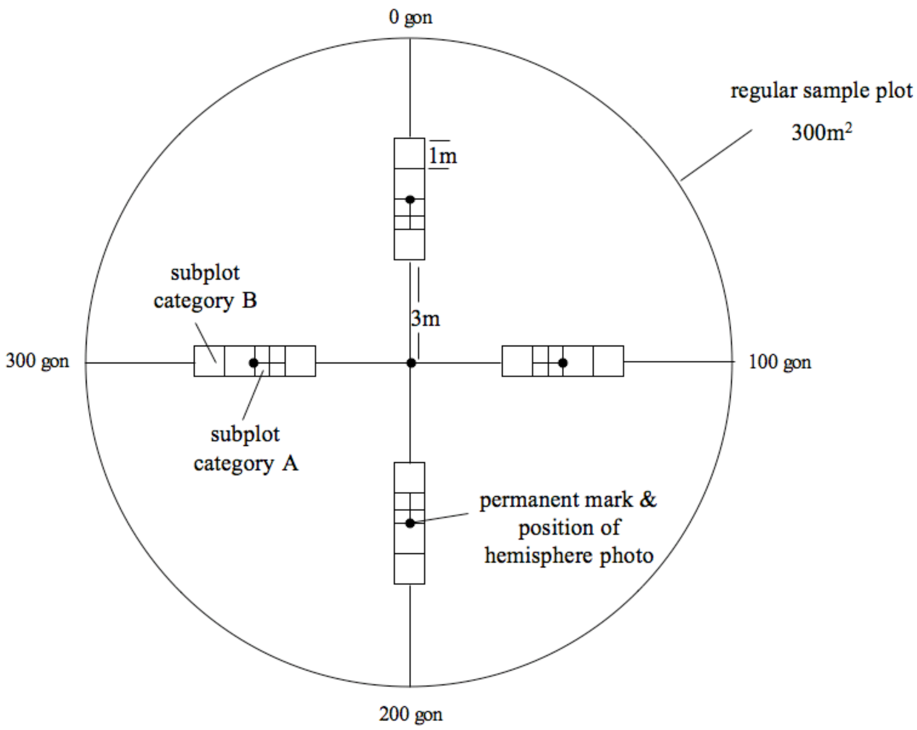

Figure 5. Sample design on the permanent sample plots (Ruprecht, 2012)

2.3 Data analysis

The collected data from the 46 fixed radius plots were digitalized using the Microsoft Excel software. Furthermore, using Excel and the statistical programming language R, the data was analysed and visualized. In this chapter I will describe the in detail how I analysis of the data.

2.3.1 Height curves

For the two most common species in the NFR Schiffwald, spruce and larch, height curves were calculated. This was done to get comparative values for the heights of the standing deadwood, which was then used for the calculation of the standing deadwood volume but also for missing data on the heights.

Several height curve types were tested with by using R software and the ones with the highest R^2 were then used for further calculations. For both the spruce and larch that was the Prodan height curve. The parameters for the Prodan height curve are shown in Table 5.

Prodan:

$$h = \frac{d^2}{a_0 + a_1 d + a_2 d^2} + 1.3$$

h – height (m)

d – diameter (cm)

a_0,a_1,a_2 – coefficients

Table 5. Parameters for the Prodan height curve

Species	Parameters			R2
	a_0	a_1	a_2	
Spruce	4.836	0.879	0.018	94.6%
Larch	4.836	0.879	0.018	97.9%

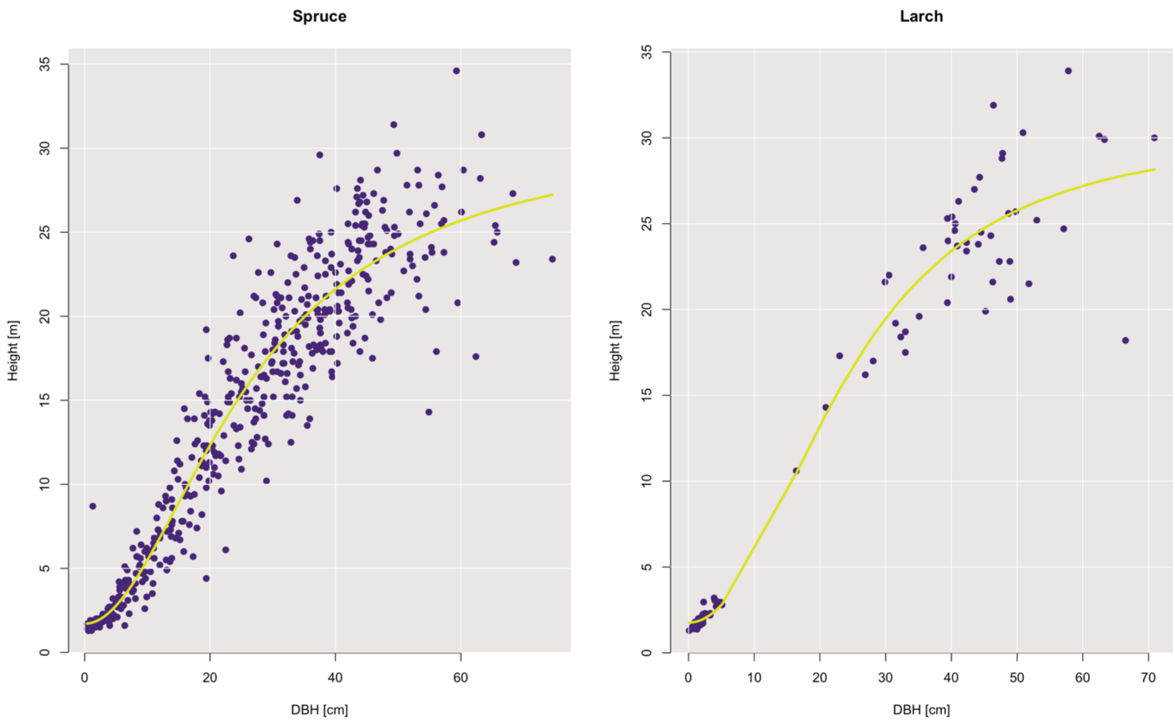

Figure 6. Height curves for norway spruce and larch in the NFR *Schiffwald*

2.3.2 Volume calculation

The volumes were calculated by using the form factor developed by Pollanschütz (1974):

$$f_{Pollanschütz} = b_1 + b_2 + \ln^2 d + \frac{b_3}{h} + \frac{b_4}{d} + \frac{b_5}{d^2} + \frac{b_6}{dh} + \frac{b_7}{d^2 h}$$

$F_{Pollanschütz}$ – form factor for stock wood with bark
d – diameter at breastheight (dm)
h – tree height (dm)
b_1-b_7 – coefficients (see Table 6)

Table 6. Parameters for the calculation of the form factor according to Pollanschütz (1974)

Species	DBH (cm)	b_1	b_2	b_3	b_4	b_5	b_6	b_7
Spruce	>10.5	0,468180	-0,013919	-28,213	0,37474	-0,28875	28,279	0,00000
	≤10.5	0,563443	-0,12731	-8,55022	0,00000	0,00000	7,6331	0,00000
Larch	>10.5	0,60944	-0,04557	-18,6631	-0,24874	0,12659	36,9783	-14,204
	≤10.5	0,48727	0,00000	-2,04291	0,00000	0,00000	5,9995	0,00000
Hardwoods	>10.5	0,686253	-0,03715	-31,0674	-0,38632	0,219462	49,6163	-22,3719
	≤10.5	0,5173	0,00000	-13,62144	0,00000	0,00000	9,9888	0,00000

By using the the form factor the volumes were then calculated for each tree.

$$V = DBH^2 * \frac{\pi}{4} * f * h$$

V – volume (m3)
DBH – diameter at breast height (m)
H – height (m)
f – form factor

2.3.3 Deadwood volume calculation

For the deadwood volume calculation three different classes were used: lying deadwood, standing deadwood and sticks. For all three classes the volumes per hectare were calculated. Besides these other attributes were also analysed such as the time of death, cause of death and deadwood type.

For the volume calculation of lying deadwood type 8: *Tree part: DBH not measurable*, the average middle diameter of the measurable lying deadwood pieces was used as an approximation. This diameter was equal to **22** cm. For the calculation of the lying deadwood volumes the following formula was used:

$$V = MD^2 * \frac{\pi}{4} * l$$

V – volume of lying deadwood [m^3]
MD – middle diameter [m]
l – length m

The volume for the standing deadwood was calculated in the following way: if the height of the deadwood is less than 80 percent of the corresponding tree height determined by the means of the height curves the volume is calculated by using the height curves. After that the volume is reduced by using the relationship between volume percentage and tree height percentage according to Bachmann (1970). The height curves are represented in Figure 3. The volumes were calculated by using the form factor according to Pollanschütz (1974) both for the actually measured heights and also for the height curve estimated heights. The parameters for the form factor are represented in Table 7.

Table 7. Parameters for the calculation of the form factor according to Pollanschütz (1974)

Species	DBH (cm)	b_1	b_2	b_3	b_4	b_5	b_6	b_7
Spruce	>10.5	0,46818	-0,013919	-28,213	0,37474	-0,2887	28,279	0,00000
	≤10.5	0,56344	-0,12731	-8,55022	0,00000	0,00000	7,6331	0,00000
Larch	>10.5	0,60944	-0,04557	-18,6631	-0,2487	0,12659	36,9783	-14,204
	≤10.5	0,48727	0,00000	-2,04291	0,00000	0,00000	5,9995	0,00000

For individual dead trees that are below 1.4 m in height, which correspond to the category of sticks, the volume was calculated according to Meyer (1999). For the calculation a neiloid stump is used as a basis for the sticks. For the estimation of the middle diameter an increase of 12 percent per meter is assumed and 24 percent for the lower diameter. The upper diameter was measured in the field. The volume of the neiloid stump was calculated using the following formula:

$$V_{stick} = \frac{\pi * l}{4} * (r_u^2 + 4 * r_m^2 + r_l^2)$$

V_{stick} – volume of the sticks [m^3]

l – stick height [m]

r_u – upper radius [m]

r_m – middle radius [m]

r_l – lower radius [m]

2.3.4 Natural regeneration

For each of the categories of natural regeneration, the mean values per hectare and standard deviation were calculated. In addition, the distribution of species within each group, as well as their vitality and damage, were evaluated.

For the determination of the average number of individuals per hectare, a blow-up factor was applied to each regeneration category based on the size of their respective sample plots. For the seedlings sampled on four square meter plots, the blow-up factor was 2500, for the <15 cm and 15-29.9 cm categories sampled on sixteen square meter plots, the blow-up factor was 625, and for the 30-129.9 cm regeneration group, the blow-up factor was 33.3.

The equation for the calculation of the mean numbers per hectare was:

$$N = n * BF$$

Where:

N – number of individuals per hectare

n – number of sampled individuals

BF – blow-up factor

2.3.5 Description of statistical tests

The Kruskal-Wallis test was applied to determine whether there are statistically significant differences between the means of specific attributes. ANOVA and the Mann-Whitney U test could not be performed because certain assumptions, such as a normal distribution and the independence of observations, could not be met. Consequently, the choice was made to employ a Kruskal-Wallis test.

The Kruskal-Wallis test is a rank-based nonparametric test, which assumes no particular distribution. It is used to examine whether there are statistically significant differences between two or more groups regarding a continuous or ordinal independent variable.

3. Results

3.1 Description of the current state of the NFR *Schiffwald*

3.1.1 Site characterization

In NFR Schiffwald, the average slope of the sampling plots is 23 percent. In this regard, the NFR Schiffwald area is rather flat, with 60 percent of the sampling plots having a slope of 0 to 20 percent. A slope of 40 to 80 percent is found in 36 percent of the plots, while a slope of more than 60 percent is found in 8 percent of the plots (Figure 7).

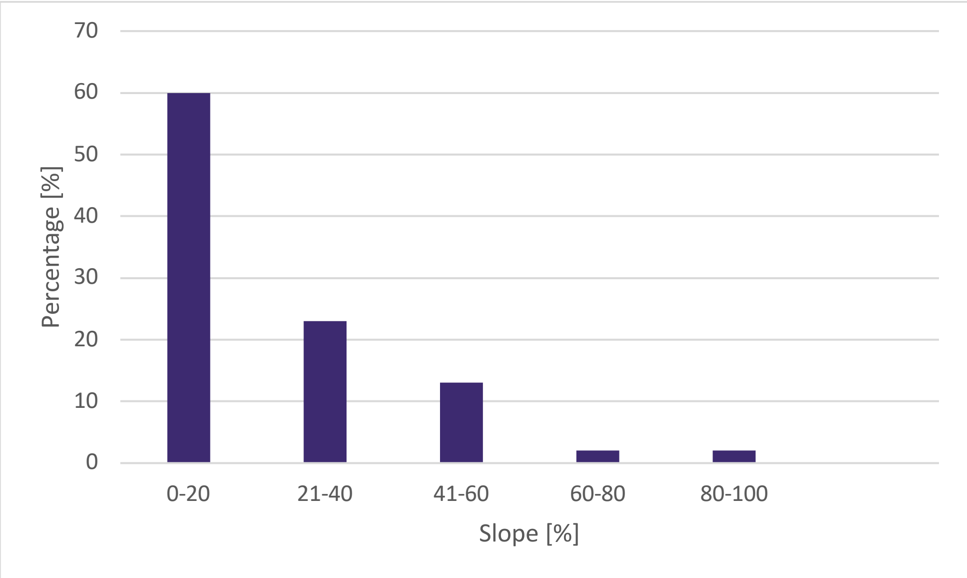

Figure 7. Distribution of sample plots in slope classes [n=56]

When it comes to exposure, the majority of the sampling plots are exposed to the south and west, with 40 percent exposed to the south and 36 percent to the west. Only 4 percent of the plots are exposed to the east, whereas 20 percent are exposed to the north (Figure 8).

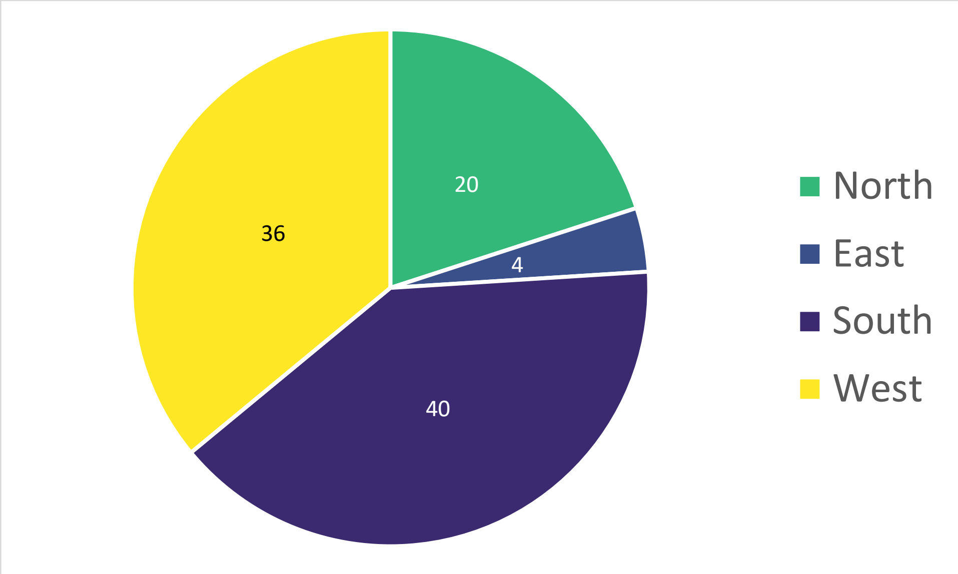

Figure 8. Distribution of sample plots in exposition classes [n=56]

The reserve's mesorelief is rather even and, for the most part, characterized by a moderate slope. Approximately a quarter of the plots have the features of some kind of depression, and only a small number of plots have the characteristics of an upper or steep slope (Figure 9).

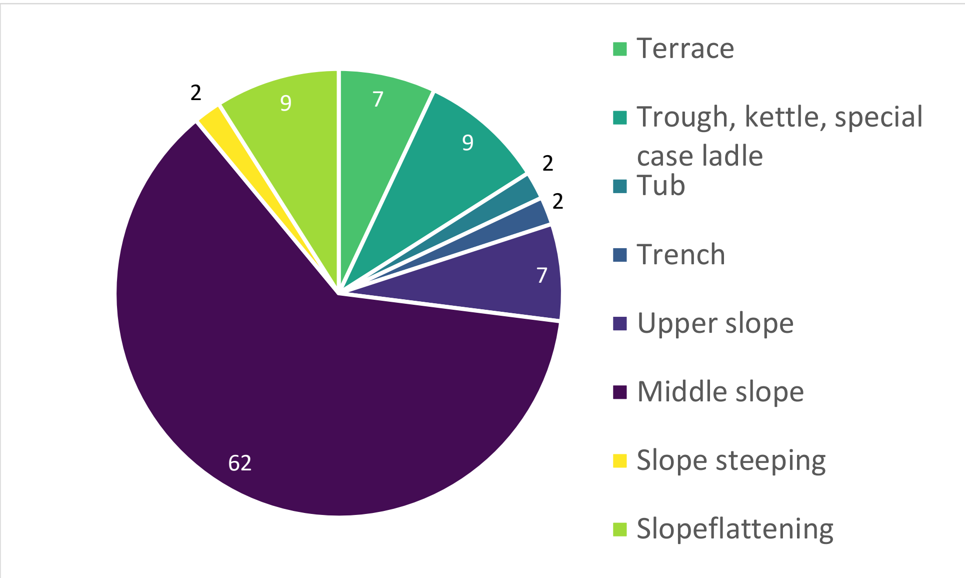

Figure 9. Percentage of sample points in mesorelief classes [n=56]

Figure 10 shows that the microrelief of the sample plots has a higher level of diversification, with a fairly equal distribution of plots between humps, depressions and flat terrain.

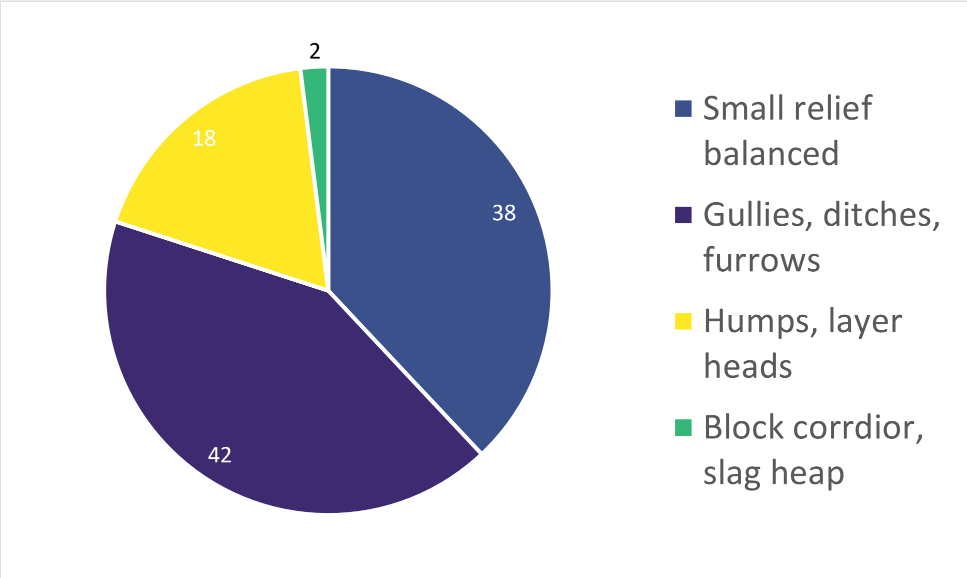

Figure 10. Distribution of sample plots per microrelief classes [n=56]

Table 8 shows a detailed description of general information on each of the sample plots of the investigation conducted in 2021. When it comes to certain site attributes such as humus form, geology and soil type there are no differences between the plots. For a detailed description of the codes used see Tables 17,18,19 and 20 in the annex.

Table 8. General information on site characteristics of sample plots of the investigation in 2021 in the NFR *Schiffwald*

Plot	Forest community	Humus form	Geology	Soil	Slope [%]	Exposition
16	3	240	41	180	2	North
17	4	240	41	180	25	North
18	4	240	41	180	35	South
19	4	240	41	180	60	South
20	4	240	41	180	5	South
21	3	240	41	180	0	South
22	4	240	41	180	20	North
23	4	240	41	180	20	South
24	4	240	41	180	30	South
25	4	240	41	180	0	North
26	4	240	41	180	25	South
27	3	240	41	180	2	East
28	4	240	41	180	0	South
29	4	240	41	180	50	South
30	4	240	41	180	20	South
31	4	240	41	180	20	South
32	4	240	41	180	60	South
34	4	240	41	180	25	South
35	4	240	41	180	30	South
36	4	240	41	180	42	South
37	4	240	41	180	18	West
38	4	240	41	180	13	West
40	4	240	41	180	5	South
42	4	240	41	180	0	South
44	4	240	41	180	5	North
54	4	240	41	180	20	West
56	4	240	41	180	5	West
64	4	240	41	180	10	North
101	4	240	41	180	20	West
102	4	240	41	180	30	West
103	3	240	41	180	30	West
104	3	240	41	180	25	West
105	3	240	41	180	100	West
106	3	240	41	180	0	North
107	3	240	41	180	50	East
108	3	240	41	180	25	West
109	3	240	41	180	15	West
110	3	240	41	180	15	West
111	3	240	41	180	10	West

112	3	240	41	180	5	South
113	3	240	41	180	10	West
114	3	240	41	130	20	West
115	3	240	41	180	45	North
116	3	240	41	180	80	West
117	3	240	41	180	0	West

3.1.2 Forest structure

Norway spruce (*Picea abies* (L.) Karst.), European larch (*Larix decidua* Mill.), European beech (*Fagus sylvatica* L.), and dwarf mountain pine (*Pinus mugo* Turra) are the predominant tree species (*Pinus mugo* Turra). Parts of the reserve are interspersed with sycamore maple (*Acer pseudoplatanus* L.), silver fir (Abies alba Mill.), silver birch (Betula pendula L.), and rowan (Sorbus aucuparia L.). Table 9 shows the means and standard deviations for stem number, basal area, and volume per hectare and in percentages based on the sampling in the fixed radius plots.

Table 9. Means and standard deviations of number of stems, basal area, and volume of the living trees in NFR Schiffwald in 2021 [n=45]

Species	Number		Basal area		Volume	
	n/ha	%	m^2/ha	%	m^3/ha	%
Spruce	324 ±183	87.43	25.41 ±10.10	84.89	240.71 ±104.93	84.49
Larch	36 ±38	9.78	4.23 ±4.18	14.13	42.53 ±45.91	14.93
Beech	1 ±0.00	0.39	0.16 ±0.00	0.53	0.92± 0.00	0.32
Sycamore	2 ±17	0.59	0.12 ±1.36	0.40	0.74 ±8.69	0.26
Dwarf pine	7 ±37	1.88	0.01 ±0.04	0.03	0.00 ±0.00	0.00
Σ	**371 ±279**	**100**	**29.93±15.17**	**100**	**284.90 ±155.03**	**100**

Based on the data in Table 9, it can be seen that the Norway spruce is the most common tree species in the reserve, followed by the larch, while dwarf pine, beech, and sycamore account for just a small percentage of the overall number of trees and volume (Figure 11). In the NFR *Schiffwald*, the average number of stems per hectare is 371±279. The large standard deviation indicates a high level of variability between the plots. The average basal area is 29.93±15.17 square meters, and the average volume is 284.90±155.03 cubic meters. A Kruskal-Wallis test was used to examine if there were any significant differences between the species in terms of stem number, basal area, and volume. Because the *p* values for all three parameters were less than 0.05, the null hypothesis is rejected and it may be concluded that there are significant differences between the species in terms of stem number, basal area and volume.

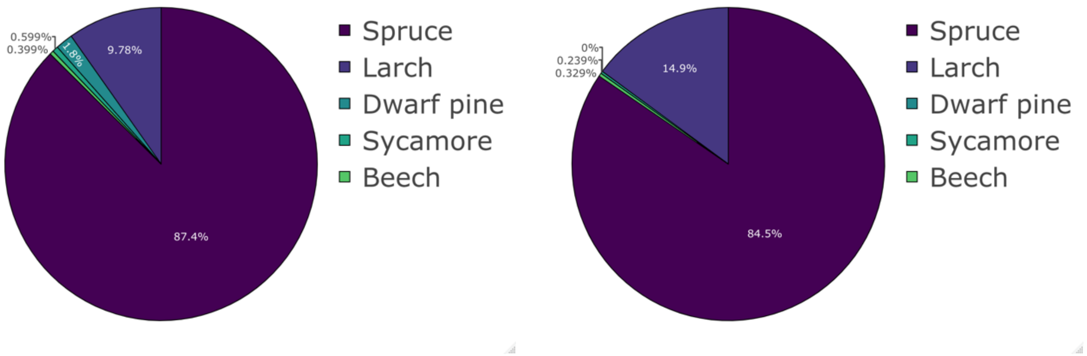

Figure 11. Species distribution of living trees (≥1.30 m height) by number (on the left) and volume (on the right) in NFR *Schiffwald* in 2021 [n=371 n/ha]

When it comes to the diameter distribution, it is evident that the 2.5 DBH class (0-5 cm) has the biggest percentage of trees (almost 20 percent), based on Figure 12. The distribution is very uniform between the 7.5 and 47.5 DBH classes, ranging between 5 and 10 percent. There are relatively few trees in the DBH classes above 50 cm, with less than 5 percent of frequency in each class.

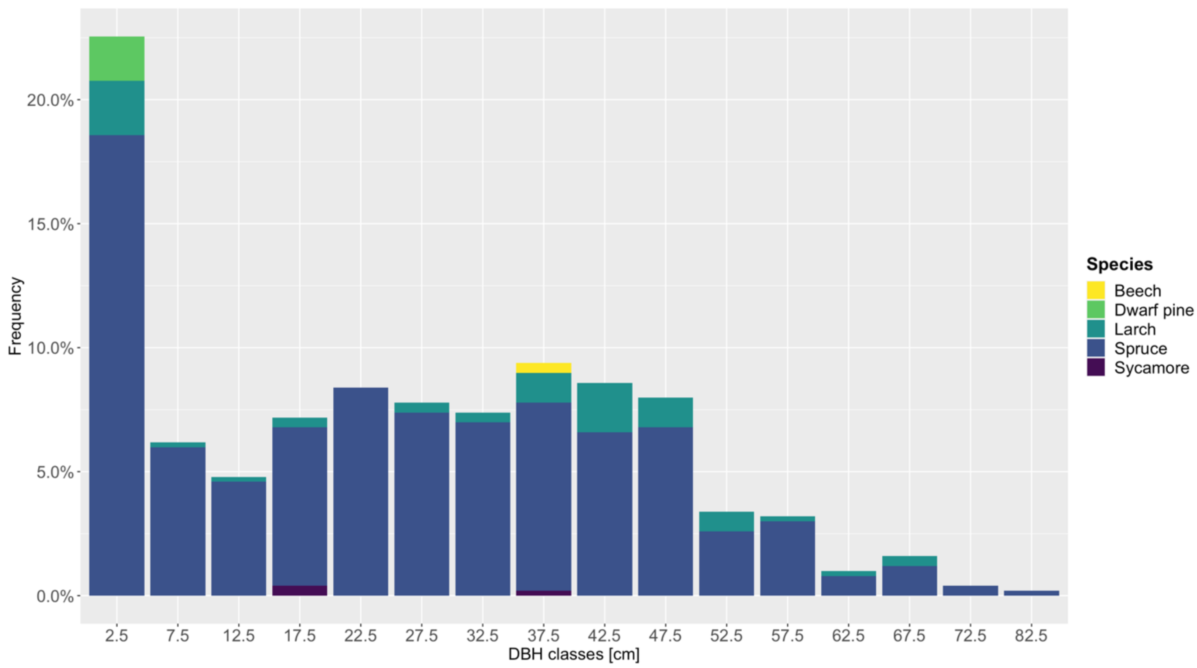

Figure 12. Frequency of living trees (≥1.30 m height) per DBH class and species in NFR *Schiffwald* in 2021 [n=371 n/ha]

The lowest and intermediate height classes have the most trees, with almost 25 percent in the lowest and 20 percent in the 22.5 cm class. As shown in Figure 13, roughly 30 percent of the trees are between 5 and 20 meters tall, while about 13 percent are between 27.5 and 30 meters tall. Only a few trees are taller than 30 meters.

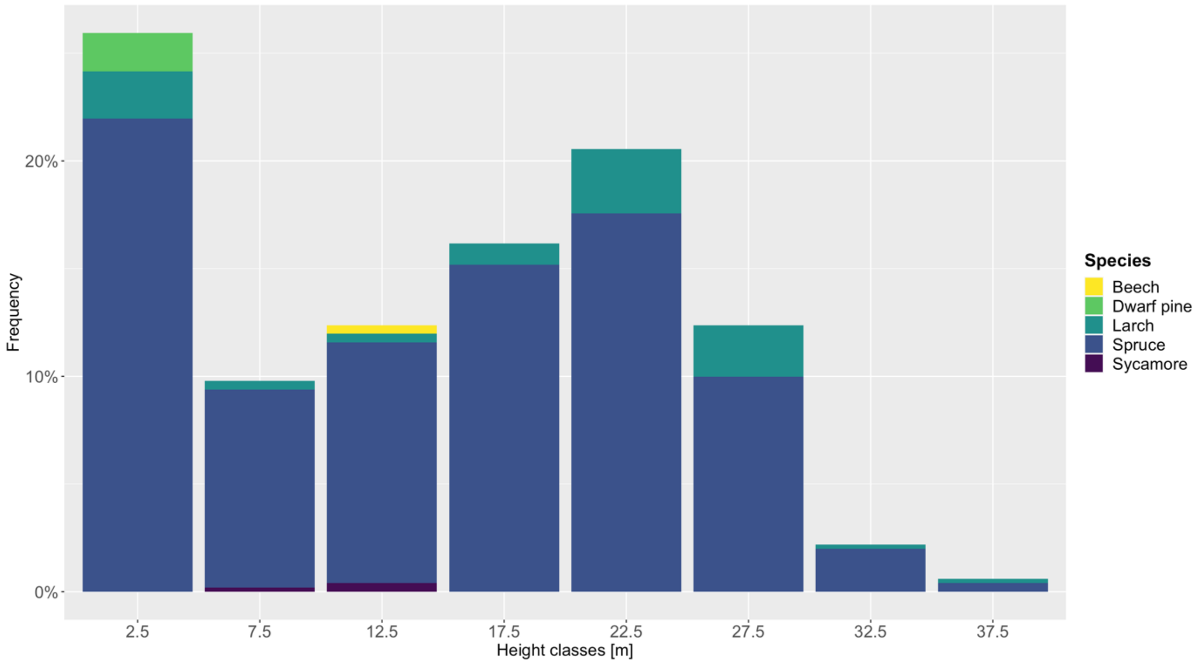

Figure 13. Frequency of living trees (≥1.30 m height) per height class and species in NFR *Schiffwald* in 2021 [n=371/ha]

The distribution of stand volume by DBH classes could be described as left-skewed, with a peek in the 47.5 cm DBH class. According to Figure 14, the majority of the volume is concentrated in the medium diameter classes.

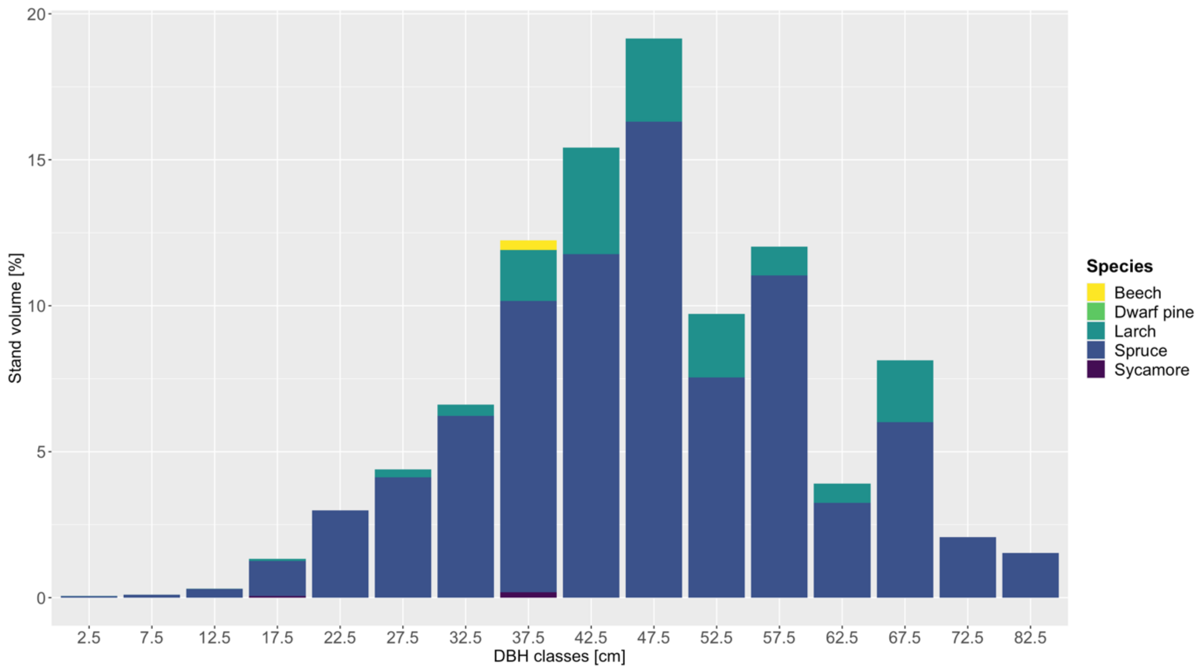

Figure 14. Volume distribution of living trees (≥1.30 m height) per DBH class and species in NFR *Schiffwald* in 2021 [n=371/ha]

The volume distribution by height classes is comparable to the DBH class distribution, but with greater volume concentrated in the middle classes. Figure 15 shows that the 22.5 and 27.5 height classes contain over 70 percent of the total volume.

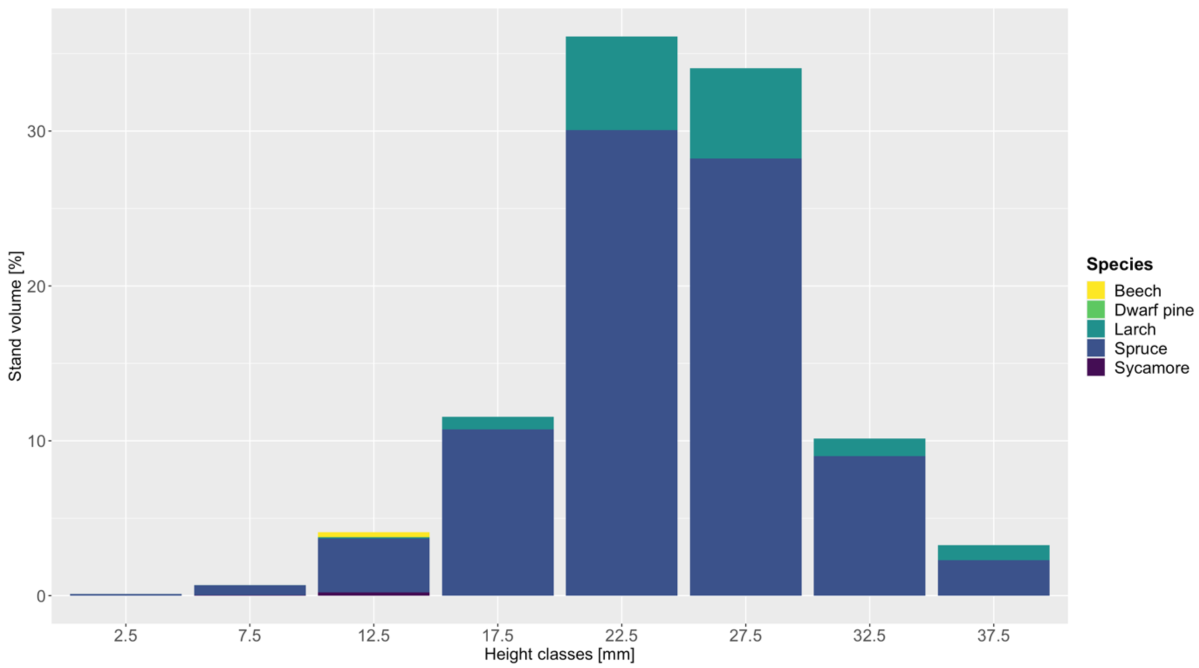

Figure 15. Volume distribution of living trees (≥1.30 m height) per height class and species in NFR *Schiffwald* in 2021 [n=371 n/ha]

94 percent of the individual trees have a crown percentage of over 50 percent and 81 percent have a height to diameter ratio of below 80 (Table 10).

Table 10. Crown percentage and height to diameter ratio per species for NFR *Schiffwald* in 2021 [n= 371 n/ha]

Species	Crown percentage				H/D ratio					
	<25%	25-49%	50-74%	>74%	<60	60-79	80-99	100-119	120-139	>139
Spruce	1	2	23	73	51	31	7	3	3	4
Larch	4	22	33	41	48	31	6	6	4	4
Sycamore	0	0	100	0	67	33	0	0	0	0
Beech	0	0	100	0	100	0	0	0	0	0
Dwarf pine	0	0	0	0	22	22	0	22	11	22
Σ	2	4	26	68	50	31	7	5	3	4

3.1.3 Natural regeneration

Results from Table 11 are based on data from 45 sample plots in the natural forest reserve *Schiffwald*, 28 sample plots cane be related to the forest community *Asplenio-Piceetum*, and 17 sample plots to the forest community *Adenostylo alliariae-Abietetum*. The regeneration category seedlings predominate in the *Piceetum*, whereas the below 15 cm class predominates in the *Abietetum*. In both forest communities the 30-129.9 cm category has a higher mean number of individuals per hectare than the 15-29.9 cm category, which is not present at all in the *Piceetum.*

Table 11. Mean numbers and standard deviation of natural regeneration per class and forest community for NFR *Schiffwald* in 2021

Forest community	Category	Mean number and standard deviation [n/ha]
Asplenio-Piceetum	Seedlings	357 ±1288
	<15 cm	246 ±654
	15-29.9 cm	0
	30-129.9 cm	275 ±306
Adenostylo alliariae-Abietetum	Seedlings	513 ±1121
	<15 cm	3346 ±5991
	15-29.9 cm	221 ±523
	30-129.9 cm	325 ±334
Schiffwald total	Seedlings	444 ±1517
	<15 cm	1583 ±4028
	15-29.9 cm	83 ±51
	30-129.9 cm	294 ±315

When it comes to the species distribution of natural regeneration, there are substantial differences across the various categories (Figure 16). For the <15 cm and 15-29.9 cm class, broadleaves are the most prevalent species with about 70 percent. *Acer pseudoplatanus* has a share of more than 50 percent in the <15 cm category and *Sorbus aucuparia* is the most common species in the 15-29.9 range, accounting for 50 percent of the total number of individuals. In the seedlings and 30-129.9 category, *Picea abies* is the dominant species with 87.5 percent and 78.8 percent, respectively.

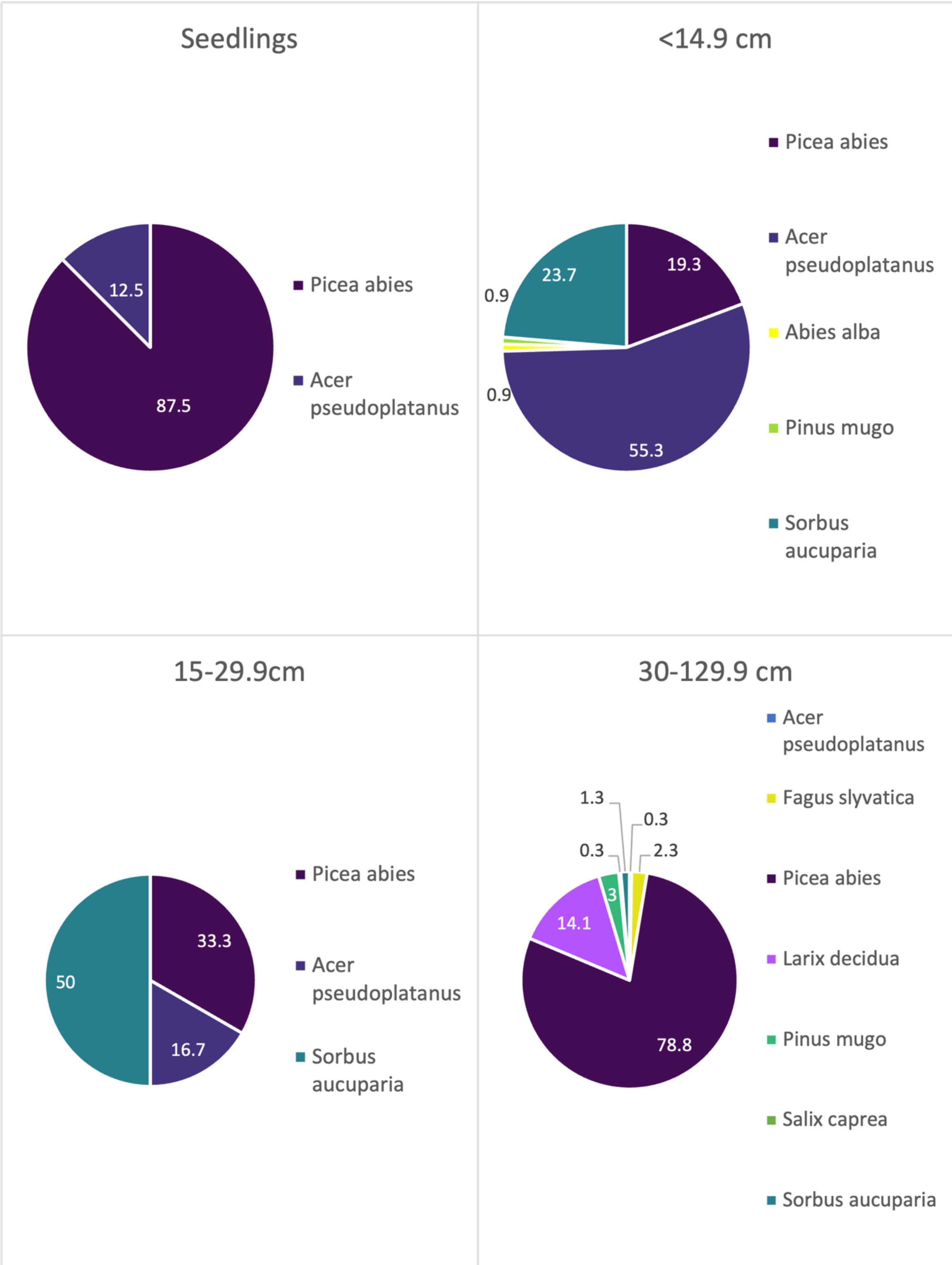

Figure 16. Species distribution of natural regeneration in percentage by number of individuals per class in NFR *Schiffwald* in 2021

The root collar diameter class <10 mm has the highest occurrence, at nearly 50 percent. With a higher root collar, the occurrence decreases (Figure 17). Height follows a similar trend, but with a more right-skewed distribution. The classes 40-50 cm and 50-60 cm have the highest occurrence. Increased height values are often represented by fewer individuals.

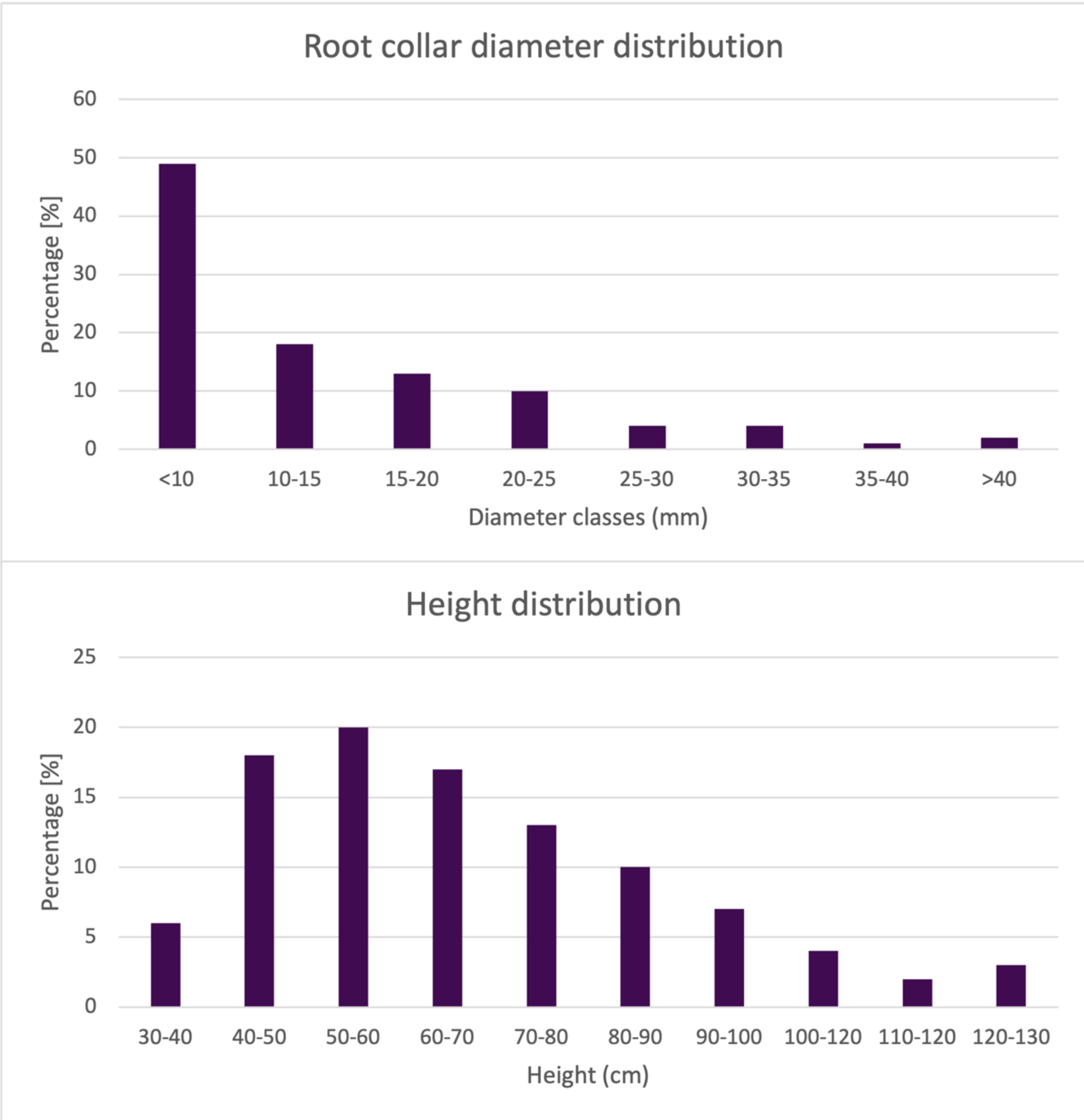

Figure 17. Root collar diameter and height distribution of the 30-129.9 cm regeneration class in percentage by number of trees for all tree species [n=294 n/ha]

With the exception of spruce, regeneration is relatively limited, as seen in Figure 18. Except for beech, which has individuals in the 30-129.9 cm class, broadleaf regeneration is mostly found in the middle classes. Across all conifer species, the 30-129.9 class has the highest number of individuals.

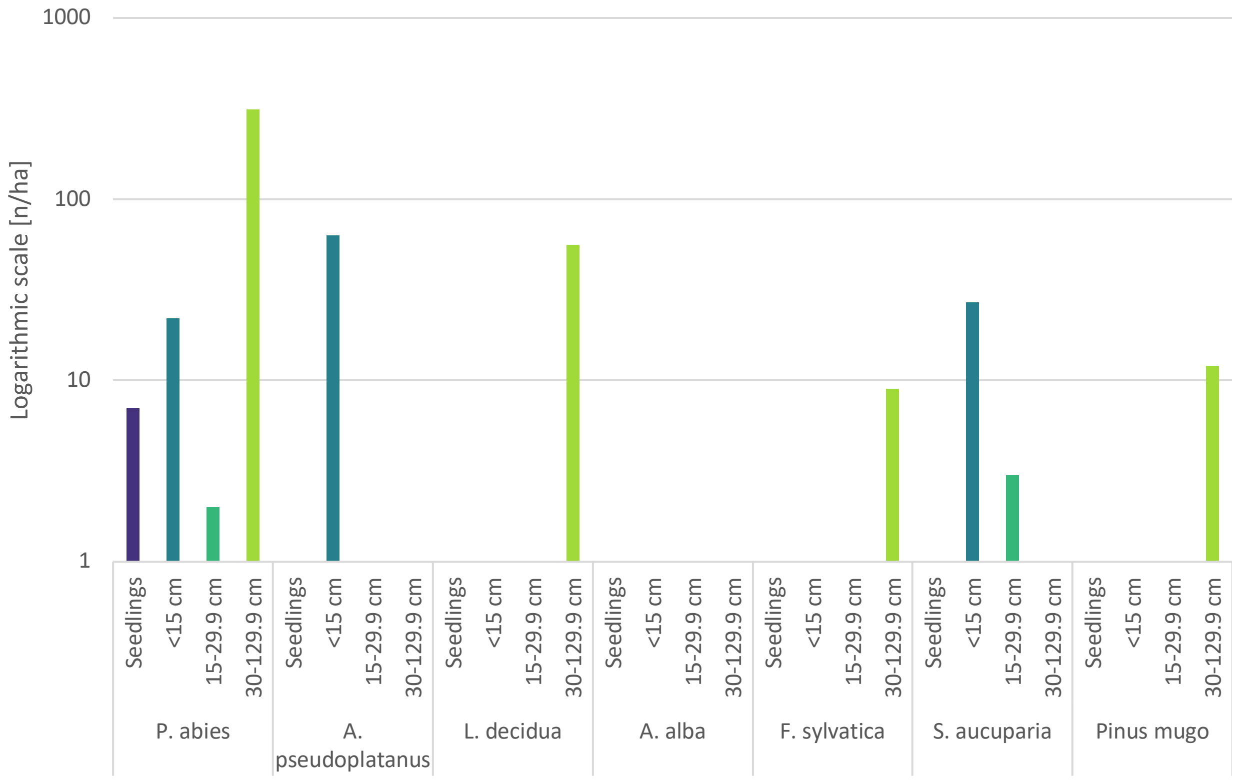

Figure 18. Species distribution by regeneration class in NFR *Schiffwald*

Except for *Pinus mugo*, where vitality class 1 is most common, and *Sorbus aucuparia*, where vitality class 3 prevails in the 15-29.9 cm class, vitality class 2 dominates across all species and regeneration classes (Figure 19).

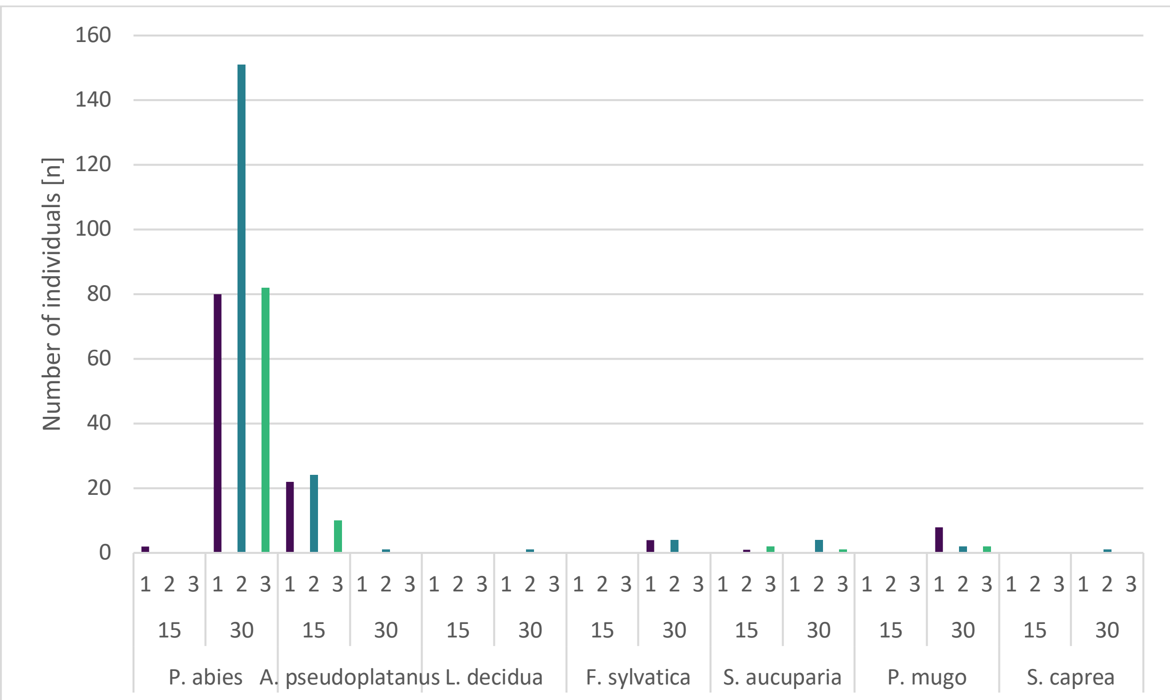

Figure 19. Vitality classes (1,2 & 3) per regeneration class (15 – 15-29.9 cm, 30 – 30-129.9 cm) and species in NFR *Schiffwald*

From the 397 individuals sampled in the 30-129.9 cm regeneration class 42.3 percent or 167 individuals are damaged by browsing. As seen in Figure 20, conifers are dominating with over 90 percent of the total damaged individuals, whereas *S. aucuparia* and *F. sylvatica* represent only less than 10 percent.

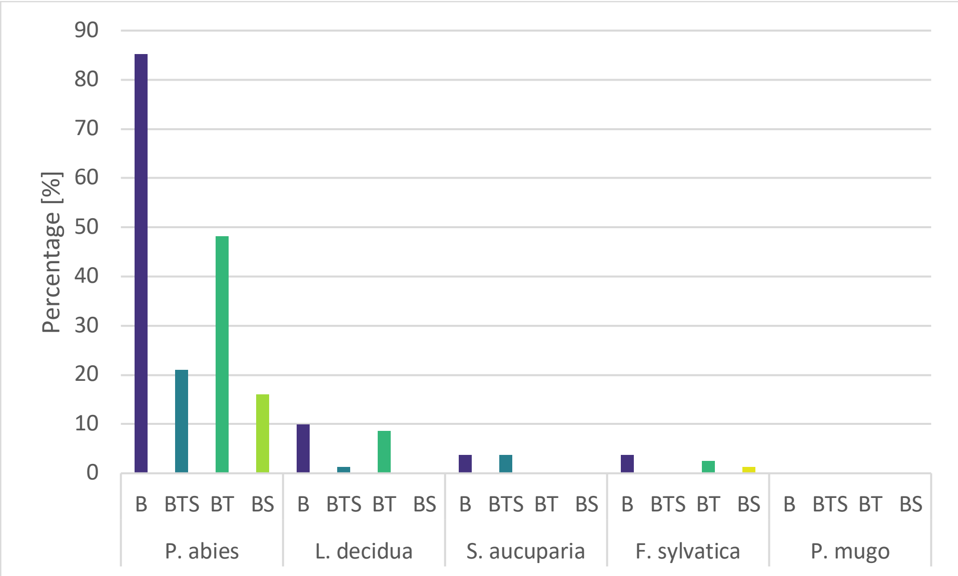

Figure 20. Percentages of damaged individuals by browsing per species in NFR *Schiffwald* (B-total browsed, BT-browsed from top, BS-browsed from side, BTS-browsed from top and side)

3.1.4 Deadwood

Due to natural disturbance events in the recent past there is a high amount of deadwood present in the NFR *Schiffwald* with 71.62±82.67 m^3/ha, which corresponds to about 25 percent of the total stand volume. Standing deadwood is the most abundant, accounting for 57.45±71.35m^3/ha, while lying deadwood accounts for 14.17±24.04m^3/ha. The average number of individuals per hectare for standing deadwood, lying deadwood and sticks, respectively, is 85±91, 42±47 and 1±5 (Table 12).

Table 12. Mean numbers and standard deviations for number of individuals and volumes for standing-, lying deadwood and sticks in NFR *Schiffwald*

Forest type	Standing deadwood		Lying deadwood		Sticks	
	Number [n/ha]	Volume [m^3/ha]	Number [n/ha]	Volume [m^3/ha]	Number [n/ha]	Volume [m^3/ha]
Asplenio-Piceetum	92 ±93	67.06 ±72.52	35 ±42	15.94 ±29.26	1 ±6	0.00 ±0.00
Adenostylo alliariae-Abietetum	74 ±87	41.65 ±65.64	55 ±46	11.25 ±10.31	0	0.00
Schiffwald total	85 ±91	57.45 ±71.35	42 ±47	14.17 ±24.04	1 ±5	0.00 ±0.00

Figure 21 depicts the species distribution of standing and lying deadwood by number of individuals and volume in the NFR *Schiffwald*. Only two species are found in both categories of deadwood: Norway spruce and larch. In both lying and standing deadwood Norway spruce dominates. It accounts for over 90 percent of standing deadwood and around 95 percent of lying deadwood.

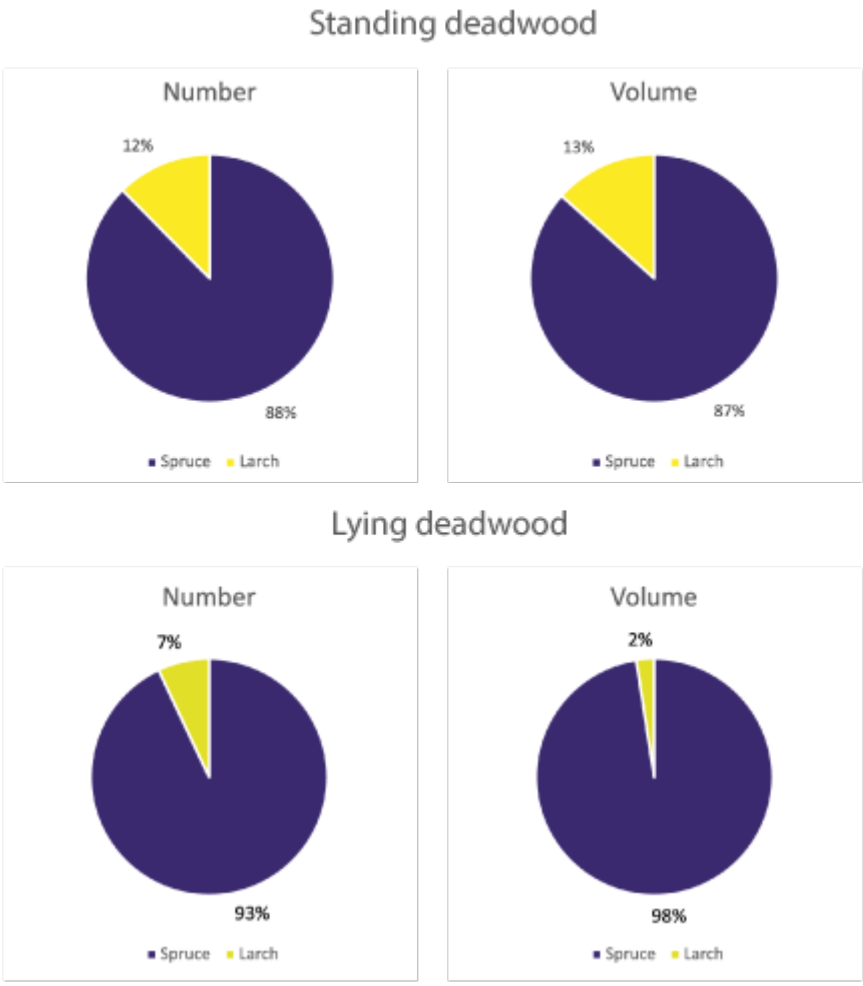

Figure 21. Species distribution of standing and lying deadwood per number of individuals and volume in NFR *Schiffwald*

The distribution of standing and lying deadwood by decomposition type can be seen in Figure 22. When it comes to standing deadwood more than 40 percent of the individuals are trees with a relatively intact crown and more than 55 percent are trees without a crown, or stems. The situation for lying deadwood appears to be different; the majority of individuals, more than 65 percent, belong to classes 7 and 8, which represent a tree part, i.e. trees that have already significantly decomposed. Trees with a relatively undamaged crown account for slightly under 19 percent of lying deadwood, whereas stems make up roughly 12 percent.

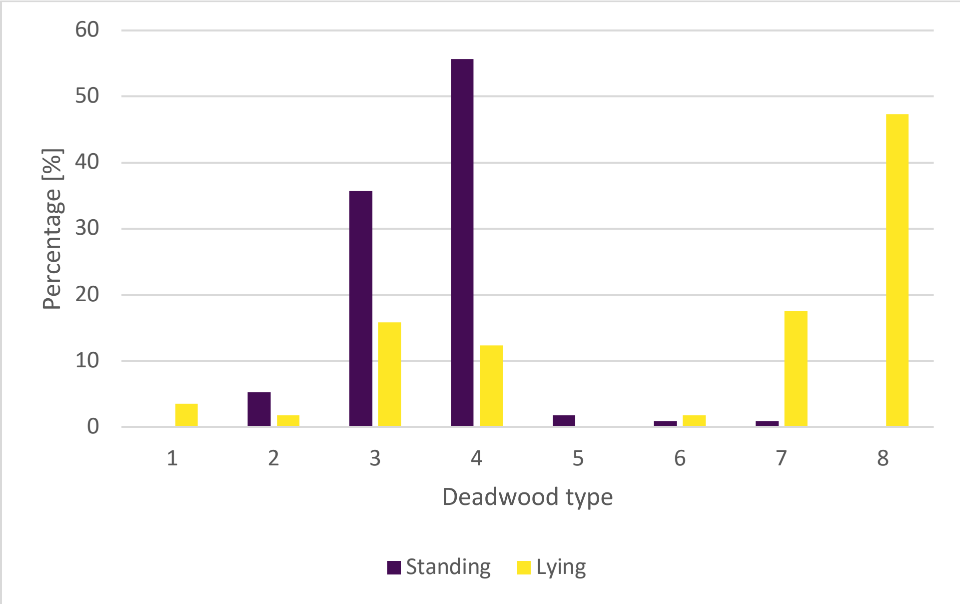

Figure 22. Distribution of standing and lying deadwood per deadwood type [n = 127 n/ha|

When it comes to the decomposition stage, freshly dead trees make up a comparable percentage of both categories, at around 5 percent (Figure 23). Trees that have begun to decompose make for more than 77 percent of the standing deadwood category, while trees that are in an advanced stage of decomposition account for roughly 16 percent. The advanced decomposition stage accounts for more than half of the lying deadwood, heavily decomposed lying deadwood accounts for nearly a quarter of all the lying deadwood, and the starting decomposition stage accounts for about a quarter as well.

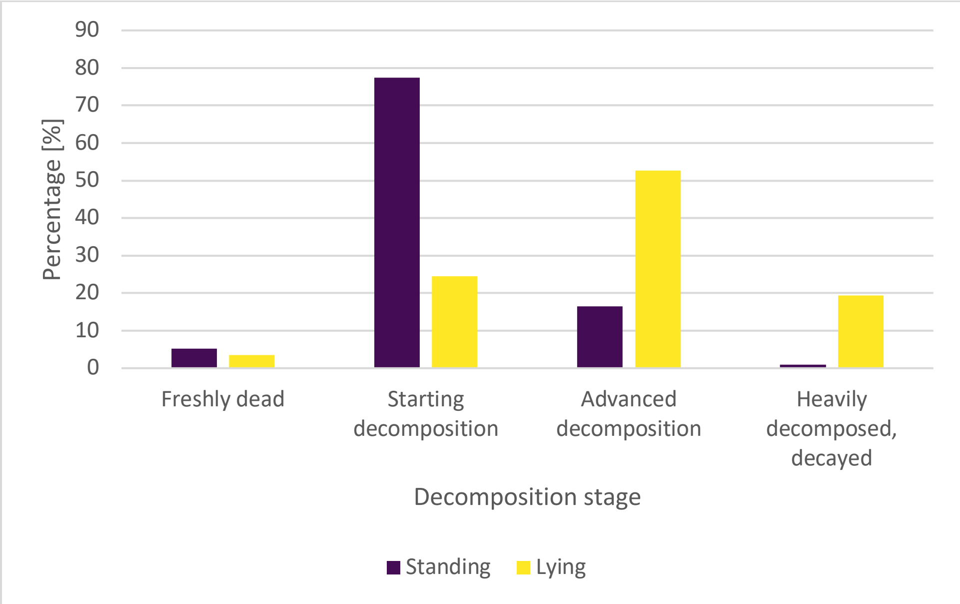

Figure 23. Distribution of standing and lying deadwood per decomposition stage [n = 127 n/ha|

For both deadwood groups, the debarking intensity follows a similar increasing trend: with a higher number of individuals in the higher debarking categories (Figure 24). This increase is more noticeable in the lying deadwood category, where number of individuals with 0-25 percent bark are outnumbering dominating with more than 60 percent. When it comes to standing deadwood, the distribution is a little more even, although individuals with 0-50 percent bark account for over 70 percent of the total number of standing deadwood individuals.

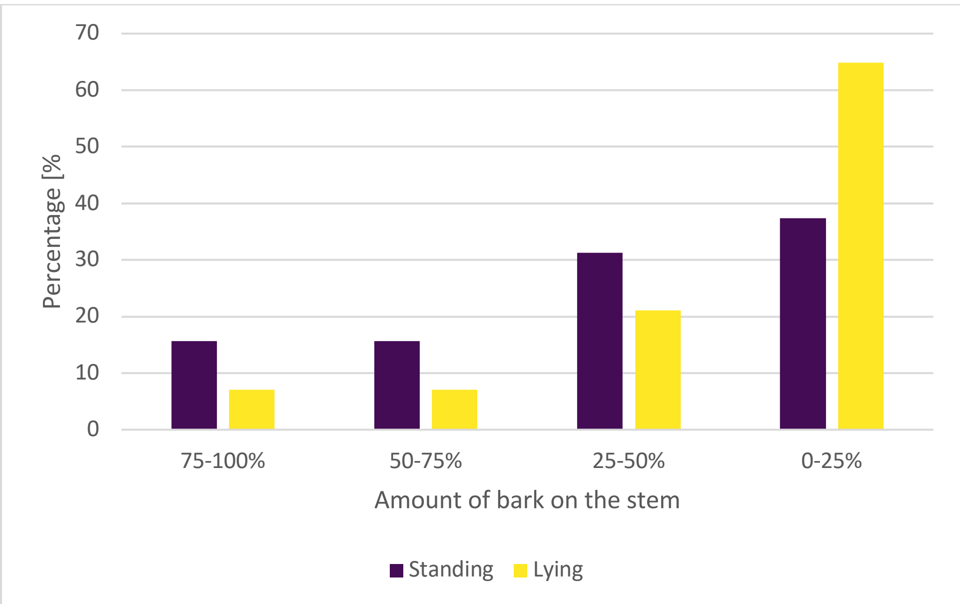

Figure 24. Distribution of standing and lying deadwood per debarking intensity [n = 127 n/ha|

As shown in Figure 25, bark beetles are the leading cause of mortality in the standing deadwood category, accounting for more than 75 percent of all deaths. The remaining standing deadwood individuals died through competition (16 percent) or an unknown cause. Windthrows account for about 12 percent of lying deadwood individuals, while snow breaks account for less than 5 percent and competition for 7 percent. The cause of death for the vast majority of the lying deadwood individuals (almost 55 percent) could not be determined.

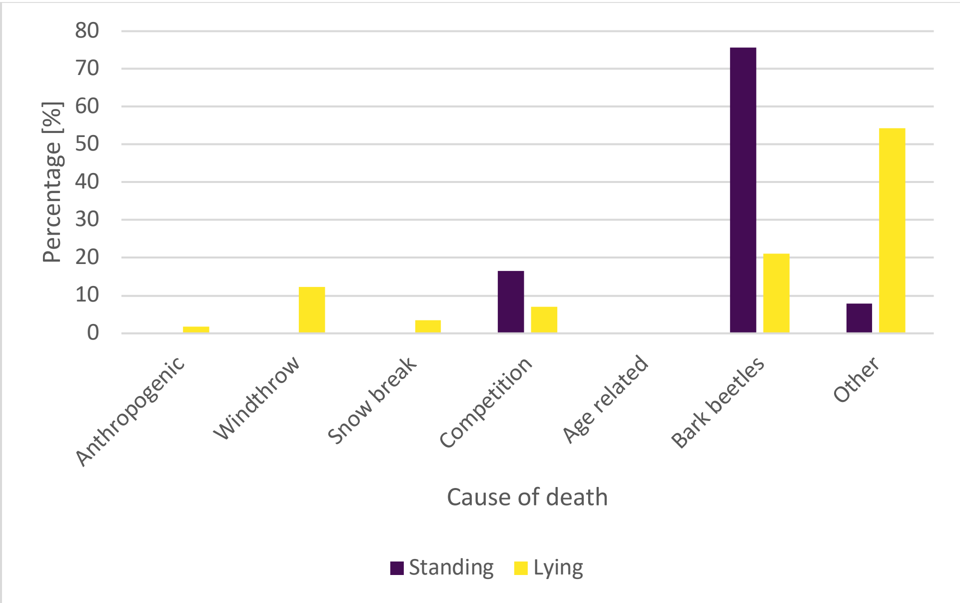

Figure 25. Distribution of standing and lying deadwood by cause of death [n = 127 n/ha|

The majority of trees in both groups died between 10 and 14 years ago, with this category accounting for more than half of the deadwood in both categories. Trees that died recently (within the last 9 years) account for over 30 percent of the standing deadwood, whereas about 15 percent of the standing deadwood died more than 15 years ago. A small percentage of the individuals in the lying deadwood category, roughly 7 percent, died fewer than 10 years ago, while more than 40 percent died between 15 and 24 years ago (Figure 26).

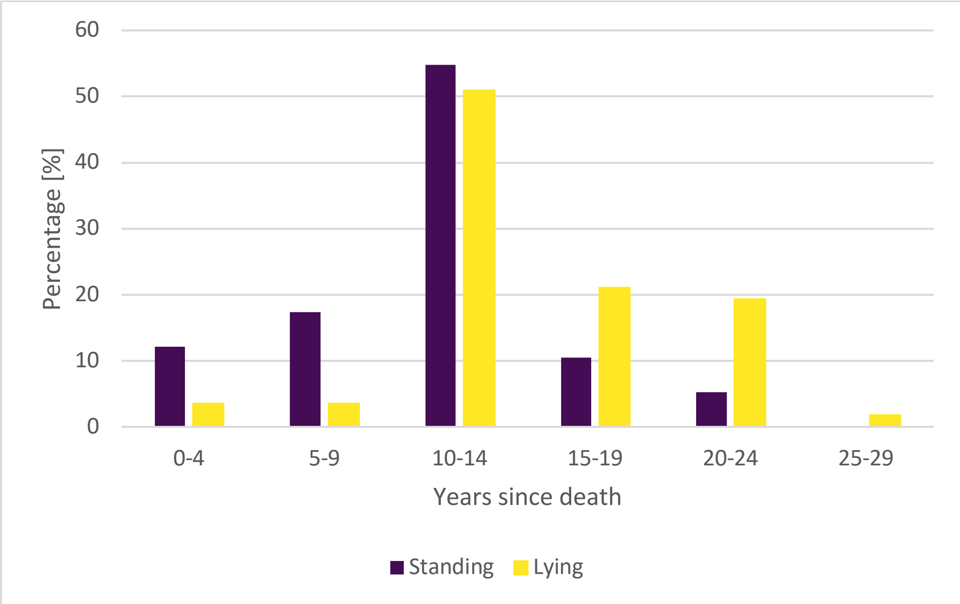

Figure 26. Distribution of standing and lying deadwood per time of death [n = 127 n/ha|

As seen in Table 13 the share of deadwood in the total stand volume is quite significant with 25 percent. The most prevalent category is standing deadwood with 80 percent, followed by lying deadwood with 20 percent, whereas sticks account for less than 1 percent of the total deadwood volume. Spruce and larch are the only species present in the deadwood categories, spruce with 26 percent and larch with 18 percent of the total stand volume of the respective species.

Table 13. Mean numbers and standard deviations from deadwood volumes and living trees and the percentage distribution of the individual deadwood categories and the share of deadwood in the total stand volume

Species	Standing deadwood	Lying deadwood	Sticks	SUM deadwood	Stand volume	Share of deadwood in total stand volume
	m^3/ha	m^3/ha	m^3/ha	m^3/ha	m^3/ha	%
	%	%	%	%		
Spruce	49.98 ±56.62	13.87 ±20.99	0.00 ±0.00	63.85 ±64.14	240.71 ±104.93	26
	78	22	0	100		
Larch	7.47 ±25.31	0.28 ±0.28	0.00 ±0.00	7.75 ±9.60	42.53 ±45.91	18
	97	3	0	100		
Sycamore	-	-	-	-	0.92 ±0.00	-
	-	-	-	-		
Beech	-	-	-	-	0.74 ±8.69	-
	-	-	-	-		
Schiffwald total	57.45 ±71.35	14.17 ±24.04	0.00 ±0.00	71.62 ±82.67	284.90 ±155.03	25
	80	20	0			

Figure 27 shows that the biggest percentages of lying deadwood below 10 cm are seen in the 1-3 percent and 4-10 percent categories. In 20 percent of the plots, there was little or no deadwood, while in the 11-50 percent category, it was less than 3 percent.

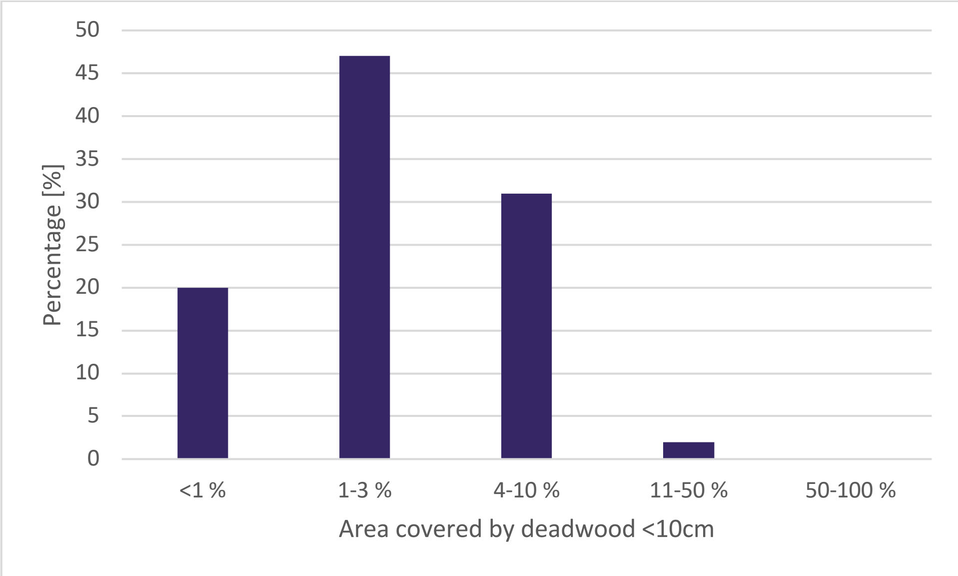

Figure 27. Distribution of <10 cm deadwood ground cover classes in percentage [n = 45 sample plots]

3.2 Description of the forest dynamics of the NFR *Schiffwald*

A comparison with data acquired for the ELENA project in 2009 is made to analyze the forest dynamics of the NFR *Schiffwald*. To ensure a consistent comparison, only data from the same plots that were resampled in 2021 were used. The purpose of the comparison is to assess the forest dynamics in the NFR *Schiffwald* in regard to stand volume, natural regeneration and deadwood.

3.2.1 Forest structure

Table 14 shows that the average number of trees per hectare decreased from 460±253 to 371±279 trees per hectare, a difference of 89 trees or nearly 19 percent. The average number of spruce trees per hectare increased by around 4 percent, whereas the number of larch trees per hectare declined by about 5 percent.

The same pattern can be seen in the basal area as well, but it is less noticeable. Overall, the average basal area declined by over 11 percent, from 33.7 m^2/ha to 29.93 m^2/ha. The average basal area of spruce has increased by 2 percent, whereas the average basal area of larch has decreased by 2 percent.

The same pattern is seen when it comes to volume, but the disparities are less significant. From 301.71±156.63 to 284.90±155.03, the average volume dropped by nearly 5 percent. The average volume of broadleaf species increased slightly. Larch had a 4 percent reduction; while spruce saw a 3 percent gain in volume. A Kruskal-Wallis test was conducted to check if there are any statistically significant differences between the total volumes from 2009 and 2021. With a *p* value higher than 0.05 the null hypothesis cannot be rejected and no statistically significant difference is assumed between the total volumes from 2009 and 2021.

Table 14. Mean values and standard deviations and differences for number of trees, basal area and volume in 2009 and 2021 in the NFR *Schiffwald*

Year	Species	Number		Basal area		Volume	
		n/ha	%	m^2/ha	%	m^3/ha	%
2009	Spruce	382 ±151	83.04	27.94 ±9.92	82.91	245.68 ±100.42	81.43
	Larch	67 ±153	14.56	5.49 ±4.89	16.29	54.73 ±52.00	18.14
	Beech	1 ±0	0.22	0.13 ±0.00	0.38	0.63 ±0.00	0.21
	Sycamore	2 ±17	0.43	0.13 ±1.24	0.38	0.64 ±10.38	0.21
	Dwarf pine	7 ±27	1.52	0.01 ±0.00	0.02	0.00 ±0.00	0
	Fir	1 ±0	0.22	0.01 ±0.00	0.02	0.03 ±0.00	0.01
	Sum	**460 ±253**	**100**	**33.70 ±15.60**	**100**	**301.71 ±156.63**	**100**
2021	Spruce	324 ±183	87.34	25.41 ±10.10	84.89	240.71 ±104.93	84.49
	Larch	36 ±38	9.71	4.23 ±4.18	14.13	42.53 ±45.91	14.93
	Beech	1 ±0	0.27	0.16 ±0.00	0.53	0.92 ±0.00	0.32
	Sycamore	2 ±17	0.53	0.12 ±1.36	0.4	0.74 ±8.69	0.26
	Dwarf pine	7 ±37	1.88	0.01 ±0.04	0.03	0.00 ±0.00	0
	Sum	**371 ±279**	**100**	**29.93 ±15.17**	**100**	**284.90 ±155.03**	**100**
Difference		**-89 n/ha**		**-3.77 m^2/ha**		**-16.81 m^3/ha**	

The diameter distribution from 2009 to 2021 is depicted in Figure 28. The number of trees per hectare decreased in most of the diameter classes. Except for classes 22.5 and 27.5, where there was a 5 to 10 percent decline, the decrease of number of trees per hectare was between 20 and 30 percent, while class 47.5 saw no change in the average number of trees per hectare. Classes 57.5, 67.5, and 82.5 show a small increase in 2021 compared to 2009.

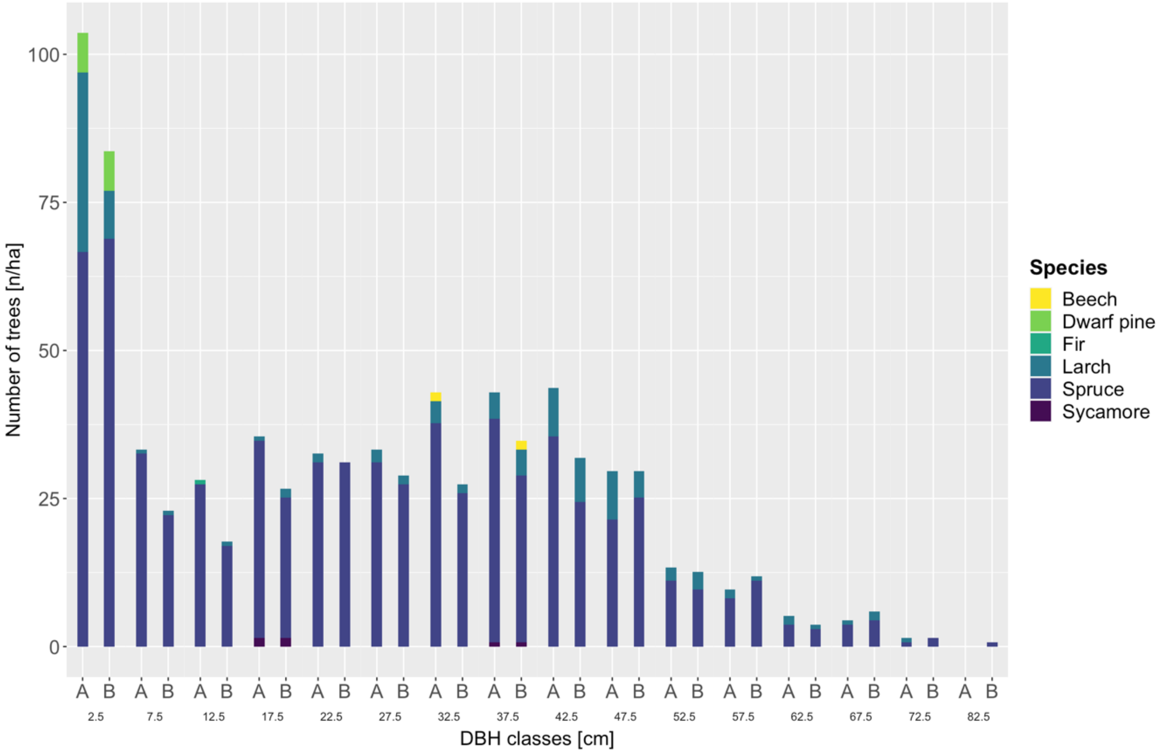

Figure 28. Diameter distribution by number of trees for the years 2009 (A) and 2021 (B) in the NFR *Schiffwald*

A similar trend may be seen in the height distribution, just as it can be seen in the diameter distribution (Figure 29). The number of trees per hectare has decreased in the low to medium height classes while increasing in the higher height classes. The number of trees in the 2.5, 7.5, 12.5, 17.5, and 22.5 height classes decreased by 20-25 percent, but there was a minor increase in the three remaining classes, 27.5, 32.5, and 37.5.

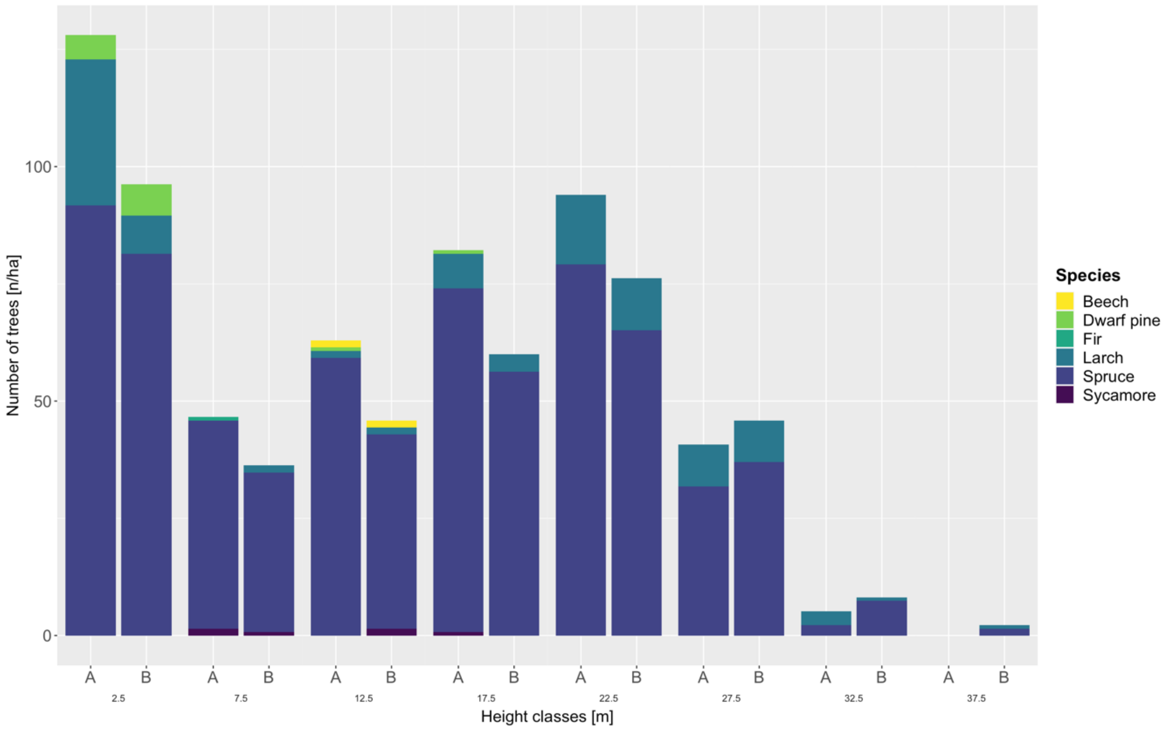

Figure 29. Height distribution by number of trees for the years 2009 (A) and 2021 (B) in the NFR Sch*iffwald*

3.2.2 Natural regeneration

Table 15 shows the mean numbers and standard deviations for the different regeneration categories for the years 2009 and 2021, as well as the differences between those numbers. In both years, the distribution of the various categories is the same, with the highest numbers in the <15 cm category, followed by seedlings, 30-129.9 cm, and 15-29.9 cm. In comparison to 2009, the number of individuals per hectare decreased in all four categories in 2021. The most significant decrease was in the seedlings category, where the number of individuals per hectare is around a fifth of what it was in 2009. The smallest difference can be seen in the 15-29.9 cm group, where the number of individuals in 2021 is around half that of 2009.

Table 15. mean numbers and standard deviations for number of individuals per hectare for different regeneration categories for 2009 and 2021

Category	Number [n/ha]		Difference [n/ha]
	2009	2021	
Seedlings	2611 ±4623	444 ±1517	-2167
<15 cm	5944 ±9394	1583 ±4028	-4361
15-29.9 cm	159 ±615	83 ±51	-76
30-129.9 cm	532 ±813	294 ±315	-238

Figure 30 depicts the species distribution over the several regeneration categories and for the different years. The proportion of spruce has increased in the seedlings category, with the species accounting for over 90 percent of total seedlings in 2021, whereas the amount of sycamore has decreased by about two-thirds. A similar trend is seen, but not as prominent, in the <15 cm category, where sycamore remains the major tree species, spruce increased from around 10 percent to 20 percent, and the numbers of rowan remained largely unchanged. The number of spruce individuals reduced by nearly 50 percent in the 15-29.9 cm category, however the number of broadleaves grew, which is especially noticeable for rowan, which increased by around 50 percent. In the 30-129.9 cm category, the species distribution remained rather unchanged; spruce is clearly the most prominent species, accounting for nearly 80 percent of the total, followed by larch with less than 15 percent in both years.

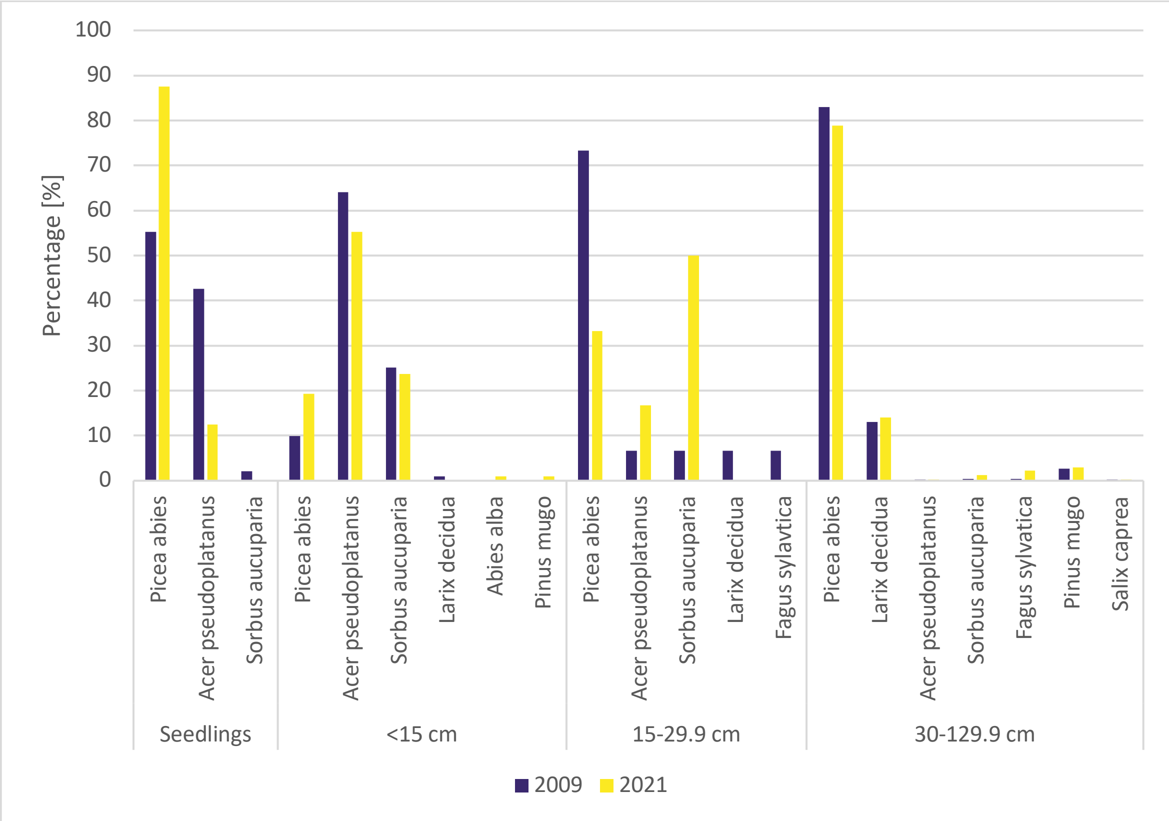

Figure 30. Species distribution for different regeneration categories for 2009 and 2021

3.2.3 Deadwood

As shown in Table 16, the total amount of deadwood has increased from 56.94 m^3/ha in 2009 to 71,62 m^3/ha in 2021, which corresponds to an increase of 14.68 m^3/ha or about 25 percent. Table 15 shows the mean numbers of individuals per hectare as well as the volume for the three different deadwood categories. For the standing deadwood category there was an increase of more than 10 percent but the increase for the lying deadwood was more prominent with about 40 percent. Also, the number for the sticks has increased but it was still negligible.

Table 16. Mean values, standard deviations, and differences for number of individuals and volumes per different regeneration categories for 2009 and 2021

Category		2009	2021	Difference
Standing deadwood	**Number [n/ha]**	64 ±68	85 ±91	21
	Volume [m^3/ha]	46.77 ±77.30	57.45 ±71.35	10.68
Lying deadwood	**Number [n/ha]**	21 ±32	42 ±47	21
	Volume [m^3/ha]	10.17 ±19.98	14.17 ±24.04	4.00
Sticks	**Number [n/ha]**	0 ±0	1 ±5	1
	Volume [m^3/ha]	0 ±0	0.00 ±0.00	0

Figure 31 illustrates the changes in the deadwood decomposition categories from 2009 to 2021. In both years the distribution shows a similar trend, the most dominant category is the starting decomposition one, followed by advanced decomposition, decayed and freshly dead trees. The percentage of the starting decomposition deadwoods has increased from 36 to 60 percent, whereas the percentages of the advanced decomposition and decayed have decreased from 36 to 28 percent and from 17 to 7 percent, respectively. The freshly dead trees remained the same at 5 percent.

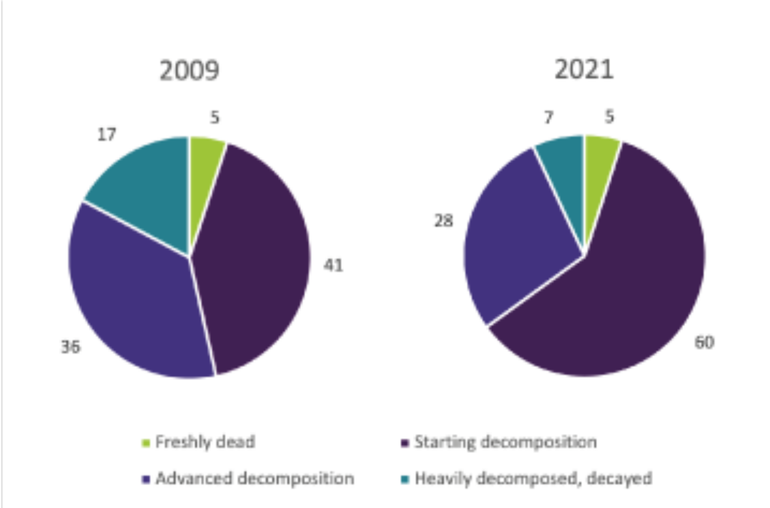

Figure 31. Distribution of deadwood (standing and lying) decomposition categories for 2009 and 2021 in percentage

With over 70 percent in 2009, the class with little or no deadwood cover was dominating. The 1-3 percent category dominated in 2021 with almost 50 percent, with the 4-10 percent category accounting for more than 30 percent.

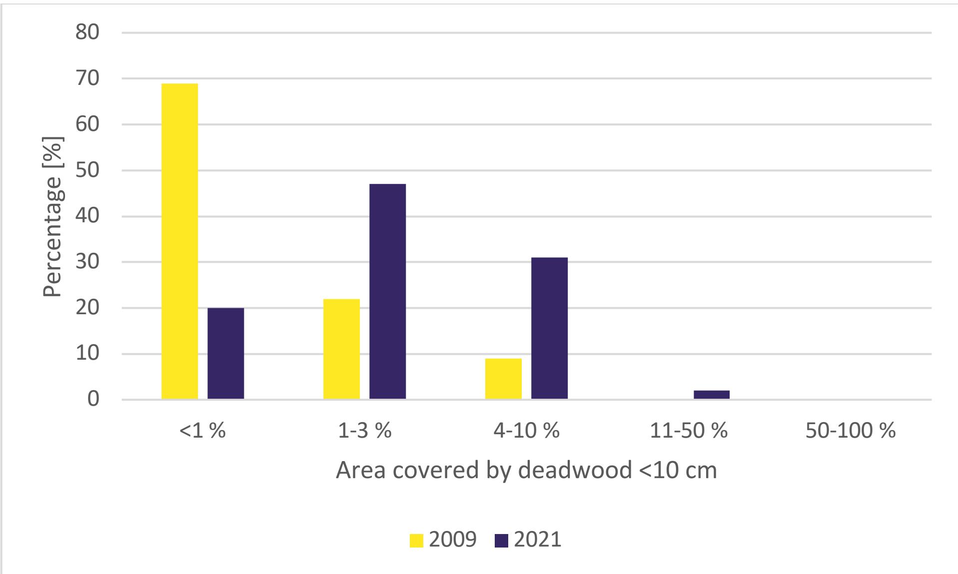

Figure 32. Distribution of <10 cm deadwood classes in percentage in 2009 and 2021

The highest number of individuals in both years are concentrated in the low to mid and mid to high diameter classes. In 2009 the highest number of standing deadwood was in the 17.5 class while in 2021 it was in the 17.5 and 32.5 diameter class. In the vast majority of diameter classes there has been an increase in the number of individuals in 2021 (Figure 33).

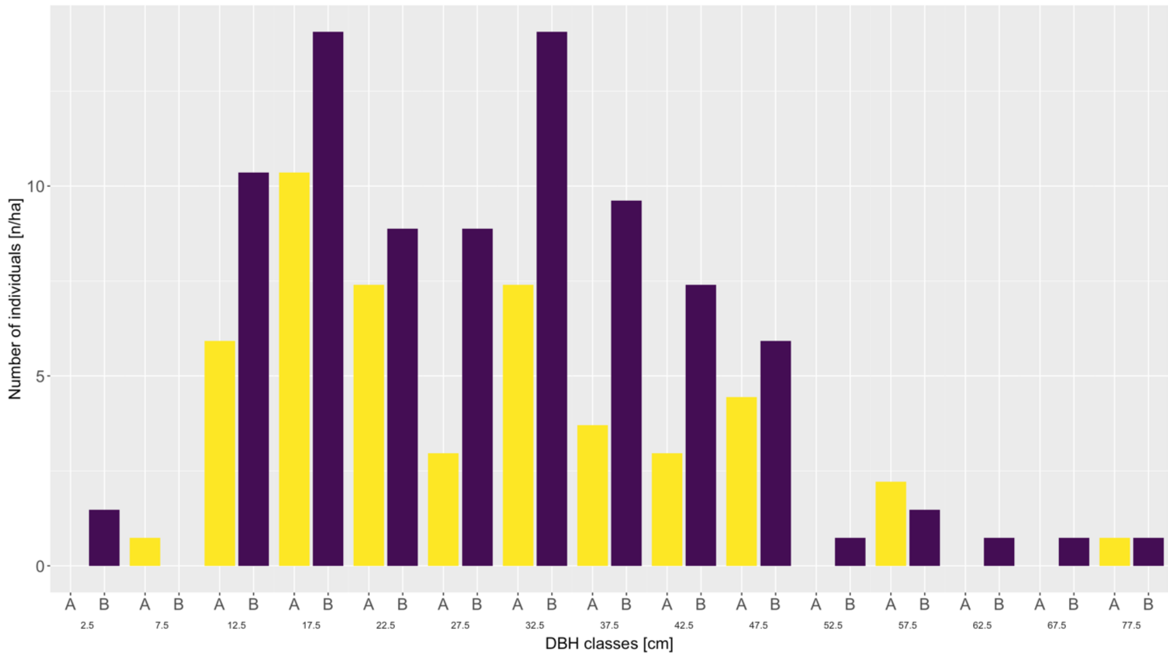

Figure 33. Distribution of standing deadwood per diameter class in 2009 (A) and 2021 (B) in NFR *Schiffwald*

In Figure 34 the distribution of lying deadwood per diameter class can be seen. The highest number of individuals in 2009 was present in the lowest, 12.5 diameter class, whereas in 2021 the 22.5 cm class had the highest number of individuals.

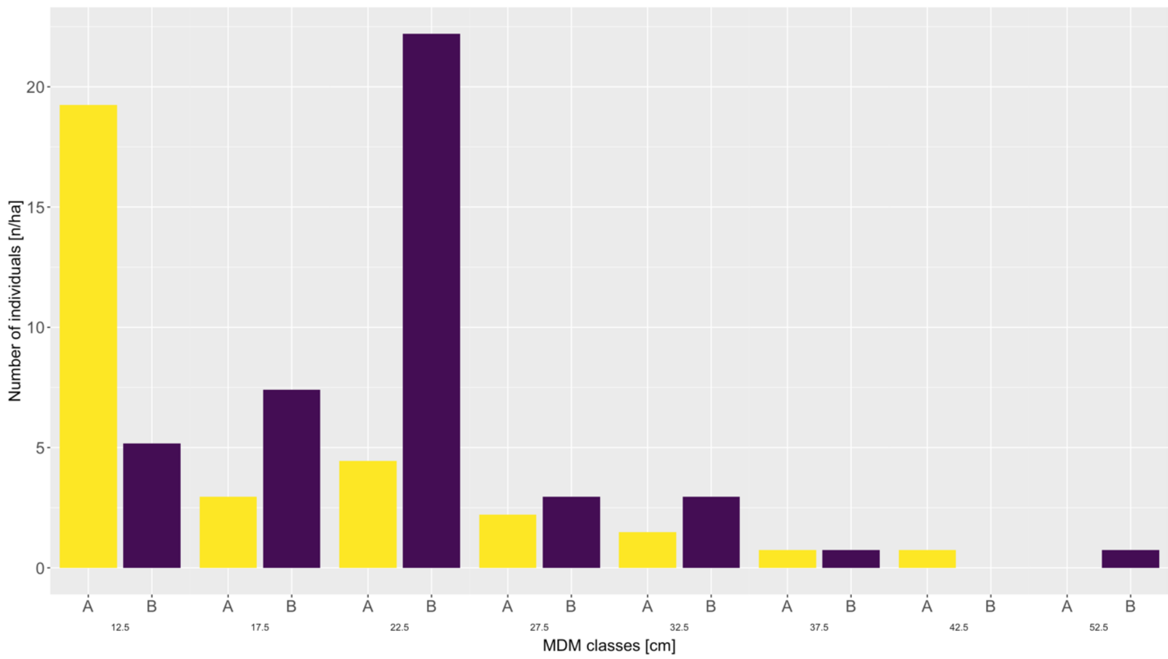

Figure 34. Distribution of lying deadwood per diameter class in 2009 (A) and 2021 (B) in NFR *Schiffwald*

To see if there were any significant differences between the total standing and lying deadwood volumes in 2009 and 2021, a Kruskal-Wallis test was performed. The null hypothesis cannot be rejected for standing deadwood with a p value greater than 0.05, and it is concluded that there are no significant differences, however for lying deadwood with a p value less than 0.05, it can be concluded that there are significant differences between 2009 and 2021.

4. Discussion

Forest dynamics of Norway spruce forests have been studied extensively across the European continent in recent years. The studies covered forests in Fennoscandia (Kuuluvainen & Aakala 2011), Romania (Holeksa et al. 2017, Tudoran et al. 2021) and in Italy (Vacchiano et al. 2017), among others.

As Norway spruce covers approximately 50% of the productive forest area in Austria (Russ 2019), studies have also covered forest dynamics of spruce forests in this country as well (Thom et al. 2017, Dinca et al. 2017). Nevertheless, these studies covered either productive or partially unmanaged forests. Except the ELENA project (Ruprecht et al. 2013) few studies have investigated forest dynamics of strictly unmanaged Norway spruce subalpine forests in Austria. With the increase of climate-induced challenges, such as bark-beetle outbreaks in recent decades for Norway spruce in Austria (Jandl 2020), an understanding of natural forest dynamics of these forests is crucial in developing forest management practices that could increase the resilience of subalpine Norway spruce forests.

This study aimed to describe the current state, in regard to the growing stock, species composition, natural regeneration and deadwood volume of a Natural Forest Reserve in Austria, in which no human management is taking place. Besides this the study investigated changes in aboveground living and dead woody biomass and natural regeneration in the past 12 years. The impact of changes of tree species composition on the share of tree species in the natural regeneration was also investigated as well as changes of the deadwood diameter distribution as a consequence of increased mortality and decreased competition.

The analysis indicates that the dominant tree species in the NFR *Schiffwald* was Norway spruce, accounting for around 85 percent of the volume, followed by larch at almost 15 percent and beech, sycamore and dwarf pine which account for less than 1 percent of the total volume. The average number of stems per hectare was 371±279 in 2021. The large standard deviation indicates a large variability between the plots. The growing stock was on average 284.90±155.03 m^3/ha in 2021. These numbers are relatively low when compared to average numbers of other natural forest reserves in Austria (Ruprecht et al. 2013). The results show that the amount of spruce in the total stand volume increased by 3 percent compared to 2009 and the number of trees per hectare decreased by 89. Also, compared to the previous inventory cycle, the average volume per hectare declined by 16.81 m^3, but a Kruskal-Wallis test revealed no significant statistical differences between the total growing stocks in 2009 and 2021. Figure 14 shows that the medium diameter classes, which range from 32.5 cm to 42.5 cm, account for a significant portion of the stand volume. The increasing number of dead trees in the medium diameter classes (Figure 33 and Figure 34) could thus explain the decline in the growing stock.

Figures 12 and 13 show a rotated sigmoid distribution for both diameter and height. The highest number of trees is represented in the low diameter classes, with the number of trees dropping as the diameter decreases and plateauing in the intermediate classes. This is consistent with previous research on unmanaged subalpine Norway spruce forests (Motta et al. 2015 & Lamedica et al. 2011). This type of distribution represents a feature of a multi-story forest that can be explained by disturbances that are less frequent and occur on a medium scale, U-shaped mortality, which means that the lowest incidence of mortality is in the middle ranges with peaks in the lower and upper ranges, and a non-linear diameter increment (Pach & Podlaski 2015, Leak 2002, Alessandrini et al. 2011). The diameter and height distribution show a similar trend, compared to 2021, in 2009 as well (Figure 28 and Figure 29) although there are less trees in most of the diameter categories in 2021 compared to 2009. On the other hand, the number of trees per hectare in the higher diameter and height classes increased slightly in 2021.

In terms of regeneration, the number of seedlings and saplings in 2021 is rather low. Medium and advanced decayed deadwood has a significant favourable effect on the establishment of seedlings, where the density of saplings increases with the rate of deadwood decomposition (Bae et al. 2012, Tsvetanov et al. 2018, Motta et al. 2006). Based on Figure 31, it can be assumed that the low number of seedlings and saplings in 2021 was due to the low amount of advanced and heavily decomposed deadwood, as the majority of the deadwood was at the beginning stages of decomposition in 2021. In all categories of regeneration, there is a considerable drop in seedlings and saplings compared to 2009. In 2009, almost fifty percent of the deadwood was either in the advanced or heavily decomposed stage, as seen in Figure 31. This may explain why there are so many more seedlings and saplings in 2009. Due to the increased amount of deadwood in 2021 compared to 2009 (Table 17), a future increase in regeneration could be anticipated.

Spruce is dominant in the seedlings and 30-129.9 cm regeneration categories with approximately 87 percent and 80 percent, respectively, whereas broadleaves such as *Sorbus aucuparia* and *Acer pseudoplatanus* are more dominant in the <15 cm and 15-29.9 cm classes, accounting for approximately 70 percent in both regeneration categories in 2021. The species distribution remained relatively unchanged between 2009 and 2021 for the <15 cm and 30-129.9 cm classes, whereas for the seedlings class there has been a significant increase in spruce, accounting for nearly 90 percent of all seedlings in 2021. In the 15-29.9 cm class there has been an increase in *Sorbus aucuparia*, from approximately 5 to 50 percent, at the expense of spruce. The significant dominance of spruce seedlings could be attributed to the higher proportion of spruce trees in 2021's total species composition. And the reason for the increase of spruce in the 30-129.9 cm category could be explained by a high browsing pressure from ungulates on the other species. Figure 16 indicates that in the recruitment establishment (30-129.9 cm), broadleaf species, which are more prevalent in the lower regeneration groups, are scarce. The reason for this scarcity of broadleaves could be attributed to the high browsing pressure (40% of all individuals) in the 30-129.9 cm height class due to high attractiveness of broadleaf species for ungulates (Pröll et al. 2015, Motta 2003, Ammer 1996).

Compared to the results of Oettel et al. (2020), which revealed an average deadwood volume of 41.06 m^3/ha for low subalpine spruce forests in Austria, the deadwood volumes of 71.62 m^3/ha in the NFR *Schiffwald* may be considered high. In 2021, around 80 percent of the deadwood was standing, while the remaining 20 percent represented lying deadwood. This contradicts earlier studies, which indicate that in unmanaged natural forest reserves, the amount of lying deadwood typically predominates (Oettel et al. 2020, Rimle et al. 2017 & Vacek et al. 2015). This may be due to the fact that the NFR *Schiffwald* has been unmanaged for approximately

23 years, which may not be enough time for a greater accumulation of lying deadwood. The average volumes of all deadwood categories together have increased by 14.68 m^3/ha since 2009, however statistical tests indicate that there was no significant difference between the mean volumes of standing deadwood in 2009 and 2021, whereas there was a significant difference between the mean volumes of lying deadwood in 2009 and 2021. Compared to 2009, there has been an increase in the amount of lying deadwood, by about 17 percent. This indicates the development of more natural attributes of the NFR *Schiffwald* throughout the years.

As with the living trees, the Norway spruce is the major species of deadwood, comprising over 90 percent of the total deadwood volume in 2021 (Figure 21). For standing deadwood, the predominant decomposition stage is *starting decomposition*, while for lying deadwood it is *advanced* and *heavily decomposed*. This makes sense given that the primary factors affecting the decay process of deadwood are soil characteristics such as soil moisture, clay content, and pH value (Fravolini et al., 2016), which mostly affect lying deadwood due to its larger contact area with the soil. The results also matched with prior research conducted on the decomposition of lying deadwood, which revealed a higher decay rate in lying deadwood compared to standing deadwood (Rimle et al. 2017). Compared to 2009, the percentage of trees in the *starting decomposition* category has increased significantly from 36 to 60 percent, indicating an increase in the number of trees that have died in recent years. As bark beetles accounted for nearly 80 percent of the mortality causes (Figure 25), and 85 percent of the trees died within the past 14 years (Figure 26), this may indicate a higher bark beetle-influenced disturbance regime. As future climate forecasts indicate higher temperatures and less precipitation in the European Alps (Gobiet and Kotlarski, 2020), a rise in bark beetle outbreaks could be anticipated in the future, as lower precipitation and higher temperature are the primary causes of such outbreaks (Marini et al. 2016). The increased bark beetle outbreaks should diversify the species composition (Winter et al., 2015), but in the case of NFR *Schiffwald*, this was not the case, as the amount of spruce in the total species composition has increased by approximately 3 percent since the last inventory cycle (Table 15). This could be attributed to the fact that the NFR *Schiffwald* was only established 23 years ago, and a more diverse species composition is anticipated in the future, especially as the susceptibility of Norway spruce to disturbances increases.

Compared to the previous inventory cycle, the diameter distribution of deadwood has shifted. There has been an increase in the amount of medium-diameter dead trees, with the maximum number of standing deadwood in the 17.5 cm and 32.5 cm classes, and lying deadwood in the 22.5 cm class in 2021. Various studies (Sproul et al. 2015, Orman and Dobrowolska 2017) demonstrate that the effect of diameter class on bark beetle susceptibility depends on the location. In our case, the lower number of dead trees in classes with larger diameters could be explained by the overall low number of trees in those classes. There is a need for additional research to determine the primary causes of tree mortality in the NFR *Schiffwald*, as certain studies indicate that factors such as slope, drought, and radial growth influence tree mortality (Krumm et al. 2012, Panayotov et al. 2016)

5. Conclusion

This chapter aims to conclude the study by summarizing the main findings in connection to the main research questions, and to discuss their significance and implications. In addition, it will review the limitations of the study and discuss and suggest opportunities for future research.

The Norway spruce is the most prevalent tree species in the NFR *Schiffwald*. With a decline in total growing stock and an increase in the deadwood volume during the past 12 years, it is reasonable to assume that the disturbance regime is intensifying. This could be due to the increasing susceptibility of Norway spruce to bark beetle outbreaks caused by climate change over the past few decades. The highest number of standing deadwood was found between the 17.5 cm and 32.5 cm diameter classes. As trees that die as a consequence of bark beetles usually die in groups, larger gaps are created for the establishment of natural regeneration. Despite this and a rise in the volume of deadwood, the number of natural regeneration in 2021 was significantly lower than in 2009. This could be attributed to the fact that the deadwood did not reach the decomposition stages that would have had an effect on the increase on the establishment of natural regeneration. Due to this, an increase in natural regeneration could be anticipated in the future, particularly among larch and broadleaves in response to the expected increase in Norway spruce mortality.

The study offers insights into the natural development of a Norway spruce subalpine forest after human management activities have been discontinued. Due to the importance of Norway spruce in the productive forests of Austria and the expected future climate-change-induced challenges to this species, such as windthrows and bark beetles, it is crucial to understand how these forests respond to these threats in a natural environment without human intervention. For instance, it is important to determine what species would establish following the expected future increase in Norway spruce mortality, or which diameter classes are most likely to be impacted by climate-change-induced threats. This could help in the development of forest management practices that could be implemented in production forests to increase their resilience in the future.

Continuous research, over several decades would be needed to have a comprehensive understanding of the impacts of climate change on Norway spruce forests. Future research should also cover different types of forests, to get a better understanding of what type of species composition will lead to higher forest resilience. Besides that, Norway spruce forests at different elevations should also be included as in this case the elevation plays a double role. First the Norway spruce shows different levels of resilience at different altitudes, and second climate change impacts also vary depending on the elevation. This is important due to the fact that the Norway spruce has been planted extensive outside it’s natural elevation range across the European continent.

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Annex

Table 17. Coding of the ecological forest types

Code	Designation
1	High subalpine larch-birch forest
2	Arch forest
3	Deep subalpine spruce forest
4	Montane spruce forest
5	Spruce-fir forest
6	Spruce-fir-beech forest
7	Beech forest
8	Oak-hornbeamforest
9	Soil-sour pine-oak forest
10	Subcontinental mixed oak forest
11	Hop hornbeam-flower ash forest
12	Mixed lime forest
13	Sycamore and sycamore-ash forest
14	High mountain maple-beech forest
15	Black alder-ash forest
16	Black alder riparian forest
17	Grey alder forest
18	Mountain-spiral forest
19	Bushes of mountain pines
20	Whit-pine-birch-moor forest
21	Carbonate pine forest
22	Silicate pine forest
23	Black pine forest
24	Soft au
25	Hard au
26	Green alder bush forest
27	Downy oak forest

Table 18. Coding of soil types according to Englisch & Kilian 1998

Code	Designation
10	Raw soils and rankers
20	Brown earth adn slope colluvia on poorer crystalline rock
30	Brown earth and colluvia on base-rich crystalline limestone-influenced brown earth
40	Semipodsol on crystalline
50	Climatic podsol

60	Substrate-related podsol
80	Light brown earth and podzolic brown earth on unconsolidated sediments
90	Cohesive brown earth on moraines, boulder sediments, barrage clay and clayey parent material in general
100	Brown earth from loess
110	Parabrown earth
120	Pseudogley on flysch, Werfen strata, spotted marl and other lcay, solid bedrock
130	Pseudogley on onconsolidated sediments
131	Pseudogley on loess
133	Dwarf pseudogley
140	Stagnogley
150	Slope pseudogley
160	Siliceous brown clay, red clay
170	Chernosem
180	Rendsina and raw soils on lime
181	Pararendsina
182	O-C soils on lime
190	Calcareous brown loam Rendsina
200	Terra fusca and acalcareous brown clay in general
210	Groundwater gley
220	Alluvial soils and stream soils
240	Raw soils, grey subsoil
250	Brown subsoil
260	Anmoor
270	Low moor
280	High moor
290	Salty floors
300	Artificial soils

Table 19. Coding of the geological units for the bedrock, the overburden and for the terrain approach (Vegkunddat)

Code	Designation
10	Greanite and granite-like gneiss
11	Granite: coarse grained, rich
12	Grained: coarse-grained, poor
13	Granite: fine-grained
14	Diorite/gabbroo, medium to coarse-grained
15	Other igneous rocks

20	Gneiss
21	Gneiss:very rich, amphibolite
22	Gneiss: intermediate and gneiss/micaschist in general
23	Poor quarts micaschist, hard quartz phyllite
31	Quartzite, poor sandstone
32	Various, also clay sandstones
33	Soft phyllite, clay state
34	Calcareous micaschist, calcareous phyllite, calcareous sandstone
35	Marl
41	Lime
42	Dolomite
51	Serpentine
52	Vulcanite
61	Lime gravel
62	Mixed gravel
63	Quartz gravel
64	Moraine
65	Conglomerate
71	Silicate sand
72	Flying sand
73	Fly ash, dust loam
74	Loess
75	Clay, tegel
80	Old weather ceilings
90	Au sediments in general
91	Ausande
92	Slurry

Table 20. Coding of humus forms according to Englisch & Kilian 1998

Code	Designation
100	Terrestrial humus forms
110	Mull
111	Typical guaze
112	Mouldy gauze
113	Mushy mould
114	Rhizomull
120	Moder
121	Typical fashion
122	Kalkmoder
123	Rhizome
124	Acid mustiness
125	Raw humus-like mould
126	Alpenmoder
130	Raw humus
131	Rypcial raw humus

132	Active raw humus
133	Inactive raw humus
134	Rhizo raw humus
135	Tangel raw humus
200	Semi-terrestrial humus forms
210	Wet gauze
220	Moist moor
230	Moist raw humus
240	Low moor
250	Transitional peat bog
260	Raised bog peat
270	Anmoor
300	Subhydric hmus forms
320	Gyttia
330	Sapropel

Table 21. Coefficients from Kruskal-Wallis test for number of stems for different species in 2021

Statistic	p.value	Parameter	Method
4	0.4060058497098380	4	Kruskal-Wallis rank sum test

Table 22. Coefficients from Kruskal-Wallis test for volume for different species in 2021

Statistic	p.value	Parameter	Method
33.12230545839860	1.12754991281645E-06	4	Kruskal-Wallis rank sum test

Table 23. Coefficients from Kruskal-Wallis test for basal area for different species in 2021

Statistic	p.value	Parameter	Method
23.261223817173800	1.12282950969581E-04	4	Kruskal-Wallis rank sum test

Table 23. Coefficients from Kruskal-Wallis test for total volumes in 2009 and 2021

Statistic	p.value	Parameter	Method
33.12230545839860	1.12754991281645E-06	4	Kruskal-Wallis rank sum test