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Master Thesis

Comparative assessment of natural regeneration across natural forest reserves in Austria

Submitted by

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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 All ideas taken in wording or in basic content from unpublished sources or from published literature are duly identified and cited, and the precise references included.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, 27.06.2022 Darius George HARDALAU *(manu propria)*

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Abstract

Natural forest reserves are protected areas in Austria where no silvicultural treatments or any management is allowed. In 2021, 200 fixed radius sample plots of 300 square meters were resampled across 6 natural reserves to examine natural regeneration dynamics. All studied reserves are in a mountainous area with similar site conditions. A descriptive analysis of the main parameters of different natural regeneration categories with various height classes was carried out for Norway Spruce (*Picea abies* L). The analysis of the capacity of all natural reserves to regenerate naturally allowed determining the parameters that influence this process negatively or positively. Additionally the height growth of Norway Spruce was analyzed to find out the growth potential of the seedlings in the 30-130 cm category and the factors influencing this process. In comparing the natural reserves differences in the mean number of seedlings per hectare in each category were identified. A lognormal distribution described the height and diameter of the 30-130 cm saplings and different intensities of browsing were found. A logistic regression model allowed to determinate the significant factors, that support a successful establishment of the seedlings. The ground vegetation, soil type and microrelief had a negative influence on the seedling occurrence, while mosses, slope, mesorelief, deadwood and basal area had a positive influence. In the growth analysis, only one significant factor (amount of deadwood) was identified. Both analyses revealed that deadwood in an advanced stage of decay has a significant positive influence on the natural regeneration. It was concluded, that the dynamics of natural forest reserves are dependent on natural disasters and environmental conditions, but even without human intervention, these forest reserves have the capacity to restore and regenerate themselves over time.

Zusammenfassung

Naturwaldreservate in Österreich sind Schutzgebiete, in denen keine waldbauliche Behandlung oder Bewirtschaftung erlaubt ist. Im Jahr 2021 wurden 200 Stichproben mit einer Probefläche von 300 Quadratmetern in 6 Naturwaldreservaten im Rahmen eines Monitorings erhoben, um die Dynamik der Naturverjüngung zu untersuchen. Alle untersuchten Reservate befinden sich in Gebirgswäldern mit ähnlichen Standortsbedingungen. Für die Fichte (*Picea abies* L.) wurde eine deskriptive Analyse der wichtigsten Parameter der Naturverjüngung von verschiedenen Höhenklassen durchgeführt. Die Analyse der Naturverjüngungsfähigkeit aller Naturwaldreservate ermöglichte die Bestimmung der Parameter, die diesen Prozess negativ oder positiv beeinflussen. Zusätzlich wurde das Höhenwachstum der Fichte analysiert, um das Wachstumspotenzial der Sämlinge in der Kategorie 30-130 cm und die Faktoren, die diesen Prozess beeinflussen, zu ermitteln. Beim Vergleich der Naturwaldreservate wurden Unterschiede in der durchschnittlichen Anzahl der Individuen pro Hektar in jeder Kategorie festgestellt. Die Höhe und der Durchmesser der 30-130 cm großen Individuen wurden durch eine Lognormalverteilung beschrieben, und es wurden unterschiedliche Verbissintensitäten festgestellt. Mit Hilfe eines logistischen Regressionsmodells konnten die wesentlichen Faktoren ermittelt werden, die eine erfolgreiche Etablierung der Sämlinge begünstigen. Die Bodenvegetation, der Bodentyp und das Mikrorelief hatten einen negativen Einfluss auf das Vorkommen, während Moose, Hangneigung, Mesorelief, Totholz und Grundfläche einen positiven Einfluss hatten. Bei der Wachstumsanalyse wurde nur ein signifikanter Faktor (Totholzmenge) als entscheidend ermittelt. Beide Analysen ergaben jedenfalls, dass Totholz in einem fortgeschrittenen Zerfallsstadium einen signifikant positiven Einfluss auf die Naturverjüngung hat. Es kann gefolgert werden, dass die Dynamik von Naturwaldreservaten von Naturkatastrophen und Umweltbedingungen stark abhängt, dass die untersuchten Naturwaldreservate aber auch ohne menschliches Eingreifen in der Lage sind, sich im Laufe der Zeit selbst zu regenerieren.

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1. Introduction

Forests in the European Alps have not only timber and non-timber production functions but also protection functions. They have the role to protect the site and adjacent areas and to stop/control ecosystem degradation, erosion, and landslides. They have the capacity to ameliorate climatic effects by reducing temperature extremes, regulating precipitation, evapotranspiration, reducing pollution, CO_2 absorption and oxygen removal. In addition to providing habitat for animals and plants, they also protect human settlements by mitigating natural disasters: debris flow, avalanches, rock falls and more. This prevention is achieved through the increased soil roughness, the stabilization of the soil by the root system of the trees, the regulation of the water circuit and the elimination of the destructive action of the wind (Clinciu & Nita, 2019; Huggel et al., 2012; Nicolescu 2018; Iverson, 1997, 2000)

In Austria, protection forests occupy 21.5% of the total forested area, of which 8.4% are classified as protective forests with timber production and 13.1% of forests have been taken out of production and are not managed. (BMLFUW, 2022) Even if around one fifth of the forests in Austria have protective functions, the question arises whether they can perpetuate without human interventions. There is a high need for these areas to ensure natural regeneration, almost 80% of the protection forests lacking a proper natural regeneration. (BMLFUW, 2022). This thesis follows the status of natural regeneration by analysing Natural Forest Reserves (Huber et al., 2022). According to the definition given by Austrian Federal Ministry of Agriculture, Forestry, Environment and Water management (BMLFUW): “Natural Forest Reserves (NFR) are forest areas destined for the natural development of the forest ecosystem where any direct form of intervention is prohibited. They contribute to the maintenance and natural development of biological diversity” (BMLFUW, 2022).

After signing the Resolution H2 of the Ministerial Conference on the Protection of Forests in Europe in Helsinki in 1993, the Austrian state committed to create a system of natural forest reserves. In the year of 1994, a taskforce was created in order to elaborate the “Basic Forest Guidelines of the Austrian Federal authorities for the establishment of an all-Austrian network of natural forest reserves”. In present, the Natural Forest Reserves Programme established over 195 natural forest reserves with an area of approximately 8600 hectares, with most of the 125 forest communities included (BMLFUW, 2022).

An important species that is well spread across Europe is the Norway spruce (*Picea abies*), which is found in its natural range in mountainous areas. Currently, across the continent a lot of studies analysed the natural regeneration in this areas, both in managed forests: Baier et al., (2007); Frehner M, (2002); Krumm et al., (2011) and in unmanaged forests: Castagneri et al., (2008); Diaci et al., (2005); Holeksa et al., (2008); Motta et al., (1999), (2010); H. , Ruprecht et al., (2012); Sorg JP, (1980); Stroheker et al., (2018). Even with diversified studies for the Norway spruce in the subalpine area, further research is needed in order to understand the capacity of the forest to regenerate by itself.

The research project ELENA (in German: *EmpfehLungEn für die NAturverjüngung von Gebirgswäldern)* started in 2008 by the cooperation of the University of Natural Resources and Applied Life Science, Vienna and the Austrian Federal Research and Training Centre for Forests, Natural Hazards, and Landscape (BFW). The project selected multiple reserves from the national network and focused on the role of the natural regeneration and its influence on the ecosystem, stand dynamics and site characteristics (Ruprecht et al., 2012; Ruprecht et al., 2013). The present study is focused mainly on the dynamics of the natural regeneration in subalpine Norway spruce stands across *Goldeck, Hutterwald, Schiffwald, Laaser Berg, Krimpenbachkessel* and *Kronawettgrube* Natural Forest Reserves.

The main objective of this thesis is to find out if the Natural Forest Reserve have the ability to regenerate without human intervention in the forests. The objective will be achieved by answering the research questions. Firstly, the general situation of natural regeneration in 2021 in the 6 reserves will be analysed. Secondly, through a wide variety of factors like soil types, geomorphological aspects, amounts of deadwood and others, the capacity of the establishment of seedlings will be tested. Lastly, using the individual characteristics (vitality, browsing, factors in their immediate vicinity and others) the growth potential of individual saplings will be analysed to find out if the natural regeneration of the forests is possible without human interventions.

1.1. Research questions

The aim of this study was to answer the following research questions:

1.What is the current situation of natural regeneration across the natural forest reserves?

2. How is the establishment potential of seedlings is affected by site conditions?

3. How is the growth potential of the saplings is influenced by the abiotic factors?

2. Material and methods

2.1. Site description

In the following sub-chapters, the site situation will be described for the Natural Forest Reserves analysed in this study: *Goldeck, Hutterwald, Schiffwald, Laaser Berg, Krimpenbachkessel* and *Kronawettgrube.* The administrative situation, location, geology, and climate will be described briefly for each reserve. The distribution of all of the Natural Forest Reserves in Austria is shown in Figure 1.

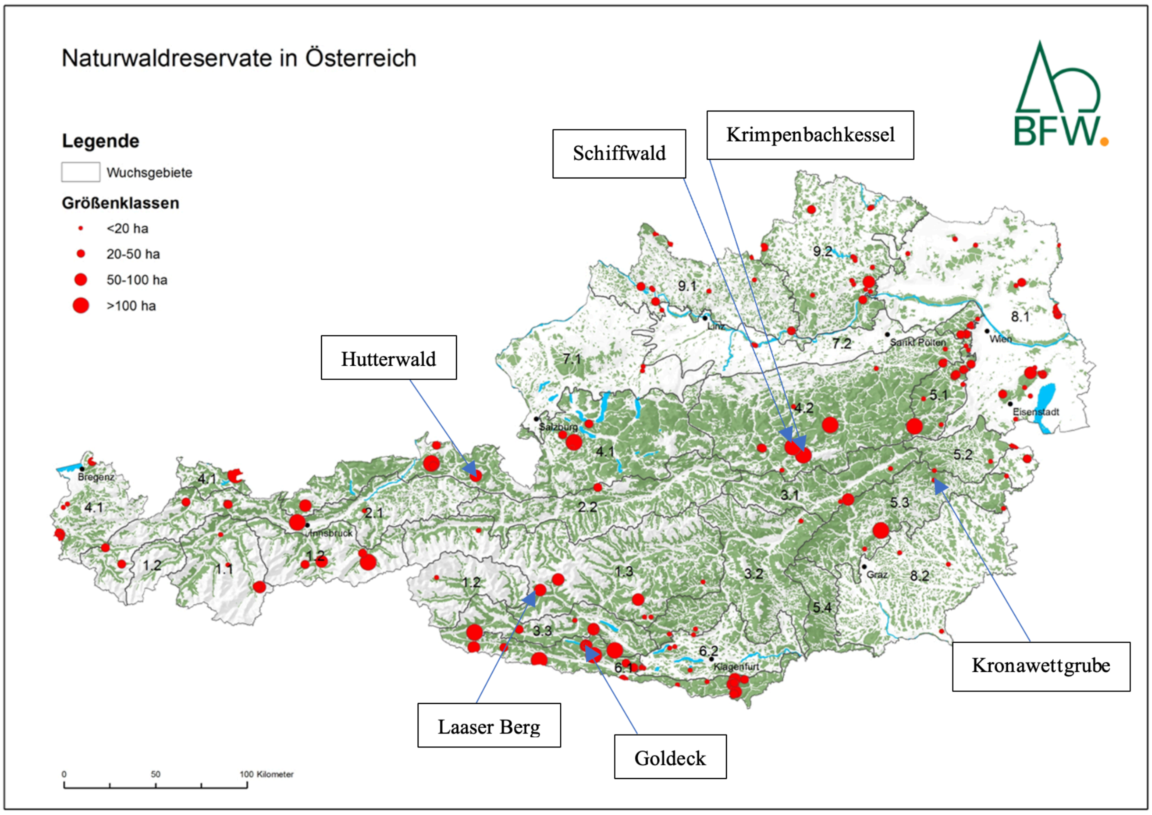

Figure 1. Distribution of natural reserves in Austria (Source: www.bfw.gv.at)

2.1.1. *Goldeck* natural forest reserve

Goldeck Natural Forest Reserve is situated in the Federal State of Carinthia, in the municipality of Baldramsdorf in the district of Spittal/Drau, Austria. The reserve is located on the north side of the *Goldeck* mountain, with an area of 58.27 ha in the altitudinal range of 1040-1620m (Vacik et al., 2010).

Goldeck NFR has a mean annual temperature of 4.7°C and a mean annual precipitation of 1107 mm between 1959-2009 (Figure 2). Summer and August have not had a single frost day since 1960. The mean annual temperature has increased from 4.1°C to 5.6°C in the last 5 decades while the mean annual precipitation has decreased from 1960 to 2000 (Table 1) (Vacik et al., 2010).

Table 1. Mean annual temperature and precipitation in *Goldeck* between 1959 to 2009 (Vacik et al., 2010)

Decade	Annual mean temperature	Mean annual precipitation
1960-1969	4.1°C	1241 mm
1970-1979	4.2°C	1135 mm
1980-1989	4.4 °C	1009 mm
1990-1999	5.1 °C	1046 mm
2000-2009	5.6 °C	1103 mm

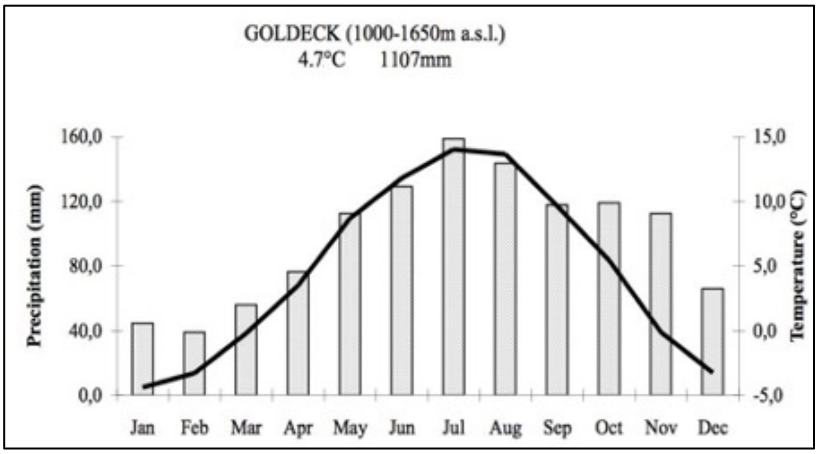

Figure 2. *Goldeck* climate diagram (Source: Winter M., 2009)

The NFR *Goldeck*' bedrock is quite inhomogeneous, including both acid and alkaline rocks. The quartz phyllite, the garnet mica schist bed is situated in the north, while lime marble strata are found in the centre (Figure 4), partially above ground, with sporadic breakoffs and rock falls (Geologische Bundesanstalt 2021).

The geological condition made the development of different soils in the study area possible: cambisols, semi-podzols, podzols and leptosols.

The vegetation types found in *Goldeck* NFR (Figure 3), according to Vacik et al., 2010 are:

- Silicate alpine larch spruce forest (*Larici-Piceetum* Ellenberg & Klötzli 1972),
- Wood sorrel fir forest (*Galio rotundifolii-Abietetum* Wraber 1955),
- Silicate grove beech forest (*Luzulo nemorosae-Fagetum* Meusel 1937),
- Gray alder forest (*Alnetum incanae* Lüdi 1921).

Figure 3. Vegetation types in *Goldeck* NFR (Source: Vacik et al. 2010)

2.1.2 *Hutterwald* Natural Forest Reserve

Hutterwald NFR is situated in the Federal State of Salzburg, in the district of Salzburg, Austria. The reserve is situated in the north-western foothills of the Scheibenhöhe, a northern fringe mountain of the Hohe Tauern mountains, with an area of 29.4 ha with altitudes between 1500-1700m (Vacik et al., 2010).

The natural forest reserve *Hutterwald* has a mean annual temperature of 3.6°C and a mean annual precipitation of 1354 mm between 1959-2009 (Figure 4). In the last five decades, the average annual temperature has risen from 3.2°C to 4.4°C (Table 2). Precipitation has increased from 1362mm in the1960-1969 decade to 1476mm in the 2000-2009 decade (Vacik et al., 2010).

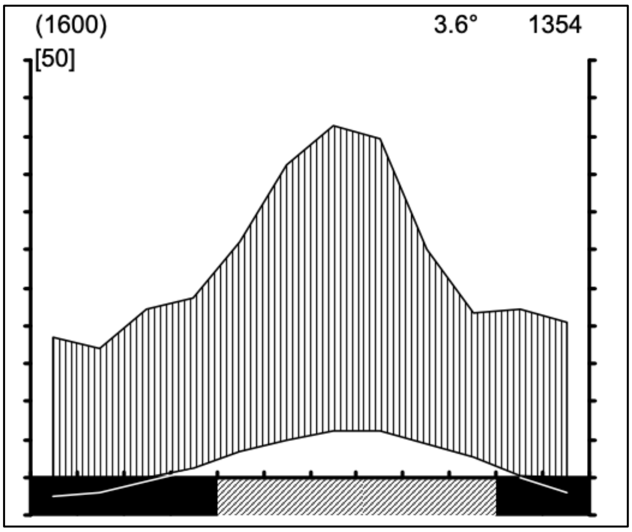

Figure 4. *Hutterwald* climate diagram according to Walther and Lieth (1967) (Source: Vacik et al, 2010)

Table 2. Mean annual temperature and precipitation in *Hutterwald* between 1959 to 2009 (Vacik et al., 2010)

Decade	Annual mean temperature	Mean annual precipitation
1960-1969	3.2°C	1362 mm
1970-1979	3.3°C	1105 mm
1980-1989	3.3°C	1377 mm
1990-1999	4.0°C	1452 mm
2000-2009	4.4°C	1476 mm

Calcareous mica schist dominates the bedrock in the *Hutterwald* natural forest reserve. There are significant variances in the soil development. In addition to ranker, semi-podzol and podzol soils can be found. Peat is also found in small amounts. The exposition spectrum varies from west to northeast. Except for a few flat spots, the gradients range from 10% to 80% (Vacik et al., 2010)

The vegetation types found in the NFR *Hutterwald* (Figure 5), according to Vacik et al., 2010 are:

- Silicate alpine-larch spruce forest (*Larici-Piceetum* Ellenberg & Klötzli 1972),
- Wood sorrel fir forest (*Galio rotundifolii-Abietetum* Wraber 1955),
- Silicate grove beech forest (*Luzulo nemorosae-Fagetum* Meusel 1937),
- Gray alder forest (*Alnetum incanae* Lüdi 1921).

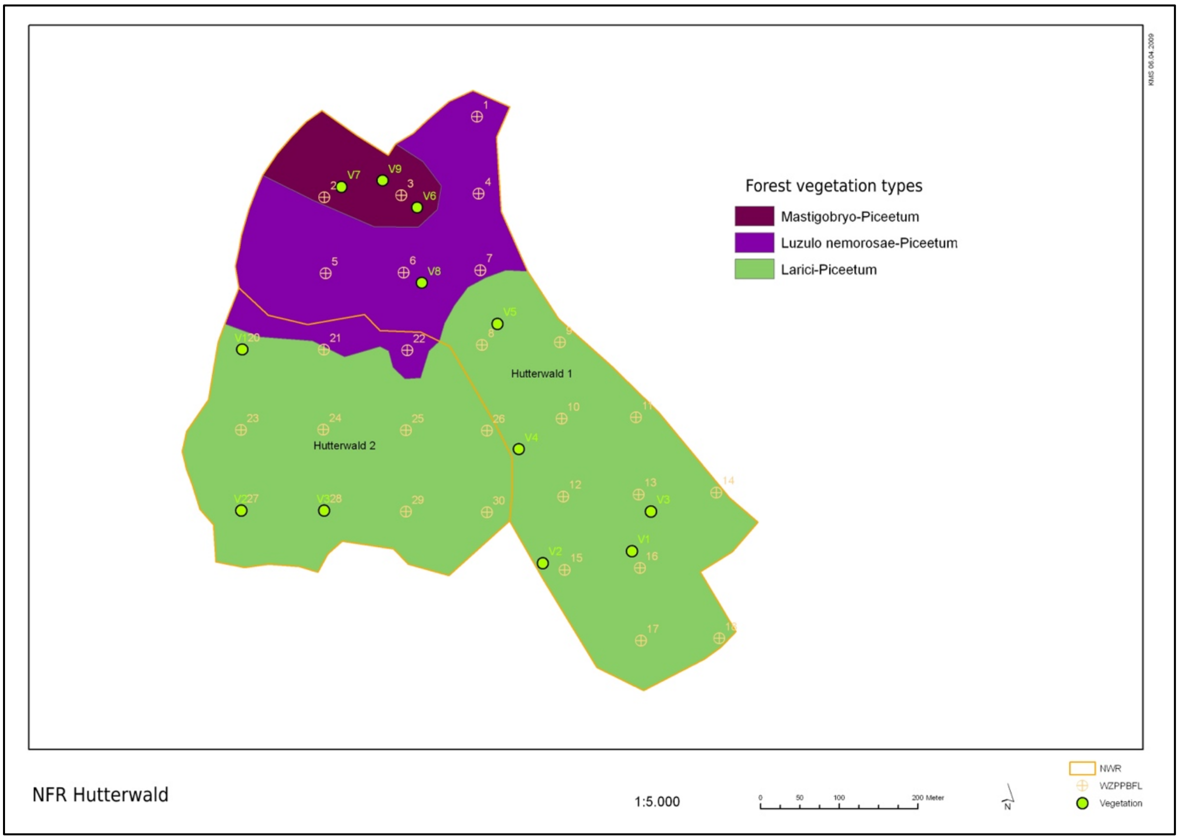

Figure 5. Vegetation types in *Hutterwald* NFR (Source: Vacik et al. 2010)

2.1.3. *Schiffwald* Natural Forest Reserve

The NFR *Schiffwald* is situated in the Federal State of Styria, in the municipality of Wildalpen, in the district of Liezen, Austria. The reserve is located on the northern slopes of the Hochschwab mountains, with an area of 692 ha, making it one of the biggest natural forest reserves in the country. The study area is situated between 1100-1500m altitude (Vacik et al., 2010).The reserve is a protection forest for the provision of the drinking water resource for the city of Vienna.

The *Schiffwald* NFR has a mean annual mean temperature of 4.6°C and mean annual precipitation of 1477 mm between 1959-2009 (Figure 6). No frost days have occurred in July and August since 1960. The mean annual temperature has increased from 3.9°C to 5.4°C in the indicated period (Table 3) (Vacik et al., 2010).

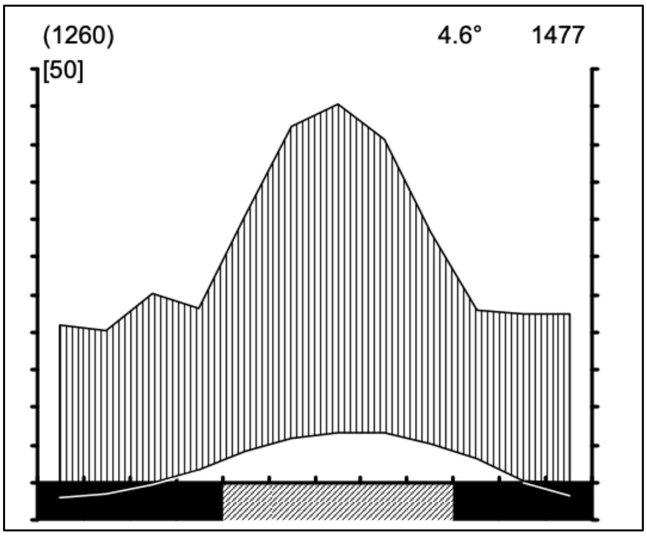

Figure 6. Climate diagram of NFR *Schiffwald* according to Walther and Lieth (1967) (Source: Vacik et al, 2010)

Table 3. Mean annual temperature and precipitation in *Schiffwald* between 1959 to 2009 (Vacik et al., 2010)

Decade	Annual mean temperature	Mean annual precipitation
1960-1969	3.9°C	1736 mm
1970-1979	4.4°C	1308 mm
1980-1989	4.6°C	1352 mm
1990-1999	4.9°C	1352 mm
2000-2009	5.4°C	1636 mm

The NFR is located next to a landslide that happened between 5,900 and 5,700 years ago (van HUSEN, 2007). During a mass movement of roughly 4-6 km3, a new basin was formed, with a terrain that is exceedingly uneven, with multiple hills and depressions (STEINER, 2012). Calcareous rock, with dolomite transitions, dominates in terms of area. The most common soils found in the reserve are rendsines (KÖCK, 1996) and the most common humus type is moder.

The vegetation types found in *Schiffwald* NFR (Figure 7) according to KÖCK, 1996; LACKNER, 1994; PRSKAWETZ, 1999 are:

- Snow Lily Beech Forest (*Helleboro nigri-Fagetum* Zukrigl 1973 (according to Wallnöfer et al. 1993)),
- Limestone-block spruce forest (*Asplenio-Piceetum* Kuoch 1954),
- High shrub spruce-fir forest (*Adenostylo alliariae-Abietetum* Kuoch 1954),
- Subalpine carbonate alpine spruce forest (*Adenostylo glabrae-Piceetum* M. Wraber ex Zukrigl 1973), Carbonate larch forest (*Laricetum deciduae* Bojko 1931),
- Subalpine mountain pine scrub (*Erico-Pinion mugo* Leibundgut 1948),
- Lycopodium spirch forest (*Lycopodio annotini-Pinetum uncinatae* Starlinger 1992),
- Carbonate dwarf scrub with rusty-leaved alpine rose (*Vaccinio myrtilli-Pinetum montane* Morton 1927),
- Snow heath-lodgepole scrub (*Erico carneae-Pinetum prostratae* Zöttl 1951).

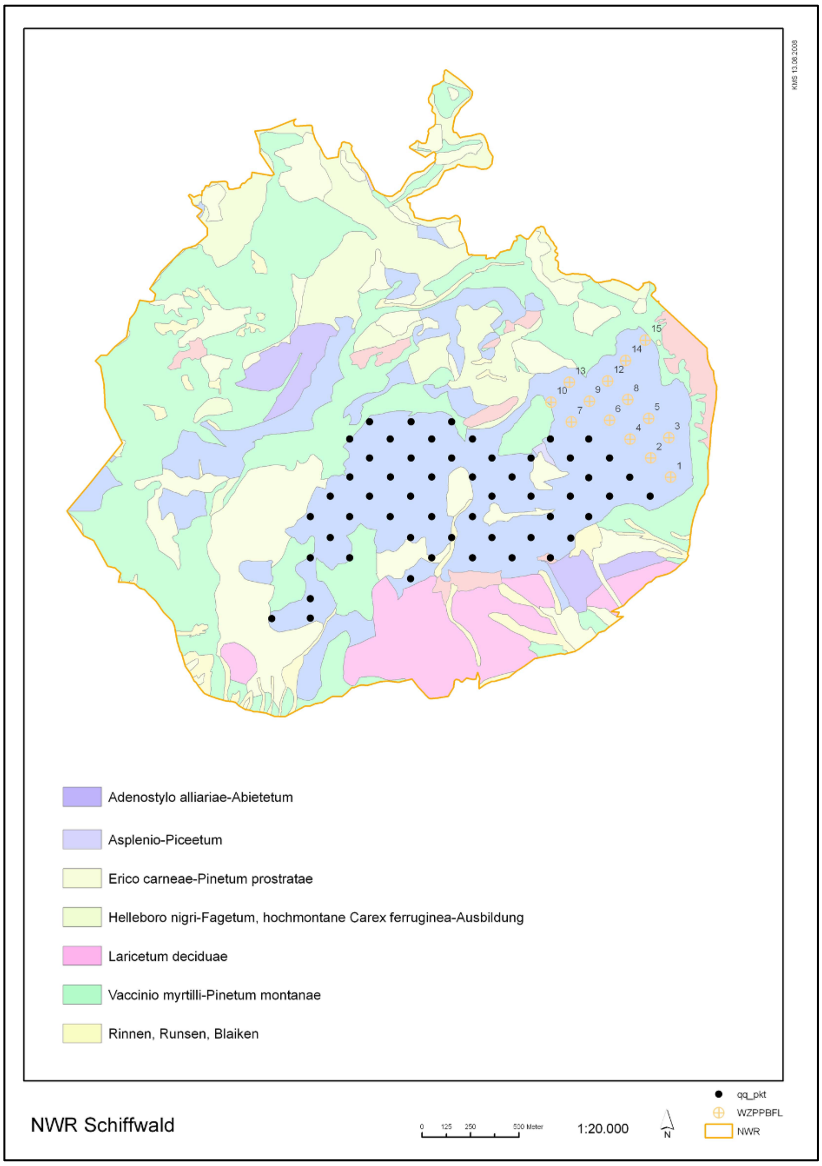

Figure 7. Vegetation types in *Schiffwald* NFR (Source: Vacik et al. 2010)

2.1.4. *Laaser Berg* Natural Forest Reserve

Laaser Berg NFR is located in the Federal State of Carinthia, in the district of Spittal/Drau, Austria. The reserve is situated in the area of the southern slope of the Hohe Tauern on the southwestern flank of the Böseck (2834m), with an area of 63 ha in the altitudinal range of 1500-2000 m (Vacik et al., 2010).

The natural forest reserve *Laaser Berg* has a mean annual mean temperature of 4.9°C and a mean annual precipitation of 1054 mm between 1959-2009 (Figure 8). No frost days have occurred in July and August since 1960. The mean annual temperature has increased from 4.5°C to 5.8°C in the 1960-2009 decades (Table 4) according to Vacik et al., 2010.

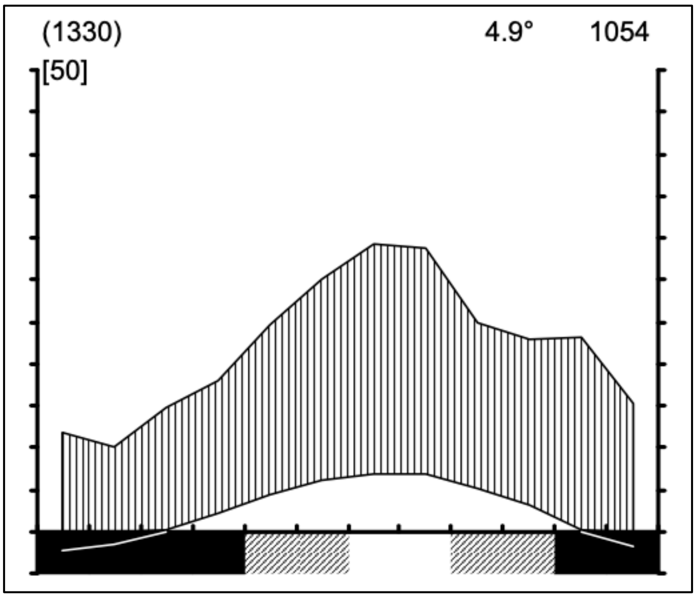

Figure 8. Climate diagram of NFR *Laaser Berg* according to Walther and Lieth (1967) (Source: Vacik et al, 2010)

Table 4. Mean annual temperature and precipitation in *Laaser Berg* between 1959 to 2009 (Vacik et al, 2010)

Decade	Annual mean temperature	Mean annual precipitation
1960-1969	4.5°C	1105 mm
1970-1979	4.5°C	1024 mm
1980-1989	4.6°C	962 mm
1990-1999	5.3°C	1031 mm
2000-2009	5.8°C	1151 mm

The natural forest reserve *Laaser Berg* is mostly situated in a landslide location. Acid silicate rocks such as gneiss, quartzites, quartz phyllite, and mica schist are formed by the bedrock. There are significant variances in the soil development. Brown and podzol soils, in addition to ranker, are found. The exposure spectrum is primarily divided into two parts: southern and western. The slopes range from 20% to 90%. Smaller sections with steeper parts and ditches, as well as partly level slopes, can be found.

The vegetation types found in *Laaser Berg* (Figure 9), according to Vacik et al., 2010 are:

- Silicate alpine larch spruce forest (*Larici-Piceetum* Ellenberg & Klötzli 1972),
- Wood sorrel fir forest (*Galio rotundifolii-Abietetum* Wraber 1955),
- Silicate larch swiss stone pine forest (*Larici-Pinetum cembrae* Ellenberg 1963),
- Gray alder forest (*Alnetum incanae* Lüdi 1921) and
- Green alder bush (*Alnetum viridis* Br.-Bl. 1918).

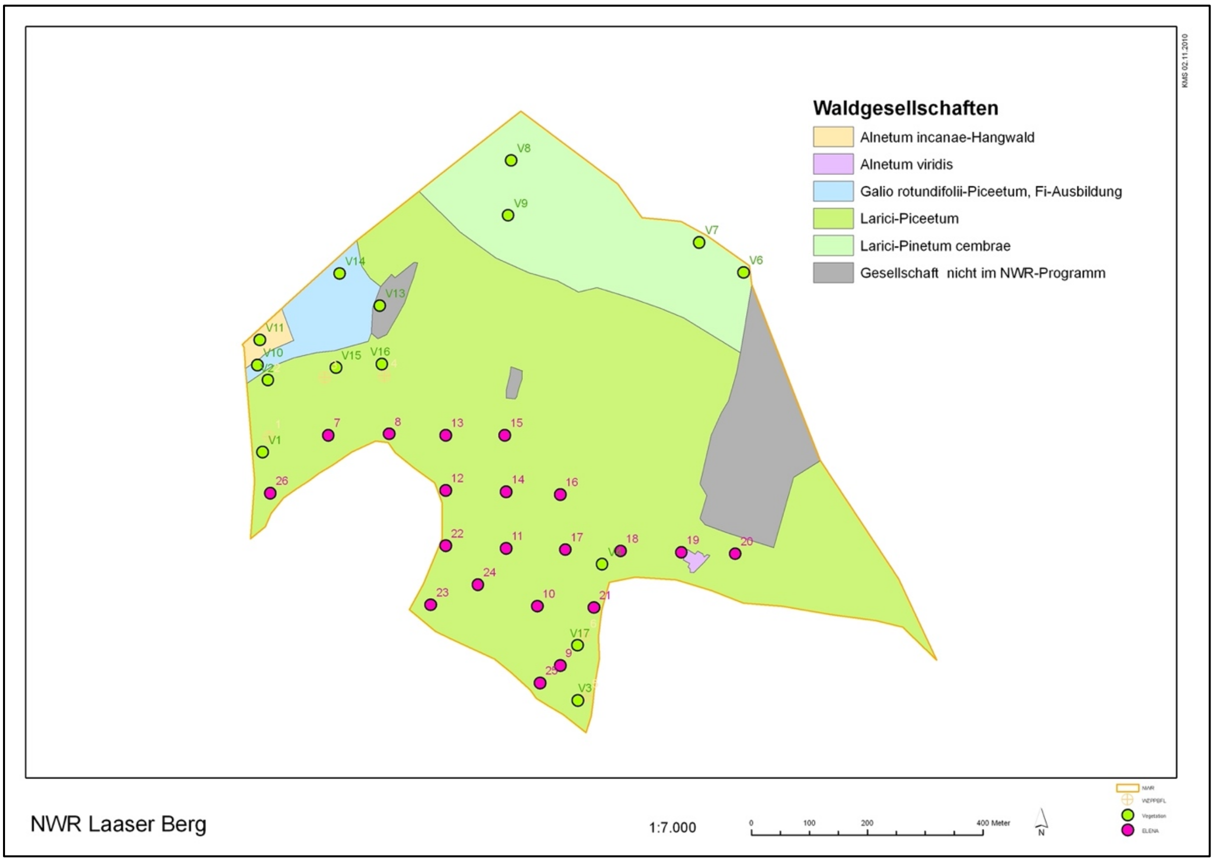

Figure 9. Vegetation types in *Laaser Berg* NFR (Source: Vacik et al, 2010)

2.1.5 *Kronawettgrube* National Forest Reserve

Kronawettgrube NFR is located in the Federal State of Lower Austria, in the district of Neunkirchen, Austria. The reserve is situated on the northeast slope of the Wechselgebirge mountain between the Hochwechsel and Niederwechsel peaks. It has an area of 7.52ha, with an altitudinal range between 1400-1540m (Vacik et al., 2010).

Between 1959 and 2009, the *Kronawettgrube* natural forest reserve had a mean annual temperature of 4.2 °C and a mean annual precipitation of 1532 mm (Figure 10). No frost days have occurred in the month of August since 1960. In the last five decades, the average annual temperature has risen from 4.0 °C to 4.7 °C (Table 5). has decreased from the 1960-1969 decade to the 2000-2009 decade (Vacik et al., 2010).

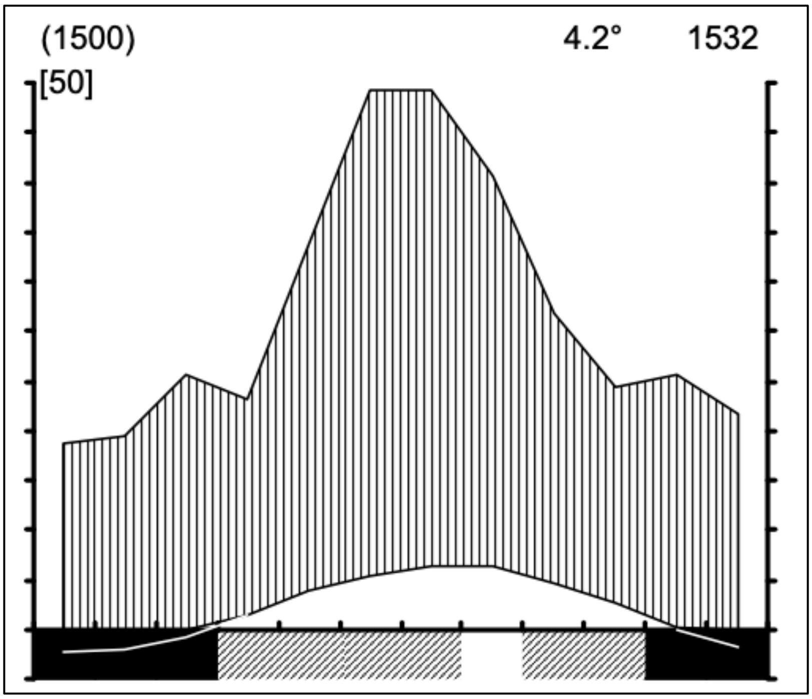

Figure 10. Climate diagram of NFR *Kronawettgrube* according to Walther and Lieth (1967) (Source: Vacik et al, 2010)

Table 5. Mean annual temperature and precipitation in *Kronawettgrube* between 1959 to 2009 (Vacik et al, 2010)

Decade	Annual mean temperature	Mean annual precipitation
1960-1969	4.0°C	1675 mm
1970-1979	4.0°C	1812 mm
1980-1989	3.8°C	1425 mm
1990-1999	4.3°C	1425 mm
2000-2009	4.7°C	1326 mm

The bedrock in the natural forest reserve *Kronawettgrube* is made up of overlapping gneiss. There are significant variances in the soil development. Apart from ranker, there are podzolic brown earths and semi podzolic soils. The mull, moder and mor humus types are found across the reserve. The spectrum of exposure is not uniform, although it primarily moves between northern and eastern exposure. The slopes range from 10% to 80%, with the steeper terrain found in limited regions.

Only one type of vegetation is found in *Kronawettgrube* NFR (Figure 11) according to Vacik et al., 2010 :

- Silicate alpine-leaved spruce forest (*Larici-Piceetum* Ellenberg & Klötzli 1972),

Figure 11. Vegetation types in *Kronawettgrube* NFR (Source: Vacik et al. 2010)

2.1.6 *Krimpenbachkessel* Natural Forest Reserves

Krimpenbachkessel Natural Forest Reserve is located in the Federal State of Styria, on the left side of the Salza River, in the district of Liezen. The study area is included in the Eisenwurzen Nature Park. The total area of the reserve is 151.2 ha, with an altitudinal between 840 to 1330 m (Kasseroler, 2011).

The nearest climate station for the reserve was Wildapen, which has the lowest monthly temperature of -4.9°C in January and the highest monthly temperature of 16.0°C in July (Figure 12). A high degree of humidity combined with a low readiness is causing valley fog, as is significantly low ventilation and the frequent occurrence of calms. The winter season takes place usually between 26th November and 24th March at an altitude of 1300m, and the vegetation season is around 174-192 days long (*https://www.umwelt.steiermark.at, 2022*).

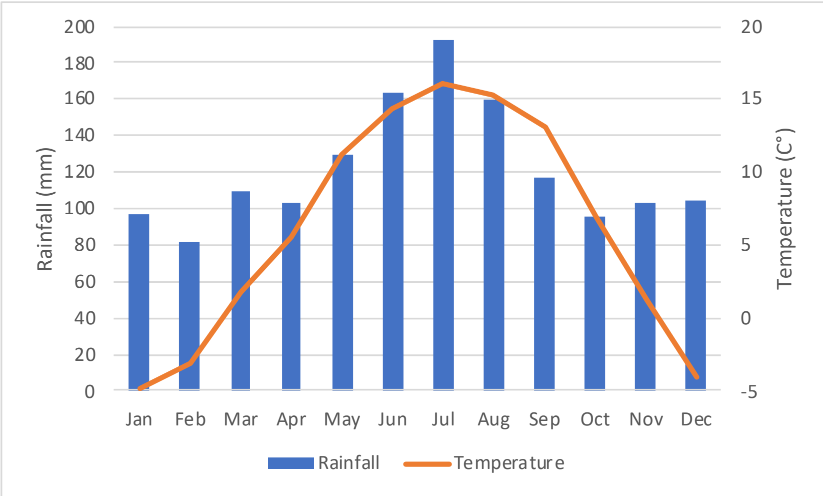

Figure 12. Climate diagram of *Krimpenbachkessel* NFR, adapted (Source: Kasseroler, M. 2011).

The geology of the NFR is mostly homogeneous, with dolomites from the Middle Ansinian to Lower Carnian periods making up the majority of the area (https://www.geologie.ac.at, 2022). Dolomites make up most of the area where the sample sites were established (Figure 21).

According to KÖCK, 1996 two forest communities were identified in *Krimpenbachkessel* NFR:

- Northern Alpine Carbonate-Alpine fir-beech forest (*Adenostylo glabrae-Fagetum* (Moor, 1970))
- Carbonate spruce fir forest (*Adenostylo glabrae-Abietetum* according to Mayer & Hofmann, 1969)

2.2. Sampling design

In order to collect the data, the sampling was carried out on 200 permanent plots by various teams across the six natural forest reserves (Table 6), which were establish in the ELENA project. Due to difficulties in identifying all plots in the field, only 45 of the 56 sample areas in *Schiffwald* were found and investigated.

Table 6. Natural Forest Reserves plots distribution and areas

NFR	Number of plots	Area (ha)
Goldeck	30	58.27
Hutterwald	29	29.4
Schiffwald	45	692.0
Laaser berg	26	63.0
Kronawettgrube	20	7.52
Krimpenbachkessel	50	151.2
Total	200	1001.39

According to the methodology developed in Vacik et al., 2010, the sample areas are circular, with an area of 300m^2 (radius of 9.77m), and for each plot an investigation on five levels was conducted:

- Location survey
- Living trees measurements
- Deadwood measurement, both standing and lying
- Angle count sampling
- Natural regeneration measurements

In this thesis only data from the location survey, the natural regeneration, lying deadwood and living trees measurements will be taken in account for further analysis.

2.2.1. Fixed radius plot - location survey

According to the methodology developed by Vacik et al., 2010 , the following attributes were measured:

- Location description: Verbal description of the sample area and special characteristics of the plot, which can help identifying the area easier
- Exposition in Gon
- Slope gradient in percentages
- Mesorelief: The mesorelief form was observed in 10s and 100s of meter range and assign to the data sheet with a code, according to Table 25 from the Appendix.
- Microrelief: The form of small or micro relief are defined as terrain forms with a length or width of below 10m and a height difference of less than 3m (Table 7):
- Other remarks

Table 7. Microrelief according to Vacik et al., 2010

Code	Designation
1	Small relief balanced
2	Ditches, furrows
3	Humps
4	Block corridor
5	Others (e.g., windthrows)

2.2.2. Natural regeneration measurements

The sampling design of these measurements is made according to the four-cardinal axis (Figure 13), where regeneration areas are found: 10, 20, 30 and 40. The radius of the circle is 9.77m and has an area of 300 m^2. Each regeneration area is divided in 7 subplots: 11, 12, 13, 14, 15, 16, 17 (VII). The subplots 15, 16 and 17 have an area of 1m^2, while 11, 12, 13 and 14 (VI) have an area of 0,25 m2. The centre of the sampling area is materialized by a wooden pole and a metal pole, while the centre of the of the subplots is materialized just by a wooden pole. The saplings with heights higher than 15 cm are marked with a coloured ribbon to make them easier to find in the next cycle of investigation.

The distance between the centre of the circle and the nearest side of a regeneration area is 3m, to the centre of the regeneration area is 5m and to the far side is 7 m.
For each regeneration area (10, 20, 30, 40) according to Vacik et al., 2010, the following parameters are measured:

- Exposition in Gon
- Soil type (see Appendix, Table 26)
- Mean height of ground vegetation (MHB) in cm
- Humus type (Hform) (see Appendix, Table 27)
- Humus thickness (Hm) in mm
- Land cover in %:

  1.Vascular plants with heights below 1.3m height
  2. Mosses
  3. Lichens
  4. Deadwood >10 cm
  5. Branches
  6. Living wood
  7. Litter
  8. Open ground
  9. Debris
  10. Rock

The circle is divided in 4 quadrants:

- Quadrant 1 (S1): Between 0 and 100 Gon
- Quadrant 2 (S2): Between 100 and 200 Gon
- Quadrant 3 (S3): Between 200 and 300 Gon
- Quadrant 4 (S4): Between 300 and 400 Gon

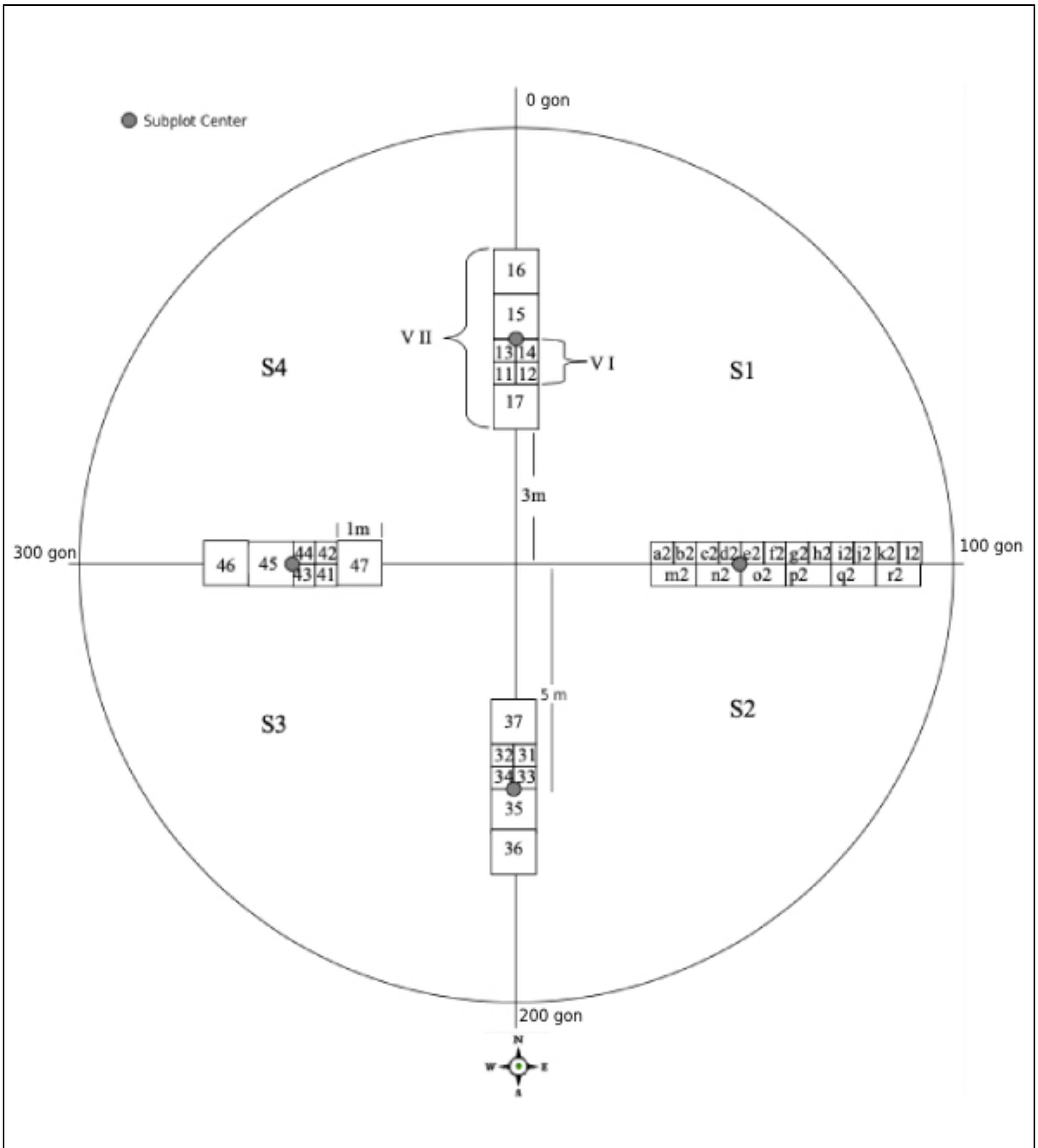

Figure 13. Sample area design Source: Vacik et al., 2010

Natural regeneration was divided into 4 classes,

- Seedlings: yearly germinated seedlings

  In this category, the species and the number of seedlings is counted for the subplots 11, 12, 13 and 14.

- Saplings until 15 cm: perennial sapling with a height below 15 cm.

  In this category, the species, the number of saplings and the annual stage (annual, biennial and perennial) are counted for all subplots in the regeneration area.

- Saplings measuring 15 to 30 cm
- Saplings measuring 30 to 130 cm

In both the 15 to 30 cm and 30 to130 cm categories, the following attributes are measured:

- Tree species
- The saplings were identified in the subplot (11,12,13,14,15... 46,47) or quadrant (S1, S2, S3, S4).
- The root collar diameter (WHD) in cm: the diameter at the ground exit point
- Sapling height in cm
- Height increment on the (HZW) terminal shoot (mm): The last 5 years' heights will be measured.
- Vitality class (Table 8):

Table 8. Vitality classes according to Vacik et al., 2010

Vitality class	Characterisation
1 (Very good)	Colour of needles is intense green and dense needling
2 (Medium)	Needles pale green and less dense
3 (Bad)	Needles pale green to yellowish, not very dense, or sparse

- Browsing damages:

  Terminal shoot browsing [Yes/No].

  Side browsing [Yes/No] and percentage of affected area.

- Microhabitat:

  1. No special feature,
  2. Former deadwood,
  3. Elevated area,
  4. Eavesdrop area of a bigger sapling/tree,
  6. Near deadwood,
  7. Near rock,
  8. Near root system,
  9. Others.

2.2.3. Fixed radius plot – living trees

The trees taller than 1,30 m were measured on the whole plot area. From all the attributes measured in the survey, just the following are in interest for this study in order to determine the basal area:

1. Species
2. Diameter at 1,30 m, in centimetres, using a measurement tape

2.2.4. Fixed radius plot – standing and lying deadwood

For the entire project, both lying and standing deadwood were measured, but for the following study, just the lying deadwood measurements were used.

The following attributes of the lying deadwood with a diameter greater than 10 cm were used in the study:

1. Diameter: measured in cm using a tape measure
2. Length: the horizontal length of the deadwood piece included in the plot measured in centimetres with a tape measure.
3. Decomposition stage (Table 9): for the current study, just classes C and D were used for interrogations.

Table 9. Lying deadwood decomposition stages (Vacik et al., 2010)

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		

The coverage of deadwood with a diameter of less than 10 cm was also measured according to the five categories, as shown in Table 10 and Figure 14:

Table 10. Lying deadwood <10 cm categories and characteristics (Vacik et al., 2010)

Category	Deadwood <10cm occurrence	Characteristics
1	<1%	None or very little occurrence
2	1-3%	Little occurrence
3	4-11%	Average occurrence
4	11-50%	Strong occurrence
5	>50%	Extraordinarily strong occurrence

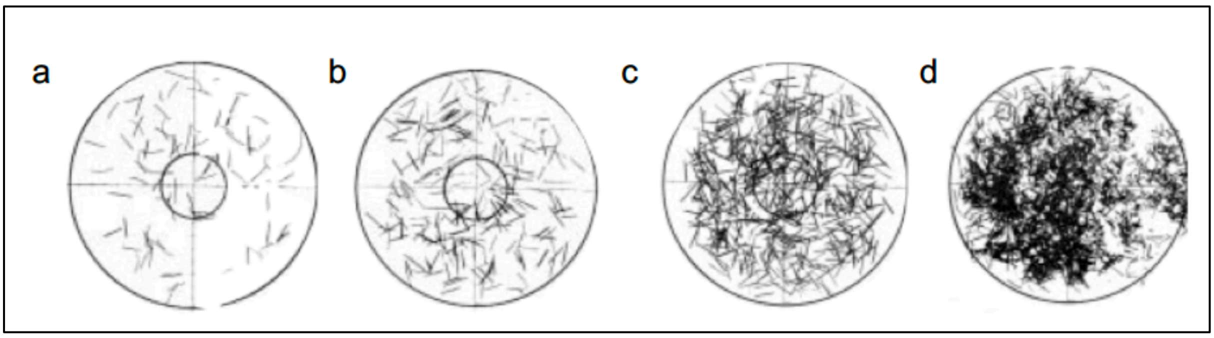

Figure 14. Lying deadwood <10 cm occurrence on the forest floor; a) 1-3%, b) 4-10%, c) 11-50%, d) >50% (Vacik et al., 2010)

2.3. Statistical analysis

The software used for the statistical analysis was Microsoft Excel 16.6 and IBM SPSS 28.0.1. The analysis developed in subchapter 2.4.1 was done using just Microsoft Excel functions. Microsoft Excel was used to develop and code two databases, one for the analysis establishment of seedlings and the other one for the growth. The variables were recoded in order to assure a homogenous analysis across the reserves and to avoid any possible errors. The statistical regression was done using the SPSS software, with each test using the appropriate setting according to the dataset. This study is focusing on Norway spruce only and all the further analysis are not taking in account other species found during the investigation.

2.3.1. Analysis of regeneration

For all the natural forest reserves, the mean number of seedlings per hectare and standard deviation were calculated in order to obtain a perspective image of the density of the seedlings/saplings in the reserves. The calculations were made just for the main species spruce, extrapolating the values per square meter using a blow-up factor (Table 11) for finding the density per hectare for each category of regeneration:

$$N/ha = BF * n$$

Where: N/ha= Number of seedlings/saplings per hectare

BF= Blow-up factor

n= Mean number of seedlings per reserve

Table 11. Sampling area and blow-up factor

Category	Investigation area (m^2)	Blow-up factor
Seedlings	4	2500
Saplings <15 cm	16	625
Saplings 15-30 cm	16	625
Saplings 30-130 cm	300	33.3

The frequencies of the parameters were calculated and presented graphically to illustrate the growth, vitality, microhabitats, and browsing damage of the spruce saplings greater 30 cm.

2.3.2. Analysis of establishment potential

A binary logistic regression model was used to examine the likelihood of natural spruce regeneration germinating and reaching the sapling stage. Based on one or more independent variables that may be either continuous or categorical, a binomial logistic regression predicts the likelihood that an observation falls into one of two categories of a dichotomous dependent variable. The binary logistic regression method looks at the likelihood of a spruce seedling as a dependent variable that is affected by many independent variables(Tabachnick, 1989).

The logistic function for calculating the likelihood of finding a seedling or sapling has the following general form:

$$P_{reg} = \frac{1}{1+e^{-1*(a+b*variable_1+c*variable_2+\ldots n*variable_n)}}$$

Where: P_{reg}= probability for the existence of a seedling

$Variable_n$= independent variable

This method does not use multivariate independent variables that are normally distributed but uses both metric and categorical independent variables. Table 12 shows the variables used in the logistic regression, and the types of values used. All the nominal values were dummy coded to distinguish between various groupings of interval scaled independent variables. The existence of correlation was used to test for interdependencies among the independent variables. The Hosmer-Lemeshow-test was used to test the quality of the model. The Omnibus Test was used to check if the new model (with explanatory variables included) is an improvement over the baseline model.

Table 12. Variables used in the binary logistic regression

Dependent variables	Values in the binary logistic
One or more spruce seedling/sapling occurred in the subplot	1
No spruce seedling/sapling occurred in the subplot	0
Independent variables	Values in the binary logistic
Slope gradient [%]	metric
Basal area of living trees (m^2)	metric
Deadwood area (>10cm)	metric
Coverage of vascular plants [%]	metric
Coverage of mosses [%]	metric
Mean height of dominant ground vegetation [cm]	metric
Microrelief	nominal
Mesorelief	nominal
Exposition	nominal
Soil type	nominal
Humus type	nominal
Humus thickness	nominal
Deadwood below 10 cm	nominal

2.3.3. Analysis of the growth potential

A linear multiple regression was used to analyse the impact that the factors have on the growth of seedlings taller than 30 cm. The high frequency of large saplings made linear multiple regression feasible. As a dependent variable, the height increment of the last 5 years prior to the investigation of each sapling accepted for analysis was used. The linear multiple regression uses the following equation:

$$\hat{Y} = b_0 + b_1X_1 + b_2X_2 + \cdots + b_pX_p$$

Where: $\hat{Y}$= predicted or expected value

b_0=value of Y when all the independent variables are 0

$b_{1\text{-}p}$= estimated regression coefficient

$X_{1\text{-}p}$= independent variables

The regression model aims to estimate the relationship between a quantitative dependent variable and two or more independent variables using a straight line. The model aims to show which of the variables has an influence on the growth in height of the saplings. Table 13 shows the variables used in the regression, and the types of values used. All the nominal values were dummy coded to distinguish between various groupings of scaled independent variables.

Table 13. Variables used in the linear multiple regression

Dependent variables	Values in the linear multiple regression
Height increment of the 30-130 sapling	metric
Independent variables	Values in the linear multiple regression
Basal area (m^2)	metric
Deadwood area (>10cm)	metric
Slope gradient (%)	metric
Exposition	nominal
Microhabitat	nominal
Vitality of saplings	Dummy variable
Very good vigourity	1
Medium vigourity	2
Bad vigourity	3
Browsing	Dummy variable
Affected by browsing	1
Not affected by browsing	0

3. Results

3.1. Description of regeneration

The mean number of seedlings/saplings per hectare for each category and the standard deviation can be found in Table 14.

The density of the spruce seedlings for all 6 of the reserves is 9485±24380 (mean± standard deviation) per hectare. 48% of the plots were occupied by at least one seedling. The maximum density per reserve and per hectare is recorded in *Kronawettgrube* NFR with 47875±54140 spruce seedlings, followed by *Goldeck* with 16167±19127 seedlings and *Hutterwald* with 12931±18934 seedling. All the remaining reserves (*Schiffwald, Laaser Berg*, and *Krimpenbachkessel*) had densities of below 1000 seedlings per hectare.

Density of saplings in the below 15 cm category reaches its maximum value in *Kronawettgrube* with 2781±5124 (mean± standard deviation) saplings per hectare, followed by *Goldeck* with 1979±3340 saplings and *Krimpenbachkessel* with 1575±2601 saplings. The minimum amount was found in *Schiffwald* with a value of 306±737 saplings per hectare.

The overall density of 15–30 cm spruce saplings is the lowest across the different regeneration categories, with a maximum of 781±2658 saplings per hectare (mean standard deviation) in *Kronawettgrube* and a minimum of 0 saplings per hectare in *Hutterwald* and *Goldeck*.

The tallest category of spruce saplings, 30-130 cm, has a maximum of 487±770 (mean±standard deviation) saplings per hectare in *Krimpenbachkessel*, followed by values of around 200 saplings per hectare in *Schiffwald, Hutterwald* and *Kronawettgrube*. The minimum density was recorded in *Goldeck*, with 63±161 individuals per hectare.

Table 14. Mean number per hectare and standard deviation

Reserve	Category of regeneration			
	Seedling	<15 cm	15-30cm	30-130cm
	N/ha	N/ha	N/ha	N/ha
Schiffwald	388 ±1503	306 ±737	28 ±186	232 ±273
Kronawettgrube	47875 ±54140	2781 ±5124	781 ±2658	168 ±256
Laaser Berg	962 ±3942	793 ±1219	24 ±123	131 ±177
Hutterwald	12931 ±18934	948 ±2214	0 ±0	229 ±520
Krimpenbachkessel	550 ±1975	1575 ±2601	238 ±534	487 ±770
Goldeck	16167 ±19127	1979 ±3340	0 ±0	63 ±161
Total	9485 ±24380	1297 ±3108	59 ±284	204 ±380

In the 30-130cm category, 1505 individuals in total were measured. The most saplings were found in *Krimpenbachkessel*, where 730 were counted, and the fewest were found in *Goldeck*, where only 57 were found.

The root collar diameter class 10-15mm shows the highest frequency with 382 individual saplings and a percentage of 25,4% for all the reserves (Figure 15). The class of 15-20 mm has a frequency of 323 individuals with a 21,5%, followed by the below 10mm class with 250 individuals and a share of 16,6%. The minimum frequency is found in the 35-40 class with 43 individuals and a share of 2,9%.

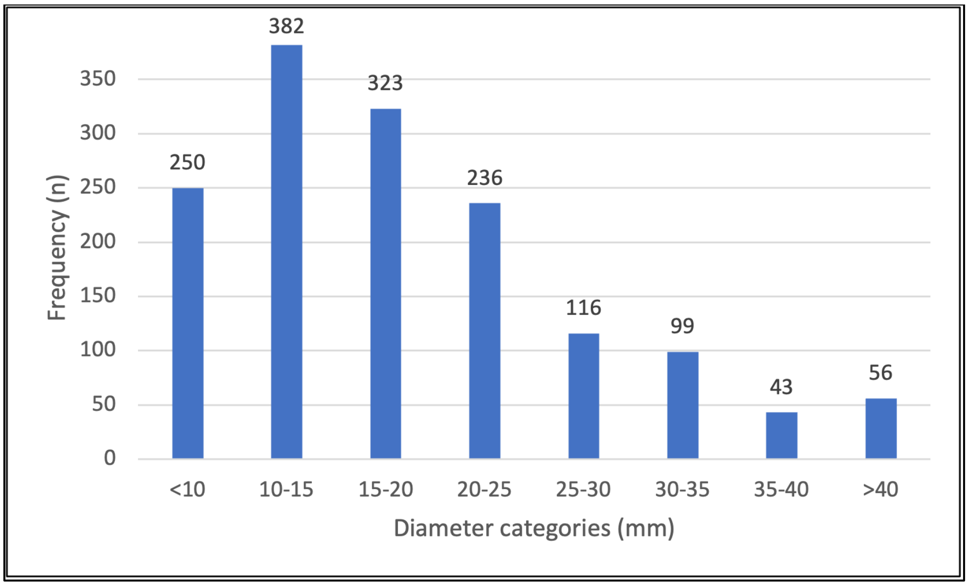

Figure 15. Root collar diameter distribution of large Norway spruce saplings (30-130cm) among root collar classes (n=1505)

In Figure 16, the root collar distribution for each reserve can be observed. *Krimpenbachkessel* and *Hutterwald* follow the same pattern, with the highest frequency in the 10-15mm class, with 230 and 55 individuals. *Schiffwald* has the highest frequency in the below 10 cm class with 152 individuals, while all of the reserves have a low frequency in the 35-40mm class and above 40mm class.

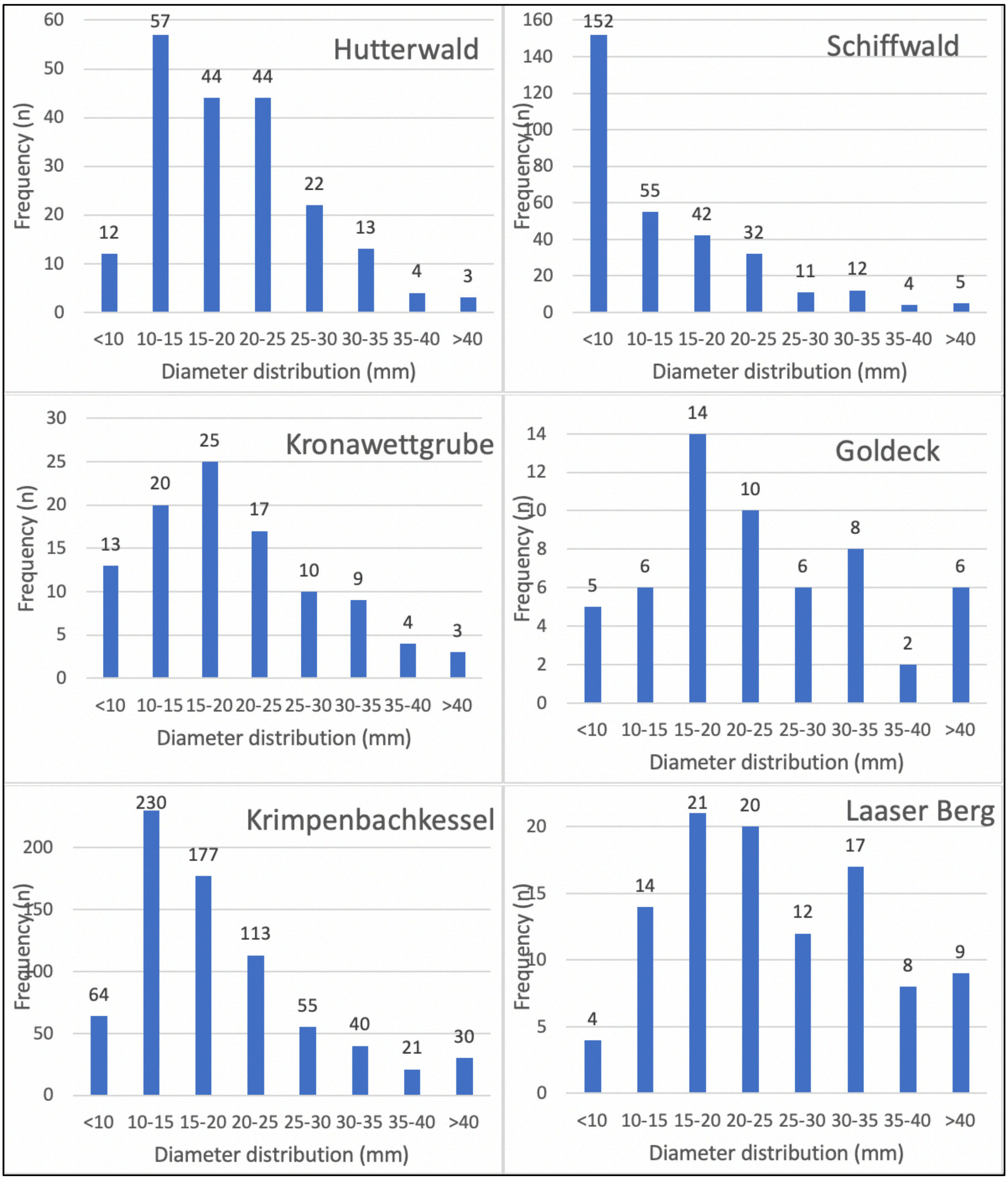

Figure 16. Root collar diameter distribution of large Norway spruce saplings (30-130cm) among root collar classes for each NFR (n=1505)

The height category of 40-50 cm has the highest frequency with 302 individuals and 20.1% for all the reserves (Figure 17). The category of 50-60cm has a frequency of 252 individuals, with 16,7%, followed closely by the 60-70cm class with 216 individuals with a share of 14,4% and the 30-40cm category with 203 individuals with 13,5%. The lowest frequency can be found in the 100-110, 110-120, and 120-130 categories with 56, 64, and 60 individuals, which equivalates to a share of 3,7%, 4,3%, and 4,0%.

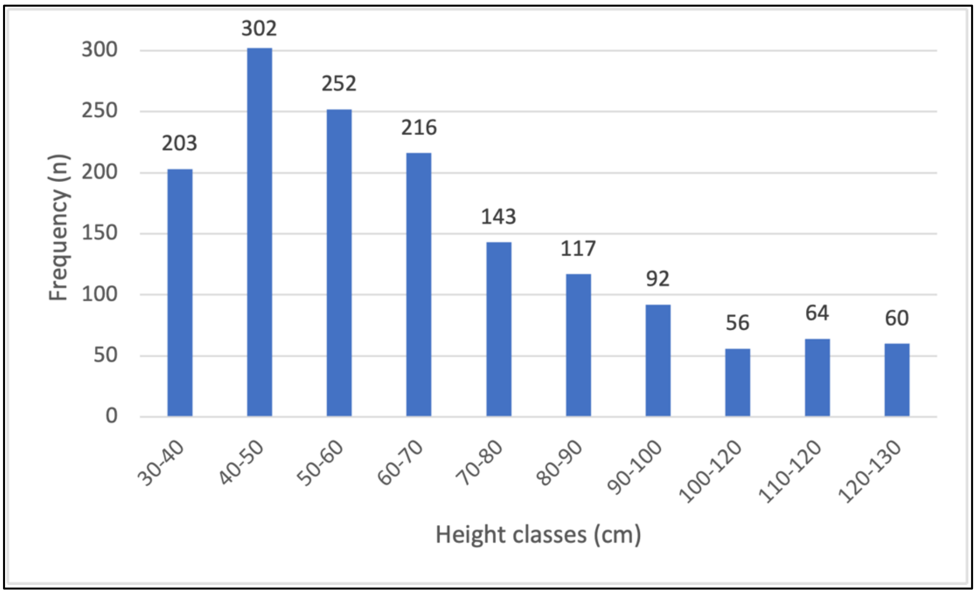

Figure 17. Height distribution of large Norway spruce saplings (30-130cm) among height classes (n=1505)

In Figure 18, the height distribution on all reserves can be observed. *Krimpenbachkessel* and *Kronawettgrube* follow the same pattern, with the highest frequency in the 40-50 cm class, with 25 and 175 individuals. *Goldeck* and *Laaser Berg* present the highest frequency in the first category, 30-40cm, with 11 and 19 individuals. The lowest frequency can be found in all of the reserves at heights between 110-130cm.

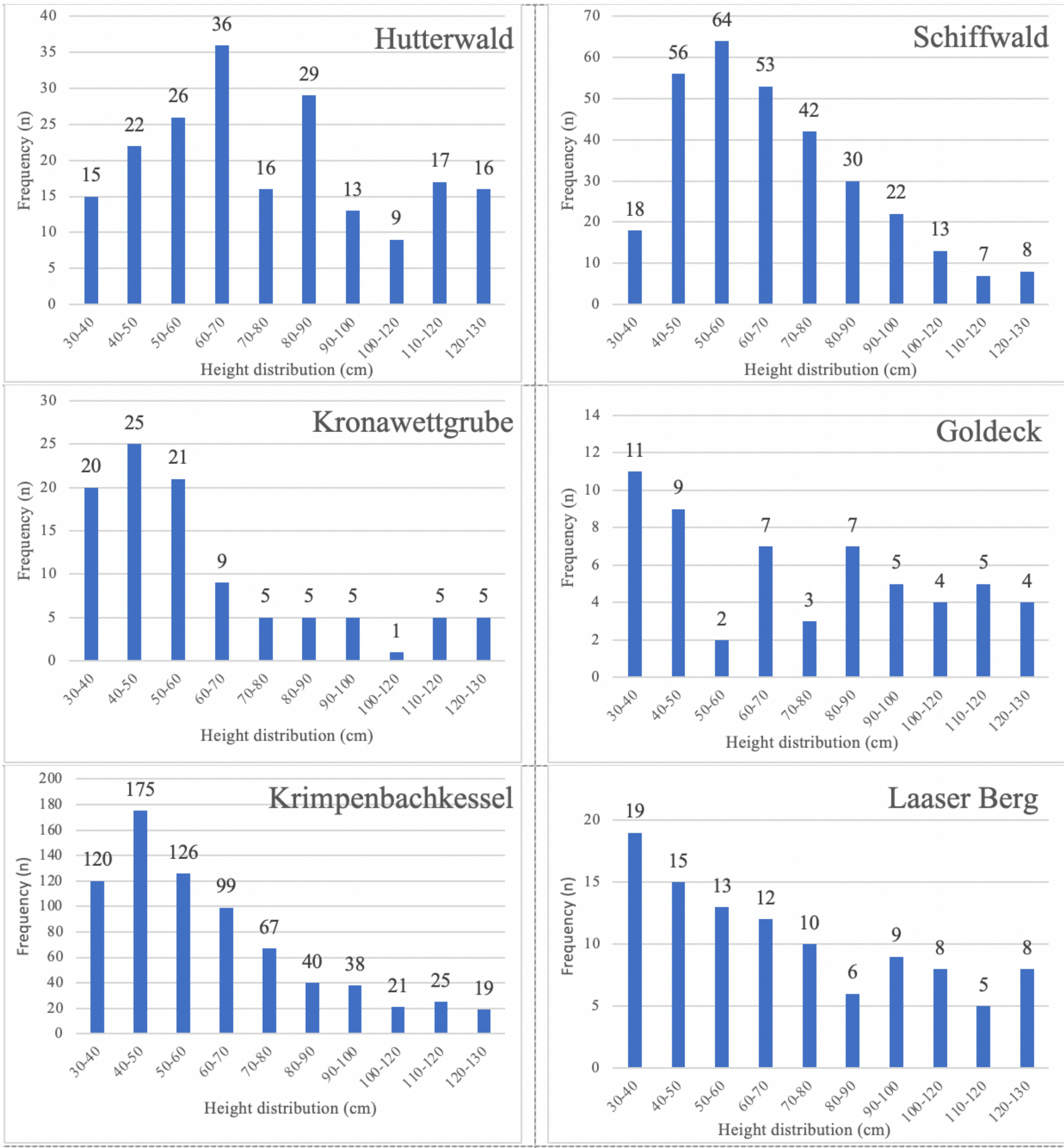

Figure 18. Height distribution of large Norway spruce saplings (30-130cm) among height classes for each NFR (n=1505)

Across all the reserves, browsing occurs in 38.9% of the cases, in 586 out of a total of 1505 saplings. Figure 19 displays the browsing situation for the individual reserves. The highest browsing percentage is found in *Goldeck*, with 84.2% of saplings affected by some type of browsing. The lowest percentage of browsing is found in *Schiffwald* with 22.0%. The highest browsing of the terminal shout can be found in *Kronawettgrube*, with 42.6% of saplings affected, while the lowest value is found in *Krimpenbachkessel*, with 8,1%. The highest share of browsing of lateral shouts and branches can be found in *Goldeck*, with 82,5% of saplings affected, while the lowest value is found in *Schiffwald* with 9,6%. The highest shares of browsing from both the top and side are found in *Hutterwald* and *Goldeck*, with 30,2% and 29,8% of individuals affected by both damages.

Figure 19. Browsing situation for spruce saplings 30-130 cm (n=1505)

Regarding the microhabitat (Figure 20) where the saplings of the 30-130 cm category were found, 20.7% of the individual were situated in the eavesdrop area and 14.5% were located near deadwood. In 52.0% of the individuals were found in category 1, which represent that no special feature was found, while other features were found in just 0.1% cases

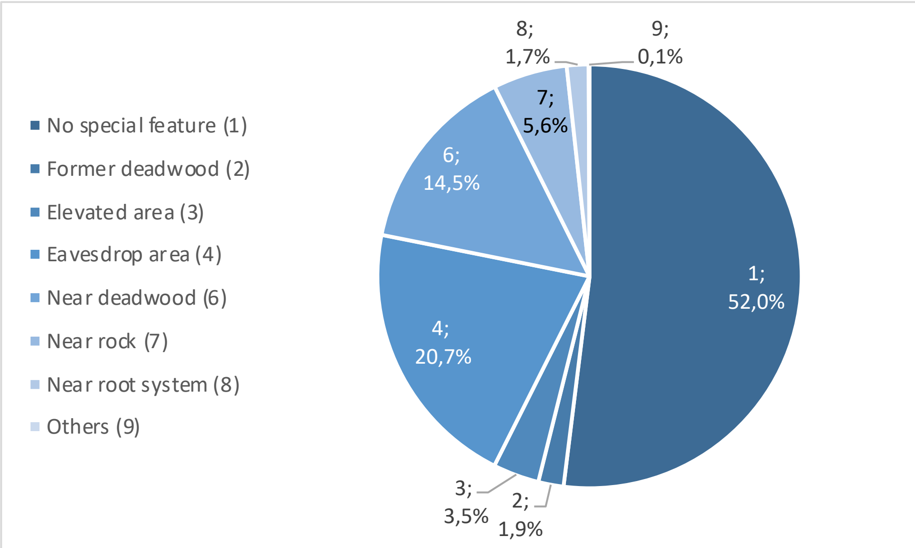

Figure 20. Microhabitat distribution for spruce saplings 30-130cm (n=1505)

For the 1505 saplings investigated, saplings with medium vigourity dominated the vitality parameter with 52.4%. Bad vigourity was present in 34.7% of the individuals, while very good vigourity was found in 12.9% (Figure 21).

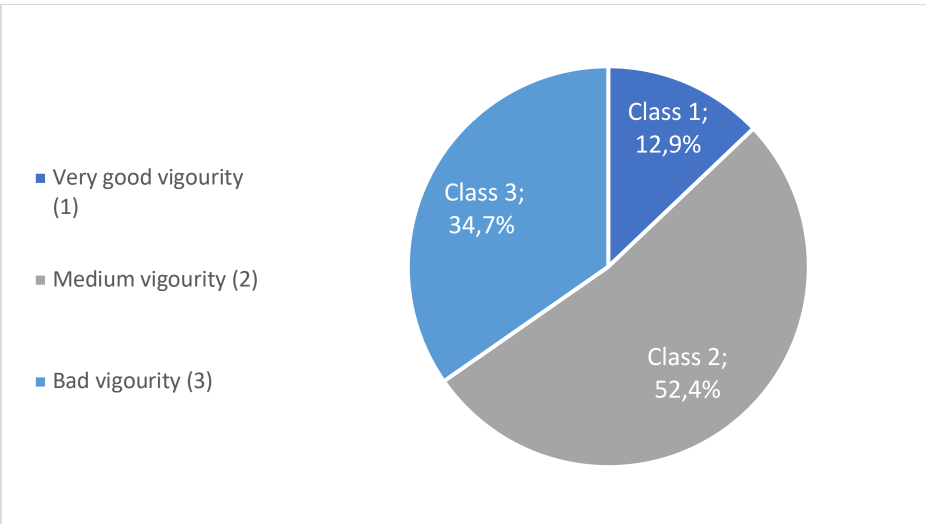

Figure 21. Vitality classes distribution for spruce saplings 30-130cm (n=1505)

3.2. Establishment potential analysis

The analysis of the correlation of the variables used in the logistic regression analysis showed some dependencies. The independent variables mean height of dominant ground vegetation, mosses, humus type, soil type, slope, microrelief, mesorelief, deadwood area, basal area, and deadwood below 10cm in diameter were suitable for the binary logistic regression (Table 15). The independent variable vascular plants, humus type, humus thickness and exposition showed a correlation value >0.3 and were excluded from the logistic regression analysis. The correlation coefficient between a variable and itself is always 1 (represented on the diagonal line), which represents the strongest correlation. The correlation coefficients above and below the diagonal are the same, which is the reason why the above diagonal numbers from table 16 were removed to allow an easier reading of the values.

Table 15. Correlation matrix of independent variables

Independent variables correlation matrix													
Variables	M.H.D.G.V	Vascular plants	Mosses	Humus type	Humus thickness	Soil type	Slope	Micro relief	Mesor elief	Expos ition	DW area	Basal area	DW <10cm
M.H.D.G.V	1												
Vascular plants	.471**	1											
Mosses	-0,137	-.149*	1										
Humus type	-0,085	0,081	-0,098	1									
Humus thickness	-0,131	-0,027	-.174*	.501**	1								
Soil type	0,127	.195**	-.378**	.171*	0,118	1							
Slope	-0,060	-.223**	.149*	-.445**	-.290**	-.375**	1						
Microrelief	-.252**	-.200**	.239**	0,108	0,068	-.273**	.196**	1					
Mesorelief	-0,112	-0,095	0,067	0,011	0,055	-.194**	.248**	0,070	1				
Exposition	-0,104	0,083	-0,131	.303**	.300**	.216**	-.241**	0,086	0,059	1			
Deadwood area	0,064	0,017	.170*	-0,055	-.176*	-.157*	0,058	.200**	0,072	0,029	1		
Basal area	-.405**	-.334**	.206**	-0,092	-0,051	-.392**	.248**	.195**	.150*	-0,116	-0,005	1	
Deadwood <10cm	-0,047	-0,047	.174*	-.223**	-.240**	-.261**	.236**	.164*	0,024	-.190**	.303**	.193**	1
**. Correlation is significant at the 0.01 level (2-tailed).													
*. Correlation is significant at the 0.05 level (2-tailed).													

The overall model is statistically significant, $\chi 2 = 131.509$, with $p < .001$, because in significance column p-values are less than 0.001 (Table 16).

Table 16. Omnibus tests of model coefficients.

Omnibus Tests of Model Coefficients				
		Chi-square	df	Sig.
Step 1	Step	131.509	9	<.001
	Block	131.509	9	<.001
	Model	131.509	9	<.001

In binomial logistic regression, measures can be considered similar to R^2 in the ordinary least-squares linear regression, which is the proportion of variance that can be explained by the model. Therefore, the explained variation in the dependent variable based on the model ranges from 48.5% to 66.1%, depending on whether the the Cox & Snell R^2 or Nagelkerke R^2 methods (Table 17), are considered leading to a likelihood estimated value of 131.224 (Tranmer & Elliot, 2008).

Table 17. Model summary of the binary logistic regression

Model Summary			
Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	131.224[a]	.485	.661

The Hosmer-Lemeshow test (Table 18) examines the null hypothesis that the model's predictions match observed group memberships precisely. The Hosmer-Lemeshow test yields a chi-squared of 6.059 by comparing observed frequencies to those projected under the linear model in the table. A nonsignificant p-value "sig" = 0.641 (p-value greater than 0.001) chi-square indicates that the data fit the model well with $\chi 2 = 6.059$ and $p > 0.001$ (Tranmer & Elliot, 2008).

Table 18. Hosmer and Lemeshow Test

Hosmer and Lemeshow Test			
Step	Chi-square	df	Sig.
1	6.059	8	.641

Table 19 shows the results of the binary logistic regression. For each of the independent variables, the Wald test is employed to establish statistical significance. The Significance column displays the test's statistical significance. From these results, it can be concluded that M.H.D.G.V (W = 5.722, p = 0.017), Mosses (W = 8.182, p = 0.004), Deadwood area (W = 4.333, p = 0.037), Basal area (W = 0.098, p = 0.754) and Deadwood below 10cm (W=8.851, p= 0.005) are statistically significant. Also, Soil type (W = 22.657, p = 0.001) and Microrelief (W = 19.275, p = 0.001) are statistically significant to the model with the p value closer to 0 compared to the other variables (Tranmer & Elliot, 2008).

When all other independent variables are constant, the information in Table 20 is utilized to forecast the chance of an event happening based on a one-unit change in an independent variable. The table shows from the column EXP (B) exponentiation of the B coefficient, which is an odds ratio that having seedlings occurrence in “1” category of deadwood 10cm is 3.615 times greater than opposed to other variables, while most of the variables’ values are around 1.0.Mean height of the dominant ground vegetation, Soil type and Microrelief have an negative impact on the seedling occurrence, while Mosses, Slope, Mesorelief, Deadwood area, Basal area and Deadwood below 10cm have an positive impact.

Table 19. Binary logistic regression for predicting the spruce seedlings occurrence

	B	S.E.	Wald	df	Sig.	Exp(B)
M.H.D.G.V	-,061	,025	5,722	1	,017	,941
Mosses	,040	,014	8,182	1	,004	1,041
Soil type	-,017	,003	25,782	1	<,001	,983
Slope	,025	,011	5,381	1	,070	1,025
Microrelief	-1,066	,209	25,981	1	<,001	,344
Mesorelief	,120	,176	,464	1	,496	1,127
Deadwood area	,114	,055	4,333	1	,037	1,121
Basal area	,147	,468	,098	1	,754	1,158
Deadwood <10cm	1,499	,535	7,851	1	,005	4,478
Constant	-1,212	2,319	,273	1	,601	,298

a. Variable(s) entered on step 1: M.H.D.G.V, Mosses, Soil type, Slope, Microrelief, Mesorelief, Deadwood area, Basal area, Deadwood <10cm.

The likelihood of an occurrence is estimated using logistic regression (in this case, the seedlings' germination potential) occurring (Table 20). SPSS Statistics characterizes an event as happening if the estimated likelihood of it occurring is higher than or equal to 0.5. (seedlings capacity to germinate). SPSS Statistics describes an event as not happening if the probability is less than 0.5. (no seedlings capacity to occur). Binomial logistic regression is often used to determine if instances can be appropriately categorized (i.e., predicted) based on the independent variables.. Because of this, there needs to be a way to compare how well the predicted classification matches the actual classification (Tranmer & Elliot, 2008).

The proportion of accurately predicted cases with the observed feature relative to the total number of cases anticipated as having the characteristic is the positive predictive value. So, this is 100 x (60 / (9 + 60)), which is 87%. That is, of all cases predicted as having seedlings occurrence, 87% were correctly predicted. The proportion of accurately predicted instances lacking the observed feature relative to the total number of cases anticipated as not possessing the characteristic is the negative predictive value. So, this is 100 x (114 ÷ (114 + 15)), which is 88.4%. That is, of all of the cases predicted as not having seedlings occurrence, 88.4% were correctly predicted (Tranmer & Elliot, 2008).

Table 20. Event probability classification table

Classification Table[a]					
	Observed		Predicted		
			Seedlings occurrence		Percentage Correct
			0	1	
Step 1	Seedlings occurrence	0	114	9	92.7
		1	15	60	80.0
	Overall Percentage				87.9
a. The cut value is .500					

3.3. Growth potential analysis

According to table 21, the "R" column represents the value of the R multiple correlation coefficient. R-squared is a statistical measure that quantifies the amount of variation explained by the independent variable or variables in a regression model for a dependent variable. R can be considered a measure of the accuracy of the prediction of the dependent variable (height). A value of 0.112 indicates a good level of prediction. The R^2 number, also known as the co-efficient of determination, is the percentage of variance accounted for by the linear regression model above and beyond that accounted for by the mean model. The independent factors explain 1.3 percent of the variability of the dependent variables, according to the value of 0.013 (West et al, 2006).

Table 21. Linear multiple regression model summary

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.112[a]	.013	.008	25.014
a. Predictors: (Constant), Basal area, Vitality, Microhabitat, Slope, Exposition, Browsing, Deadwood area				

From the Anova table (Table 22), it can be concluded that the overall regression model is a good fit for the data. According to the table, the independent variables vitality, microhabitat, browsing, slope, exposition, deadwood area, and basal area statistically significantly predict the dependent variable height F (7.1495) = 2.732. The p-value is 0.008, which is less than 0.05, so the results are statistically significant (West et al, 2006).

Table 22. Analysis of variance table

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	11964.810	7	1709.259	2.732	.008[b]
	Residual	935439.705	1495	625.712		
	Total	947404.515	1502			
a. Dependent Variable: Height						
b. Predictors: (Constant), Basal area, Vitality, Microhabitat, Slope, Exposition, Browsing, Deadwood area						

When all other independent variables are maintained constant, unstandardized coefficients show how much the dependent variable fluctuates with an independent variable. The unstandardized coefficient B1 for vitality is equal to-1.658, B2 for microhabitat is equal to 0.200, B3 for browsing is equal to 0.992, B4 for slope is equal to 0.059, B5 for exposition is equal to 0.160, B6 for deadwood area is equal to 0.269, and B7 for basal area is equal to -2.207, data from the coefficients table. The t-value and corresponding p-value are in the "t" and "Sig." columns, respectively, shows that the only significant result with regard to the analysis of the height is the deadwood area, with t = 2.409 or p-value = 0.016 which is less than 0.05 (p=0.05) and the rest of all independent variables are statistically insignificant in the coefficient Table 23. The independent variable deadwood area is represented by the area occupied by deadwood found in an advanced decaying stage (C, D and E). The dependent value is represented by the increment in height of the 30-130 cm saplings in the last 5 years prior to the investigation (West et al, 2006).

Table 23. Linear multiple regression results

Coefficients[a]							
Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
	B	Std. Error	Beta			Lower Bound	Upper Bound
(Constant)	65.374	3.394		19.260	.000	58.716	72.033
Vitality	-1.658	1.045	-.043	-1.586	.113	-3.708	.392
Microhabitat	.200	.301	.018	.664	.507	-.391	.791
Browsing	.992	1.448	.019	.685	.493	-1.849	3.833
Slope	.059	.032	.050	1.856	.064	-.003	.121
Exposition	.160	.559	.008	.287	.774	-.936	1.256
Deadwood area	.269	.112	.068	2.409	.016	.050	.488
Basal area	-2.207	1.417	-.044	-1.557	.120	-4.987	.573
a. Dependent Variable: Height							

4. Discussion

To ensure the protective functions of the forests over time, sufficient representation of natural regeneration is required. In the subalpine region, due to the rather harsh site conditions, regeneration takes place rather slowly and forest succession takes much longer compared to plains and hill regions. (Kimmins, 2004; Krebs, 1985). Besides the factors analysed in this thesis, other factors that have an impact on natural regeneration can be mentioned: seed supply, light conditions, fungi and others (Huber et al., 2022).

The mean number of seedlings per square meter for *Goldeck* and *Hutterwald*, 1.29 and 1.62, is similar to the mean number of 1.30 found in the study of Hunziker & Brang (2005) regarding microsites patterns on establishment and growth in coniferous stands. On the other hand, *Kronawettgrube* has a value of around 3.7 times higher, with 4.79 seedlings per square meter. The low representation of the saplings in the 15 to 30 centimetres category might be explained by a high rate of mortality of the seedlings due to inhibitor effects from the environment and other limitative causes like insufficient light, root penetration and water availability (Sofletea, 2007). The mast years are important for seed abundance, and the lack of synchrony with those years in *Goldeck*, *Schiffwald*, and *Laaser Berg* prior to the investigation cycle could explain the lack of regeneration (Duchesneau & Morin, 1999, Hanssen, 2003). To fully understand the relationship between the mast years and the reserves, a monitoring with seed traps and documentation of mast is needed (Mencuccini et al., 1995). The absence of a high density in 15-30 cm saplings in the study sites might indicate that the conditions of the natural reserves are suitable for establishment, but not favourable for further development.

The results indicate that browsing represents an important problem on natural regeneration in the studied natural reserves. Browsing damages have been found in 38.9% of the saplings analysed, a proportion similar to Winter et al., (2009), where 40% of the saplings were affected. This disturbance is caused by large ungulate populations that have increased exponentially in recent decades (Apollonio et al., 2010; Kupferschmid & Bugmann, 2005; Unkule et al., 2022), with improved hunting management being the only solution to control the populations. Due to the eradication of large carnivore populations in the 19th century in

Austria, the current predator populations are insignificant and cannot bring an ecological balance that can reduce the damage created by browsing (Zedrosser et al., 2001).

The study found out that bad vitality in 34.7% was encountered due to intraspecific competition and browsing but also due to insect and pathological attacks. Excellent vigourity was encountered in only 12.9% of cases, with this class consisting of exceptionally desirable specimens that are most desirable in future forests. However, with 87.3 percent, the good and medium vigourity (Figure 21) represented a sufficient percentage for the replacement of the old stand (Winter et al., 2009).

The study indicated that almost half of the saplings over 30 cm were identified in the sample areas as having no special features in their immediate vicinity in terms of microhabitat (Figure 20). A fifth of the saplings were identified in the eavesdrop area, which may result in partial protection from the top and sides from a taller sapling or tree, that can provide a supplementary amount of water and protection. Of the investigated specimens, 14.5% were located close to deadwood, which may provide additional micronutrients and an increased water holding capacity. In the vicinity of the rocks, just 5.6% of the specimens were identified, which can cause an early melting of snow due to the sun exposure. In some cases, the rocks can create a higher effort for root anchoring, although in Baier et al., (2007) study this hinderance did not cause any difference in the sapling development. The microsite of seedlings near former deadwood, elevated areas, near root systems and others occupied only 7.2% of the total.

The evaluation of the results showed that the microrelief as a factor had a significant influence on the seedlings occurrence, which was found also significant in Štícha et al., 2010, a study that used a similar method of recording this parameter and where an elevated microrelief is most preferred by seedlings. The microrelief variation causes different water availability and specific conditions where seedling can develop in proper conditions. Hunziker & Brang, (2005) used a different classification of microrelief in their study, utilizing three classes using the center of the plot as the reference point (convex, concave and even elevation), which made the microrelief not significant in their study. The soil variable is of significant importance in this study and negatively influences the seedlings occurrence. It is predominantly encountered in sample areas containing soils of the rendzina class and in brown clay, where both seedling occurrence and seedling frequency are very low or zero. The characteristics of these soils make seedling germination difficult, and in combination with a deficient humus layer and a dead humus type, the establishment is almost impossible (Sofletea, 2007; Tarziu D.R. et al., 2004; Tarziu D.R. & Sparchez G., 2013). The mean height of dominant ground vegetation in this study has a negative impact on regeneration due to its impact on partial or total shading of seedlings and due to light deprivation, as shown in Diaci J, 1995. In this study, the majority of seedlings occurred mostly in stands with mosses because this variable has a positive influence on the establishment of the seedlings, but this is found in Hunziker & Brang, (2005); Iijima et al., (2007). This is confirmed in similar studies for Norway spruce (Moser O, 1965; Sorg JP, 1980). Moss mats, moisture content of the mosses (Brang, 1996) and moss species are the characteristics that determine the positive influence (Brang, 1996; Hunziker & Brang, 2005; Motta R et al., 1994). Moss depths of below 1 cm encourage spruce germination, while greater depths inhibit it (Frehner M, 2002). In the case of plots with both mosses and northern exposure, it has been proven to have a homogeneous distribution of moisture content throughout the year (Hunziker & Brang, 2005).

Norway spruce is a softwood that does not form heart wood and thus decomposes faster than any other conifer species. The presence of deadwood with a diameter of less than 10 cm, a variable that was significant in the statistical analysis of establishment potential, can be considered a parameter that facilitates seedling establishment, confirmed also by other studies (Zielonka & Niklasson, 2001). The deadwood area was also found to have significant importance for the seedling's occurrence analysis, mostly due to the positive influence that the deadwood has on the nutrient recycling and soil formation, but also from the light availability created after the falling of the trees.(Grassi et al., 2004; Lonsdale et al., 2008). Overall, the deadwood in advanced decomposition stages has a positive impact on the establishment of the seedlings in correlation with the other factor present (Ruprecht et al., 2013; Zielonka & Niklasson, 2001).

The projected area of the deadwood in advanced decomposition stage is one of the major factors influencing the site conditions. This is possible by retaining more water and increasing the moisture content and the amount of micronutrients, but also increasing the forest protection functions (Kupferschmid et al., 2003; Pichler et al., 2012). From the above-mentioned functions, the most important for saplings' growth is the supply of nutrients and water, which can be observed by higher growth in height in plots with a high amount of deadwood. In similar studies, this supplementation has a positive effect and results in higher annual growth, but only where the deadwood is in advanced decay stages (Błońska et al., 2017; Takahashi et al., 2000; Zimmerman et al., 1995).

The limitations of these studies are the hard identification of the plots, the long cycle (10 years) between measurements and modern technologies. Using the modern technologies on these studies can offer more accurate data for interpretation and overall better knowledge. For future studies it would be recommended to extend the studies to other vegetation areas and other tree species. This extension could lead to a better knowledge of forest dynamics at European level and their capacity to combat climate change.

5. Conclusion.

The present study, carried out within the ELENA project, aimed to deepen the knowledge about the dynamics of natural regeneration in Natural Forest Reserves that, from a forest management point of view, which do not foresee silvicultural interventions. Observing and studying the behaviour of forest ecosystem in the absence of any type of anthropic intervention can help to better describe silvicultural approaches, that focus on minimum interventions. In these areas, natural disturbances such as windthrow, snow breakage, insect attacks, thunderstorms, and others are not attempted to be combated, but are studied to find out if the present forest ecosystem is able to survive and perpetuate over time.

The present study was based entirely on quantitative analysis of natural regeneration of spruce. With the magnitude of the data that was collected in the summer of 2021, it was possible to create a sufficiently representative database to allow analysis from several perspectives on regeneration. Through the multitude of inventory micro-characteristics plots, it was possible to identify an overview of natural regeneration in the 2021 inventory cycle for the 4 defined categories. The analysis and statistical interpretation allowed to draw conclusion on the natural regeneration patters of Norway spruce in subalpine forests and for the establishment of a new generation of seedlings, showing, and confirming the importance that some factors (mosses, vegetation, soil and deadwood) have in the establishment of spruce natural regeneration was demonstrated. The analysis of the growth of already established saplings have confirmed that deadwood in advanced stages of decay have an important influence on the release of nutrients which can be assimilated. Other studies in the field of Norway spruce in mountain areas show similar results (Baier et al., 2007; Błońska et al., 2017; Brang, 1998; Hunziker & Brang, 2005; Kasseroler, 2011; Kupferschmid & Bugmann, 2005; Ruprecht et al., 2012; H. Ruprecht et al., 2013; Steiner, 2012; Štícha et al., 2010; Winter et al., 2009), with slight differences depending on the classification and type of data collected.

All the analyses carried out confirms that Norway spruce forests can regenerate without the human intervention, except that the time allocated for forest succession is much longer than for classical silvicultural treatments. These Natural Forest Reserves evolve simultaneously with climate change and natural disasters (windthrows, snow breaks, bark beetles outbreaks) and tend to achieve equilibrium with nature. This study confirms that the forest is a complex system that has the ability to regulate itself through its own powers. The overall results of the thesis shows that Natural Forest Reserves can assure the regeneration of the Norway Spruce in the subalpine region, while simultaneously offering support for biodiversity and conservation.

Appendix

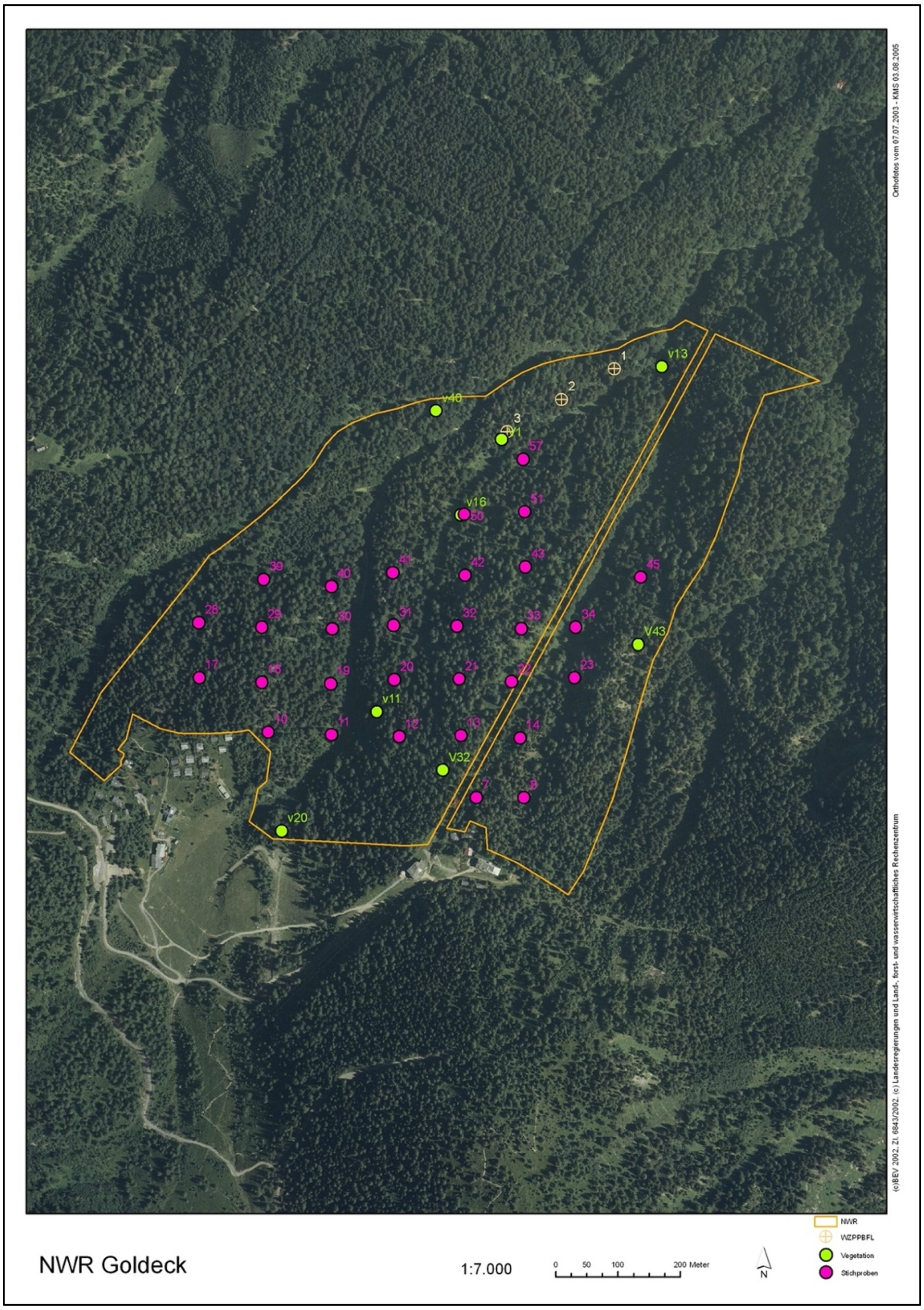

Figure 22. *Goldeck* natural reserve aerial photo with sample points, vegetation survey and borders (Source: Vacik et al., 2010)

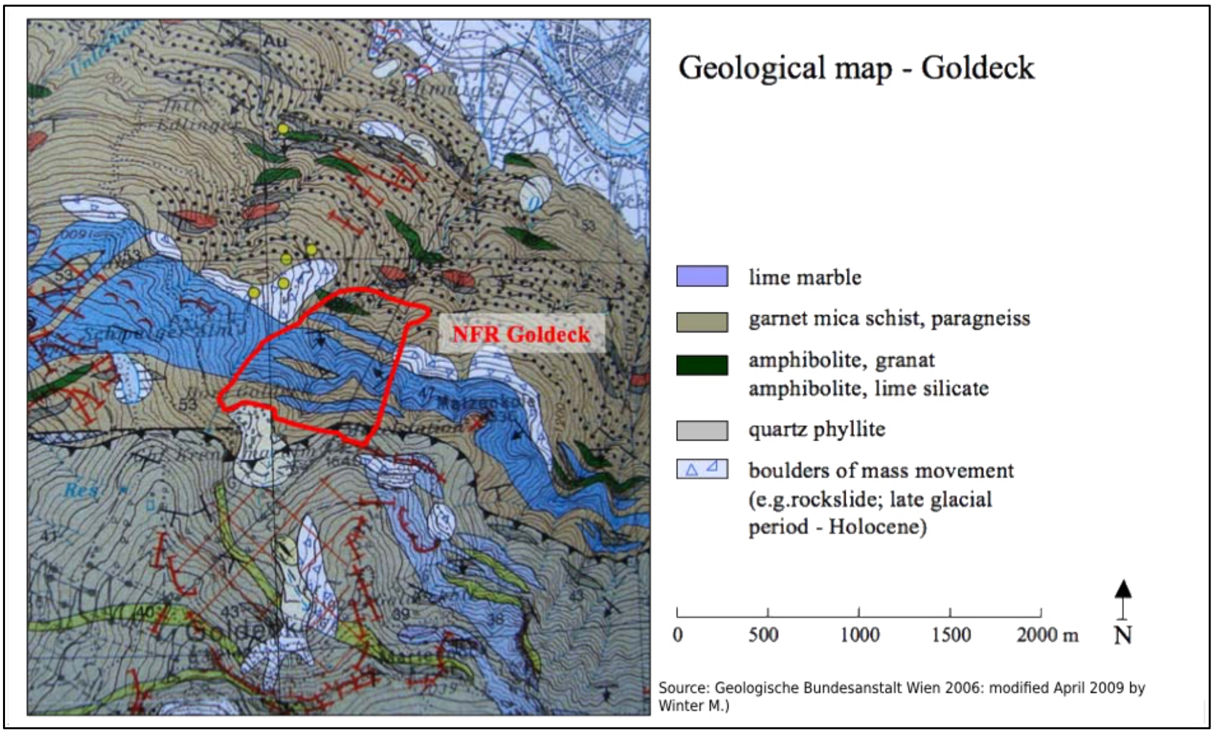

Figure 23. *Goldeck* geological map (Source: Winter M.B., 2009)

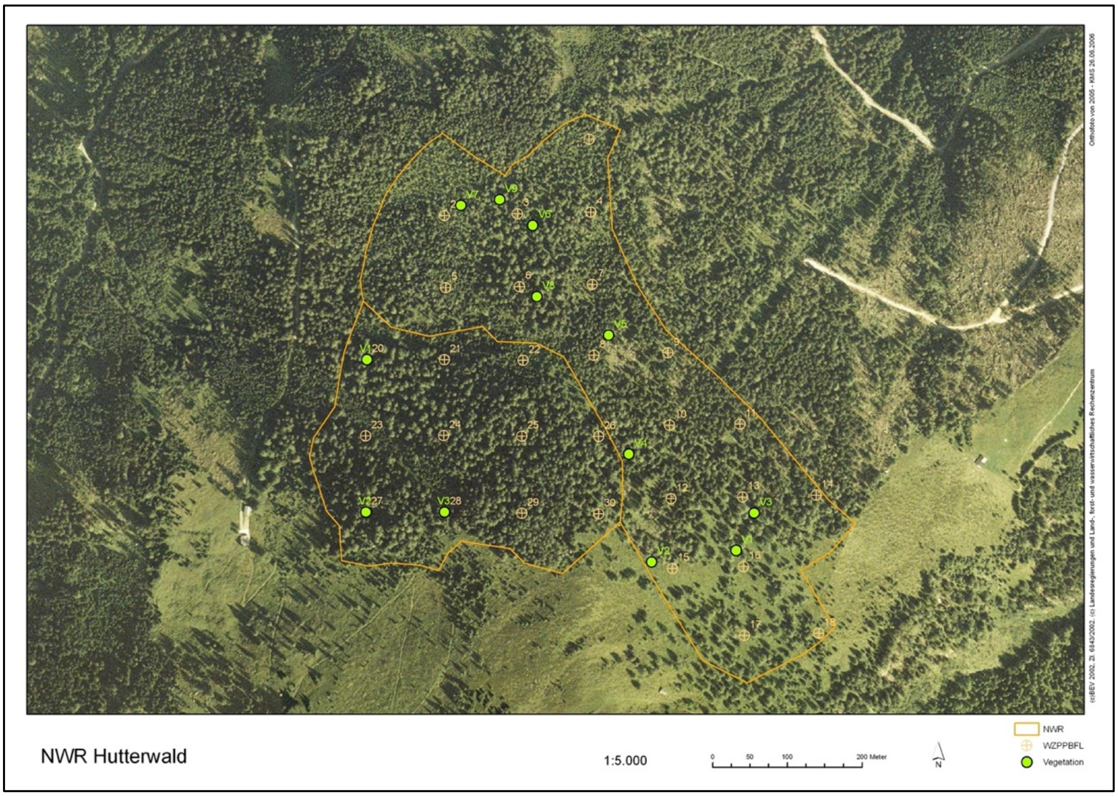

Figure 24 *Hutterwald* NFR aerial photo with sample points, vegetation survey and borders Source: (Vacik et al., 2010)

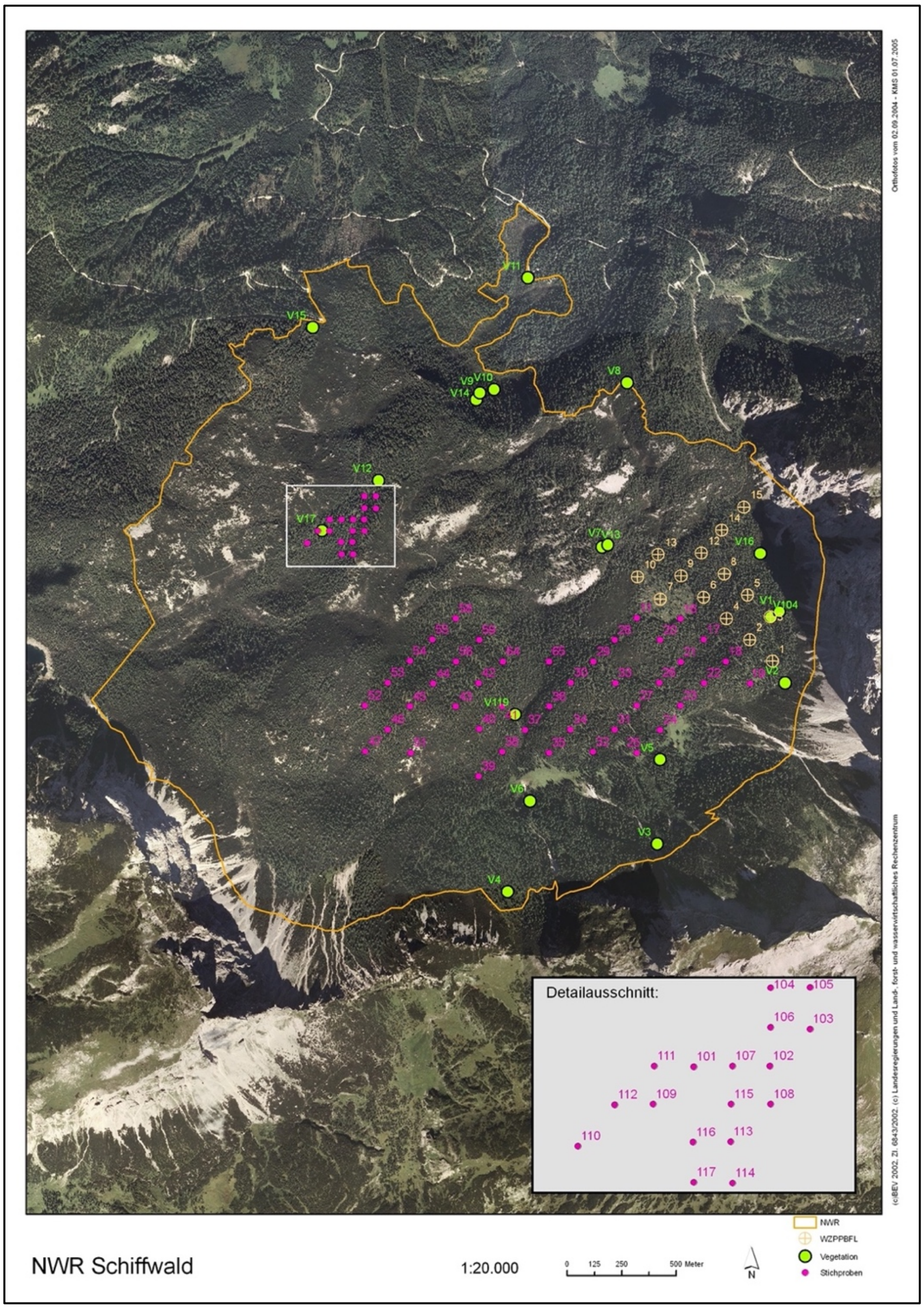

Figure 25. *Schiffwald* NFR aerial photo with sample points, vegetation survey and borders
Source: (Vacik et al., 2010)

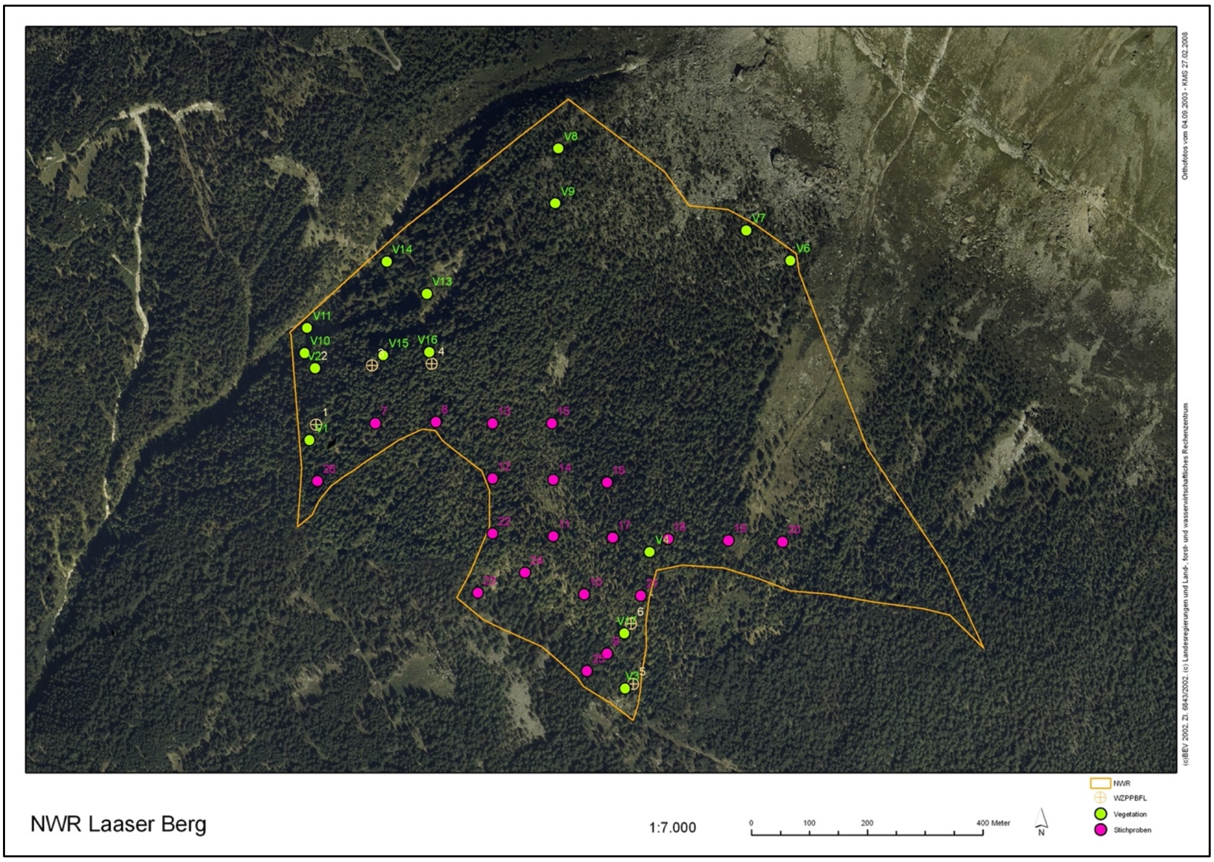

Figure 26. *Laaser Berg* NFR aerial photo with sample points, vegetation survey and borders, Source: (Vacik et al., 2010)

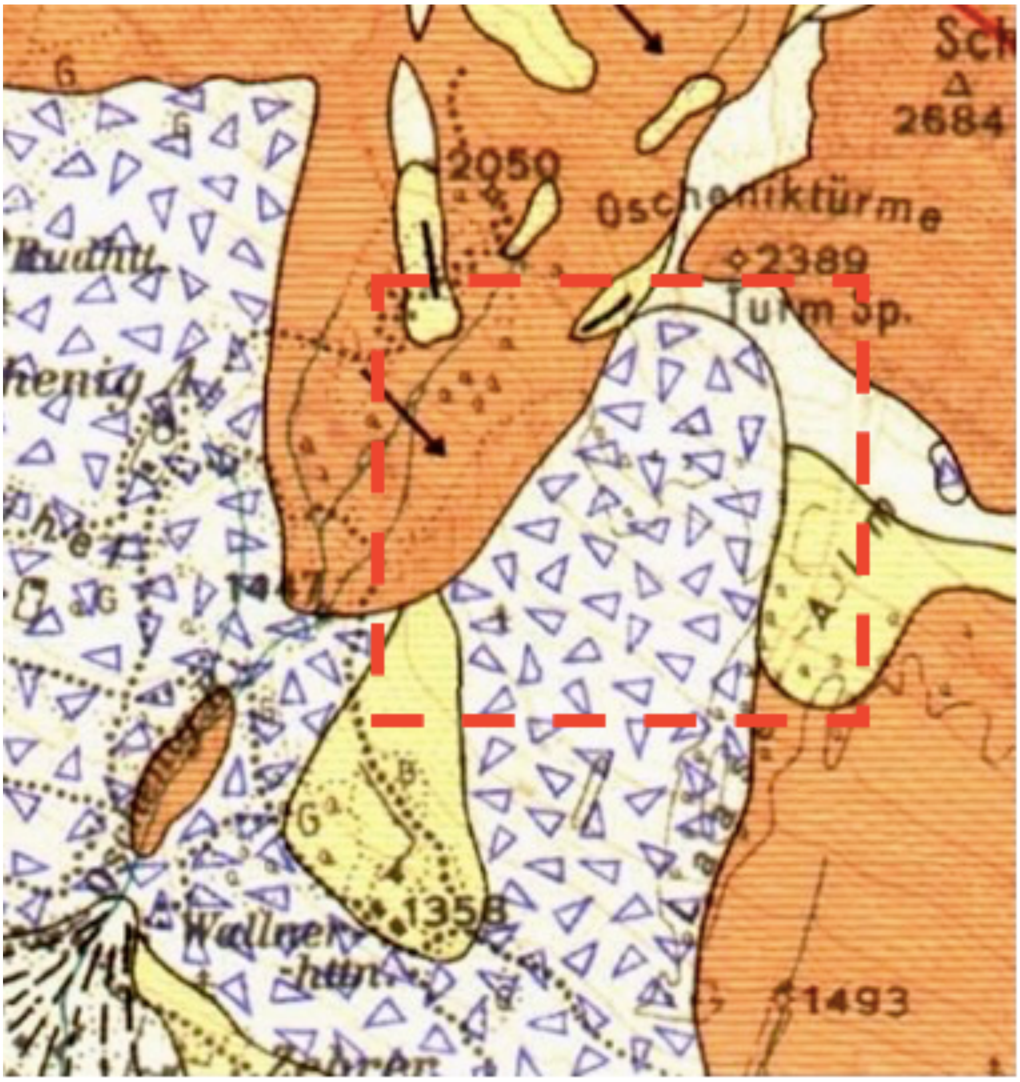

Figure 27. *Laaser Berg* Geological map (Source: https://www.geologie.ac.at, 2022)

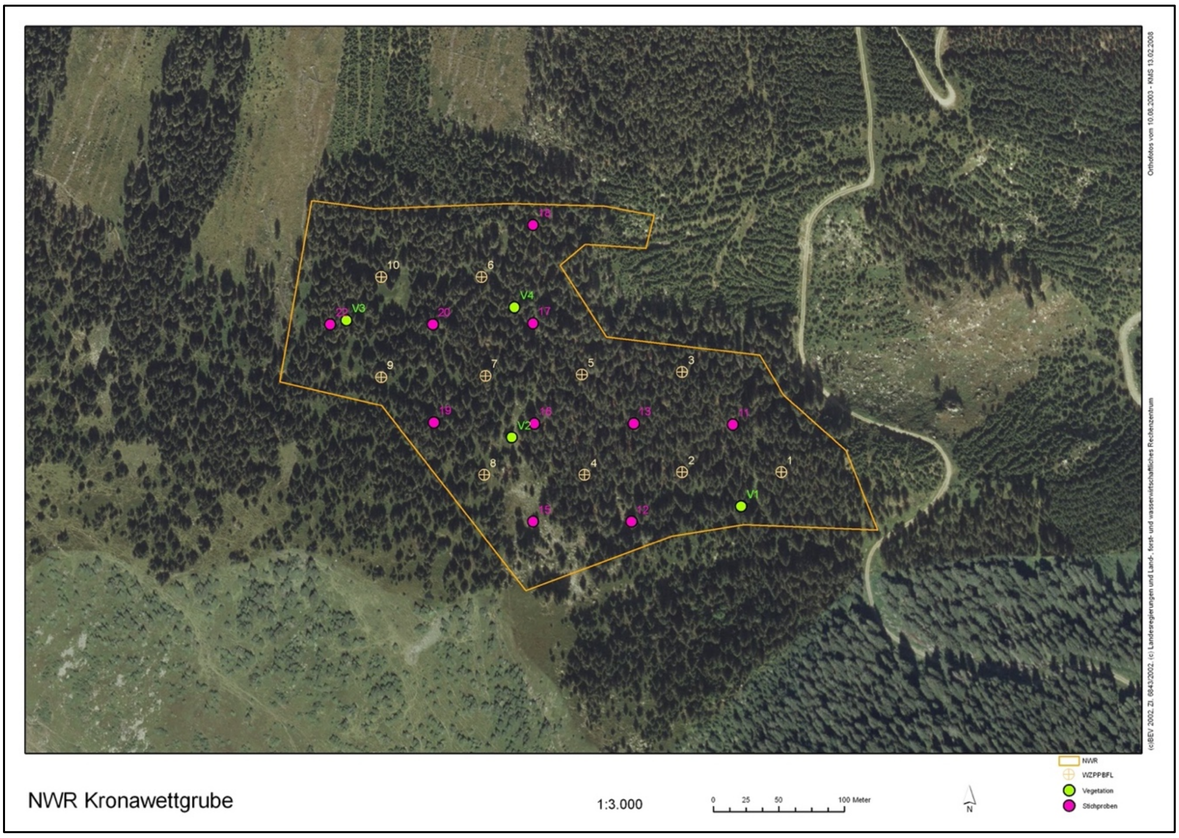

Figure 28. *Kronawettgrube* NFR aerial photo with sample points, vegetation survey and borders, Source: (Vacik et al., 2010)

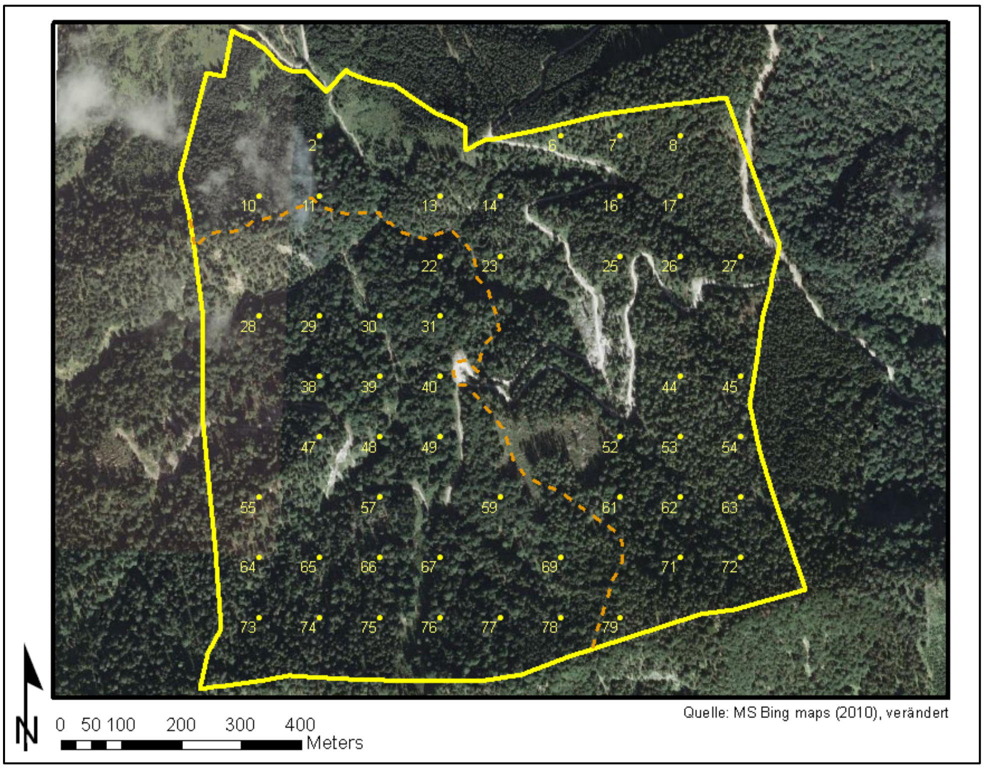

Figure 29. *Krimpenbachkessel* NFR aerial photo with sample points, vegetation survey and borders, Source: Kasseroler, 2011

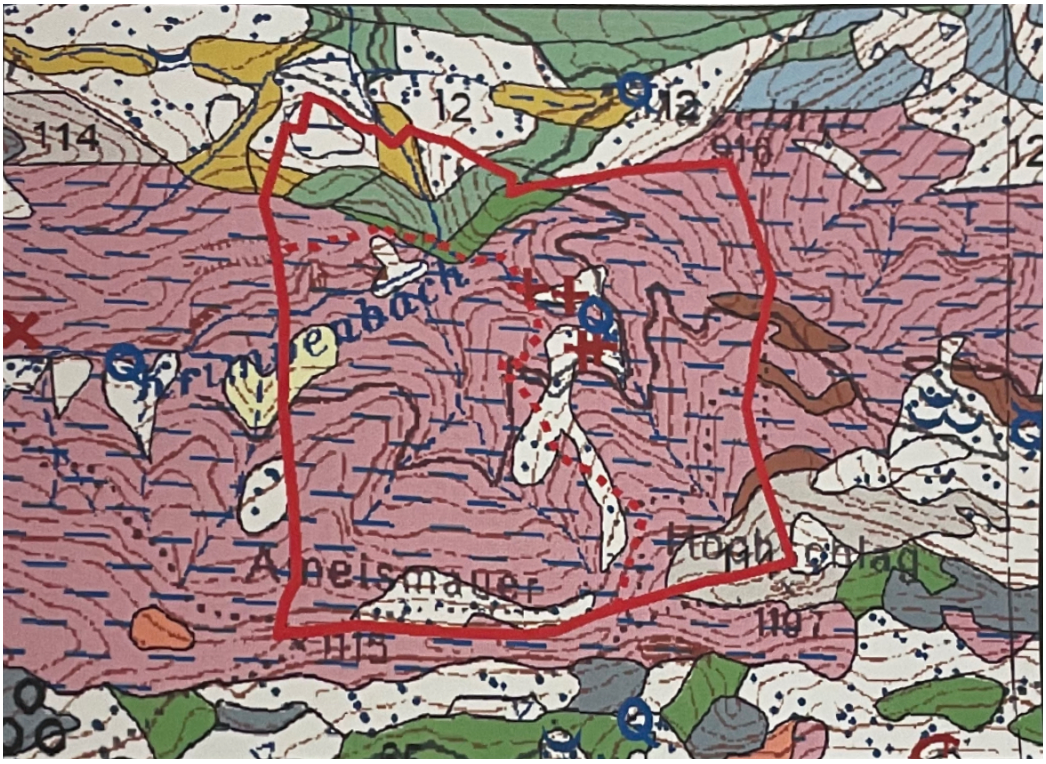

Figure 30 . Geological map of *Krimpenbachkessel* NFR (Source: Kasseroler, M. 2011)

Table 24.. Mesorelief adapted according to Vacik et al, 2010

Code	Designation	Definition of terms
2	Revelling	Flat shape of small extension
3	Valley bottom	Flat shape bordered by rising surfaces
4	Terrace	Shallow form bordered by rising and sloping surfaces
5	Plateau	Flat shape bordered by sloping surfaces
6	Depression	Concave shape with circular ground plan
7	Tub	Concave shape with oval ground plan
8	Trench	Concave shape with elongated ground plan, special case of the lower slope
9	Upper slope	Convex terrain, material removal outweighs material supply
10	Curtain	Concave terrain, material supply outweighs material removal
11	Middle slope	Material supply and removal balanced
12	Slope steepening	Above and below through areas of lower slope limited
13	Slope flattening	Bounded above and below by surfaces of higher slope
14	Dome	Convex shape with circular ground plan
15	Back	Convex shape with oval ground plan
16	Wall	Convex shape with elongated ground plan
17	Slope foot	Transition of the lower slope end into a flat surface
18	Debris fans	Flat backfill

19	Debris cone	Fill form with stronger curvature and mostly steep lateral boundary surfaces

Table 25. Soil type codes and description according to Vacik et al, 2010

Soil	Description
10	Rankers
20	Brown earth and slope colluvia on poorer crystalline rock
30	Brown earth and colluvia on base-rich crystalline and limestone-influenced brown earth
40	Semipodzol
50	Podzol
80	Light brown earth and podsolic brown earth on unconsolidated sediments
90	Cohesive brown earh on moraines
130	Pseudogley on unconsolidated sediments
180	Rendsina
181	Pararendsina
190	Calcareous brown loam Rendsina
200	Calcareous brown clay

Table 26. Humus type and description according to Vacik et al., 2010

Humus form	Description
110	Mull
112	Mouldy gauze
120	Moder
121	Typical Moder
122	Calcareos Moder
124	Rhizomoder
125	Raw humus-like mould
130	Mor
132	Active mor humus
134	Rhizomor

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Curicullum vitae

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DATE OF BIRTH:
24/05/1997

CONTACT

Nationality: Romanian

Gender: Male

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415200 Beius, Romania

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europass

WORK EXPERIENCE

15/08/2019 – 20/09/2019

Field work

O.S. LAZARENI R.A. Forest Administration

- clear-cutting in hornbeam (*Carpinus betulus)* stands

- selecting the future crop trees in sessile oak (*Quercus petrae)* and beech (*Fagus sylvatica)* stands

Gepiu, Romania

25/07/2018 – 15/09/2018

Field work

O.S. BEIUS - Romania State Forest Institute Enterprise-ROMSILVA

- early silviculture (cleaning) of young sessile oak (Quercus petrae), beech (*Fagus sylvatica*) and mixed stands.

- selecting future crop trees in sessile oak (*Quercus petrae)* and beech (*Fagus sylvatica) stands*

-fauna monitoring and construction of hunting facilities and special feeding places for game

BEIUS, Romania

20/07/2017 – 20/08/2017

Field work

O.S. Soimi R.A. - Forest Administration

One month of field working with the staff of the company including:

- Early silviculture (cleaning-respacing) of young pedunculate oak (*Quercus robur*), sessile oak (Quercus petrae) and beech (*Fagus sylvatica*)

- Inventory and marking trees stands of sweet chestnut (*Castanea sativa)*

- Selecting future crop trees in sessile oak (*Quercus petrae)* stands

Soimi, Romania

EDUCATION AND TRAINING

01/08/2020 – CURRENT – Tulliportinkatu 1 , Joensuu, Finland

Master degree- European Forestry

University of Eastern Finland

www.uef.fi

01/10/2016 – 01/07/2020 – 1 Ludwig van Beethoven, Brasov, Romania

Bachelor degree in Forestry - Top of class, Average 10

Faculty of Silviculture and Forest Engineering, Transilvania University of Brasov

Dendrology, Botany, Forest Economy, Silviculture, Afforestation, Forest Management, Dendrometry, Forest Genetics europass

EQF level 6 | https://www.unitbv.ro/en/faculties/faculty-of-silviculture-and-forest-engineering.html

15/09/2012 – 15/06/2016 – Beius, Romania

High school diploma - Mathematics and Informatics

Colegiul National "Samuil Vulcan"

General:

Mathematics, Informatics, Physics, Biology

EQF level 5

LANGUAGE SKILLS

MOTHER TONGUE(S): Romanian

English

Listening	Reading	Spoken production	Spoken interaction	Writing
C1	**C1**	**C1**	**C1**	**C1**

DRIVING LICENCE

Driving Licence: **AM** / Driving Licence: **B1** / Driving Licence: **B**

CONFERENCES AND SEMINARS

Conferences

Participation in two projects with scientific student communications, in session organised by Faculty of Silviculture and Forest Engineering in Brasov in May 2017

-Analysis of plant association with dwarf juniper [*Juniperus communication ssp. n ana(Wild.)*] from Apuseni Natural Park and Rodnei Mountains Natural Park

-Soils characterisation through morphological characteristics and laboratory analysis in Production Unit Noua

Conferences

Participation in "**14th Annual International Junior Foresters' Competition**" in Moscow, Russia in September 2017 with the oral presentation:

-Thinning in a young Norway spruce (*Picea abies*) dominated stand: a case of study

Conferences

Participation in **EU Regulation 995/2010 (due diligence) and FSC (Forest Stewardship Council) certification, tools for promoting responsible forest management**

The conference took place in Rasnov, Brasov county, Romania from 14th to 15th June 2018 and was organised by WWF Romania

INTERNATIONAL STUDENTS' COMPETITION

International students' competition

Participation with the team of Faculty of Silviculture and Forest Engineering of Brasov in "**32nd International Forestry Competition- Forestry Versatility**" in Brno, Czech Republic between 16.04 - 21.04.2018, which obtained the 5th place.

I was also the coordinator of the team. The 15 teams were competing in the following disciplines:

• shooting (shotgun – skeet, battery (at ISSF level)/small bore rifle)
• harvester simulator - John Deere model
• setting up of chainsaw cutter part
• disc slicing from round billet laying on base
• disc slicing from standing round billet
• disc slicing with a two-man saw •disc slicing with a one-man saw supervised by the Czech Republic' Still Timbersports Team
• branching tree
• ascertainment of basic forest inventory quantities
• orienteering, identification of natural objects

International students' competition

Participation with the team of Faculty of Silviculture and Forest Engineering of Brasov in "**33nd International Forestry Competition- Forestry Versatility**" in Brno, Czech Republic between 25.03 - 30.03.2019 which obtained the 4th place.

I was also the coordinator of the team.

International students' competition

Second place on individual order in "**33nd International Forestry Competition- Forestry Versatility**" in Brno, Czech Republic between 25.03 - 30.03.2019.

I gained the second place in the individual ranking of the contest competing with other 44 participants. The disciplines involved were:

• shooting (shotgun – skeet, battery (at ISSF level) /small bore rifle)
• setting up of chainsaw cutter part
• disc slicing from round billet laying on base
• estimation of the species, diameter, height and volume of a tree without using any instruments

PRACTICAL WORK

Practical work

For two weeks, between 15th to 29th of October 2018, I was one of the five students who did practical training **in Beijing, China**.

This practice involved: afforestations, artificial pruning, landscape improvement, identifying the local tree and shrub species, live fence care etc.

Practical work

Practical training in **Beijing, China**, between 13th and 24th of April 2019 involving: afforestation, seedling' care, artificial pruning, landscape improvement, identifying the local tree and shrub species, live fence care, outdoor design and others.

I was the coordinator of 7 students.

Practical work

Practical training in **Beijing, China**, between 28th of September and 7th of October 2019 involving: afforestations, seedling' care, artificial pruning, landscape improvement, identifying the local tree and shrub species, live fence care, outdoor design and others.

I was the coordinator of a group of 14 students.

DIGITAL SKILLS

Microsoft

Microsoft Office / Microsoft Word / Outlook / Microsoft Powerpoint / Microsoft Excel

Video editing

Sony Vegas (video editing) / VideoPAD

Adobe

Familiar with Photoshop / Adobe Indesign, Adobe Audition, Adobe Photoshop, Adobe Illustrator, Adobe Premiere / Adobe Premiere Adobe Premiere pro

GIS, statistic and others

CloudCompare / GIS software: ArcGIS, QGIS / Google Docs / Basi di HTML / GIS (QGIS, QrcGIS, SAGA GIS) / R

Social media

Facebook / Instagram