

**"Coexistence of *Pinus mugo* and
Fagus sylvatica in the national park Gesäuse"**

Master thesis

of

Hanna WATZL

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Supervisor: Ao.Univ.Prof. Dipl.-Ing. Dr.nat.techn. Georg Gratzer
Co-Supervisor: Dipl.-Ing. Dr.nat.techn. Michael Grabner

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Institute of Forest Ecology

University of Natural Resources and Life Sciences, Vienna

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Kurzfassung

Im Alpenraum finden sich häufig gemischte Waldbestände aus *Pinus mugo* und Bäumen unterhalb der Waldgrenze. Diese Wälder weisen je nach Ablauf von sukzessionalen Prozessen, Standortsfaktoren und -dynamik unterschiedliche Koexistenzzeiträume auf.

In der vorliegenden Arbeit wurde untersucht, ob es eine dauerhafte Koexistenz zwischen *P. mugo*, eine Pionierbaumart, und *Fagus sylvatica*, ein in Mitteleuropa dominanter Laubbaum, geben kann und welche Faktoren ebendiese ermöglichen. Daten wurden in einem Waldbestand, bestehend aus den Hauptgehölzarten *P. mugo* und *F. sylvatica*, in einem Wassereinzugsgebiet im Nationalpark Gesäuse erhoben. Standortmerkmale, Baumartenzusammensetzung, Einzelbaummerkmale und Bestandesstruktur wurden auf 21 10x10m Flächen untersucht. Anhand von Bohrkernentnahmen wurden Rückschlüsse auf das Bestandesalter und -entwicklung gezogen sowie Freistellungsereignisse ausgewertet. Lawinensimulationen mittels ArcGIS und ELBA geben Aufschluss über die potentielle Beeinflussung der Untersuchungsflächen durch Lawinenabgänge und die daraus resultierende Schaffung von unterschiedlichen Standortsfaktoren.

Die Ergebnisse zeigen, dass wiederholte Freistellungsereignisse das System zurück setzen und das Vorkommen von Buche eingrenzen können. Obwohl sich *F. sylvatica* im Untersuchungsgebiet erfolgreich verjüngt, hat sie durch Samenlimitierung noch nicht alle Nischen besetzen können. Es konnten Hinweise gefunden werden, dass auch eine Nischendifferenzierung zur Koexistenz beiträgt.

Schlagwörter

Koexistenz, Störungsgeschichte, Bestandesstruktur, Samenlimitierung, *Pinus mugo*, *Fagus sylvatica*

Abstract

In the Alps you can see often mixed forest stands consisting of *Pinus mugo* and other trees below the timber line. These forests show different periods of coexistence due to successional processes, site factors and site dynamics.

It was analyzed if there is permanent coexistence of *P. mugo*, a pioneer species, and *Fagus sylvatica*, a dominant broad leaf species in central Europe, and which factors allow for it. Data was collected in a forest stand, consisting of the main tree species *P. mugo* and *F. sylvatica*, in a watershed in the national park Gesäuse. Site factors, species composition, tree features and stand structure were analyzed on 21 10x10m plots. By means of tree cores conclusions about the age of the stand and its development as well as release events were drawn. Avalanche simulation, created with ArcGIS and ELBA, give information about the potential interference of plots by avalanche release and the resulting creation of diverse site factors.

The results show that repeated release events can set the system back and limit the distribution of *F. sylvatica*. Although regeneration of *F. sylvatica* can establish successfully in the area it has not occupied all niches yet due to seed limitation. Indications were found that a differentiation of niches accounts for coexistence as well.

Keywords:

Coexistence, disturbance history, stand structure, seed limitation, *Pinus mugo*, *Fagus sylvatica*

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1. Introduction

Identifying and quantifying the role of processes, which allow for coexistence of plant species are major topics in plant ecology. Apart from the importance of such knowledge in its own right, an understanding of coexistence is a prerequisite for the development of adequate nature conservation schemes as well as for close to nature forest harvesting schemes. It may also lead to an identification of eventual bottlenecks in protective functions of forest in alpine regions.

Coexistence is possible if the subordinate species can (1) escape the stress caused by resource limitation by the dominant species through temporal partition, (2) tolerates the resource limitation it is exposed to, or (3) exploits habitats, which are unfavorable for the dominant species on a fine scale. Variations in edaphic, climatic and topographic factors and a differential species-specific response in terms of growth and survival, selective predation, different dispersal syndromes or certain spatial configurations of plants can explain their coexistence. According to Hubbell's unified neutral theory (2001), coexistence is not a result of niche differences between species but the result of a spatial saturation process where the probability of replacement of an individual plant is driven by the abundance of conspecific individuals in the neighborhood.

According to Chesson (2000) and Grime (2001), two processes are required for long-term coexistence, namely equalizing and stabilizing mechanisms (Chesson, 2000; Grime, 2001). Equalizing mechanisms tend to minimize differences in average fitness between species (e.g. predators), whereas stabilizing mechanisms "tend to increase negative intraspecific interactions relative to negative interspecific interactions" (e.g. resource partitioning) (Grime, 2001; p.343).

In contrast to the context of these two authors, *F. sylvatica* and *P. mugo* are representatives of different successional stages; *P. mugo* is an early successional species, whereas *F. sylvatica* is a late successional, climax species and the most abundant tree species in Central Europe. *F. sylvatica* is highly competitive under various site conditions. At first glance, it seems impossible that patches of these two species may coexist in close spatial proximity over several life cycles of the species, particularly since they usually do not show large overlaps in their elevational distributions.

Interspecific trade-offs are seen as one aspect allowing for coexistence between species (fig. 1.1).


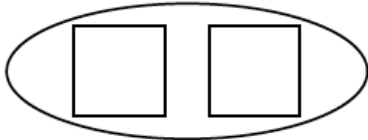
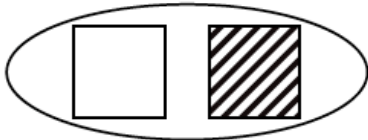
Habitat type	Trade-off traits
<p>(a) Local community:</p> 	<ul style="list-style-type: none"> • Competitive ability • Predator tolerance • Abiotic factors • Stress tolerance
<p>(b) Regional community (homogenous):</p> 	<ul style="list-style-type: none"> • Competitive ability • Colonization ability • Patch use
<p>(c) Regional community (heterogenous):</p> 	<ul style="list-style-type: none"> • Degree of habitat specialization • Among patch trade-offs • Colonization within heterogeneous patches (source–sink)

Fig. 1.1: Coexistence is possible on a different spatial scale, and within a spatial scale, different types of trade-off may occur (Kneitel & Chase, 2004; p.70).

Trade-offs can occur on many scales and in many fields of life affecting a plant. For example, different regeneration strategies are an important parameter for maintenance of coexistence. A trade-off in regeneration would be seed size versus number of seeds, with either many small seeds or less bigger seeds. The first strategy is typical for early successional species showing good dispersal features, whereas the second type has an increased competitive ability (Grime, 2001; Kneitel & Chase, 2004).

Seedling establishment is crucial in plant life. Seed predation by animals and fungi is a limiting factor as seedlings act as main food resources for many species. Therefore, herbivores show selective behavior and favor certain species. Some authors (e.g. Motta, 1996) state that rejuvenation of forests gets suppressed by browsing. Recent studies show that browsing is at least in *P. mugo* stand dynamics no driving factor (Schütz, 2005; BMLFUW, 2006). Before it is possible to establish successfully, seeds have to be dispersed and colonize terrain. Dispersal distance depends much on the type of dispersal (e.g. barochory, zoochory), on seed size and other factors (e.g. release height, wind speed, etc.) (Jongejans & Schippers, 1999; Grime, 2001; Meyer & Carlson, 2001).

Coexistence may result from disturbances as well, allowing early successional species and late successional species to exist and reproduce in close

neighborhoods. Early successional species will grow on spots more affected by disturbances, late successional species will establish on spots less often and severely affected by avalanches. In their study, Abrams et al. (1998) name frequent disturbance events apart from altitudinal variation as supposedly crucial to coexistence between the light-demanding red oak and the shade-tolerant species sugar maple and basswood.

Disturbances are defined by three dimensions; namely time (frequency/ return interval, duration), space (area, location, patchiness) and magnitude (severity) (Glenn-Lewin & Co, 1992).

The most commonly applied definition for disturbances is by White & Pickett (1985): “disturbance is a relatively discrete event in time that disrupts the ecosystem, community or population structure and changes resources, substrate availability or the physical environment”. In the underlying study, this definition for disturbance is used. The definition points out that structural and physical variables of an ecosystem get changed by disturbances, which influences its functions and processes; creation of bare ground, loose soil, light gaps and modified availability of resources are only some results of disturbances. Therefore, disturbance is a viable connection to coexistence.

We see that disturbances are multifaceted processes and are inextricably linked with succession. After disturbances, the affected areas are colonized by early successional species. In case of short rotation periods of natural disturbances (e.g. avalanches), the disturbed plant communities will be repeatedly set back and remain in early successional stages. They will not reach steady state or climax conditions (Forman & Godron, 1986; Glenn-Lewin et al., 1992; Abrams et al., 1998).

Different processes and forces, such as seed dispersal, competition, disturbances and patchiness of resources cause spatial patterns of plant species. Each process and force acts on a specific spatial scale. Therefore, by analyzing the spatial structure of a community it may be possible to point out the underlying process or force. The identification of processes has to be done carefully as many processes can cause similar or equal patterns (Wiegand & Moloney, 2004).

Studies about coexistence, interspecific competition or succession are mainly carried out at one point in time only, like this study. But forest composition, patterns and structure are influenced by its history in which disturbances, release events, change of growth conditions etc. took place (Dang et al., 2009). Analyses of long-term dynamics are fundamental when looking for factors allowing for coexistence (Grime, 2001; Kneitel & Chase, 2004).

Due to timeframe or availability of funds, it is often impossible to carry out long-term studies. Thus, dendroecological investigations are a useful tool to analyze stand dynamics and draw conclusions about disturbance history. The importance of dendroecological techniques in ecology has increased in the past decades and is an often-used tool. Conclusions about age structure and release events can be made (Bonn, 1998; Dang et al., 2009).

1.1 Aim of the study

It is well established (e.g. Ellenberg, 1996) that *P. mugo* is an early successional component establishing after disturbances or abandoned pasture use and a typical element above timberline. Ellenberg (1996) points out that *P. mugo* cannot persist under competitive pressure caused by trees.

The present study is carried out well below the timberline in areas where *P. mugo* occurs in mixture with *F. sylvatica*.

The aim of the study is thus to prove if there is lasting coexistence between the predominating species, *P. mugo* and *F. sylvatica*, below the timberline and to distinguish processes and factors allowing for coexistence.

The following factors potentially allowing for coexistence are analyzed:

- Site differences: fine scaled spatial partitioning versus competition
 - Are there site differences which allow for coexistence, and which parameters do so?
 - Is *F. sylvatica* able to outcompete *P. mugo* on specific sites?
- Disturbances: coarse scaled spatial partitioning
 - Do avalanches shape the distribution of *F. sylvatica* and *P. mugo*?
 - Does a correlation between the spatial pattern of tree species and the occurrence of avalanches exist?
 - Does the frequency of potential disturbance events correlate with age and age structure of the trees?
- Seed limitation
 - Does seed limitation of *F. sylvatica* allow for coexistence of the two species?

2. Study site

2.1 Location

The study area is located in the national park Gesäuse in the Austrian province of Styria.

The Gesäuse is an east western oriented gorge with a length of 18 km and was formed by the river Enns, which divides the Gesäuse Mountains into a southern (Reichenstein and Hochtor group) and northern part (Buchstein group). The Gesäuse Mountains are part of the Ennstaler Alps (Ampferer, 1935; Wiche, 1950 & Büchner, 1970).

The study was carried out in a watershed called Hinterwinkel. The Hinterwinkel (N47°37', E14°37') is an eastern-exposed caldera in the northern part of the national park (fig. 2.2); it is located between the mountains Großer Buchstein (2224 m), Kleiner Buchstein (1990 m), Tieflimauer (1820 m) and Tamischbachturn (2035 m) in the northeast (fig. 2.1). In its lower parts (below 1000 m), beech forests dominate. In its upper parts, the frequency of fens of debris flow is increasing, along with increasing abundance of *P. mugo* (Carli, 2009a).

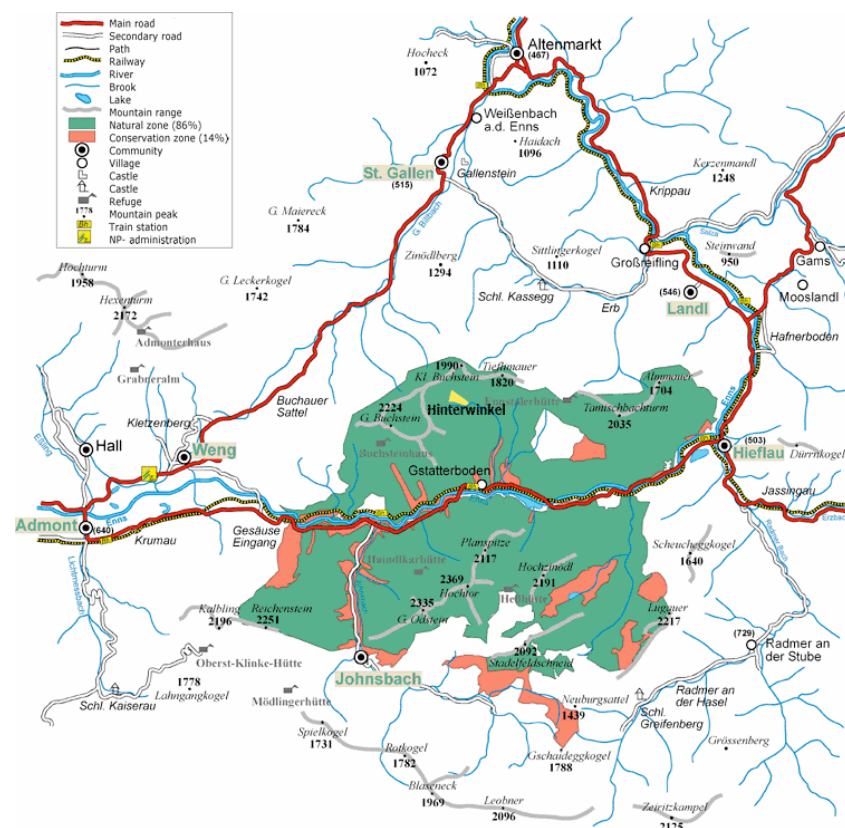


Fig. 2.1: Location of the study area (National park Gesäuse, 2010).



Fig. 2.2: View of the caldera Hinterwinkel in the back.

2.2 Geology and Soils

The calcareous Gesäuse mountain range was sedimented during the Triassic-Jurassic-Cretaceous period, forming layers of 3500 to 4000 m in height. The final lift out of the sea happened in the Cretaceous period; orogeny took place (Ampferer, 1935).

A bulging covering the whole mountain range followed after the formation of the Hieflauer Tertiär (Miocene), which led to the appearance of the mountains close to their present shape. In the northern part of the Gesäuse, this bulging is less well preserved, as it was more affected by the Gesäuse-disturbance. Next, the Miocene layers were eroded and Dachstein limestone was exposed. Erosion of Dachstein limestone started immediately (Ampferer, 1935).

Tectonics of the Gesäuse Mountains is described as complicated due to many folds and thrust faults. The plates are broken and lowering towards the southeast. The plate out of Dachstein limestone ends at its western border, at the Gr. Buchstein (Ampferer, 1935 & Büchner, 1970).

The prevailing rocks are Dachstein limestone and Dachstein dolomite. A short description is given below:

Dachstein limestone

The predominating bedrock is Dachstein limestone, a light, hard and thick rock. It is rarely less than several 100 m thick and was formed in the Triassic.

Dachstein limestone is responsible for the rugged shapes of the mountain range. Broken rocks and boulders often form big talus fens at the base of the rock faces (Ampferer, 1935; Wiche, 1950 & Büchner, 1970).

Dachstein dolomite

Beneath Dachstein limestone is Dachstein dolomite; the transition is mainly abrupt. This dolomite has a higher content in magnesium than Dachstein limestone and is more brittle and fragile. What follows next is a thin layer, the so-called Raibl layer. Underneath the Wetterstein dolomite is found, a very soft material (Ampferer, 1935 & Wiche, 1950).

The bedrock of the Hinterwinkel is covered by a talus fan. This is the youngest debris to be found in the Gesäuse Mountains. If there is no material coming down for some time, talus fans are colonized by vegetation (Ampferer, 1935).

Ice Ages

Before the Würm Ice Age the glacier Ennsjoch was about 1600 m deep and even moved the glaciers of the Gesäuse Mountains. During the Würm Ice Age, the Ennsjoch reached heights up to 1100 m in the basin of Admont. The Gesäuse Mountains were covered with huge glaciers.

After the Würm Ice Age and during the final glacial stage, the valley of the Gesäuse Mountains was no longer covered with big glaciers; only some glaciers with local importance remained (Ampferer, 1935).

The Hinterwinkel was influenced by glaciers originating from the Buchstein plateau. (Wiche, 1950).

Soil types occurring at the study site

Rendzina (WRB: Leptosol)

Horizons: (F-H) Ahb-C; (F-) H-C.

Rendzina is a well-structured, shallow soil and occurs over (continuous) carbonate (limestone, dolomitic limestone, dolomite). It has a high stone and/or gravel content. The A-horizon is black to dark brown coloured and rich in humus (Kilian, et al. 2002 & IUSS Working Group WRB, 2007).

Typically it occurs on sites prone to erosion, as on steep slopes or mountain ridges. Here it forms an intermediate or permanent stage of soil cover as in the Pleistocene strong displacement of material removed old soils and carbonate debris. Regular disturbances hamper the development of deep soils (Rehfuess, 1990 & IUSS Working Group WRB, 2007).

Rendzinas are usually well drained and water storage capacity is low. Rendzinas containing relictic loams have a higher water storage capacity and have higher moisture. The ph-value is between 5-7 (Rehfuess, 1990).

Rendzina mixed with relictic loams

Horizons: (F-) Ahb-AB-C; Ahb-BrelCv (Kilian, 2002).

The humus of Rendzina mixed with relictic loam is mixed with relictic loam above pure carbonate. This soil type is the transitional stage from rendzina to relictic loams. Ahb is loamy with a high content of humus and dark brown to black. This horizon is followed by AB or Brel, which contains relictic loam (Rehfuess, 1990 & Kilian, 2002).

Relictic loam

Horizons: A-Bv,rel-C or A-Bv-C (Kilian, 2002).

Parent material of relictic loam is carbonate. It has a yellow brownish to red brown Bv or Bv, rel horizon, which is enriched in clay (Kilian, 2002).

2.3 Climate

North of the Enns valley is a meteorological dividing line. The whole area to the northeast of this line (nearly identical with the Northern Limestone Alps) forms a climate and weather entity, called the Northern Orographic Barrier. It is the main barrier for all currents from western and northeastern directions (Wakonigg, 1978).

The weather characteristically features frequent and continuous periods of precipitation with high amounts of precipitation. This phenomenon is called "Schnürlregen"; there are hardly fewer than 150 days of precipitation per year. Winter is harsh and cold with a well-developed snow coverage, and summer faces many cool and rainy days (Wakonigg, 1978).

Periods of favourable weather occur at high-pressure conditions and in periods with southern currents (SW, S, deep in the south-west) (Wakonigg, 1978).

Annual course of the weather

Spring

In April, the weather conditions can change very quickly; there are no stable or continuous weather periods. May starts out in a similar manner. Cold air masses are still possible, and there is a high amount of precipitation (Wakonigg, 1978).

Weather can change very abruptly, and many temperature drops and sudden temperature changes occur (Wakonigg, 1978).

Summer

June usually starts out with high precipitation and is a cool and wet period. In its second half, stable high-pressure weather conditions can be observed again as well as the first peak in high temperatures of the early summer (Wakonigg, 1978).

In July, there are many days of high-pressure weather conditions. Temperature decreases, precipitation increases. In the middle of August, the cold and wet situation is replaced by warm and wet conditions. Weather becomes more stable (Wakonigg, 1978).

Autumn

From the beginning of September to the end of October there is a tendency of increasingly good weather periods and a decreasing amount of adverse weather conditions. Southern and southwestern currents are frequent. This period includes the so-called "Altweibersommer" and the "Mittherbst". With transition to November, this situation changes abruptly; precipitation from the north reaches its minimum, southern currents reach their maximum. The first snowfall occurs in the valley bottoms (Wakonigg, 1978).

Autumn is often the period with the best weather, lowest precipitation and low cloud coverage (Wakonigg, 1978).

Winter

The total alpine precipitation decreases. Temperatures are not very cold, emergence of cold arctic air masses are an exception in early winter. The main influence comes from the Atlantic and leads, especially in the northern Limestone Alps, to a high amount of precipitation. In the first half of January, there is a considerable likelihood of thawing events. The last half of January is a very stable period. Characteristically there are low temperatures, frost and high snow reliability (Wakonigg, 1978).

In March, radiation is increasing, typical are periods with good weather; severe morning frosts are likely. Snowfall is still possible in the northern parts of Styria (Wakonigg, 1978).

Temperature

In a 30-year mean (1971-2000), maximum monthly temperatures are measured in Admont in July and August and minimum monthly temperatures in December and January. The highest temperature measured is 35.0°C in July and the absolute minimum is -29.4°C in January (fig. 2.3) (Zamg, 2002).

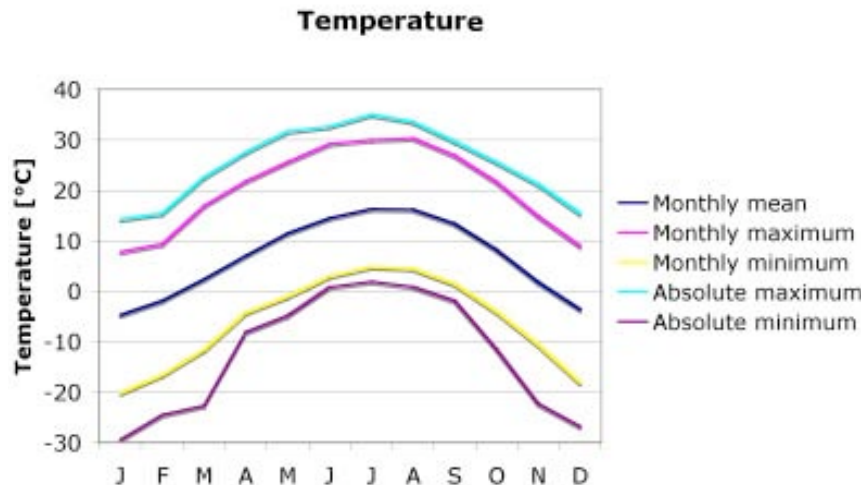


Fig. 2.3: Annual course of temperatures; measured over 30 years (1971-2000) (Zamg, 2002).

The period free of frost lasts in Admont lasts 92 to 180 days, from April 24/June 22 until September 21/October 20 (Wakonigg, 1978).

The study area is located in an altitude of between 1050 to 1250 m. As temperatures are decreasing with an increasing altitude, they are lower in the Hinterwinkel.

Thum (1978) calculated change in temperature as follows:

Table 2.1: Temperature per altitude calculated by Thum (1978).

<i>Altitude [m]</i>	<i>Annual temperature [°C]</i>
600	7.1
800	6.0
1000	4.8
1500	2.5

Precipitation

The accumulation of precipitation along the Northern Alps is very important for the local distribution of precipitation; it can be seen quite often during the whole year and causes a high overall precipitation in the northern Limestone Alps. A clear minimum occurs in autumn (Wankonigg, 1978).

Annual precipitation is 1300 to more than 2500 mm. The highest monthly precipitation is reached in the summer months, with a maximum in July (fig. 2.4), caused by a northwestern current. A secondary precipitation maximum occurs in winter. The number of days with precipitation higher than 1 mm range between 130 to more than 180 days annually (Wankonigg, 1978; Zamg, 2002).

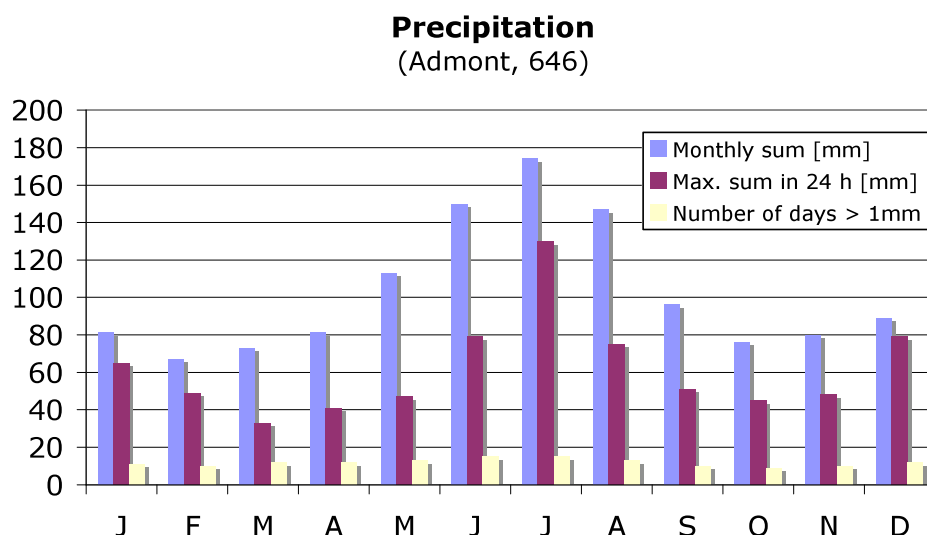


Fig. 2.4: Precipitation characteristics of Admont (Zamg, 2002).

Snow coverage

The share of snow in total precipitation in Admont is, depending on the formula used, between 19.1 and 21.3 % (table 2.2) (Wakonigg, 1978).

Table 2.2: Share of snow of the annual precipitation in % after the sums of new snow heights (A), the formula $A\% = 50 - 5t$ (B) and F. Lauscher 1976 (C) from 1951-1970 (Wakonigg, 1978).

Station	Altitude (m)	A	B	C
Admont	615	21.3	19.1	21.2

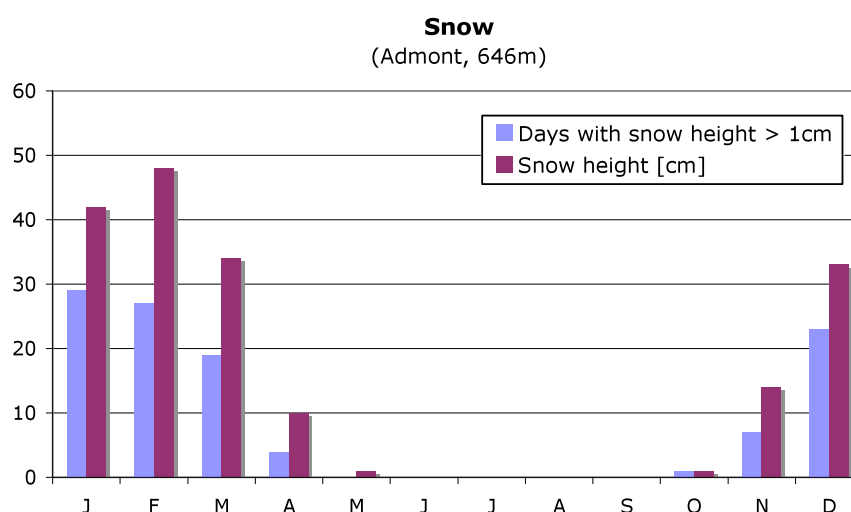


Fig. 2.5: Amount of days with snow height of more than 1 cm and average maximum snow height in Admont (Zamg, 2002).

The total amount of days of snow coverage at the study site ranges from 125 to 140 days, winter snow coverage ranges from 100 days up to 115 days (table 2.3).

Tab. 2.3: Average amount of days with snow coverage in total (S) and winter coverage (W) for the whole of Styria (1950/51-1969/70) (Wakonigg, 1978). The study site is located in altitudes from 1050 to 1250 m.

Altitude (m)	S	W
900	112	91
1000	119	99
1100	127	107
1220	137	114
1300	145	123

Wind

In July, eastern and southeastern winds dominate, while in January western, northwestern and south-eastern winds prevail (fig. 2.6).

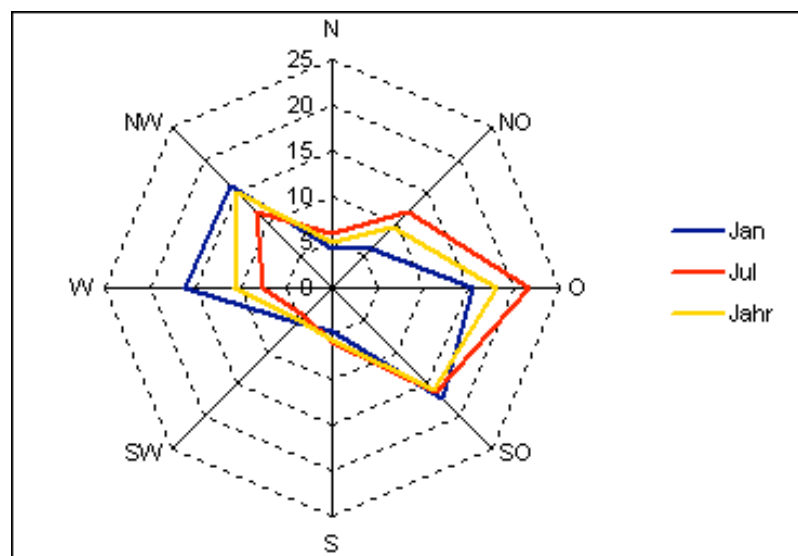


Fig. 2.6: Main wind distribution in Admont (Zamg, 2002).

Upper winds

In winter, winds from the north-west are most common in all altitudes. During spring time, a daily periodical influence is recognisable in 1000 m altitude and reaches its maximum in summer (Wankonigg, 1978).

Wind close to surface

In the inner alpine valleys, calms are to be found quite often, especially in the morning and in the evening. They show a pronounced periodicity during the day, there is no wind during the night, and the winds become stronger during the day. This daytime wind follows mainly the direction of the valley, therefore also occurs in Admont (Wankonigg, 1978).

Northern foehn

This foehn is mainly cold and bora-like. In the transition periods, there is often the danger of night frosts. Typical are a low relative humidity and strong

gustiness of wind. It occurs least in autumn and relatively often in summer (Wankonigg, 1978).

The northern foehn is caused by northern currents with a supply of mostly weak, mature, highly unstable polar air. It can last several hours up to many days. Northern foehn is often followed by high-pressure weather conditions (Wankonigg, 1978).

Vegetation period

The vegetation period is defined by average temperatures higher than 10°C and defines the period of plant growth. Hardly any frosts occur during this period (Wakonigg, 1978).

In an altitude of 1000 to 1200 m, the average amount of days with temperatures higher than 10°C is 105 to 120 days in the northern part of Styria. 180 to 185 days have temperatures higher than 5°C. In the montane zone, the vegetation period is from April 19/May 16 to August 15/25 (Wakonigg, 1978).

2.4 Ecozone

The study site is located in ecozone 4.2, “northern fringe of the Alps – eastern part” (fig. 2.7).

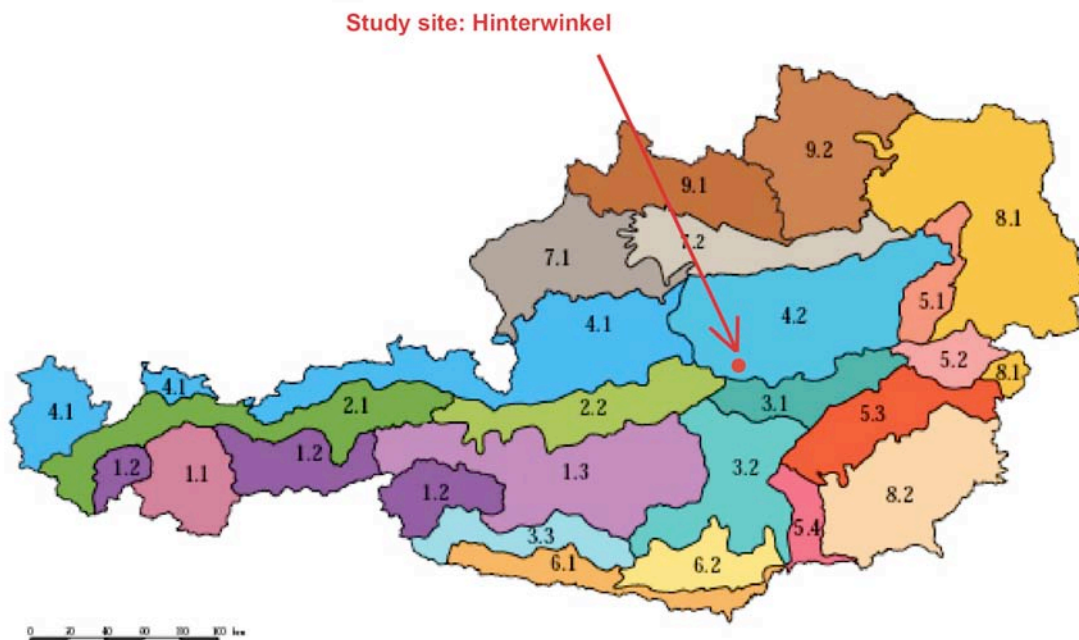


Fig. 2.7: Eco zones of Austria (Kilian et al., 1994; modified).

Altitudinal zonation at the northern fringe of the Alps: m (Kilian et al., 1994) is as follows:

Sub montane 312 - 600 (700)

Lower montane (550) 600 - 800 (900)

Mean montane (700) 800 - 1200 (1400)

Upper montane (1100) 1200 - 1450 (1500)

Lower subalpine (1300) 1450 - 1600 (1750)

Upper subalpine (1500) 1600 - 1900 (2000)

Due to the high range in altitude of the montane level, the mean and maximum values show wide spreads. Besides that, this area shows coherence in landscape and in climate and weather (Wakonigg, 1978).

The study site is located in the mean montane and the upper montane levels.

2.5 Potential forest community

The mean montane ranges of the ecozone 4.2 are typically dominated by spruce-fir-beech forests. In the middle to upper ranges of the montane zone, *Polygonatum verticillatum* is an indicator species. On carbonate, it is found with *Adenostyles glabra* in mid- montane altitudes and with *Carex ferruginea* and *Luzula sylvatica* at upper montane regions (Kilian et al., 1994).

Carbonate-*P. mugo* stands occur typically in the upper sub alpine level; at unfavourable sites, such as avalanche tracks and on talus fens, they range down to the montane level (Kilian et al., 1994).

2.6 Current forest community

Carli (2009a) specified site units close to nature. He named the plots of his inventory closest to the study site “talus fens of higher altitudes” (fig 2.8). Classification was done according to their geology, soil components, local climate and composition of herbs and mosses.

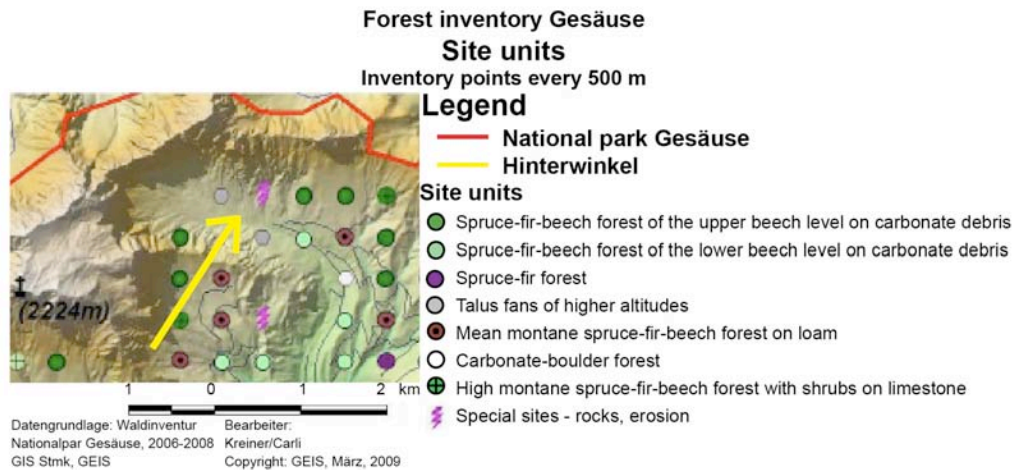


Fig. 2.8: Classification of site units close to nature (Carli, 2009a; modified). The yellow arrow indicates the location of the study area.

On the slopes of the Hinterwinkel-valley head, there is a spruce-fir-beech-forest of the upper *F. sylvatica* belt on limestone debris. In the middle parts of the caldera, there are slope talus fans of higher altitudes as well as special sites (erosion). In lower altitudes a spruce-fir-beech-forest of the lower *F. sylvatica* distribution on limestone debris grows, as well as a mean montane loam-spruce-fir-beech forest and a carbonate block forest (Carli, 2009a). In the north-eastern part, poor beech forests grow; in the south-western part are *L. decidua* stands which are growing openly due to natural disturbances (Carli, 2009a).

Forest stand types

Two of the inventory points closest to the study site are *F. sylvatica* stands in a developmental stage. These stands are grown naturally. Hierarchy by Carli (2009a) is as follows:

- Poor sites¹ with spruce forest species
 - Unweathered debris soils in higher altitudes (stand type 3.1)
 - Stands of *F. sylvatica* in a developmental stage
 - Mean montane beech variant

¹ Poor sites are classified by low occurrence of fine earth and a limited decomposition of humus.

At the valley head, there are special oceanic conditions, and beech forests can develop directly out of patches of *L. decidua* (cf. Kammerer, 2007). In spite of places with immature soil, *F. sylvatica* is the dominating tree species. This can be explained by the oceanicity of the valley head (Carli, 2009a). According to Zukrigl (1961) and Neumann (1978), such beech forests on rendzina in higher altitudes get intermixed only secondarily with *P. abies* and

A. alba. Dbh-classes from 20-35 cm dominate, *A. alba* occurs on the plots and on one plot, a shade slope, *S. austriaca* and *A. pseudoplatanus* are to be found as well. Regeneration of *A. alba* is successful on both plots, browsing is moderate.

Soil formation is immature and can be assessed using the following indicator species: *Lycopodium annotinum*, *Huperzia selago*, *Sesleria albicans*, *Erica carnea*. Species composition can be classified as a variant of *Adenostylo glabrae*-Fagetum calamagrostietosum variaie by Willner (2007), influenced by raw humus (Carli, 2008).

The browsing level observed was 0 – II (II: 26-50% of buds browsed) for *F. sylvatica* and *A. alba*, for *S. austriaca* and *S. aucuparia* up to III (III: 51-75% of buds browsed) (Carli, 2009b).

Avalanches are seen as obstacles for regeneration within forest stand (Carli, 2009b).

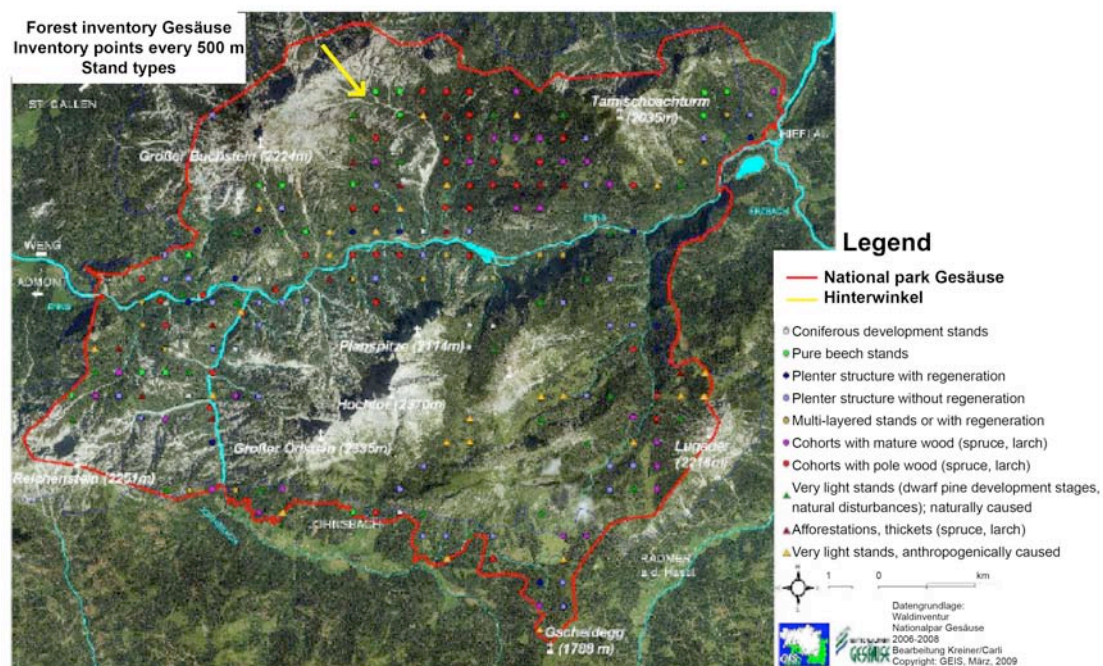


Fig. 2.9: Forest stand types of the national park Gesäuse. The study area is indicated by a yellow arrow (Carli, 2009a; modified).

Hemeroby

Carli (2009a) defined the Hinterwinkel as ahemerob (level 1a) (fig. 2.10), where natural beech-development stages or first stockings of *F. sylvatica* grow. Classification was done according to hemeroby level, regarding stand structure defined by Grabherr et al. (1998).

Plots to the northeast of the research area are close to nature (level 2), which means by definition that the stand consists of the natural main tree species,

but the mixture differs to a small extent from its natural composition (Carli, 2009a).

Stands, adjacent to the study area, were heavily modified by humans. Natural beech stands were replaced by the main economical tree species *Picea abies*, especially at the entrance to the valley head (Carli, 2009a).

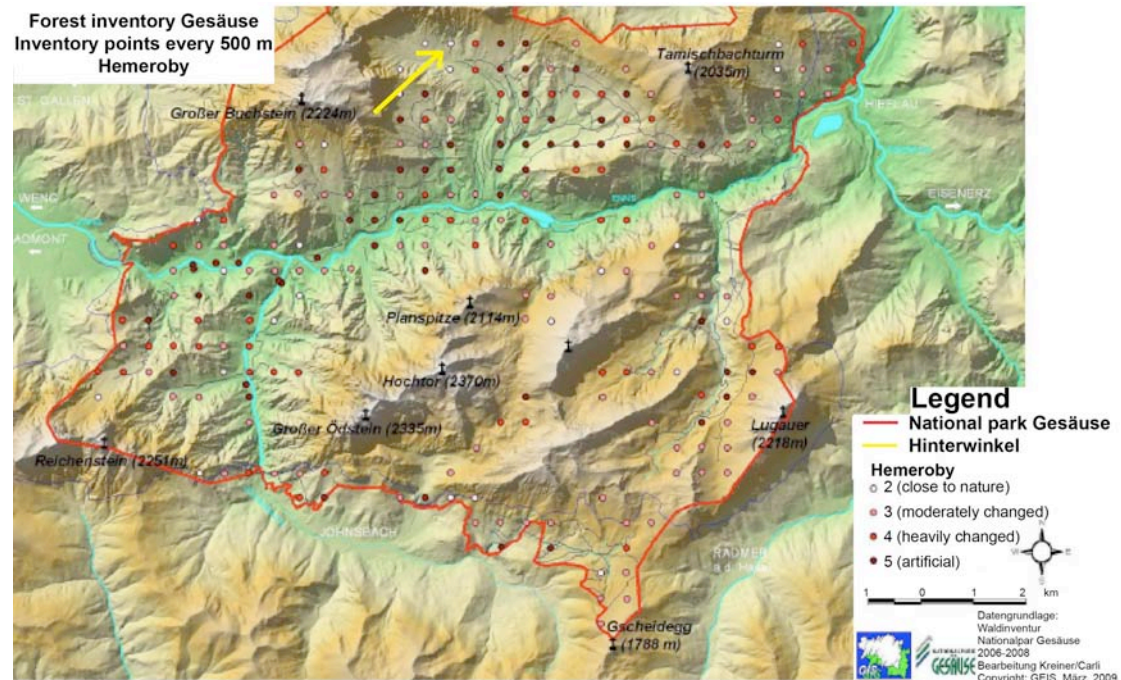


Fig. 2.10: Hemeroby of the national park Gesäuse. The study area is indicated by a yellow arrow (Carli, 2009a; modified).

2.7 Wildlife management in the national park

Till 2004, hunting was leased to private persons on nearly the total area of the national park. Since 2004 the Styrian Forest Administration has been responsible for wildlife management. It is allowed to hunt on 41% of the area of the national park; on the remaining 59% no hunting is done (incl. the Hinterwinkel). Regulation of ungulates is necessary due to missing predators. Targets of prescribed quota for red deer is reached; for roe deer data are incomplete. Fences keep red deer in winter in the national park; four feeding stations exist in the national park (Getzner et al., 2008 & Holzinger, 2010).

2.8 Species

Dwarf pine (*Pinus mugo* Turra)

Geographic distribution

P. mugo is distributed in the Eastern Alps, the Dinarid Mountains, the Harz Mountains, the Carpathian Mountains and scattered in the northern Balkan Mountains, the Abruzzi, the Jura, the Vosges and the Black Forest (Vierhapper, 1916) (cf. fig. 1.2).

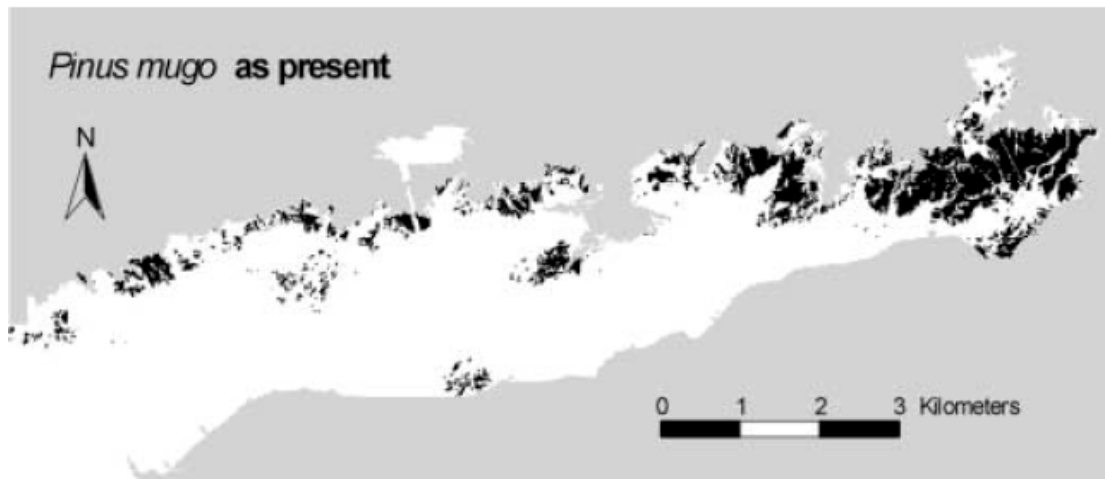


Fig. 2.11: Present distribution of *P. mugo* above 1600 m.a.A. (Dirnböck et al., 2003).

Habitat

P. mugo is a typical species of high elevations. But it has a broad ecological amplitude regarding the elevation in which it can grow; it is found from the sub alpine zone down to deep montane sites. The upper distribution line is caused by climatic conditions, the lower one by interspecific competition. Its lowest occurrence is on poor sites such as raised bogs, rock faces or gorges as well as basins with cold air pending and reaches down to an altitude of 450 to 550 m. *P. mugo* grows under extreme conditions in lower elevations. In case of high snow cover, it is replaced by *F. sylvatica* ("Legbuchen") due to higher danger of snow mould infection for *P. mugo* (Hafenscherer, 1985; Gallmetzer, 1994 & Ellenberg 1996).

Scharfetter (1938) put up a vertical distribution of *P. mugo* in the northern limestone Alps:

Dachstein	1300 – 2000 m
Totes Gebirge	1300 – 2000 m
Ötscher	1200-1700 m
Schneeberg	1350-1850 m
Hochschwab	1400-2000 m

P. mugo grows at a lowest point of approximately 900 m above sea level in the study area.

It can grow under various edaphic and climatic conditions. This results in diverse undergrowth and a couple of communities (Ellenberg, 1996).

Sites, regularly influenced by avalanches, promote the growth of *P. mugo* also within the forest zone on even more productive sites (Hafenscherer, 1985). If

the water storage capacity of the soil is high enough, it is replaced by *Alnus viridis* (Ellenberg, 1996).

Alpine communities free of *P. mugo* are the result of competition with later successional species, infection by snow mould, flooding along torrents or sites in low altitudes, which are too warm and too dry (Hafenscherer, 1985).

Due to alpine pastures, the timberline was lowered, and *P. mugo* forms substitute and forest pioneer communities. This led to an enlargement of its habitat by human intervention (Hafenscherer, 1985 & Gallmetzer, 1994).

Ecology

P. mugo is a pioneer species reaching an age of 200 to 300 years. It has a low growing height. In case of natural and anthropogenic catastrophes, it is able to spread on disturbed and early successional sites because of its colonizing abilities. *P. mugo* can occur in all initial phases of stand development (Mayer 1984 & Hafenscherer, 1985).

The ecological optimum is on permeable carbonate sites at the margins of the Alps, where there is high precipitation. It needs constant soil moisture during the vegetation period, or, if this is not the case, a high air humidity. It is not susceptible to snow gliding and can therefore grow in avalanche tracks. Demands on nutrient supply are low (Hafenscherer, 1985).

On avalanche cones rich in fine soil, the shape of *P. mugo* is more erect, whereas on sites low in fertility the branches are laying down. Below the timberline, development stages rich in *P. mugo* can lead to forest communities with trees, if the soils (mostly rendzinas) are at least moderately deep. Avalanche disturbances set the system back by breaking less elastic tree species, leading cyclically to communities dominated by *P. mugo* again. Also, in case of annual avalanche release, *P. mugo* stands remain permanently (Rubli, 1976 & Hafenscherer, 1985).

P. mugo has only low requirements regarding warmth, vegetation periods of 6 to 8 weeks are sufficient. Dormancy has to be five months. It is resistant against wind and frost events in winter and tolerates late frost (Vierhapper, 1914; Mayer, 1984 & Hafenscherer, 1985).

On sun slopes exposed to wind, frost desiccation can cause death of *P. mugo*. It happens only in rare cases that whole groups of this species die (extreme events) (Hafenscherer, 1985).

Branches are oriented along a slope line, and grow on the soil or below the ground before they start to erect. Usually it is very hard or impossible to allocate branches to their original plant individual (Rubli, 1976).

Roots spread to the sides and build some sinker root in the cracks of parent material below shallow rendzinas or leptosols (Vierhapper, 1914). Secondary rooting of branches, which touch the ground, is possible and was observed in the Hinterwinkel as well (cf. Wessely, 1853).

P. mugo can grow and reproduce on sites, where trees are missing due to harsh conditions also in lower altitudes. There are various reasons for the absence of trees:

- Too cold temperatures in winter (inverse timber line in karst formations)
- High and late melting snow coverage below the timberline
- Very strong winds
- Hardly any soil accumulation on rocks
- Destruction of trees by disturbances
- Very wet and nutrient poor soil

It is often the case that at least some of these factors occur at the same time (Ellenberg, 1996).

Bark peeling by red deer and browsing by chamois was observed by Hafenscherer (1985), but hardly noticed in the Hinterwinkel.

Regeneration

At the age of 6 to 10 years, *P. mugo* starts fruiting for the first time. Contrary to that, Dullinger et al. (2004) state that generative regeneration becomes important only at a higher age of *P. mugo*. At ages younger than 50, fecundity is low. Cones are produced annually. Seeds ripen in the second year and are spread in the following year. The germination rate is 55 % (Hafenscherer, 1985).

Within closed stands of *P. mugo*, there is scarce generative regeneration. *P. mugo* hardly regenerates generatively, only on sites with less competition and with locally high moisture. No spatially continuous regeneration can be found (Rubli, 1976 & Hafenscherer, 1985). It shows only low success in recruitment, 0.0005 individuals/m²/year on average. Seeds are quite frequent in a radius of 20 m to seed source. There is a sharp decline in recruitment kernels at 100 m distance (fig. 1.3) (Dullinger et al., 2004).

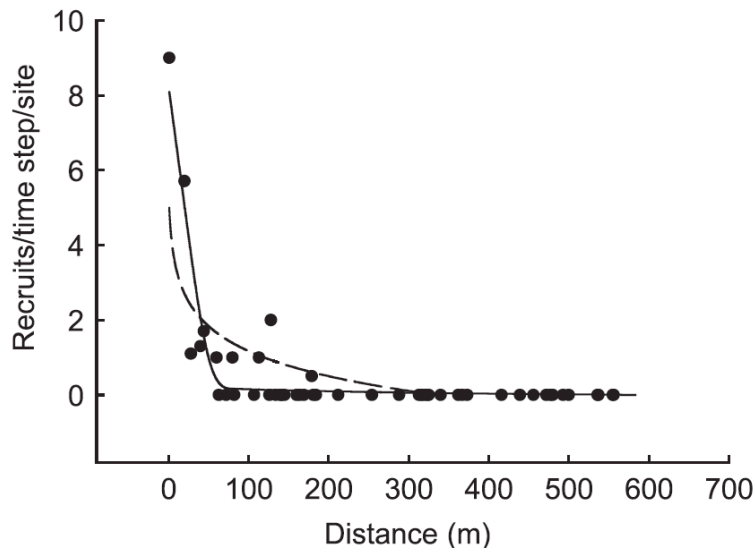


Fig. 2.12: Recruitment of *P. mugo* by Dullinger et al. (2004; p. 246). Dashed line: negative exponential function; solid line: restricted cubic spline function. X-axis shows the distance to nearest site with cover of *P. mugo* > 10%.

Factors hampering generative regeneration are dense grass cover, high layer of humus, sites influenced by fire, sedges, and organic layers. On the other hand, wounded and bare soil on grassy slopes, moist humus, humous cleavages and moist debris promote its generative regeneration (Grembichl, 1893).

There is evidence that growth and fecundity of *P. mugo* are mainly driven by temperature (Dullinger, unpublished data).

Vegetative regeneration is the more important regeneration strategy of *P. mugo* stands. Secondary rooting of branches and branches covered by soil regenerate a stand. Branches lying on the soil due to age, snow pressure, coverage by organic and inorganic material often form roots. At sites that have been disturbed lately, the connection between branches can still be found. But the more time has passed since the connection was formed, the harder it is to find it. Secondary branches, also if still connected, can be seen as individual parts and show a different growth than the parental individual (Hafenscherer, 1985).

Types of dwarf pine stands

Hafenscherer (1985) classified distinct types of *P. mugo* stands. The classification was undertaken by a separation into different habitats. Only the types relevant for the study area are mentioned:

- Avalanche talus cone - type

Avalanches lead to accumulation of inorganic and organic material especially at the end of avalanche tracks. Therefore, this region is especially rich in nutrients. Species of the spruce-fir-beech forest indicate the availability of

nutrient, namely *Mercurialis perennis*, *Prenanthes purpurea*, *Hepatica nobilis*, *Dactylis glomerata*, *Calamagrostis varia*, *Fragaria vesca*. Especially at the margins of the avalanche track, *P. mugo* is replaced by trees and shrubs if the danger of avalanches is low.

In lower elevations, *F. sylvatica* can replace *P. mugo* even within the avalanche tracks if there is a high threat of snow mould.

The stand structure of this type is tessellated due to different ages of single groups. Protected by *P. mugo*, *Picea abies*, *Abies alba*, *F. sylvatica* and other tree species can germinate.

- *P. mugo* on debris talus

P. mugo can grow on debris talus. Colonization, development, stand structure, all these features depend on the stability of the deposition and the level of soil formation. Secondary covering can drive the system back to initial stand development phases. Inside the stand, the successional stage is more developed than in the marginal area (Hafenscherer, 1985).

- Sub alpine to montane community in transition

Hafenscherer (1985) also classified a *P. mugo* community rich in end successional tree species as deep sub alpine to montane community in transition. This type can be found on edaphic less extreme sites, with an advanced soil formation and a low danger of avalanches. Tree species can colonize the avalanche tracks fluctuating.

European beech (*Fagus sylvatica* L.)

Geographic distribution

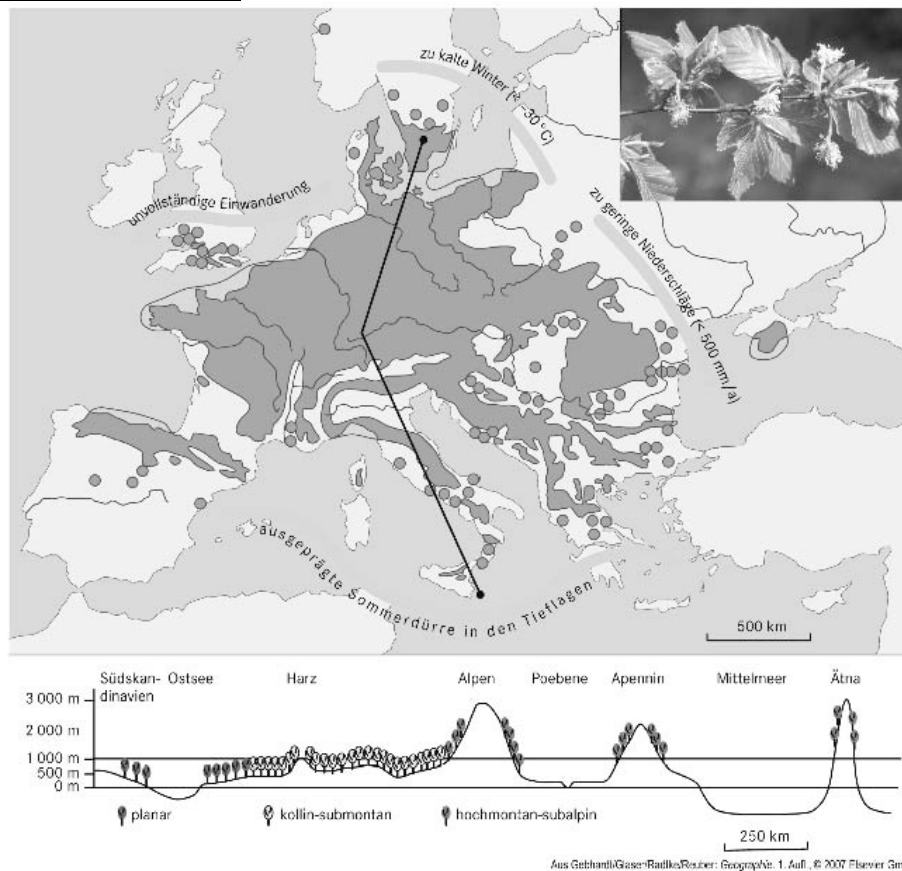


Fig. 2.13: Geographic and orographic distribution of *F. sylvatica* (Gebhardt et al., 2007).

Habitat

F. sylvatica is the dominating species of Central European forests. It can grow on all types of soil, but preferably on limestone, and grows in close connection to oceanic climate. It can compete with other shade-tolerant species very well under the following conditions: soil which is neither too wet nor too dry, soil which is not too fertile, climate which is not too cold. In Central Europe, *F. sylvatica* is the dominating species under various conditions, which has its ecological optimum in the lower montane zone (Leibundgut, 1991; Ellenberg, 1996). Beech forests grow at up to 1430 m elevation, the highest growing individual Zukrigl (1961) can be found above 1500 m in the limestone Alps of lower Austria. Their growth is shrub-like in such elevations. *F. sylvatica* can even be the tree-line forming species in the south west of Central Europe. Furthermore, it can grow on slopes with any aspect (Ellenberg, 1996).

Fresh beech forests above rendzina or pararendzina are typically found on slopes of the Limestone Mountains, therefore also in the montane zone of the northern limestone Alps. Soil reaction is neutral to slightly acidic, the fertility is low (Ellenberg, 1964; Grimme, 1975).

Ecology

F. sylvatica is a shade-tolerant species and able to regenerate under closed canopy. At dry or acidic sites, it has higher demands regarding light conditions (Mayer, 1984 & Leibundgut, 1991).

F. sylvatica is susceptible to wet snow masses in late autumn or after having grown leaves in spring time. Heavy damages can occur. Late frost events can damage *F. sylvatica* as well; due to the low ability of regeneration, effects can be severe. Frost events and hail promote tree canker especially in young stages (Leibundgut, 1991).

Growth optimum is found above deep, fresh, alkaline brown soils or calcareous brown loam, which are well drained and aerated. The root system is the Heart root system, reaching depths of 120 to 140 cm in deep soils. The root system is usually well developed, especially under the canopy and in the stem area. At poor sites, the dense root network leads to competition with other species (Mayer, 1984).

At an age of 50 to 150 years, mature beech stands form so-called "Hallenwälder", which form a very dense crown cover. If there are no disturbances, regeneration of *F. sylvatica* and herbs can hardly come up. Undergrowth is scarce (Ellenberg, 1996).

On bigger clearings of slopes in high elevation, and there especially above rendzina, *F. sylvatica* can start colonizing immediately and forms a nearly pure stand in the beginning. Later, it is joined by *Abies alba* and *Picea abies*, pioneer and light-demanding species are hardly found in this system (Zukrigl, 1961).

Regeneration

F. sylvatica starts reproduction at an age of 40 to 50 years. Wagner (1999) presents evidence that seed production is related to tree diameter. Major mast years occur every 2 to 20 years (Watt, 1923). Climatic conditions influence good seed production; seed production is higher if carbohydrate build-up is favoured during two consecutive years (Piovesans & Adams, 2001).

Beechnuts are dispersed by barochory up to a distance of 20 m (fig. 1.4). Zoochorous dispersal can lead to higher dispersal distances (Wagner et al., 2010). Some mammals and birds store beechnuts for harsh winter times. This behaviour of animals affects the seed dispersal.

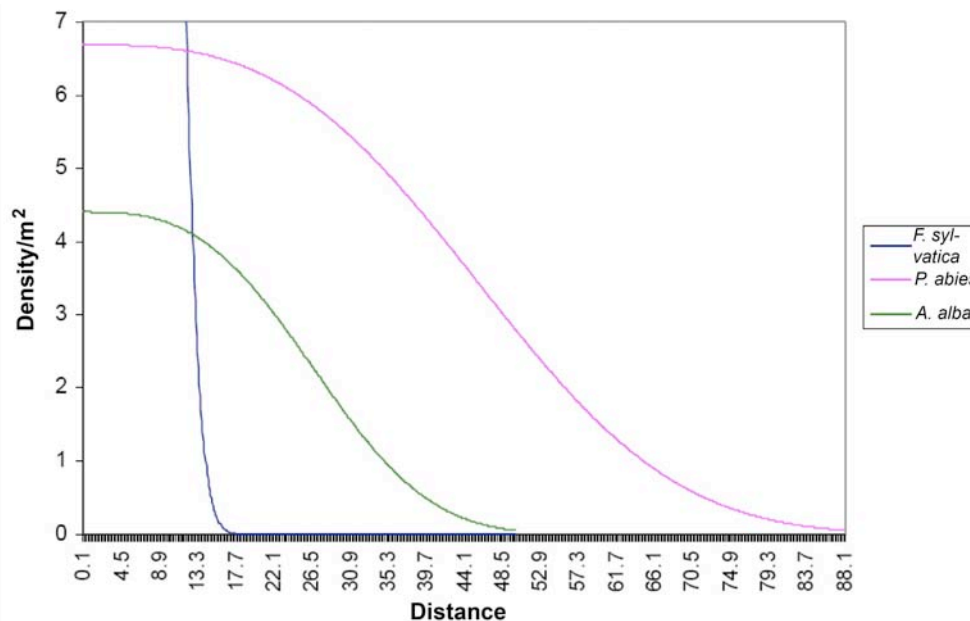


Fig. 2.14: Model of seed dispersal of *F. sylvatica*, *P. abies* and *Abies alba* by applying an empirical model (Kutter, 2007; p. 46; modified).

Regeneration of *F. sylvatica* gains best results in height and diameter growth under open canopy, but shows similar increment under closed canopy. A high plastic morphology is characteristic for its seedlings and depends on genotype, light conditions, water household, nutrient availability and occurrence of frost (Nicolini, 1997; Kunstler et al., 2005). After canopy opening, height growth of *F. sylvatica* increases (Canham, 1990; Collet et al., 2001). On clearings, *F. sylvatica* regeneration is more endangered by frost events and by browsing as well. Typical signs of browsing are the so-called “Kollerbüsche” (Zukrigl, 1961).

The ability to build stump sprouts after disturbances is an important feature on slopes influenced by avalanches. Avalanche tracks can be colonized in pure stands, mainly growing dwarf pine-like (Zukrigl, 1961). At a dbh of 10 cm, the potential to form sprouts decreases (Hamilton, 1955).

Sycamore maple (*Acer pseudoplatanus* L.)

A. pseudoplatanus grows in Central Europe (without Western Europe), Poland, and in southern and south-eastern mountain ranges. In the Eastern Alps it grows in an altitude of up to 1400/1700 m. This species is found in mountain forests of the montane zone, which are rich in beech (Mayer, 1984). *A. pseudoplatanus* is a half-shade/ shade species and can persist under closed canopy. It grows in upper montane to sub montane warm climate with sub-Atlantic, wet influence. It is highly competitive on calcareous debris soils rich in humus, which are located on shade slopes. The rooting system is similar to *F. sylvatica* (Mayer, 1984).

Rowan (*Sorbus aucuparia* L.)

S. aucuparia is distributed in Europe up to a northern latitude of 70°. In inner alpine mountains, it can establish up to an altitude of 2400 m. In late successional broad leaf forests, *S. aucuparia* is missing due to competition (Mayer, 1984).

S. aucuparia is resistant against winter and late frost events as well as against snow. It is a light-demanding species and grows due to competition mainly at sites poor in nutrients, in bogs, clearings or debris fens (Mayer, 1984).

Haw (*Sorbus austriaca* Hedl.)

S. austriaca is a frost-tolerant, light-demanding species. Roots penetrate deep into the soil. On dry sites with low soil formation, it improves the water household and accumulates humus (Mayer, 1984).

Ash (*Fraxinus excelsior* L.)

The main geographical distribution of *F. excelsior* is found in the Northern Alpine front range, in the Baltic provinces above loam and in sub-atlantics and atlantics West. In the northern Eastern Alps it grows up to an altitude of 1200/13700 m (Mayer, 1984).

An optimum growth occurs in wet to fresh soils in the sub montane zone where highly competitive late successional species are missing. *F. excelsior* is able to regenerate well under closed canopy, but when growing older, it becomes a light-demanding species (Mayer, 1984).

Green alder (*Alnus viridis* (Chaix) D.C.)

A. viridis is found up to sub alpine zone and grows in the Alps and the Carpathian mountains. It is a frost-tolerant pioneer species (Mayer, 1984).

In the Central Alps, it replaces *P. mugo* nearly completely above silicate. In the upper montane and sub alpine zone, it grows at sites free of forests if they are located in the lee and are rich in snow. *A. viridis* grows as well on sites affected regularly by avalanches, debris flow or erosion (Mayer, 1984).

Silver fir (*Abies alba* Mill.)

A. alba is distributed in the Alps, Carpathian Mountains, Dinaridian mountains and the Balkans. In the northern parts of the Eastern Alps it can be found in an altitude of 500 to 1400 m (Mayer, 1984).

A. alba is a shade-tolerant species which is able to establish even after a long time under closed canopy. Precipitation of 1000 to 2500 mm annually is its optimum. A minimum vegetation period of three months is required. On calcareous soils, *F. sylvatica* is its competitor (Mayer, 1984).

Larch (*Larix decidua* Mill.)

L. decidua grows in the Alps, where its current geographic distribution was increased by anthropogenic influence, and in the Carpathian Mountains. In

the eastern Eastern Alps it grows in an altitude of 400 to 2100 m (Mayer, 1984).

L. decidua is a pioneer species whose abundance is influenced by competition even in its maximum. In lower sub alpine and montane mixed forests it can only establish if slope inclination is high enough and energy input is high. Its optimum is found in deep and well-aerated soils; frequent occurrence on rendzina shows its pioneer character (Mayer, 1984).

Seedlings can only establish on sites without a well-developed humus layer as roots are not able to penetrate this and dry out. Seedlings are very light-demanding and cannot compete with *Vaccinium* spp., *Erica*, *Rhododendron* or dense grasses (Leibundgut, 1993).

3. Material and methods

3.1 Study design

Recordings for this study were carried out on 21 plots along five transects. Transects were selected in order to cover the whole ecotone and are located in an altitude of between 1050 and 1250 m. They follow the contour lines and are positioned in 50 m altitudinal distance from each other. The length of transects is varying due to topographical conditions of the study area (fig 3.1). Along these transects, plots were laid out randomly. The points on transects (as fixed on the orthophotos) act as reference points and show the north-western point of the 10x10 m plots. The plots are oriented along the gradient. The number of plots per transect is varying due to different length of transects.

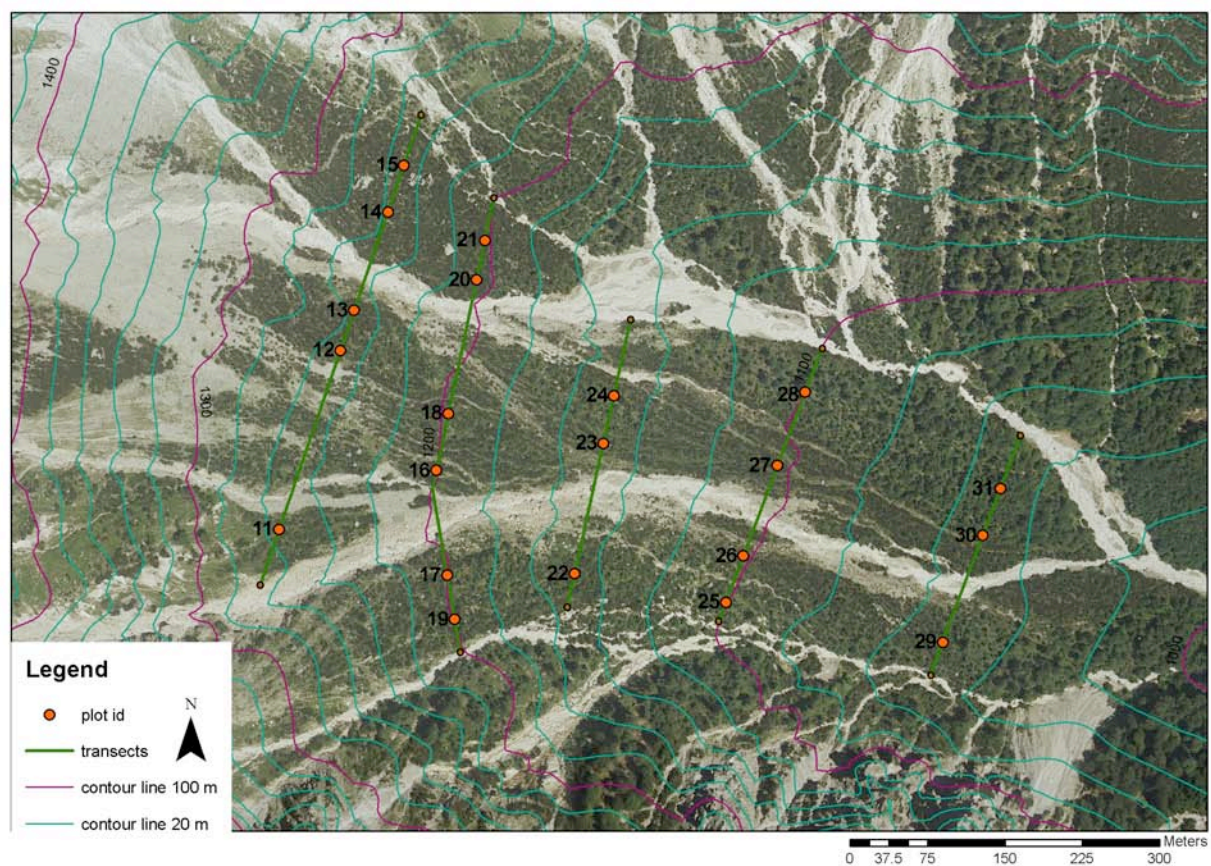


Fig. 3.1: Study area "Hinterwinkel" and location of the 21 plots along five transects. Numbers along transects denote the plot ID.

3.2 Fieldwork

Material

The following tools and materials were used for fieldwork:

- Positioning and setting of the plots: GPS Garmin and control with orthophotos; compass, measuring tapes (50 m), wooden plugs, ranging poles
- Aspect: compass [°]
- Inclination: Inclinator [°]
- Soil: probe, iron ruler (50 cm)
- Trees: calliper, measuring tape (30 and 50 m), Vertex III, levelling board (6 m)
- Regeneration: Iron ruler (50 cm), digital calliper ruler
- Dead wood: Measuring tape (30 and 50 m), calliper, compass (in °)
- Vegetation: Flora von Österreich (Fisch et al., 2004)
- Sketches: measuring tapes (50 m)
- Dendrochronology: wood corer, straws
- Hemispherical photographs: analogous camera with fisheye lens, films, tripod
- Inventory: modified key of Diethardt (2007)
- Digital camera.

Parameter at the macro relief scale ($r > 30$ m)

The following parameters of the macro relief were surveyed:

- | | |
|---------------|-------------|
| • Altitude | • Aspect |
| • Inclination | • Orography |

Parameter at the meso relief scale ($r = 30$ m)

The following parameters of the meso relief were surveyed:

- | | |
|-----------------------------|----------------------------|
| • Local climate | • Geology of loose rocks |
| • Aspect | • Grain size |
| • Inclination | • Geomorphologic unit |
| • Orography | • Concavity |
| • Geology of mountain stock | • Anthropogenic influences |

Parameter at the micro relief scale (equals plots 10x10 m)

The following parameters were surveyed in the micro relief:

- | | |
|--|-----------------------------|
| • Evenness of terrain | • Total share of rocks |
| • Gullies, trenches, channels
(naturally occurring) | • Rocks covered with lichen |

- Pathways of chamois
- Bumps
- Rocks covered with mosses
- Water balance

Soil erosion

- Erosion/ accumulation
- Level of soil development
- Causing factor
- Extent (total)
- Extent (horizontal)
- Extent (vertical)

Soil

Five soil profiles were described on each plot. The profiles are located in the middle of subplots (see fig. 3.3). An identification number is given according to the numbering of subplots.

In case that a profile hit a stone, it was moved 50 cm uphill.

The following soil parameters were surveyed:

- Humus layer
 - Horizons
 - Depth
 - Source material
 - Transition zone between horizons and condition of horizons
- Mineral soil
 - Horizons
 - Depth
 - Level of rooting

Droppings

The amount of droppings of the following herbivores were counted:

- Roe deer
- Red deer
- Chamois
- Others

Dead wood

Downed dead wood was divided into two classes:

a) < 10 cm (central diameter)

- Amount
- Ground covering [%]

b) > 10 cm (central diameter)

- Species
- Length [m]
- Azimuth
- Wind throw/ Breakage

- Central diameter [cm]
- Stage of decomposition (fig. 3.2)

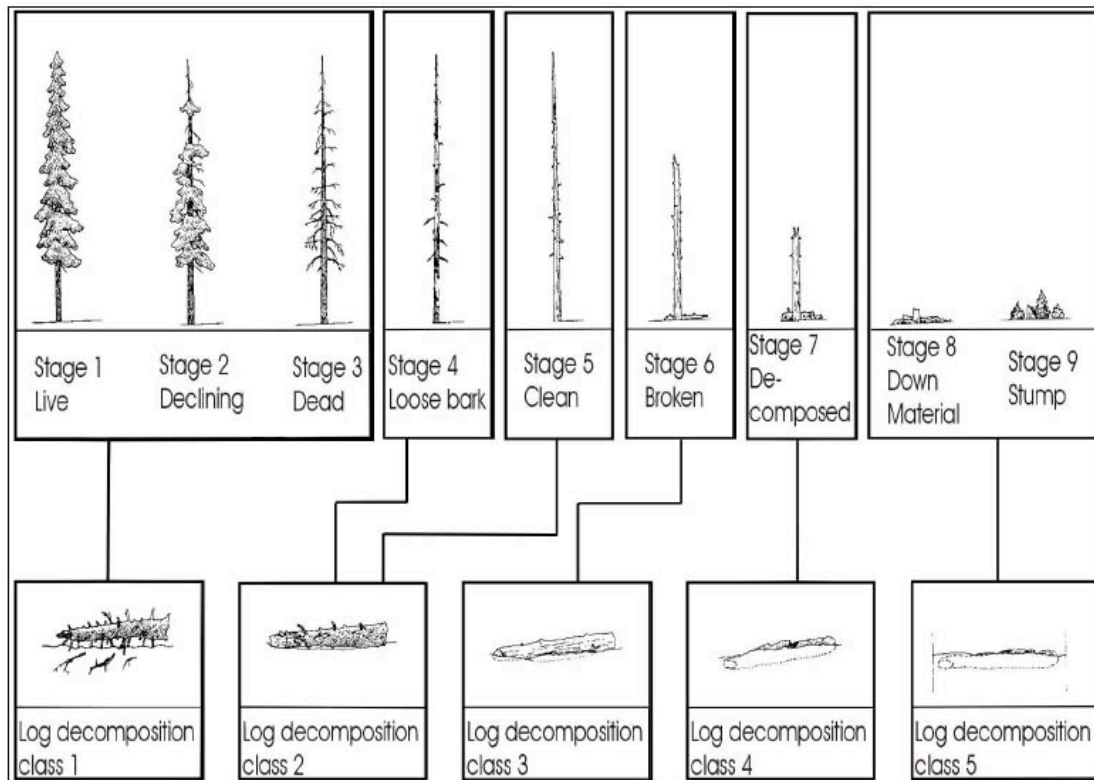


Fig. 3.2: Stages of decomposition by Maser et al. (1979).

Ground vegetation layer

The Braun-Blanquet (1964) scale was used to analyze herb layers. For identification, “Exkursionsflora für Österreich, Liechtenstein und Südtirol” (Fischer et al., 2005) was used. Unknown plants were collected and dried. Botanists of the national park Gesäuse helped with identification.

Sketch

A sketch of each plot was drawn. The sketches show the stem of trees or the rooting point of *P. mugo*, as well as orientation, horizontal distance and crown cover. Adult trees and *P. mugo* originating outside the plots are shown when their crowns reach at least 50 cm into the plot.

Assessment of regeneration

Seedlings (< 1 year)

The number of seedlings growing on a 10x10 m plot was counted. It was differentiated if seedlings are growing directly on the soil or on dead wood.

Regeneration (> 1 year)

All tree species with a diameter < 5 cm at root base were categorized as regeneration.

On every plot, the total number of regeneration for each species was counted, and height classes were formed (25 cm steps).

To gain a more detailed understanding of performance of regeneration, it was analyzed in depth on five subplots. Therefore, five 2x2 m subplots were evenly distributed and arranged in each plot (fig. 3.3). Subplots were laid in 1 m distance to the border to avoid edge effects.

	3	3					4	4	
	3	3					4	4	
				5	5				
				5	5				
	1	1					2	2	
	1	1					2	2	
x									

Fig. 3.3: Distribution of regeneration-plots. 1x1 m raster. "X" represents the north-western point of the plot.

A sketch was drawn of every subplot. The following characteristics were included in the sketch:

- Identification number of regeneration
- Chamois pathways
- Stones and rocks
- Vegetation (scarce, medium, dense)
- Main species of the herb layer and dwarf-shrubs respectively
- Amount of dead wood with a diameter > 10 cm [%]
- Canopy cover (hemispherical photographs)
- Gullies, trenches, slopes

Within subplots the following parameters of each individual tree were surveyed:

- Species
- Height [cm]
- Length [cm]
- Length of the terminal shoot of the previous year [cm]
- Browsing
- Age
- Bark rubbing
- Distance to potential seed tree [m]

- Horizontal distance [cm]
- Diameter at the root base [cm]
- Crown cover and species
- Bark peeling
- Insect attack
- Fungi attack
- Mouse damage
- Vitality

Light regime

Light is a crucial factor for regeneration. Each species has different requirements regarding light. Light regime for regeneration was tested in two ways: Once it was noted if a seedling (growing on a subplot) was shaded by another plant and to which extent. Another, and more quantitative method to assess light regime is using hemispherical photographs.

Hemispherical photographs are pictures, which are oriented upwards towards the sky. Through the use of a hemispherical (fisheye) lens, it is possible to cover the whole sky and objects (e.g. branches) obscuring it. The resulting photographs are used for further analysis with the software HemiView 2.1. The software calculates indices, such as Global Site Factor, Leaf Area Index and others, based on “measurements of the geometry of sky visibility and sky obstruction” (Rich et al., 1998-99; p. 5).

On each subplot, five hemispherical photographs were taken with an analogous camera and fisheye lens. The camera was placed in the centre of the subplots (see fig. 3.3) and pointed north to be able to calculate sun tracks for analysis. Due to growth features of dwarf pine the camera was placed with the help of a tripod as low as possible, at an average of 60 cm.

To avoid reflections, pictures were taken under obscured sky conditions or in the afternoon when the sun was no longer very bright. Reflections can lead to errors during picture analysis (Rich et al., 1998-99).

Assessment of adult trees

Every tree and stone pine was measured on the plots:

- Species
- DBH [cm]
- Height [m]
- Height of crown beginning [m]
- Horizontal crown distance [m]
- Tree canker
- Curved trunks
- Bark rubbing
- Bark peeling
- Forking
- Insect attack
- Cause of death
- Degree of decomposition by Maser (fig. 3.2)
- Crown cover (shading), species
- Lichen and mosses
- Tree sponge
- Other injuries
- Position of wood

- Trunk abnormality
- Water sprout
- Broken tree tops
- Occurrence of mistletoes
- Rock fall
- Vitality by Kraft¹
- Fertility

¹ Vitality by Kraft was developed for trees and not for krummholz. Nevertheless, it was applied to krummholz as well, but comparison of vitality is valid for dwarf pine only. Information about access to sunlight is given in the category crown cover (shading).

Spatial distribution

To assess spatial distribution of adult trees a raster was applied to each plot. The raster was oriented along a slope line. In each plot, 100 raster points were laid (fig. 3.4). The distance between raster points is 1 m. To avoid edge effects, the points were laid within 50 cm of the edges of the plot. On every raster point the following parameters were measured and noted:

- Species
- Contact dead² or alive
- Height (height classes) in which the contact occurred

² A dead contact does not imply that the whole individual tree was dead but that the branch touching the leveling board was obviously dead - having no green parts left, only dry or no leaves/ needles. In most cases the individual tree to which the branch belonged was still alive.

Measuring was done with the help of a 6 m long levelling board. Due to the length of the instrument, but mainly also because of visual restrictions, the number of contacts was only counted up to a height of 4 m; above this height contacts were summed up as “indefinable number > 4 m”.

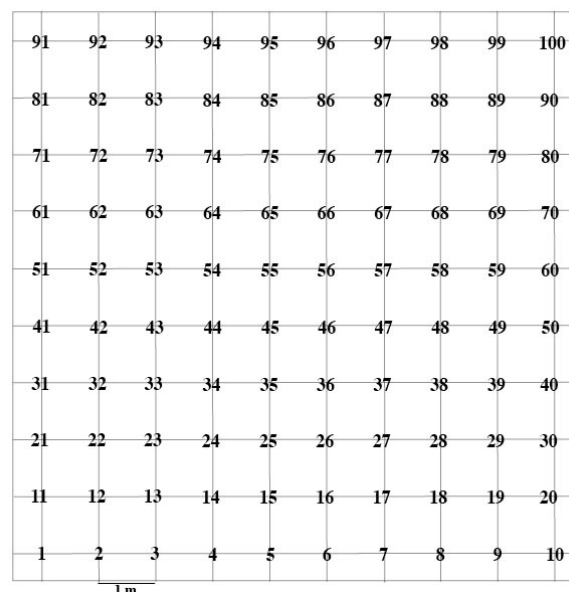


Fig. 3.4: Scheme of the positions of the 100-raster points. Point 1 is located at the north-western corner of the plot.

Age structure & analysis of disturbances

Dendroecological methods are standard tools for forest dynamic research.

In this work, analysis of tree rings was used to receive two results: Age structure of tree species within the study site and analysis of disturbances (release events of trees).

In each plot, eight trees/ *P. mugo* were cored. The coring was done along a transect with a width of 2 m. If there were less than eight individuals within a transect, more transects were laid, according to the structure in fig. 3.5. Additionally, in the subplots the dominant *P. mugo* was cored.

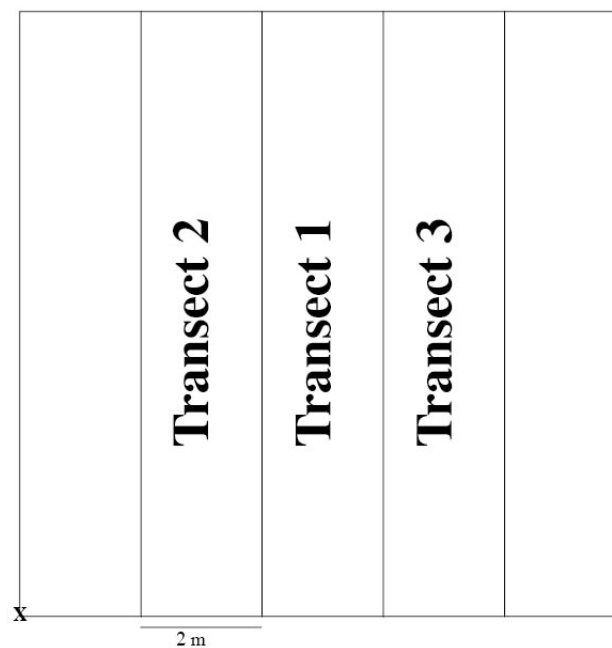


Fig. 3.5: Scheme of transects used for coring trees. "X" acts as reference point and shows the north-western point of a plot.

Cored trees had a minimum diameter ≥ 5 cm in 1 m height, *P. mugo* a minimum diameter ≥ 5 cm in this height, where the growth of the usually curved stem is directed upwards. Trees were cored in 1 m height (standing upslope); trees with curved trunks were cored at 1 m distance to the root collar. Coring was always done along a slope gradient and the stems were cored completely through.

F. sylvatica has very hard wood, and coring was only possible when pushing with a person's whole weight. The disadvantage of coring a tree in this direction is that obtaining reaction wood cannot be avoided.

P. mugo, located in transects, was cored twice. Once as close as possible to that point, where the stem left the soil, and a second time at the point where the branches started to grow upwards. As stems usually creep along the soil, coring had to be done starting at the top and finishing at the bottom. Coring

was carried out only to the pith of the trunk to decrease the risk of damaging the corer.

In the subplot *P. mugo* was cored only once, namely on the dominating element (branch or stem) within the plot.

The core samples were transported in a straw and put into the freezer until further preparation.

3.3 Statistical Analysis

Data was fed into Excel and analyzed with “SPSS 15.0 for Windows” and Excel.

In the beginning, a plausibility check was made to detect measuring and typing errors and made corrections if necessary. For this purpose box plots, scatter diagrams, line charts and histograms were used.

Variables were tested for normality. Hardly any data showed normal distribution. To get normally distributed data, square root and logarithmic (ln) transformations were carried out.

To detect a significant relationship between groups of variables, the following statistical methods were applied:

Correlations were used for ordinal and interval-scaled data. Interval-scaled data with normal distribution were analyzed using Pearson's correlation. Interval-scaled data with non normal distribution or ordinal-scaled data were analyzed using Spearman-Rho.

Univariate analysis of variance (ANOVA) was used to analyze categorical and interval-scaled data showing normal distribution.

Categorical data was analyzed by using cross-classified tables. It was not possible to apply Chi-square-test as expected values < 5 were gained.

Study site

Site parameters and soil profiles were described and elaborated.

To represent a type of soil and humus for each plot, the most frequent type of all five subplots was taken.

To detect relatively homogenous plots regarding their aspect, altitude, inclination, share of relictic loam, total soil depth and avalanche hazard, cluster analysis was applied. Analyses with different sets of parameters were made to identify clusters, which best described the performance of species. For cluster analysis, hierarchical clustering with Euclidean squared distance was used. Dendrograms were displayed using complete linkage.

Ground vegetation can compete with regeneration for light. To get a reasonable value of the overall ground coverage of herbal vegetation, the scale of Braun-Blanquet (1964) was transformed into percentage ground coverage. For the transformation, abundance greater or equal to category “2m - covering” was summed up.

Light regime

Hemispherical pictures were scanned, labelled and some modified with Photoshop to increase picture quality (rain droplets, contrast, etc.).

A problem occurring was fog, which covered parts of the surrounding mountains; in some cases, their edges had to be estimated.

Analysis was carried out with the software HemiView 2.1. After having specified the geographical location of the study area/ plots, pictures were analyzed. Therefore, a threshold for each picture has to be chosen subjectively. The threshold is an algorithm with which it is possible to determine intensity values. Values above the threshold match visible sky, values below the threshold match obscured sky (fig. 3.6) (Rich et al., 1998-99).

In this stage, modifications of the original pictures were sometimes necessary to gain the most satisfying results.

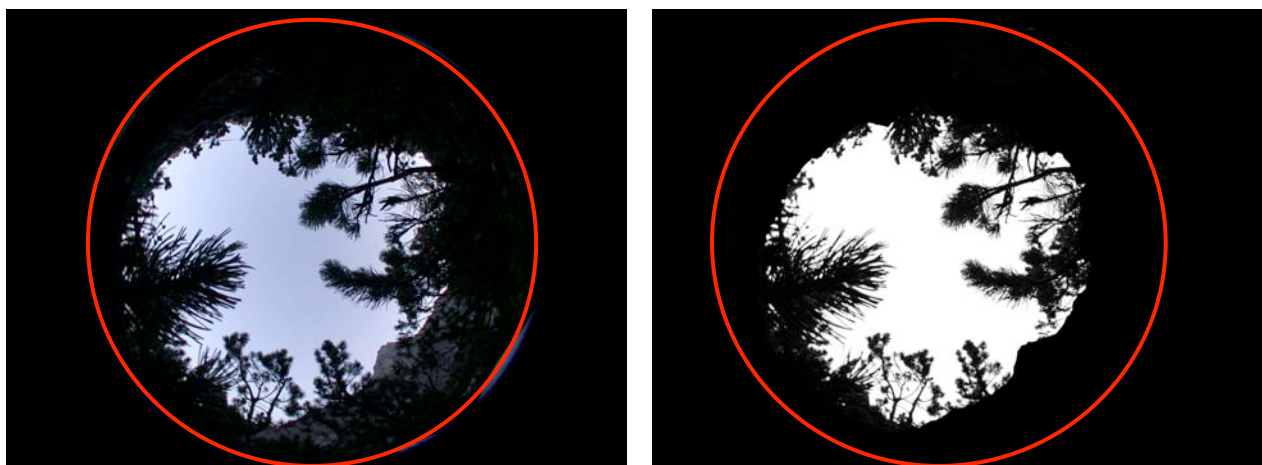


Fig. 3.6: a) Example of an original photograph; b) the same picture after having set the threshold between visible and obscured sky with HemiView 2.1. The red circle represents the extent of the lens.

The following parameters were calculated using the software: Indirect Site Factor (ISF), Direct Site Factor (DSF) and Global Site Factor (GSF). Definitions of these site factors are given by Rich et al. (1998-1999, p. 17): “ISF is the proportion of diffuse solar radiation reaching a given location, relative to a location with no sky obstructions. DSF is the proportion of direct solar radiation reaching a given location, relative to that in a location with no

sky obstructions. GSF is the proportion of global radiation (direct plus diffuse) under a plant canopy relative to that in the open.”

Resulting data were used for statistical analysis with SPSS. Mean value was calculated out of the five subplots for each plot.

Species’ interaction and performance (regeneration and adult trees)

Species’ interaction and performance were analyzed with statistical methods. Therefore, the software SPSS 15 and SPSS 18 was used.

The unit of analysis was a plot for trees (Hinterwinkel 11-31; n=21) and a subplot for regeneration (Hinterwinkel 111-315; n=105). Therefore, data had to be transformed and broken down to the unit of the plot. The procedure was very similar for trees and regeneration: Classes (height, diameter, vitality, tree coverage etc.) were formed and these classes were summed up per each plot. This data was put into new files. Data transformation (ln and square root) was carried out in order to get normally distributed data. Soil data and site classification data were added.

Correlations, ANOVA and cross tables as specified above were applied.

Spatial distribution

Point-pattern analysis is used to test the spatial distribution of tree species. For this reason the software Programita was used. Programita performs univariate and bivariate point-pattern analysis by using Ripley’s *K*- and *L*-function and Wiegand-Moloney’s *O*-ring statistic. Both methods measure “the distance between all pairs of points of a pattern and count the number of points within (or at) a certain distance, *r*, of each point, with *r* taking a range of scales” (Wiegand, 2004, p. 7). Whereas Ripley’s *K*-function uses circles for calculating and is cumulative, the *O*-ring statistic uses rings for calculations and is more suitable to isolate distance classes (fig. 3.7). The *K*-function has the disadvantage to confound large distance effects with short distance effects (Wiegand & Moloney, 2004). For these reasons *O*-ring statistics were used only.

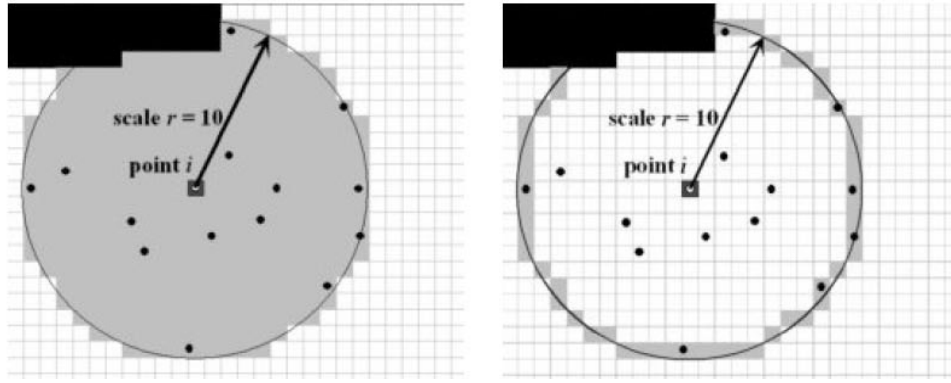


Fig. 3.7: The circle on the left represents the cumulative function of Ripley's K, the ring on the right represents O-ring statistics, where only points at a certain radius are used for analysis (aus: Wiegand, 2004; p. 25)).

O-ring statistics

Wiegand-Moloney's O-ring statistic is a second order statistic, which characteristics don't depend on direction and location of the points. Only the distance (r) is used in the mark-correlation function $g_{12}(r)$:

$$g_{12}(r) = \frac{dK_{12}(r)}{dr} / (2\pi r)$$

"The O-ring statistic $O_{12}(r) = \lambda_2 g_{12}(r)$ gives the expected number of points of pattern 2 at distance r from an arbitrary point of pattern 1" (Wiegand, 2004; p. 27).

If $O_{12}(r) = \lambda_2$ patterns are distributed independently (random), if $O_{12}(r) < \lambda_2$ patterns show repulsion (segregation) and if $O_{12}(r) > \lambda_2$ patterns show attraction (aggregation) (Wiegand, 2004).

For calculating the confidence envelopes, 99 simulations were run, thus providing 5% confidence envelopes (Stoyan and Stoyan 1994).

Data preparation

Raw data were assigned to three categories: *F. sylvatica* (alive), *P. mugo* (alive) and *P. mugo* dead. As there were only very few contacts with dead *F. sylvatica* (<10 in total) no extra category was created. For each category on each plot a table was generated.

To analyze how each category is spatially distributed, data were transformed in a binary code with the format 1/0 (contact/no contact) and typed in matrix mode using SPSS 15 (fig. 3.8). Data had to be transformed to a space delimited ASCII file in *.dat format (Wiegand, 2004).

	variant 7 ($g_{12}(r)/g_{1,1+2}(r)$)
<i>F. sylvatica</i> – <i>P. mugo</i> dead Pattern 1: <i>F. sylvatica</i> Pattern 2: <i>P. mugo</i> dead and <i>P. mugo</i> dead & <i>F. sylvatica</i>	Pattern 1 fix, pattern 2 random (relation of points of pattern 2 in respect to points of pattern 1 are investigated)

Table 3.2: Random labeling offers several tests, which allow for different interpretation of data (Wiegand, 2004; p. 103; modified).

Variant	Test	Assumption for interpretation	Basic relation tested with the variant	Interpretation of test for scale r
1	$g_{12}(r) < g_{1+2,1+2}(r)$	$A_1 = A_2$	$g_{12} > b^2 g_{11} + (1 - b^2) g_{22}$ with $b = n_1 / (n_1 + n_2)$ $g_{12} > (g_{11} + g_{22})/2$	Type 2 points are stronger correlated than expected by the average aggregation of the two component patterns.
4	$g_{22}(r) - g_{11}(r) > 0$	$A_1 = A_2$	$P_{22}/n_2 > P_{11}/n_1$	Pattern 2 is more clustered than pattern 1, conditional on the structure of the joined patterns.
7	$g_{12}(r)/g_{1,1+2}(r) - g_{21}(r)/g_{2,1+2}(r) > 0$	—————	$P_{21} + P_{22} > P_{12} + P_{11}$	Heterogeneity of the joined pattern interacts with the process that assigns the labels. Type 2 points are mainly located in areas with high intensity of the joined pattern.

Data output

Programita produces two graphs as an output, one for univariate analysis, one for bivariate analysis. In the graph you can see the confidence envelopes of random point distribution at a certain radius. The confidence envelope shows the minimum and the maximum values occurred during the 99 simulations. The software places the calculated function within the confidence envelope (fig. 3.9).

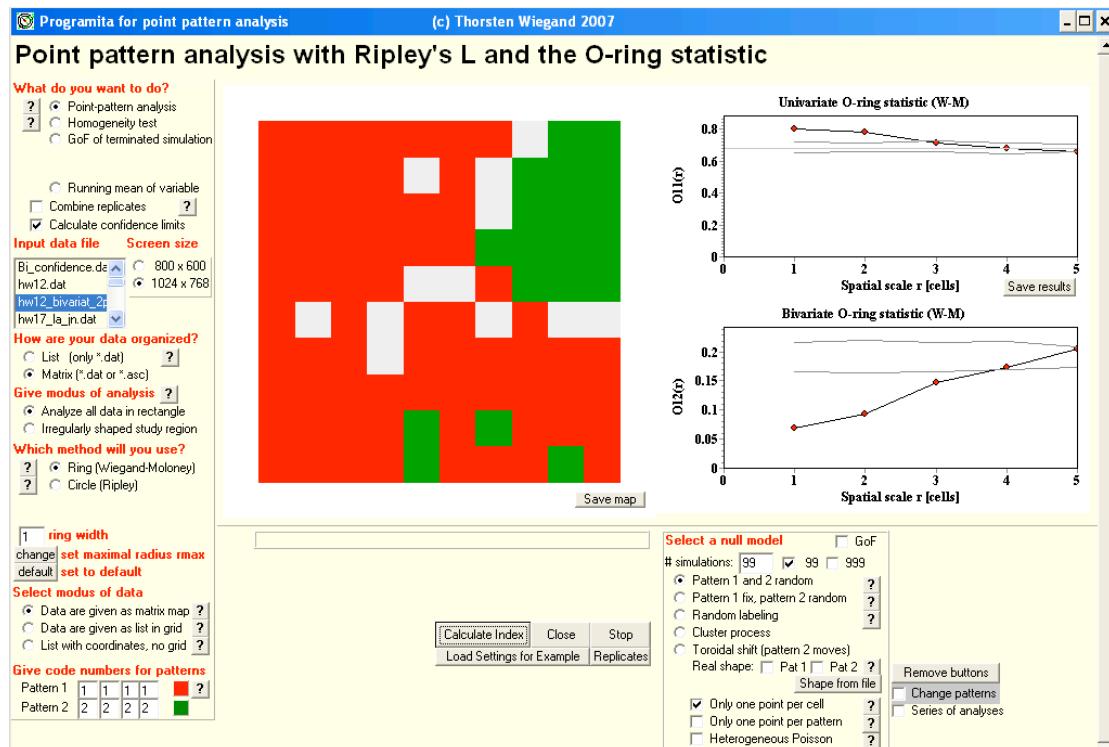


Fig. 3.9: Example of a bivariate point-pattern analysis using Programita 2007.

The red patches within the square represent *F. sylvatica*, the green ones *P. mugo*. Grey patches are empty cells with no tree cover. On the right side you see the confidence envelopes for univariate (upper figure) and bivariate (lower figure) analysis. Analysis is done for a radius from 1-5 cell width. Points lying below the confidence envelope show segregated distribution, within random distribution and above the envelope aggregated distribution.

Besides the graphical output, it is possible to save data in an Excel file (table 3.3).

Table 3.3: Output file of Programita.

The first rows show the information about the settings of the analysis. The first column shows the radius, the second (univariate) and third (bivariate) column "provide a summary of the Monte Carlo significance test of the null model" (Wiegand, 2004. p. 12) ("−": below confidence envelope; "r": within confidence envelope; "+": above confidence envelope). In column 4 and 7 the data of the *O*-statistic are given, in column 5 and 6 and as well as in column 8 and 9 the lower and upper confidence envelopes are presented.

Pointpattern analysis of file

\\psf\Home\Desktop\diplomarbeitm\rasterdaten\programita\Programita_2008

hw12_bivariat_2pattern.dat

Method Wiegand-Moloney (ring) with 99 replicates for confidence interval, ring width = 1 15th lowest and highest values of 99 simulations

Test Model= 12 random

the null assumed homogeneous pattern(s)

Analysis modus= standard

only one point per cell allowed

All cells within the rectangle were considered for calculating the indices

number points of pattern1 = 69

number points of pattern2 = 19

the rectangular area contains 10*10 = 100 cells (= dim1*dim2)

pattern 1 was coded with numbers 1 * 1 * 1 * 1

pattern 2 was coded with numbers 2 * 2 * 2 * 2
the mask was coded with numbers -1 -1 -1 -1

			<i>Univariate analysis</i>			<i>Bivariate analysis</i>		
Scale	r	r	O ₁₁ (r)	E11-	E11+	O ₁₂ (r)	E12-	E12+
0	r	r	1.0000000	1.0000000	1.0000000	0.0000000	0.0000000	0.0000000
1	+	-	0.8034188	0.6394850	0.7366260	0.0683761	0.1477730	0.2260130
2	+	-	0.7819549	0.6408540	0.7303920	0.0939850	0.1493830	0.2348390
3	r	-	0.7119048	0.6386550	0.7368420	0.1464286	0.1514810	0.2368420
4	r	r	0.6768508	0.6309380	0.7283110	0.1727380	0.1598560	0.2400960
5	r	r	0.6578631	0.6469140	0.7212340	0.2040816	0.1660740	0.2227720

Age structure of adult trees

Before starting to analyze tree cores, they were defrozen, taken out of the straws and if contorted they were made straight again. Then, cores were fixed on wooden plates temporarily so that they could dry. After drying, they were glued on wooden plates permanently. After that, they were sanded with three types of sandpaper (coarse, medium and fine) to achieve a smooth surface.

The age of the cores was counted under a microscope (due to very narrow year rings).

In case that the pith of the stem was missed, the missing rings to the pith were estimated by using a model assuming a circular growth pattern and by assuming a same average growth rate between oldest preserved and missing tree rings: The degree of arcing of the oldest captured tree ring was matched with a ring of the model. Starting from the matching ring, I counted the number of rings to the center of the model. The average amount of tree rings fitting into the ring of the model was multiplied with the sum of rings on the model. This number was added to the counted age. Due to the very narrow tree rings of dwarf pine it was difficult to match the degree of arcing with the model.

Cores whose age could neither be counted completely or estimated were excluded from analysis (11% of total number of cores).

Analysis of disturbances

Dendroecological method

All core samples of *F. sylvatica* and some of *P. mugo* were measured under a reflected-light microscope (Zeiss) and on a measuring table (LINTAB™) of the company RINNTECH. The measuring table is connected with a computer (Software TSAP-Win).

The measurements of *P. mugo* were hard to synchronize, probably also due to the fact pointed out by Hafenschner (1985 & 1987), namely the different annual increment rates of generative and vegetative branches; data, which could not be noted separately. Therefore, I used *P. mugo* cores only for age determination.

Cores of *F. sylvatica* were synchronized and compared with existing tree chronologies. As there are no data of *F. sylvatica* available from this region, I

used chronologies of *P. abies* (Gesäuse mountains) and *A. alba* (eastern Alps) instead (Geihofer et al., 2005; Dendrolab Boku, unpublished). *F. sylvatica* shows similar reactions to ecological influences as these species do (Grabner, unpublished).

The samples of *F. sylvatica* were cross-dated with the two chronologies to prove measurements and to detect missing year rings. Measuring errors were eliminated as far as possible. Not all samples (approx. 50%) could be synchronized.

In a next step, chronologies out of the already synchronized *F. sylvatica* samples were formed. Then those *F. sylvatica* cores that had not been synchronized yet were compared. It was possible to synchronize 78% samples in total.

Running mean method

To be able to detect release events, which may be caused by disturbances, running mean method was applied. Release events of trees result in higher radial growth (Nowacki & Abrams, 1997).

$$GC\% = \frac{M_1 - M_2}{M_1} \times 100\%$$

“**GC%** = percentage growth change between preceding and subsequent 10-yr means

M₁ = preceding 10-yr mean

M₂ = subsequent 10-yr mean”

GC% has to be affixed to the last year of M₁. For example, if M₁ is from 1960 to 1969 and M₂ is from 1970-1979, then the GC-value is calculated for the year 1969.

In order to depict canopy disturbances, threshold values were set: 25 % GC for a minimum growth response (moderate-temporary) and 50-100% for a sustained radial-growth release. These thresholds were empirically tested by Nowacki & Abrams (1997) and used by Diethardt (2007) in the same region.

Avalanche simulation

In order to gain more profound insight into distribution of avalanches within the study area, an avalanche simulation was done with ArcGis 9.2 and ELBA (**E**nergy **L**ine **B**ased **A**valanche Model). ELBA is a 2-dimensional avalanche simulation model, which performs simulations under various conditions (Volk & Kleemayr, 2000). It is based on the avalanche calculation of Voellmy (1955) with variable flow parameters.

$$v_{\max} = \sqrt{\xi * h * (\sin \psi - \mu * \cos \psi)}$$

This concept of Voellmy is widely distributed. It is based on the hydraulic theory and describes the shear forces of the two parameters μ (dry coefficient of friction) and ξ (velocity dependent turbulent friction). Regarding Swiss guidelines μ varies mainly due to the extent of the event whereas ξ depends on the roughness of the terrain (Volk & Kleemayr, 2000).

In ArcMap9.2, release areas were delineated based on orthographical pictures and a digital elevation model. No field survey was done. Features of a potential release area are the steepness of the terrain and its roughness (Maggioni & Gruber, 2003). Slope steepness ranges between 30 and 60° according to Maggioni & Gruber (2003). On slopes < 30° steep, the gravity force is not strong enough to initiate an avalanche. On slopes > 60°, snow hardly accumulates and no avalanches will be released. In a first step, delineation was done according to the steepness (25-55° to be on the safe side). In a second step, the shape of the release areas was adapted to the terrain (trenches, ridges, etc.) with the help of orthographical pictures.

The second category delineated is potential zones of resistance. Zones of resistance are forested areas (areas with dwarf pines only were not included). Forests increase the stability of the snow cover and therefore reduce the possibility of avalanches being released. They do not stop avalanches starting higher than a forest (Margreth, 2004).

The third type of shape-files that was delineated is snow entrainment area. Initially, small avalanches can increase in size when taking up snow along their path (Volk & Kleemayr, 2000). These areas have usually a narrow shape and follow bigger trenches affected by erosion.

Simulation parameter were set as follows:

Table 3.4: Simulation parameter. The snow height of 1,3 m is approximately equivalent to a three-day intensive snowfall.

<i>Parameter</i>	<i>Feature</i>
Release zone	Snow height: 1.3 m
Entrainment area	Snow depth: 0.3 m
Zone of resistance (forest)	Resistance: 1

Having delineated all polygons, the parameterization of the release areas had to be done, applying the following scenario:

Table 3.5: Scenario setting of the avalanche simulation using ELBA.

<i>Variable flow regime</i>	
Average height of release	1.3 m
Critical normal stress	200 kg/m ²
Release density	300 kg/m ³
Flow density	300 kg/m ³

DEM, entrainment areas and areas of resistance were assigned during parameterization.

Then the simulation of avalanches could be started. Simulation was done for each single release area; in combining spatially close release areas, different scenarios were developed.

The chance of a small avalanche to come down is greater than for large avalanches. Therefore, to gain relative data about avalanche hazard on each plot, avalanches were weighted regarding their size (table 3.6) (Bacher, pers. Comm.). The number of strikes was summed up for each plot and each size category. The gained sum was multiplied with a probability factor. To see the relation between the plots, percentage was calculated out of the weighted sum.

Table 3.6: Figures of delineated release zones.

	<i>Release zone < 5ha</i>	<i>Release zone > 5ha</i>
n	29	4
%	87.9	12.1
Probability factor	0.5	0.25

Using this percentage, three categories were formed:

Table 3.7: Avalanche hazard classification of plots.

<i>Category</i>	<i>Share (%)</i>	<i>Description</i>
1	≤ 33.3	Hardly affected plot
2	33.4 – 66.6	Medium affected plot
3	>66.6	Much affected plot

These values were used for further statistical analysis.

4. Results

4.1 Study site

4.1.1 Macro relief

62% of the plots are oriented ESE, 33% E and 5% ENE. The maximum inclination reached is 50%, the average is 33% (fig 4.1). The plots of the four higher transects (86% of all plots) were classified as middle slope, with an even distribution of material supply and removal. Only the three plots of the lowest transect (1050 m a.s.l.) were classified as lower slope in which removal of material prevails (fig. 4.2).

4.1.2 Meso relief

In the meso relief, the predominating aspect is ESE with 52% of all plots, followed by an eastern aspect (38%) and SE 10% (fig 4.1).

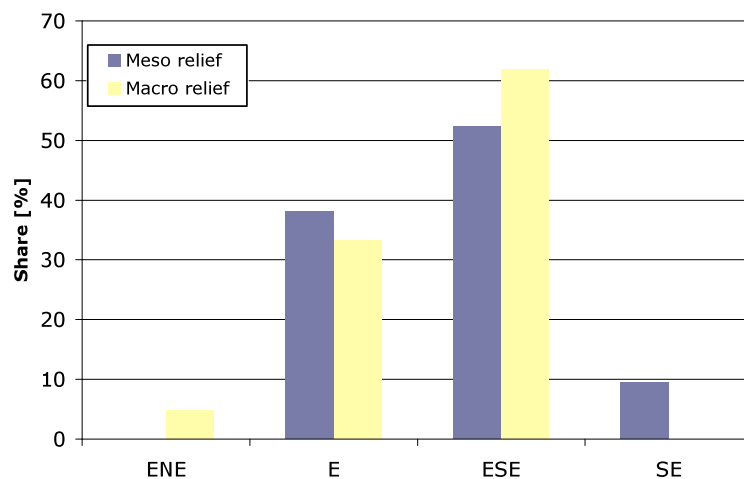


Fig. 4.1: Aspect of macro and meso relief given in percentage of the observed plots.

Maximum inclination is 60%, the average is 33% +/- 11.4.

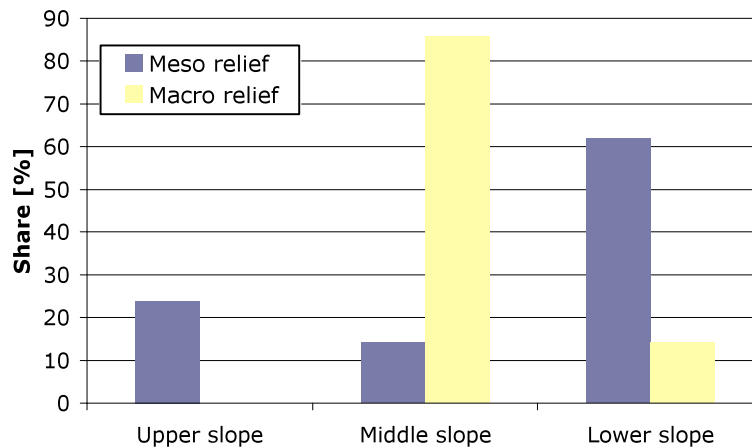


Fig. 4.2: Relief of macro and meso relief given in percentage of the observed plots.

The bedrock is comprised of dolomite. Parent material of coarse surface fragments is limestone. Its grain size varies. The following grain size classes were found on the plots: pebbles-debris (19% of all plots), blocky (14%), and mixed grain sizes, blocky and toma (57%) as well as pebbles-debris, blocky and toma (5%). There were no coarse surface fragments on one plot only (5%) (fig. 4.3).

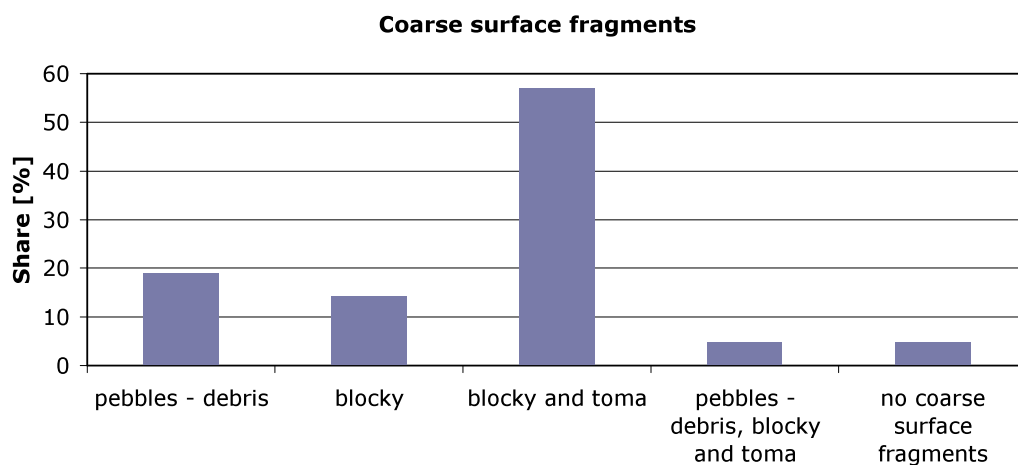


Fig. 4.3: Share of grain size of coarse surface fragments given in percentage of the observed plots..

Slope form

The majority of the observed plots (67%) have an intermediate relief, 24% are convex and 10% concave.

Local climate

No specific local climate could be distinguished on any of the 21 plots.

Human influence

On none of the plots any anthropogenic influence (paths, forest roads, influence of pasturing, yarding tracks) could be observed.

4.1.3 Plot characteristics (Micro relief)

Soil erosion

On 16 plots (76% of all plots) no erosion was detected. Erosion was observed on five plots (24%) (fig. 4.4). The maximum extent of soil erosion is 0.3 m. Characterization of soil erosion is given in table 4.1.

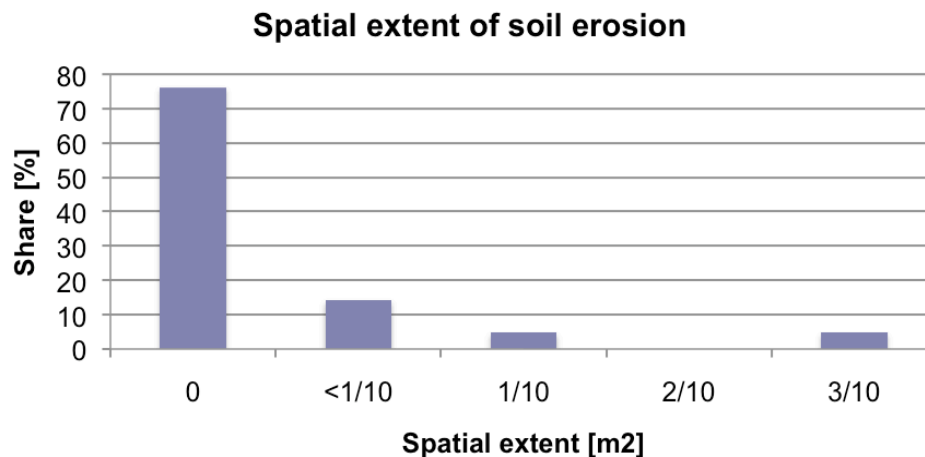


Fig. 4.4: Spatial extent of soil erosion. The x-axis gives the tenth of a plot.

Table 4.1: Characterization of soil erosion.

<i>Type of erosion</i>	<i>Share of plots [%]</i>
Gully caused by rock fall	60
Sliding surface	20
Sliding body	20
<i>Development</i>	<i>Share of plots [%]</i>
Recent	20
Pioneer vegetation	60
Mature soil	20
<i>Cause of erosion</i>	<i>Share of plots [%]</i>
Inclination/ water	20
Inclination/ water and slide	80

Erosion does hardly occur within the plots. On the study area erosion is more developed in big channels. These channels and their close margins were excluded of analysis as no trees grow there. Parameters influencing this part of the study area are different than for the selected area.

Droppings and paths of ungulates and other animals

Droppings of the following species were found: reed deer, chamois and roe deer. Droppings of red deer are most frequent on the study site (table 4.2).

Table 4.2: Share of plots with droppings for each species.

<i>Ungulate</i>	<i>Share of plots with droppings [%]</i>
Red deer	38
Chamois	10
Roe deer	5

Paths of chamois and other ungulates occur on nearly all plots, showing the regularly distributed abundance of ungulates within the study area. The absence of hiking paths minimizes disturbances by humans and increases habitat quality for ungulates. The caldera Hinterwinkel is an important rutting area of red deer in autumn (NP Gesäuse, pers. Comm.).

Dead wood (diameter < 10 cm)

The ground of 90% of the plots is covered with $\leq 3\%$ dead wood, 10% are covered with 3-10% dead wood.

Relief

The micro relief of the study area is very heterogeneous with changing slope form and inhomogeneous terrain, leading to a diverse micro relief with ditches, bumps, big boulders or it shows little changes in inclination. On most of the plots (81%), chamois paths are located.

Water balance

The water balance of the territory differentiates ranges from moderately dry to moderately fresh.

Humus layer

The dominating type of humus is moder on 27% of the subplots, followed by mull (25%) and moder-like mull (14%). Other types are alpenmoder and mull-like moder (each 12%). Tangel (4%) and row humus (1%) are only rarely abundant. From 5% (5 plots) no data are available, as rainy weather made part of the notes unreadable. Mainly sharp transition zones between humus horizons indicate low biological activity (FAO, 2006).

For statistical analysis, subtypes of humus were assigned to the predominating types as follows: Mull: Mull and moder-like mull; moder: moder; alpenmoder: alpenmoder, tangelmoder and mull-like moder.

Moder

Moder humus forms in the study area are dominated by F-Horizons with an average depth of 2.4 cm followed by an H horizon. Most of these (71% of the Moder profiles) H-horizons are not smeary. The average depth of the whole humus layer is 5.3 cm. The litter is loose (29% of the Moder profiles), clotted

(32%) or layered (29%). Transitions between horizons are mainly gradual (43% of all Moder profiles) and moderately sharp (32%), followed by gradual transition (18%) and sharp (7%). There are no particles > 2 mm in any profile. In 47% of the Moder profiles mycorrhizae were found. The humus of these profiles is mainly composed of needles (43%), followed by leaves & needles (29%) and leaves and needles & Ericaceae (each 14%). Half of the plots have a dense root mat.

Mull

L-horizon is the most dominant horizon; its average depth is 1.3 cm. The average depth of the whole humus layer is 2.4 cm. No particles >2 mm were found. The litter is loose (80% of the Mull profiles), clotted (15%) and layered (4%). Transitions between the horizons range from sharp (12%), moderately sharp (46%) to gradual (27%) and gradual transition (15%). The h-horizon is not smeary. Only in 23% of the Mull profiles a mycorrhizae could be detected. Main sources for the Mull layer are leaves (54% of Mull profiles), followed by leaves & needles and needles & grass roots (each 12%) and Ericacea and needles & Ericaceae (each 8%). In a majority of 58% of these humus types, no root mats developed.

Moder-like mull

L-horizon is the dominating horizon with an average of 1.8 cm depth. The F-horizon is 1.3 cm deep on average, and the H-horizon 0.6 cm. The average depth of the total humus layer is 3.7 cm. The horizons are mainly stored loose (53% of the Moder-like mull profiles) and clotted (20%). The rest of the profiles were either layered, have a loose L-horizon and a F-horizon with mycorrhizae, a loose L-horizon and a brittle F-horizon or a loose L-horizon and a layered F-horizon (each 7%). The majority of the transition zones is transeunt (47% of these humus profiles), or shows gradual transition (27%), and moderately sharp transition (20%). The remaining 7% have a sharp transition. No particles > 2 mm are contained in the soil. 60% of these humus profiles have no myccorhiza and no root mat. The main sources of the Moder-like mull layer on the subplots are leaves & needles (33%), followed by leaves (27%) and needles (13%).

Mull-like moder

F-horizon dominates with an average depth of 2 cm, followed by the L-horizon (average depth 1.1 cm) and H-horizon (average depth 0.4 cm). The average total depth of the humus layer is 3.5 cm. A majority of subplots with Mull-like moder (62%) of the litter is loosely arranged. The remaining humus materials are arranged in layers and brittle (each 15%). The transition between horizons is mainly moderately sharp and gradual (each 31% of Mull-like moder profiles), gradual transition (23%) and only 15% show a sharp transition. 31%

of the H-horizons are smeary. In 62% of the mull-like moder profiles myccorhizae occur. Root mats are found on 46% of this humus type. The humus of mull-like moder is made out of leaves and needles (each 23%) and grass roots & Ericaceae and needles & grass roots (each 15%).

Alpenmoder

Here, the H-horizon dominates with an average of 9.2 cm, followed by the F-horizon (3.3 cm) and the L-horizon (1.8 cm). The total average depth of the Alpenmoder layer is 9.2 cm. 62% of the Alpenmoder profiles show a clotted and 31% a layered storage.

Most Alpenmoder profiles (62%) have a moderately sharp transition and 31% a sharp transition. Only 8% of the H-horizons are smeary. No particles > 2 mm were seen. Myccorhiza occurs in 77% of Alpenmoder and 62% have a root mat. The main sources of this humus layer are needles (46%), followed by leaves & needles (31%).

Soils

The bedrock is comprised of dolomite on which rendzina, relictic loams and rendzina mixed with relictic loams have developed. The predominating soil type is rendzina, occurring on nearly 80% of the sampled subplots. A tenth of the soil samples are relictic loams and the remaining 10% are rendzinas mixed with relictic loams. The soil is with less than 20 cm in average very shallow.

The average depth of Ahb horizon is 11.7 cm, of AC-horizon 5.8 cm, Bvrel horizon 2.4 cm. The average depth of total soil is 18.7 cm.

In less than 5% of the subplots no roots penetrate the soil. Low root penetration of soils (< 2/10 of soil volume penetrated by roots) occurs in 45% of the sampled profiles. 40% of the subplots have average root penetration (2/10 - 6/10 of soil volume), and 20% show a high penetration of roots (> 6/10 of soil volume) in soil (fig. 4.5).

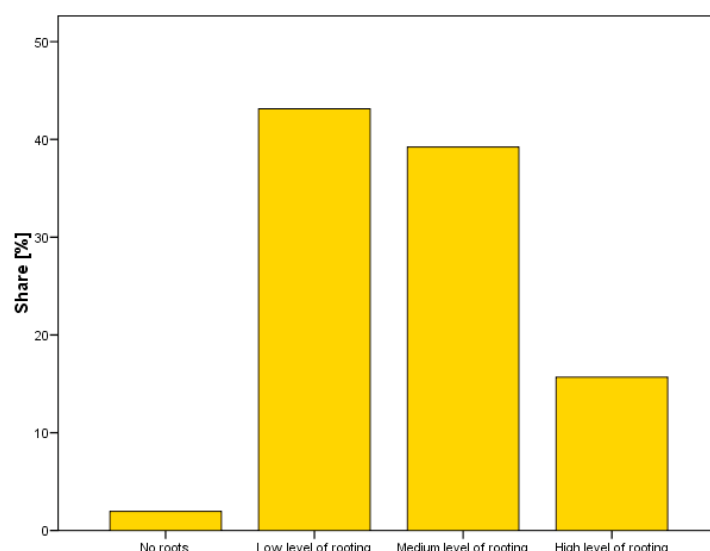


Fig. 4.5: Root penetration of soil in subplots given in percentage. In the category “low level of rooting” less than 2/10 of the soil volume were penetrated by roots, in “medium level of rooting” 2/10 to 6/10 were penetrated and in the category “high level of rooting” more than 6/10 of soil volume were penetrated by roots.

Table 4.3 gives the share of humus type developed above soil type. All three types of humus have developed mainly above rendzina.

Table 4.3: Share of humus type on soil type

	Mull [%]	Moder [%]	Alpenmoder [%]
Rendzina	85	72	86
Rendzina mixed with relictic loams	10	7	11
Relictic loams	5	14	4

Vegetation analysis

It was not possible to identify all the collected plants; many grew vegetatively at the time of collection. Therefore, some species, probably including indicator species, may be missing. The dominant plant species could all be identified.

The dominating species with highest abundance and highest consistency on all plots are *Rhododendron hirsutum*, *Erica carnea*, *Vaccinium myrtillus*, *Vaccinium vitis-idaea* and *Calamagrostis varia* (table 4.4).

Table 4.4: Indicator values by Ellenberg (2001) and consistency in the study area: L- light; F- soil moisture; R- pH. Highest consistency to be gained is 21.

Species	L	F	R	Consistency
<i>Calamagrostis varia</i>	7	5~	8	16
<i>Erica carnea</i>	5	x	4	21
<i>Rhododendron hirsutum</i>	7	4	7	21
<i>Vaccinium myrtillus</i>	5	x	2	20
<i>Vaccinium vitis-idaea</i>	4	4~	2	20

The plots show high homogeneity in species composition; exclusions are plot 31, a stand dominated by *F. sylvatica* and plot 25. Also on plot 31, the dominant herbaceous species occurred, but in a much lower abundance than on the other plots (fig 4.6).

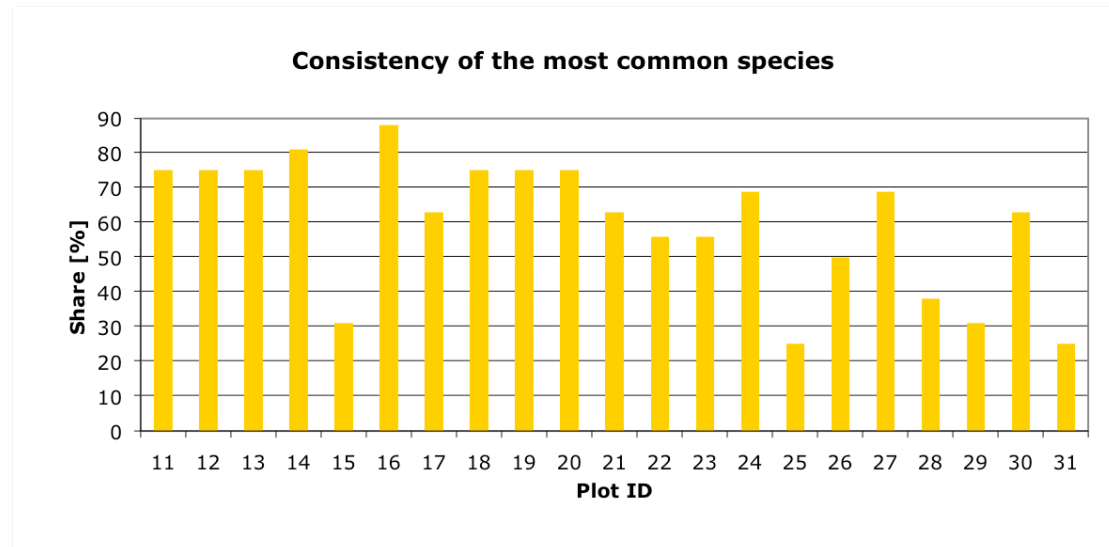


Fig. 4.6: The frequency of the following species up to a consistency of 9 times was summed up and its share on each plot was calculated: *Gymnocarpium robertianum*, *Phyteuma spicatum*, *Polygala chamaebuxus*, *Homogyne alpina*, *Potentilla erecta*, *Euphorbia amygdaloides*, *Paris quadrifolia*, *Helleborus niger*, *Calamagrostis varia*, *Knautia maxima*, *Clematis alpina*, *Polystichum lonchitis*, *Prenanthes purpurea*, *Betonica alopecuros*, *Campanula scheuchzeri*, *Melica nutans*.

Coverage of soil by ground vegetation was assessed by using Braun-Blanquet (1967) and a subsequent transformation of data was performed. Competition between tree regeneration and dense ground vegetation can hamper the establishment of tree regeneration (Grembichl, 1893 & Mayer, 1986). In this study, scarcely distributed herbs are not counted as competitors for regeneration. Transformed data include only species with ground coverage of minimum 5%. The coverage of each species was summed up. This comprises an error; growth patches of species are interlocking. The total share of ground covered by included species is in total less than the results gained.

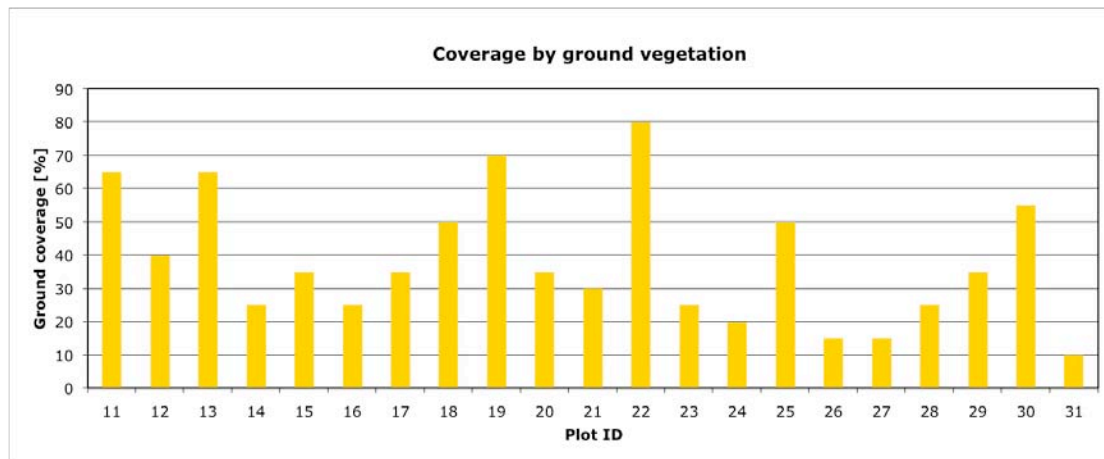


Fig. 4.7: This figure shows relative coverage of plot area by grasses and dwarf-shrubs (including *Rhododendron hirsutum*, *Erica carnea*, *Vaccinium myrtillus*, *V. vitis-idea* and *Calamagrostis varia*).

The single plots show a big variance in ground coverage (fig. 4.7). Highest ground coverage is reached on plot 22 with 80% ground coverage. Plot 31 has the lowest ground coverage with 10% only.

4.1.4 Analysis of avalanche hazard

Avalanche hazard for each plot was estimated by the use of ELBA and ArcGis. The results are displayed as can be seen in fig. 4.8. In addition to that, a table is produced, containing all relevant information about the avalanche (table 4.5).

Avalanche simulation using ELBA

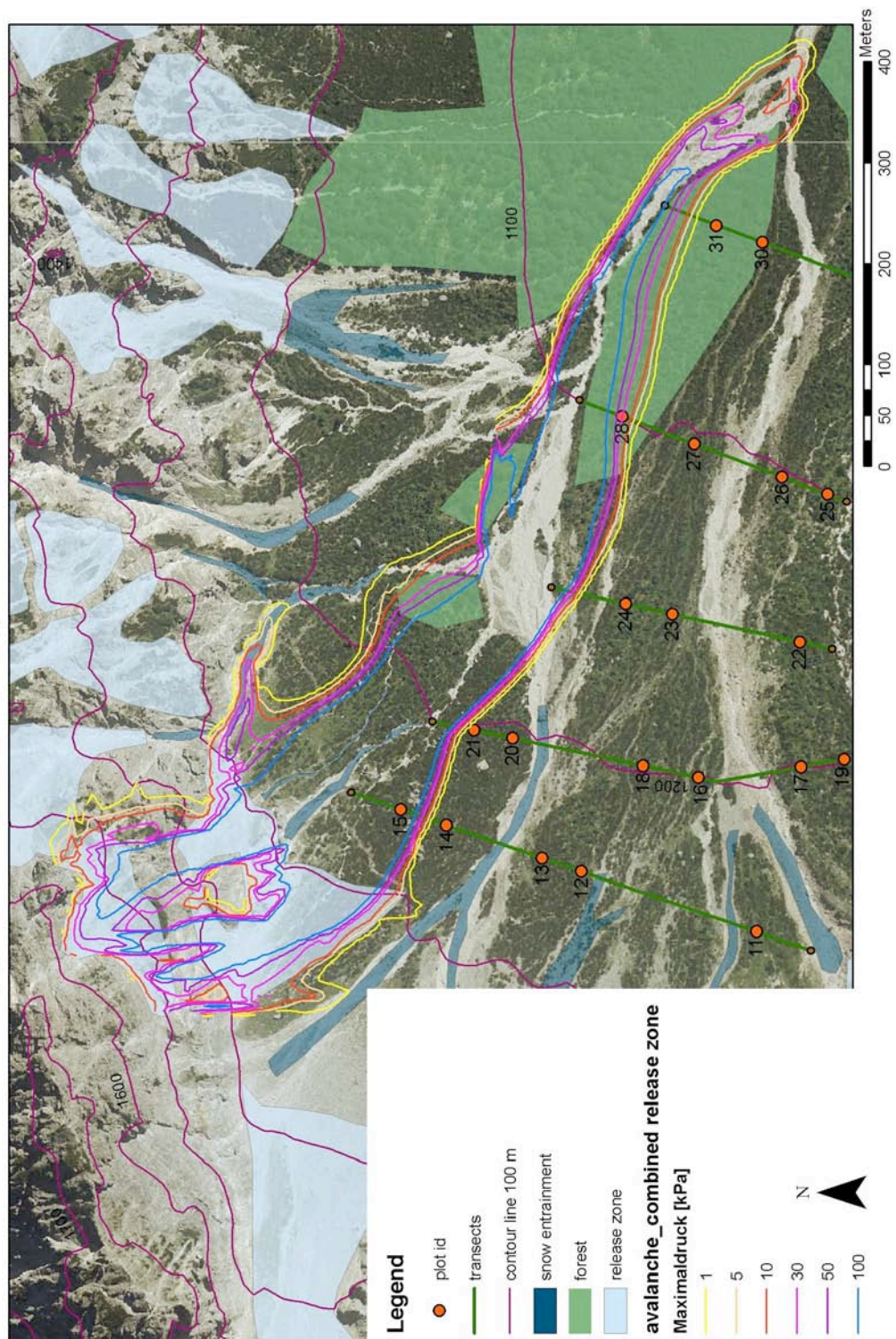


Fig. 4.8: Avalanche simulation in the study area by using ELBA.

Table 4.5: Parameter of an avalanche simulation using ELBA.

General description	ID: 83
Catchment area	Ges01
Variant	Variante 6
Terrain model	gesauese_tin01_Ges01
Raster width [m]	5

Release zone	
Name	kom10_09
Area [ha]	3.414
Mean release height [m]	1.3
Release volume [10^3m^3]	44,525
Feature class	D:\tempHanna\Daten\shp\Anbruchgebiete.shp.hoehe
Model parameter and site conditions	
Friction model	Variable flow regime
μ -Starting phase []	0.25
μ -Flow phase []	0.155
μ -Deposition phase []	0.35
t-max Starting phase [s]	10
Lower velocity limit [m/s]	3
Upper velocity limit [m/s]	7
Length of roughness [m]	0.1
Length of roughness.-Feat.cl.	D:\tempHanna\Daten\shp\Wald.shp.Widerstand
Entrainment [m]	0.1
Entrainment-Feat.cl.	D:\tempHanna\Daten\shp\Schneeaufnahme.shp.EntHoehe
Critical normal stress [kg/m ²]	200
Release density [kg/m ³]	300
Flow density [kg/m ³]	300
Simulated	TRUE
Log-Interval	2000
Simulation - assumptions	
Result - comment	
Relevance	Average

The delineation of avalanches was used to count how often an avalanche potentially affected a plot. The area of the release zone was used to give weight to each avalanche; avalanches with small release zones happen more frequently than such with bigger release zones (> 5 ha). Under these assumptions, avalanche hazard was calculated for each plot and a classification of relative avalanche hazard was generated (table 4.6).

Table 4.6: Classification of avalanche hazard on each plot. The second column gives the weighted sum of potential avalanche frequency on a plot, the third column gives the relative share of avalanche frequency. Avalanche hazard classification was done by using results of the fourth column; "3" indicates high avalanche hazard, "1" indicates low avalanche hazard.

<i>Plot ID</i>	<i>Weighted sum of avalanche frequency</i>	<i>Share of avalanches within group</i>	<i>Avalanche hazard category</i>	<i>Announcements</i>
23	3	100	3	
27	3	100	3	No <i>F. sylvatica</i>
30	2.75	92	3	
25	2.25	75	3	No <i>P. mugo</i>
15	2	67	2	No <i>F. sylvatica</i>
28	2	67	2	
29	2	67	2	
22	1.75	58	2	

17	1,5	50	2	
24	1,5	50	2	
19	0.75	25	1	
11	0.5	17	1	No <i>F. sylvatica</i>
12	0.5	17	1	
13	0.5	17	1	
16	0.5	17	1	No <i>F. sylvatica</i>
18	0.5	17	1	
21	0.5	17	1	
31	0.25	8	1	No <i>P. mugo</i>
14	0	0	1	No <i>F. sylvatica</i>
20	0	0	1	

4.1.5 Cluster analysis of multiple site parameters

To be able to detect a response of adult trees to multiple site factors, cluster analysis was performed. Plots with squared Euclidian distance up to five cases were divided into groups for further analysis. Parameters used for clustering were the following (Cluster analysis 1):

- Aspect of macro relief
- Slope gradient of macro relief
- Altitude
- Share of relictic loams
- Soil depth
- Avalanche hazard category (fig. 4.9)

Using these parameters, five clusters were formed, one cluster (cluster 3) consisting of one plot only. By including avalanche hazard frequency in the analysis, the same results were achieved.

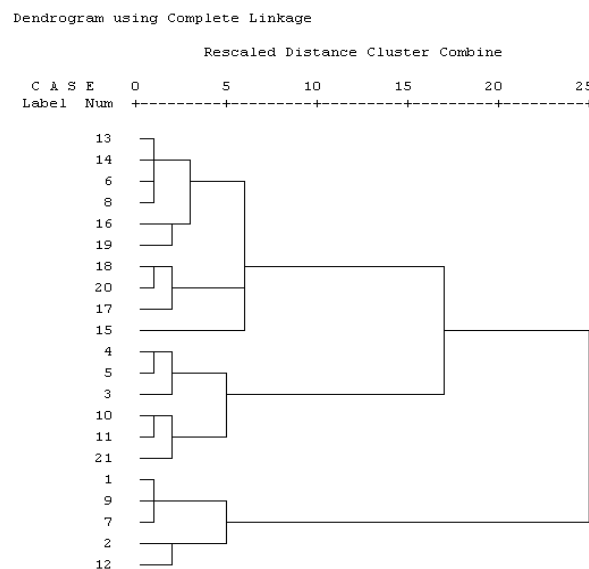


Fig. 4.9: Cluster analysis was performed to find plots with similar site characteristics. The column "num" does not correspond to the plot ID.

Characteristics describing clusters of cluster analysis 1 are given in table 4.7:

Characteristics of cluster analysis 1

Table 4.7: Characteristics of clusters of cluster analysis 1. For numerical data mean value, for ordinal or categorical data, modal value is displayed. The range of altitude is given.

	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
Main aspect	ESE	ESE	ESE	ESE	E
Altitude	1050-1200	1050-1100	1100	1050; 1200-1250	1150-1250
Inclination [%]	25	21	32	45	36
Share of relictic loam	None	Medium	None	None	None
Soil depth [cm]	14.5	27.0	29.5	18.0	19.0
Avalanche hazard category	Medium	High	High	Low	Low

In a second cluster analysis performed (fig. 4.10) species abundance of all adult tree species or, for *F. sylvatica* and *P. mugo*, abundance within diameter distribution, was used to form clusters. Aim of this cluster analysis was to detect plots with similar species composition, and, in a next step, to detect factors of species composition. Table 4.8 proves the quality of the clusters, which is sufficient.

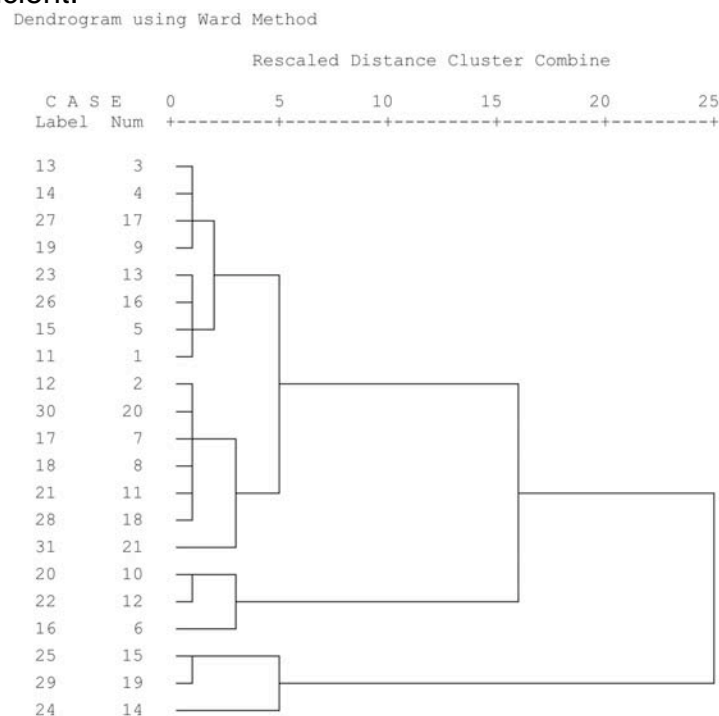


Fig. 4.10: Cluster analysis 2 under use of following data: abundance of abundance of all tree species and for *F. sylvatica* and *P. mugo* abundance within diameter distribution.

Table 4.8: Wilks' Lambda was carried out to proof relationship of the clusters.

Test of Function(s)	Wilks' Lambda	Chi-square	df	Sig.
1 through 4	.000	163.643	56	.000
2 through 4	.000	86.712	39	.000
3 through 4	.022	40.183	24	.020
4	.316	12.098	11	.356

Taking together abiotic and biotic disturbances, species composition in cluster analysis 2 (table 4.9) cannot be explained by the abundance, frequency and intensity of abiotic and biotic disturbances.

Table 4.9: Discriminate analysis carried out to see if abiotic and biotic disturbances influence the development of species composition on plot.

Test of Function(s)	Wilks' Lambda	Chi-square	df	Sig.
1 through 4	.002	28.837	24	.226
2 through 4	.347	4.764	15	.994
3 through 4	.853	.716	8	.999
4	.964	.166	3	.983

4.2 Performance of regeneration

4.2.1 Seedlings (< 1 year)

F. sylvatica (52% of species abundance), *A. pseudoplatanus* (32%) and *S. aucuparia* (6%) are the most frequent species of seedlings < 1 year old (fig. 4.11).

Only three individuals (*P. mugo*, *L. decidua*, *A. alba*) (3% of species abundance totally) were found on dead and decaying wood, all other seedlings are growing on the soil.

Seedlings < 1 year are concentrated on plots number 25, 28 and 31.

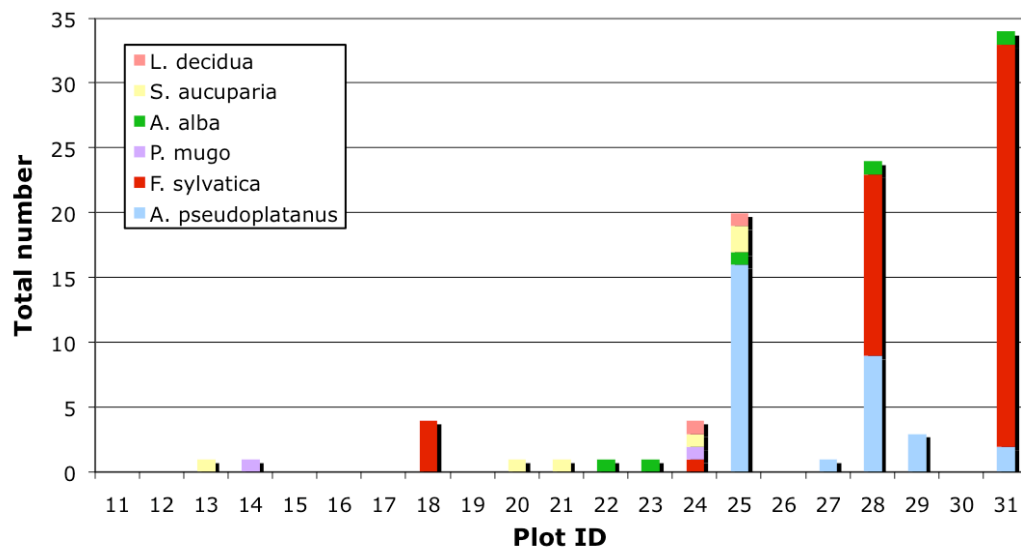


Fig. 4.11: Total amount of seedlings < 1 year on the sampled plots.

Highest density of *F. sylvatica* seedlings < 1 year per ha are abundant in low altitude (fig. 4.12). Only two seedlings < 1 year of *P. mugo* were found within the whole study area. *A. pseudoplatanus* and *A. alba* show significantly negative correlations with altitude (table 4.10).

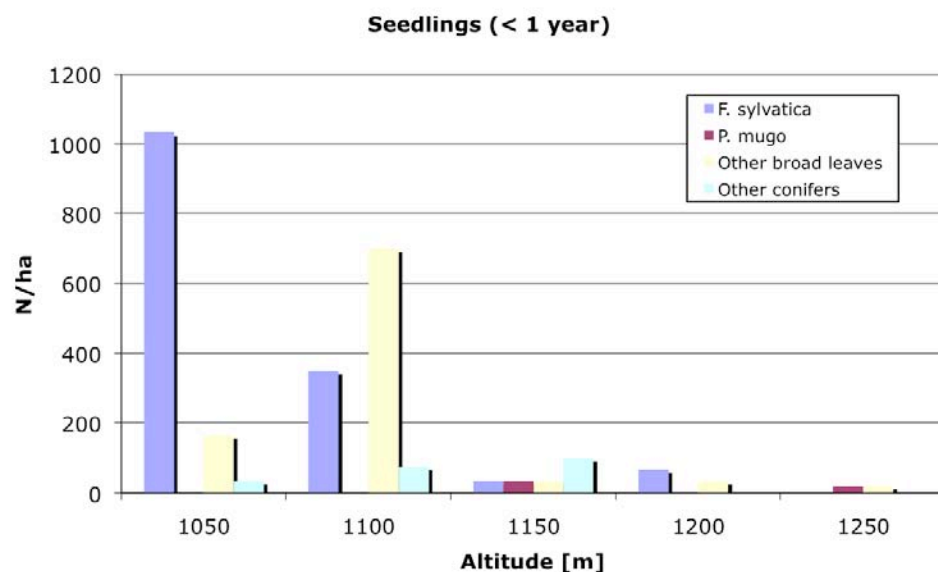


Fig. 4.12: Number/ha of seedlings in increasing altitude.

Table 4.10: Correlation (Spearman-Rho) of seedling abundance and altitude. * Correlation is significant at 0.05 (2-tailed). ** Correlation is significant at 0.01 (2-tailed).

	Altitude [m]	
<i>A. pseudoplatanus</i> seedling < 1 year [n]	Coefficient of correlation	-.639(**)
	Sig. (2-tailed)	.002
	N	21
<i>F. sylvatica</i> seedling < 1 year [n]	Coefficient of correlation	-.313
	Sig. (2-tailed)	.167

<i>S. aucuparia</i> seedling < 1 year [n]	N	21
	Coefficient of correlation	.074
	Sig. (2-tailed)	.750
<i>A. alba</i> seedling < 1 year [n]	N	21
	Coefficient of correlation	-.451(*)
	Sig. (2-tailed)	.040
Total sum of seedling < 1 year [n]	N	21
	Coefficient of correlation	-.453(*)
	Sig. (2-tailed)	.039
	N	21

F. sylvatica seedlings < 1 year have significant correlations with the abundance of potential mother trees. For *P. mugo* seedlings, correlation shows no significant results (table 4.11).

Table 4.11: Correlation (Spearman-Rho) between abundance of seedling and adult *F. sylvatica* and *P. mugo* with fruits during sampling period. * Correlation is significant at 0.05 (2-tailed).

		Seedling < 1 year <i>P. mugo</i> [n]	Seedling < 1 year <i>F.</i> <i>sylvatica</i> [n]
Adult <i>F. sylvatica</i> [n]	Coefficient of correlation	.068	.460(*)
	Sig. (2-tailed)	.770	.036
	N	21	21
Adult <i>P. mugo</i> [n]	Coefficient of correlation	-.228	-.433
	Sig. (2-tailed)	.320	.050
	N	21	21

Light regime

None of the seedlings shows significant correlation with the percentage of ground cover (table 4.12).

Table 4.12: Correlation (Spearman-Rho) between regeneration < 1 year and site factors/ ground vegetation cover. * Correlation is significant at 0.05 (2-tailed).

		Ground vegetation cover [%]	Indirect Site Factor	Direct Site Factor	Global Site Factor
Seedling < 1 year <i>A. pseudoplatanus</i> [n]	Coefficient of correlation	-.258	-.406	-.252	-.270
	Sig. (2-tailed)	.260	.068	.270	.236
	N	21	21	21	21
Seedling < 1 year <i>F. sylvatica</i> [n]	Coefficient of correlation	-.308	-.252	-.066	-.085
	Sig. (2-tailed)	.175	.271	.775	.713
	N	21	21	21	21
Seedling < 1 year	Coefficient of	-.245	-.214	-.161	-.161

<i>P. mugo</i> [n]	correlation				
	Sig. (2-tailed)	.285	.351	.486	.486
	N	21	21	21	21
Seedling < 1 year other conifers [n]	Coefficient of correlation	-.058	-.211	-.123	-.123
	Sig. (2-tailed)	.801	.360	.594	.594
	N	21	21	21	21

4.2.2 Regeneration (> 1 year)

The most frequent species in regeneration older than 1 year are *A. pseudoplatanus* (36% of species abundance), *F. sylvatica* (25%) and *S. aucuparia* (23%). Regeneration of *P. mugo* was found but at 3% it is not very abundant (fig. 4.13). The highest abundance of regeneration is found on plots 28, 29 and 25 (similar to regeneration < 1 year).

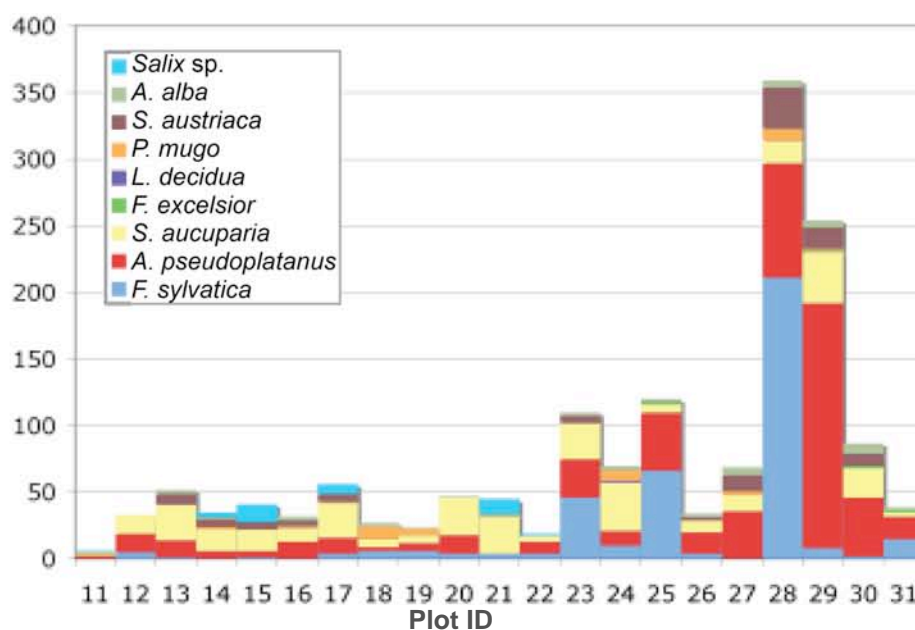


Fig. 4.13: Total number of regeneration on each plot.

Abundance of *F. sylvatica* regeneration is significantly decreasing with increasing altitude; the same is true for *A. alba*. *A. pseudoplatanus* and *F. excelsior* show a highly significant decline of abundance in higher altitude. *Salix* sp. is the only species with a significant increase in abundance with elevation (fig 4.14 and table 4.13).

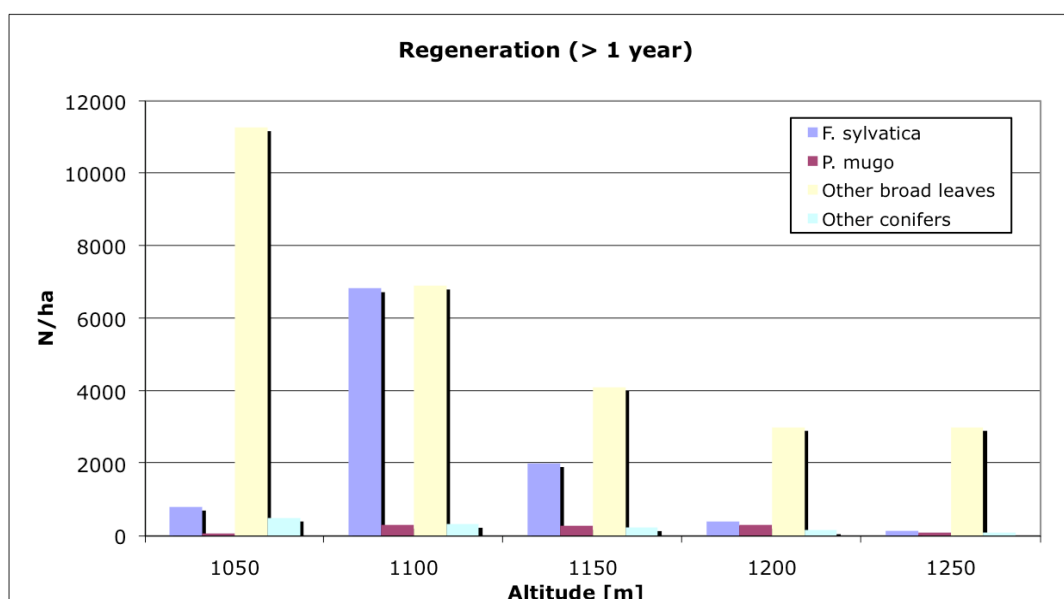


Fig. 4.14: Altitudinal distribution of regeneration in number per ha.

Table 4.13: Correlation (Spearman-Rho) between regeneration and altitude. ** Correlation is significant at 0.01 (2-tailed), * Correlation is significant at 0.05 (2-tailed).

	Altitude [m]	
<i>A. pseudoplatanus</i> regeneration [n]	Coefficient of correlation	-.739(**)
	Sig. (2-tailed)	.000
	N	21
<i>F. sylvaticus</i> regeneration [n]	Coefficient of correlation	-.497(*)
	Sig. (2-tailed)	.022
	N	21
<i>S. aucuparia</i> regeneration [n]	Coefficient of correlation	-.027
	Sig. (2-tailed)	.909
	N	21
<i>F. excelsior</i> regeneration [n]	Coefficient of correlation	-.653(**)
	Sig. (2-tailed)	.001
	N	21
<i>L. decidua</i> regeneration [n]	Coefficient of correlation	-.076
	Sig. (2-tailed)	.744
	N	21
<i>P. mugo</i> regeneration [n]	Coefficient of correlation	.026
	Sig. (2-tailed)	.912
	N	21
<i>S. austriaca</i> regeneration [n]	Coefficient of correlation	-.288
	Sig. (2-tailed)	.205
	N	21
<i>A. alba</i> regeneration [n]	Coefficient of correlation	-.527(*)
	Sig. (2-tailed)	.014
	N	21
<i>Salix</i> sp. regeneration [n]	Coefficient of correlation	.488(*)
	Sig. (2-tailed)	.025
	N	21

To test if the relationship between regeneration and altitude is correlated with density of adult trees, correlation between densities of adult trees and regeneration in each altitude was carried out (table 4.14). No significant correlations were detected.

Table 4.14: Correlation (Pearson) between species' density of adult trees and regeneration per altitude. Number of samples is quite low.

		<i>F. sylvatica</i> adult [N/ha]	<i>P. mugo</i> adult [N/ha]	Other broad leaves adult [N/ha]	Other conifers adult [N/ha]
<i>F. sylvatica</i> regeneration [N/ha]	Correlation (Pearson)	.159	-.366	.380	-.372
	Significance (2-tailed)	.799	.545	.528	.538
	N	5	5	5	5
<i>P. mugo</i> regeneration [N/ha]	Correlation (Pearson)	.049	.520	.046	-.232
	Significance (2-tailed)	.938	.370	.941	.707
	N	5	5	5	5
Other broad leaves regeneration [N/ha]	Correlation (Pearson)	.629	-.796	.753	.148
	Significance (2-tailed)	.256	.107	.142	.813
	N	5	5	5	5
Other conifers regeneration [N/ha]	Correlation (Pearson)	.493	-.825	.749	.241
	Significance (2-tailed)	.399	.086	.145	.697
	N	5	5	5	5

F. sylvatica regeneration shows a highly significant positive correlation between its abundance and the occurrence of propagable *F. sylvatica* trees. Whereas its regeneration is less frequent on plots, where more individuals of *P. mugo* grow (table 4.15).

The test shows no significant correlation between regeneration of *P. mugo* and propagable krummholz.

Table 4.15: Correlation (Spearman-Rho) between abundance of adult trees and occurrence of regeneration. ** Significance at 0.01 level (2-tailed); * Significance at 0.05 level (2-tailed).

		<i>F. sylvatica</i> regeneration [n]	<i>P. mugo</i> regeneration [n]
<i>F. sylvatica</i> adult [n]	Correlation coefficient	.767(**)	.023
	Sig. (2-tailed)	.000	.922
	N	21	21
<i>P. mugo</i> adult [n]	Correlation coefficient	-.511(*)	.069
	Sig. (2-tailed)	.018	.765
	N	21	21

Table 4.16: Correlation (Spearman-Rho) between frequency of regeneration per plot. * Correlation significant at 0.05 (2-tailed); ** Correlation significant at 0.01 (2-tailed).

		<i>A. pseudopla tanus</i> [n]	<i>F. sylvatic a</i> [n]	<i>S. aucupar ia</i> [n]	<i>F. Excelsi or</i> [n]	<i>L. decidua</i> [n]	<i>P. mugo</i> [n]	<i>S. austriac a</i> [n]	<i>A. alba</i> [n]	<i>Salix sp.</i> [n]
<i>A. pseudopla tanus</i> [n]	Coefficient of correlation	1.000	.411	.206	.571(**)	-.111	-.156	.586(**)	.465(*)	-.650(**)
	Sig. (2-tailed)	.	.064	.370	.007	.632	.501	.005	.034	.001
	N	21	21	21	21	21	21	21	21	21
<i>F. sylvatica</i> [n]	Coefficient of correlation	.411	1.000	.103	.353	.224	.045	-.122	-.019	-.428
	Sig. (2-tailed)	.064	.	.657	.116	.329	.845	.598	.936	.053
	N	21	21	21	21	21	21	21	21	21
<i>S. aucuparia</i> [n]	Coefficient of correlation	.206	.103	1.000	-.085	.333	-.083	.386	.376	-.012
	Sig. (2-tailed)	.370	.657	.	.713	.140	.720	.084	.093	.958
	N	21	21	21	21	21	21	21	21	21
<i>F. excelsior</i> [n]	Coefficient of correlation	.571(**)	.353	-.085	1.000	-.108	-.283	.157	.158	-.300
	Sig. (2-tailed)	.007	.116	.713	.	.642	.214	.495	.493	.187
	N	21	21	21	21	21	21	21	21	21
<i>L. decidua</i> [n]	Coefficient of correlation	-.111	.224	.333	-.108	1.000	.320	-.232	.189	-.139
	Sig. (2-tailed)	.632	.329	.140	.642	.	.158	.313	.413	.548
	N	21	21	21	21	21	21	21	21	21
<i>P. mugo</i> [n]	Coefficient of correlation	-.156	.045	-.083	-.283	.320	1.000	.073	.281	-.141
	Sig. (2-tailed)	.501	.845	.720	.214	.158	.	.752	.217	.543
	N	21	21	21	21	21	21	21	21	21
<i>S. austriaca</i> [n]	Coefficient of correlation	.586(**)	-.122	.386	.157	-.232	.073	1.000	.560(**)	-.094
	Sig. (2-tailed)	.005	.598	.084	.495	.313	.752	.	.008	.686
	N	21	21	21	21	21	21	21	21	21
<i>A. alba</i> [n]	Coefficient of correlation	.465(*)	-.019	.376	.158	.189	.281	.560(**)	1.000	-.471(*)
	Sig. (2-tailed)	.034	.936	.093	.493	.413	.217	.008	.	.031
	N	21	21	21	21	21	21	21	21	21
<i>Salix sp.</i> [n]	Coefficient of correlation	-.650(**)	-.428	-.012	-.300	-.139	-.141	-.094	-.471(*)	1.000
	Sig. (2-tailed)	.001	.053	.958	.187	.548	.543	.686	.031	.
	N	21	21	21	21	21	21	21	21	21

It was not possible to normalize distribution of most regeneration data, therefore, Spearman-Rho correlation was used (table 4.16). For normally distributed data, Pearson's correlation was performed: Using this test, significant correlation between *A. pseudoplatanus* and *F. sylvatica* was gained. All other results are equal in significance to Spearman-Rho.

The frequency of *A. pseudoplatanus* per plot shows very significant positive correlations with *F. excelsior* and *S. austriaca* as well as significant positive correlation with *A. alba*. Besides that, it has a highly significant negative correlation with *Salix* sp. *Salix* sp. is also negatively correlated with *A. alba*. *S. austriaca* and *A. alba* are highly significantly positively correlated.

Growth

The distribution of height, diameter and length of terminal shoot for all species found in regeneration is shown in fig. 4.15 – fig. 4.17.

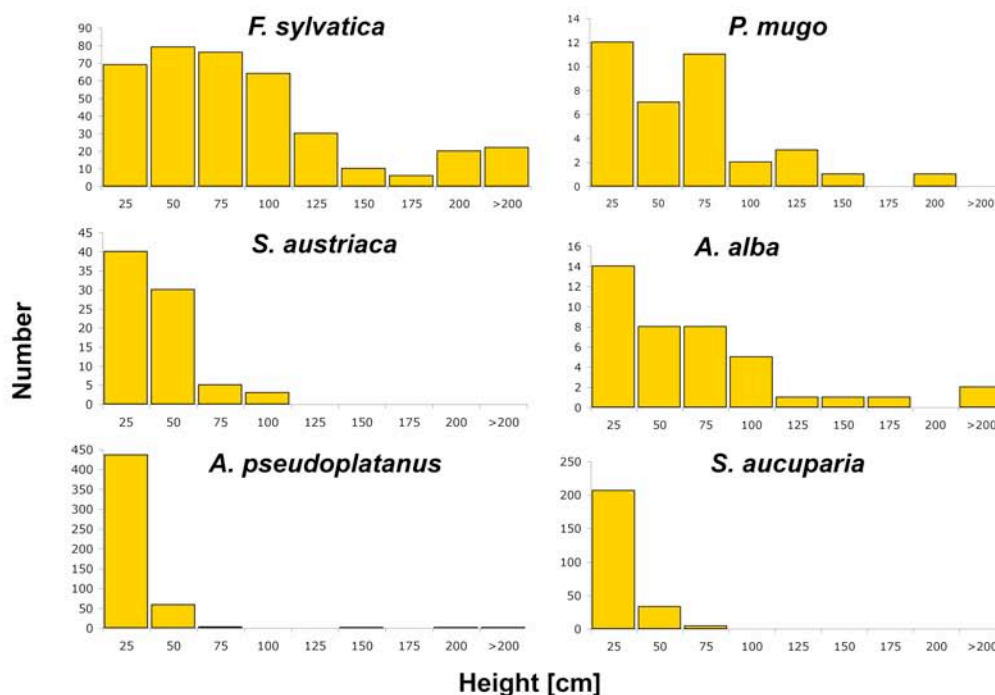


Fig. 4.15: Height distribution of regeneration in 25 cm steps. Take into account different labelling of y-axis.

F. sylvatica, *A. alba* and *P. mugo* are the only species with regeneration in nearly all height classes. This is an important indicator, which shows that regeneration of these species is able to reach maturity. The threat of terminal shoots being browsed decreases with an increasing height, and higher plants have bigger chances to succeed in competition with other individuals.

Especially *A. pseudoplatanus* and *S. aucuparia*, but also *S. austriaca*, have high abundances in early stages. Less than 1 % of regeneration of *A. pseudoplatanus* reaches heights > 100 cm, and no *S. aucuparia* and *S. austriaca* were found higher than 100 cm.

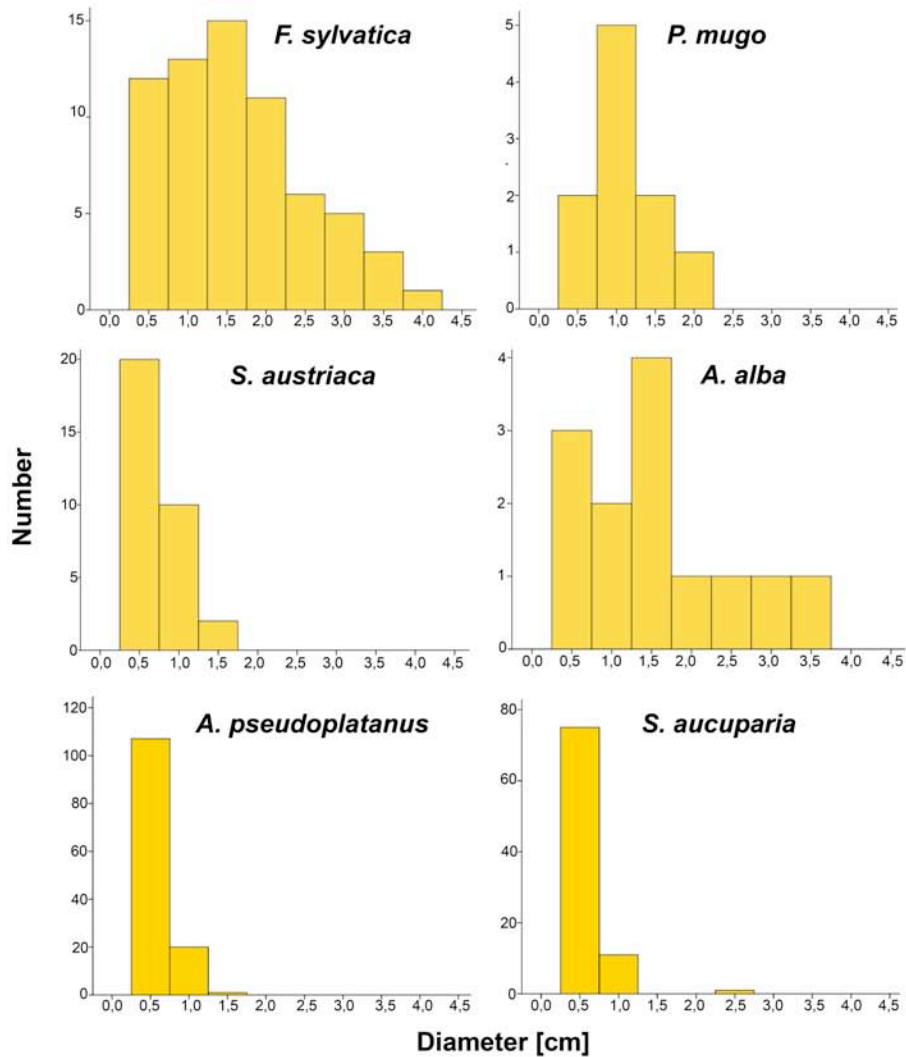


Fig. 4.16: Diameter distribution of regeneration in 0.5 cm steps. Take into account different labelling of y-axis.

Regeneration was defined as diameter at root base ≤ 5 cm. *F. sylvatica* and *A. alba* are abundant in nearly all diameter classes. *P. mugo*, *S. austriaca*, *A. pseudoplatanus* and *S. aucuparia* have the highest abundance in low diameter classes.

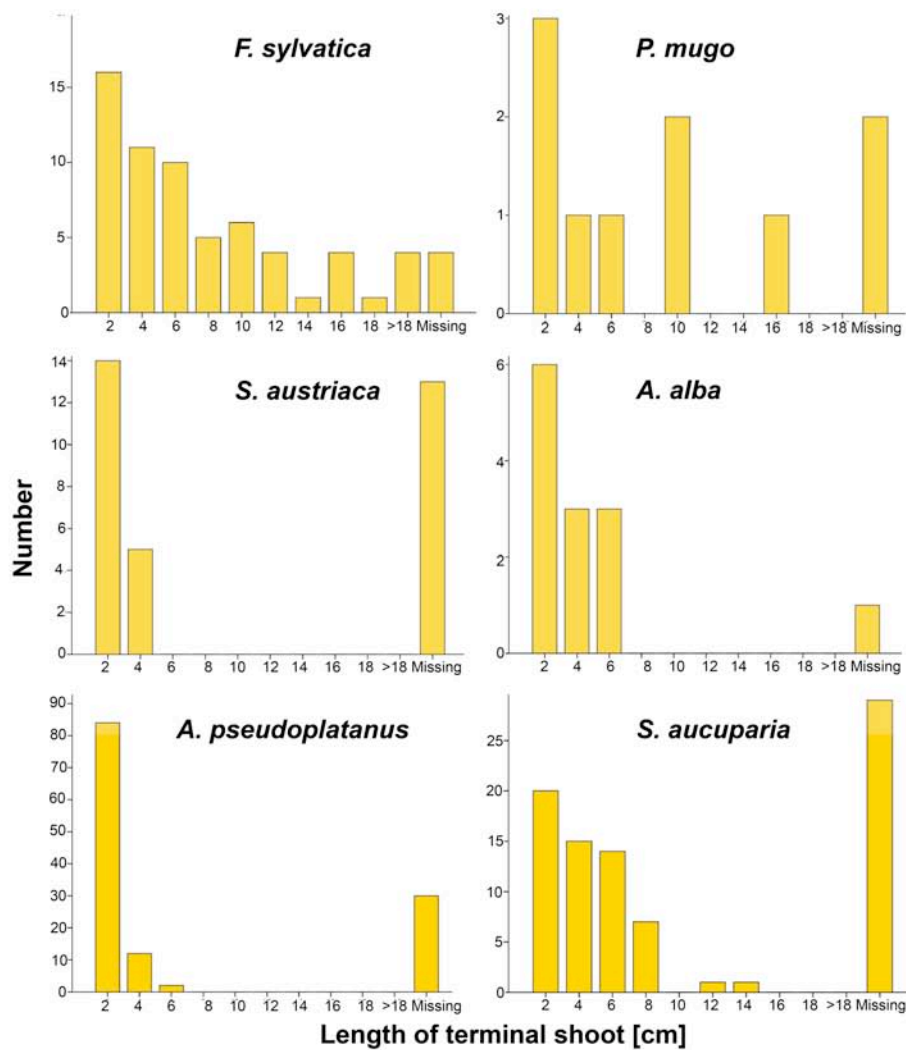


Fig. 4.17: Distribution of length of terminal shoot of regeneration in 2 cm steps. Take into account different labelling of y-axis.

Many individual plants had missing terminal shoots (of the previous year). These plants also showed other signs of browsing in most cases. *F. sylvatica* was the species performing best; terminal shoots reach lengths up to more than 18 cm. *P. mugo* and *S. aucuparia* grow up to 14 and 16 cm annually, respectively. *A. alba*, *S. austriaca* and *A. pseudoplatanus* have the lowest performance; the annual growth of terminal shoots was not more than 6 cm.

To test if the growth of regeneration is influenced by altitude, correlation (table 4.17) and analysis of variance was performed. For data of length of terminal shoot, which are normally distributed, analysis of variance was applied. No significant variations between average length at each altitude was found using analysis of variance. The correlation shows no relationship between altitude and length of terminal shoot.

Table 4.17: Correlation (Spearman-Rho and Pearson) between length of terminal shoot of each species and altitude.

	<i>Altitude [cm]</i>	
<i>F. sylvatica</i>		
Length of terminal shoot [cm]	Coefficient of correlation	.140
	Sig. (2-tailed)	.279
	N	62
<i>S. aucuparia</i>		
Length of terminal shoot [cm]	Coefficient of correlation	.087
	Sig. (2-tailed)	.516
	N	58
<i>A. pseudoplatanus</i>		
Length of terminal shoot [cm]	Coefficient of correlation	-.061
	Sig. (2-tailed)	.548
	N	98
<i>S. austriaca</i>		
Length of terminal shoot [cm]	Coefficient of correlation	.061
	Sig. (2-tailed)	.803
	N	19
<i>P. mugo</i>		
Length of terminal shoot [cm]	Correlation (Pearson)	.425
	Sig. (2-tailed)	.294
	N	8
<i>A. alba</i>		
Length of terminal shoot [cm]	Correlation (Pearson)	.475
	Sig. (2-tailed)	.119
	N	12

The correlation between level of shading and length of terminal shoot was tested. Significant results were only achieved for *S. aucuparia*, which has higher growth in higher canopy densities (table 4.18).

Table 4.18: Correlation (Spearman-Rho) between length of terminal shoot (of previous year) and level of shading. ** Correlation is significant at 0.01 (2-tailed).

	<i>Level of shading</i>	
<i>F. sylvatica</i>		
Length of terminal shoot [cm]	Coefficient of correlation	-.091
	Sig. (2-tailed)	.480
	N	62
<i>S. aucuparia</i>		
Length of terminal shoot [cm]	Coefficient of correlation	.434(**)
	Sig. (2-tailed)	.001
	N	58
<i>A. pseudoplatanus</i>		
Length of terminal shoot [cm]	Coefficient of correlation	.095
	Sig. (2-tailed)	.350
	N	98
<i>S. austriaca</i>		
Length of terminal shoot [cm]	Coefficient of correlation	.138
	Sig. (2-tailed)	.572
	N	19
<i>P. mugo</i>		
Length of terminal shoot [cm]	Coefficient of correlation	-.228
	Sig. (2-tailed)	.587
	N	8

<i>A. alba</i>		
Length of terminal shoot [cm]	Coefficient of correlation	-.124
	Sig. (2-tailed)	.700
	N	12

Growth of regeneration in sites with high snow covers for broadleaf species, is often not vertical but inclined or creeping along the soil. Therefore, apart from height also the length of shoots was measured. Length and height correlate well for all species; in figure 4.18 it is indicated for *F. sylvatica* regeneration.

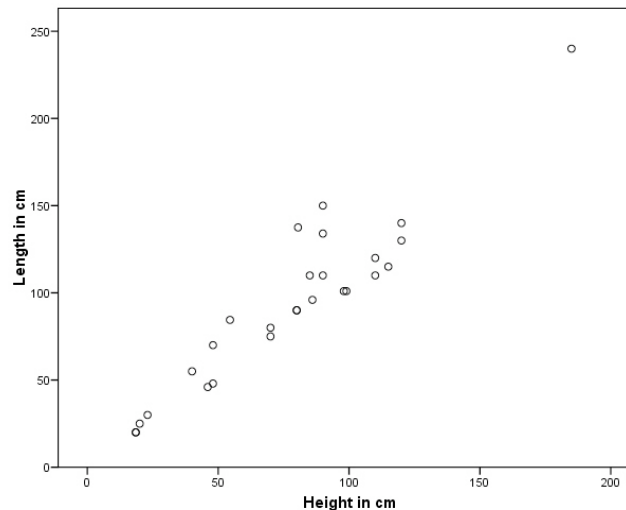


Fig. 4.18: Correlation between height and length of *F. sylvatica* regeneration.

Humus and soil

The highest average abundance of all regeneration, excluding *P. mugo*, is found on mull; more than half of *F. sylvatica* and *A. pseudo-platanus* regeneration grows here. The majority of *P. mugo* regeneration grows on moder, followed by mull. Especially *S. aucuparia* has a high average abundance on Alpenmoder. All broad leaf species show the lowest average abundance on moder (fig. 4.19).

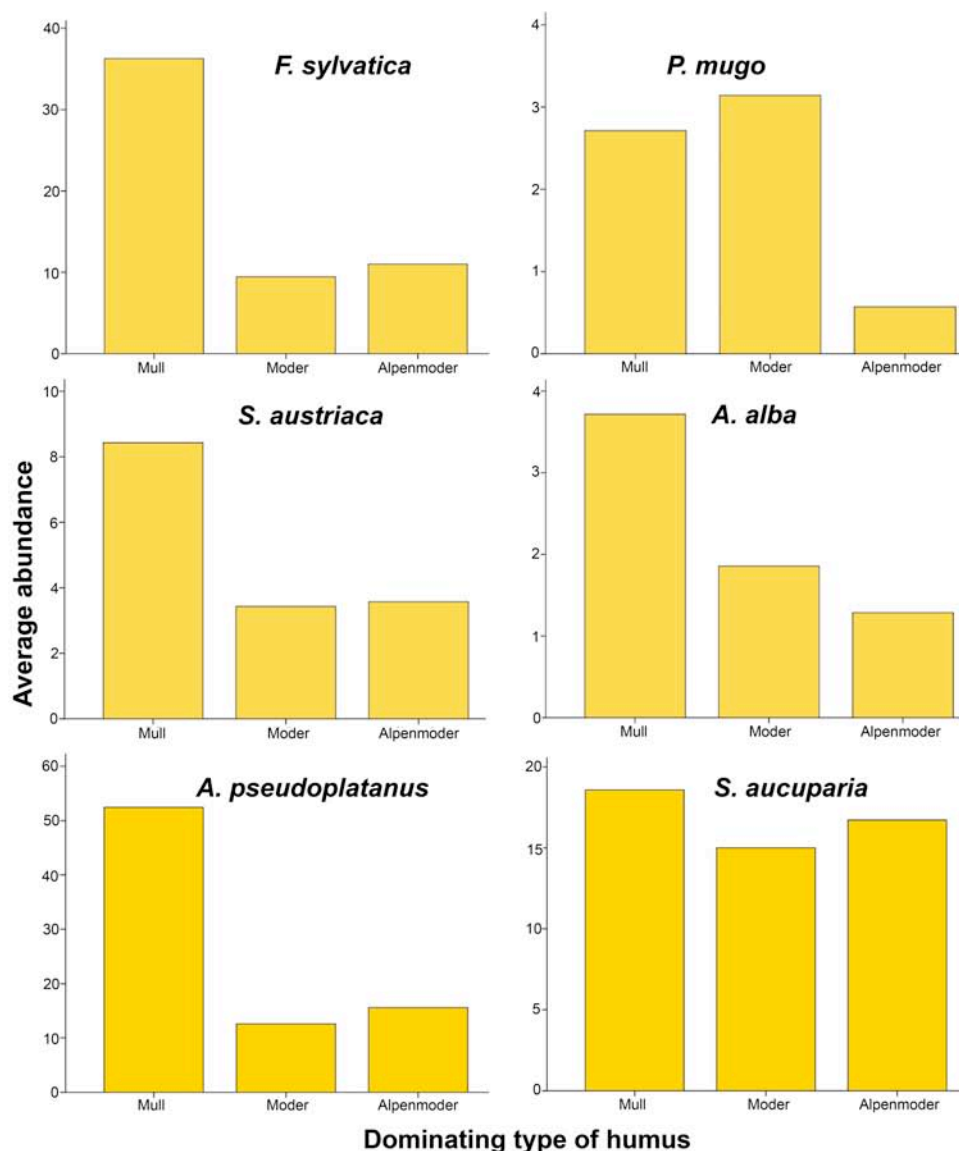


Fig. 4.19: Average abundance of regeneration on different humus types (above the sampled soil profiles).

Analysis of variance shows that all species' regeneration analyzed is randomly distributed over the dominant humus type on the plot when assuming CI of 5% (table 4.19). Regular distribution of *A. pseudoplatanus* and *A. alba* on all types of humus cannot be assumed using 10% CI.

Table 4.19: Analysis of variance of regeneration and dominant humus type.

		Sum of squares	df	Mean square	F	Significance
<i>F. sylvatica</i>	Between groups	5.611	2	2.805	1.309	.295
	Within groups	38.570	18	2.143		
	Total	44.180	20			
<i>A. pseudoplatanus</i>	Between groups	8.132	2	4.066	3.366	.057
	Within groups	21.744	18	1.208		

<i>S. aucuparia</i>	Total	29.876	20			
	Between groups	.640	2	.320	.342	.715
	Within groups	16.831	18	.935		
<i>A. alba</i>	Total	17.471	20			
	Between groups	3.751	2	1.875	3.074	.071
	Within groups	10.981	18	.610		
	Total	14.732	20			

Regeneration is nearly completely missing on plots with high share of relictic loam (fig. 4.20); exceptions are *P. mugo* and *A. pseudoplatanus*. While *P. mugo* is, compared to other soil categories, very abundant, only a minority of *A. pseudoplatanus* grows there. All species gain their highest frequency on plots with an average share of relictic loam in soil profiles; more than half of *F. sylvatica*, *S. austriaca* and *A. alba* regeneration is abundant on these plots.

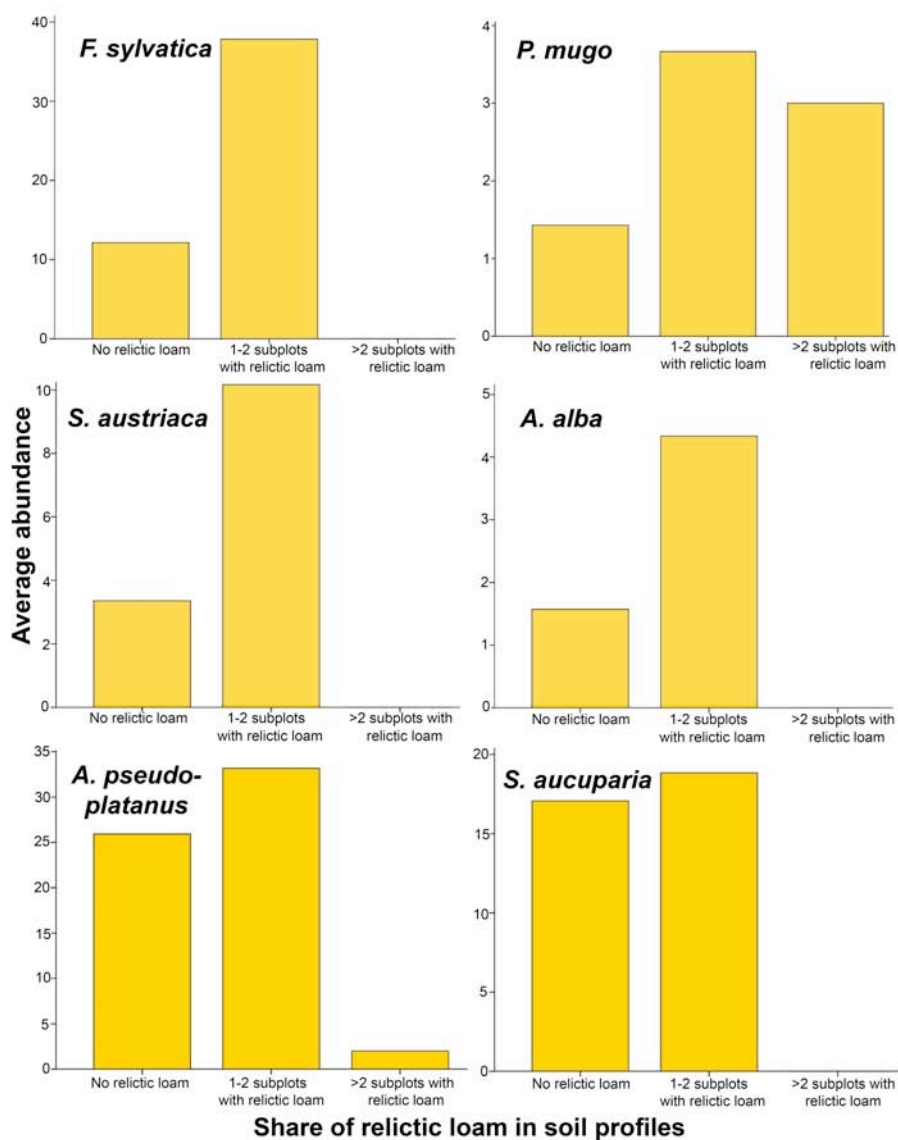


Fig. 4.20: Average abundance of regeneration above soil types (situated around the sampled soil profiles).

For *S. aucuparia* and *A. alba* (table 4.20), relictic loam seems to influence abundance of regeneration using a 5% CI. No regeneration grows on plots, where relictic loam is dominating. *A. alba* has the highest abundance on plots with average relictic loam influence (1 to 2 out of 5 subplots), *S. aucuparia* is nearly equally distributed on plots with no and average relictic loam influence.

Table 4.20: Analysis of variance of regeneration and influence of relictic loam

		<i>Sum of squares</i>	<i>df</i>	<i>Mean square</i>	<i>F</i>	<i>Significance</i>
<i>F. sylvatica</i>	Between groups	2.652	2	1.326	.575	.573
	Within groups	41.529	18	2.307		
	Total	44.180	20			
<i>A. pseudoplatanus</i>	Between groups	5.506	2	2.753	2.033	.160
	Within groups	24.370	18	1.354		
	Total	29.876	20			
<i>S. aucuparia</i>	Between groups	6.945	2	3.473	5.939	.010
	Within groups	10.525	18	.585		
	Total	17.471	20			
<i>A. alba</i>	Between groups	5.754	2	2.877	5.768	.012
	Within groups	8.978	18	.499		
	Total	14.732	20			

Site parameters

No significant dependence between the following variables could be detected using ANOVA or correlation (Pearson) (CI 5%):

All species of regeneration and

- Water household
- Concavity of terrain
- Level and stage erosion
- Average depth of soil
- Average depth of humus

Age

The age of each seedling (> 1 year) found on subplots was counted (Fig 4.21; table 4.21). As especially broad leaf species show a high level of being browsed in the study area, it was often not possible to determine age correctly (71% of all sampled cores); in this case the minimal age was noted. Besides browsing, growth features made it hard to determine age: When trees are growing older, it becomes more difficult to determine their age with help of annual rings on the bark.

Using non-invasive methods, it was not possible to determine the exact age of *F. sylvatica* higher than 30 cm. Therefore, the time of reaching mature age cannot be estimated using this data.

F. excelsior, *L. decidua* and *Salix* sp. were not included into fig 4.21. as they have low abundance in regeneration (< 4 plants).

Table 4.21: Average age of regeneration. Only plants with exactly determined age included.

Species	Average age
<i>F. sylvatica</i>	4.3
<i>A. pseudoplatanus</i>	5.4
<i>S. aucuparia</i>	2.4
<i>F. excelsior</i>	3.5
<i>P. mugo</i>	4.8
<i>S. austriaca</i>	5.4
<i>A. alba</i>	14.8
<i>Salix</i> . sp	5.0

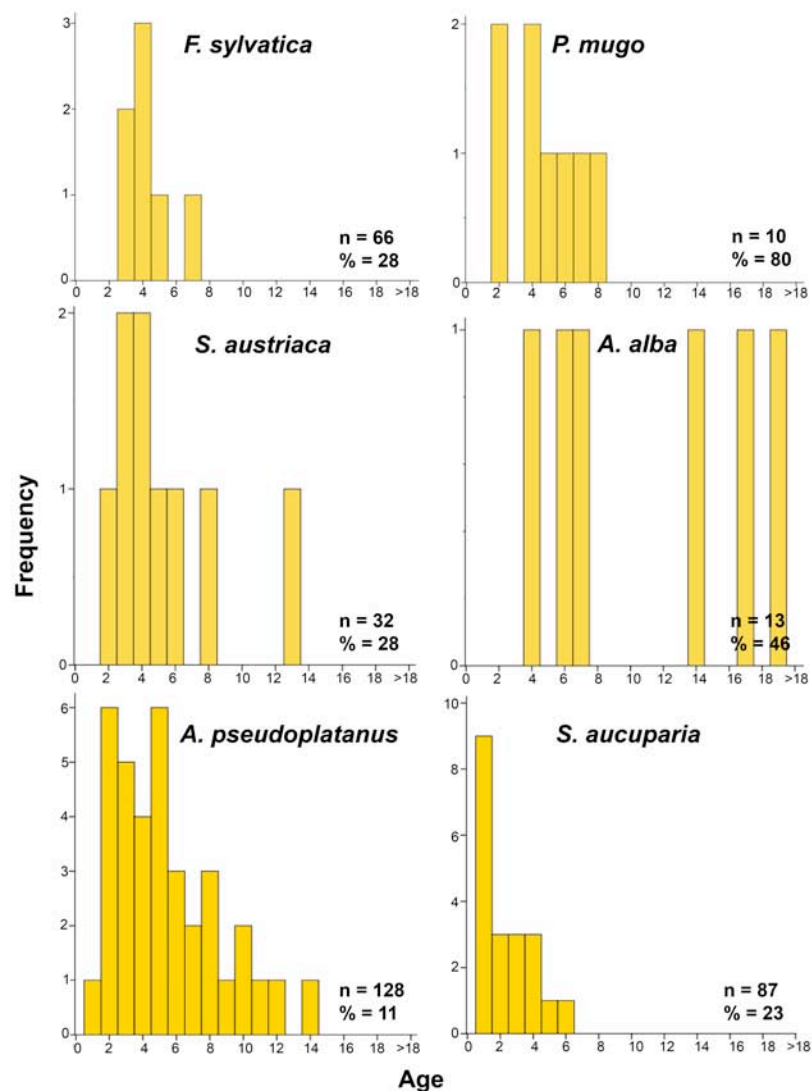


Fig. 4.21: Age distribution of regeneration whose age could be determined exactly (29% totally). "n" gives the total number of each species, "%" gives the share of plants with exactly determined age. Take into account different labelling of y-axis.

Maximum distance to mother tree

Maximum distance to a potential propagable tree was estimated, which was not possible in all cases (42% of all sampled regeneration).

The distances given in table 4.22 are the result of potential mother trees, which either could be spotted in the surrounding of a plot or there was the knowledge about a potential mother tree in one of the other plots. In case that both conditions were not to be fulfilled or the distance was longer than 300 m, I set the distance as “not to be determined”.

Table 4.22: Maximum distance to potential mother tree given for each species. The first column gives the share of regeneration, which had a potential mother tree growing in the same plot as the regeneration. These data are contained in distance classes as well.

Species	Distance to mother tree					
	Mother tree within plot [%]	Up to 50 m [%]	51-100 m [%]	101-200 m [%]	201-300 m [%]	Not to be determined [%]
<i>A. pseudoplatanus</i>	8	9	2	0	42	47
<i>F. sylvatica</i>	99	100	0	0	0	0
<i>S. aucuparia</i>	13	31	5	0	0	64
<i>F. excelsior</i>	0	0	0	0	0	100
<i>L. decidua</i>	0	100	0	0	0	0
<i>P. mugo</i>	100	100	0	0	0	0
<i>S. austriaca</i>	8	19	25	0	0	56
<i>A. alba</i>	0	8	8	8	23	54
<i>Salix. sp</i>	3	33	0	0	0	67

Browsing

All broad leaf species are browsed heavily (table 4.23). Terminal shoots of all browsed *A. pseudoplatanus* and *S. aucuparia* found are missing. *F. sylvatica* shows a more diverse picture; side shoots were browsed only as well. When *F. sylvatica* is browsed, it forms so-called “Kollerbüsche”; it develops many side shoots at its border and thereby protects its terminal shoot growing in the centre of the tree. This type of growth is strongly present within the study area. No *P. mugo* was found to be browsed.

Table 4.23: Level of browsing of the most frequent broad leaf regeneration and *P. mugo*.

	<i>F. sylvatica</i> [%]	<i>A. pseudoplatanus</i> [%]	<i>S. aucuparia</i> [%]	<i>P. mugo</i> [%]
Not browsed	27	16	23	100
Up to 50% of side shoots	38	0	0	0
51-90% of side shoots	8	0	0	0
>90% of side shoots	0	0	0	0
Terminal shoot and up to 50% of side shoots	20	71	60	0
Terminal shoot and 51-90% of side shoots	6	7	11	0
Terminal shoot and >90% of side shoots	2	5	6	0

There is no significant indication that game has a higher/lower impact on *F. sylvatica* in different altitudes (table 4.24).

Table 4.24: Correlation (Spearman-Rho) between level of browsing on *F. sylvatica* and altitude.

	<i>Altitude</i>	
Level of browsing	Coefficient of correlation	.146
	Sig. (2-tailed)	.243
	N	66

F. sylvatica regeneration does not show a significant relationship between the level of being browsed and height. A slight tendency of higher browsing effects on small *F. sylvatica* regeneration was observed.

Other damage

None of the examined regeneration showed damage of browsing, bark peeling or damage caused by mice.

30% of regeneration (stem, roots) is infected by mould fungi, the species were not determined. The most affected species are *A. pseudoplatanus* (46% of affected regeneration), *S. aucuparia* (24%), *S. austriaca* (18%) and *F. sylvatica* (10%).

F. sylvatica regeneration as well as adult trees show a high degree of infection by insects, quite likely *Phyllaphis fagi* (L.) (table 4.25). On the infected trees, these insects are very frequent, but a direct disadvantage/damage was not obvious.

The impact of insects, which chewed foliage, was more apparent (table 4.20). The impact on regeneration is relatively low; out of 80% regeneration, which has chewing damage, less than 1/10 of foliage is chewed.

Table 4.25: Percentage of damage within species.

<i>Species</i>	<i>Other insects</i> [%]	<i>Foliage chewed by insects</i> [%]
<i>A. pseudoplatanus</i>	7	14
<i>F. sylvatica</i>	51	9
<i>S. aucuparia</i>	2	10
<i>F. excelsior</i>	0	0
<i>L. decidua</i>	0	0
<i>P. mugo</i>	0	0
<i>S. austriaca</i>	6	13
<i>A. alba</i>	0	0
<i>Salix</i> sp.	0	0

Light regime

Table 4.26: Correlation (Spearman-Rho) between regeneration and site factors. * Significant correlation at 0.05 (2-tailed). All species with regeneration were tested.

		<i>Indirect Site Factor</i>	<i>Direct Site Factor</i>	<i>Global Site Factor</i>
Sum <i>F. excelsior</i>	Coefficient of correlation	-.529(*)	-.412	-.429
	Sig. (2-tailed)	.014	.063	.052
	N	21	21	21
Sum <i>F. sylvatica</i>	Coefficient of correlation	-.228	-.082	-.102
	Sig. (2-tailed)	.319	.724	.661
	N	21	21	21
Sum <i>P. mugo</i>	Coefficient of correlation	.152	.176	.144
	Sig. (2-tailed)	.509	.444	.533
	N	21	21	21

F. sylvatica and *P. mugo* do not show significant correlation with site factors at 0.05. Only ash has a significant negative correlation (table 4.26).

No relationship between standardized density of *P. mugo* and abundance of regeneration was detected.

Shading

Shading by other species and level of shading was noted (table 4.27).

Table 4.27: Share of regeneration under canopy.

<i>Species</i>	<i>n</i>	<i>No canopy cover above [%]</i>	<i>Marginal canopy cover [%]</i>	<i>Partial canopy cover [%]</i>	<i>Total canopy cover [%]</i>	<i>High canopy cover [%]</i>
<i>F. sylvatica</i>	66	47	12	11	17	14
<i>P. mugo</i>	10	70	0	10	20	0
<i>A. pseudoplatanus</i>	128	16	8	23	44	10
<i>S. aucuparia</i>	87	9	5	30	52	13
<i>S. austriaca</i>	32	23	8	23	46	0
<i>F. excelsior</i>	2	0	0	0	50	50
<i>Salix</i> sp.	3	67	33	0	0	0
<i>L. decidua</i>	2	0	0	0	100	0
<i>A. alba</i>	13	23	8	23	46	0

Vitality

Vitality of regeneration was evaluated (fig. 4.22; table 4.28).

No dead regeneration was found. Most regeneration of broad leaf species and *P. abies* is well-growing but has mechanical damages. Mechanical damage includes damage to terminal shoot/ side branches. *S. aucuparia*, *S.*

austriaca, *A. pseudoplatanus* and *A. alba* have a high share of plants with low vitality; this means that it is hard to estimate the chances of a plant's establishment.

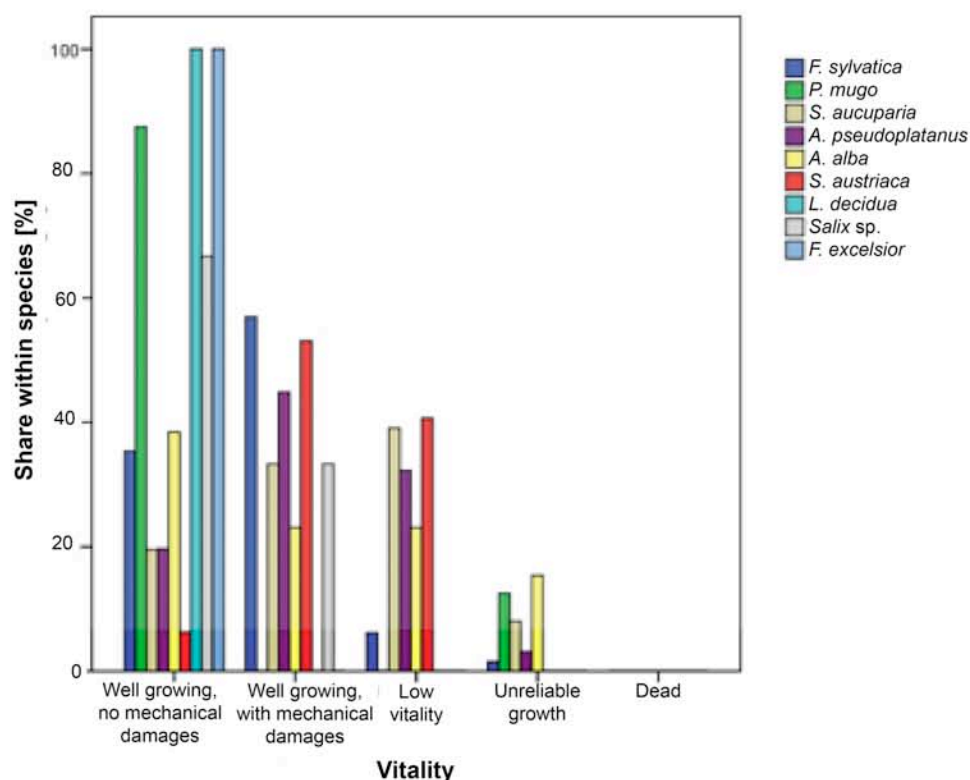


Fig. 4.22: Vitality classification for each species abundant in regeneration.

Table 4.28: Vitality of regeneration within species abundance (in %).

Species	Number of samples	Well growing, no mechanical damage [%]	Well growing, with mechanical damage [%]	Uncertain [%]	Low vitality [%]	Dead [%]
<i>F. sylvatica</i>	66	35	57	6	2	0
<i>P. mugo</i>	10	87	0	0	13	0
<i>A. pseudoplatanus</i>	128	20	50	32	3	0
<i>S. aucuparia</i>	87	20	33	40	8	0
<i>S. austriaca</i>	32	6	53	41	0	0
<i>F. excelsior</i>	2	100	0	0	0	0
<i>Salix sp.</i>	3	67	33	0	0	0
<i>L. decidua</i>	2	100	0	0	0	0
<i>A. alba</i>	13	39	23	23	15	0

Table 4.29: Correlation (Spearman-Rho) shows the very significant relationship between vitality and level of browsing of regeneration. ** Correlation is significant at 0.01 (2-tailed), * Correlation is significant at 0.05 (2-tailed). Regeneration with less than 5 plants is excluded from analysis; *P. mugo* not browsed.

<i>Level of browsing</i>	<i>Vitality</i>	
<i>F. sylvaticus</i>	Coefficient of correlation	.509(**)
	Sig. (2-tailed)	.000
	N	65
<i>A. pseudoplatanus</i>	Coefficient of correlation	.361(**)
	Sig. (2-tailed)	.000
	N	127
<i>S. aucuparia</i>	Coefficient of correlation	.333(**)
	Sig. (2-tailed)	.002
	N	87
<i>S. austriaca</i>	Coefficient of correlation	.414(*)
	Sig. (2-tailed)	.019
	N	32
<i>A. alba</i>	Coefficient of correlation	.513
	Sig. (2-tailed)	.073
	N	13

Levels of browsing and vitality show very significant and significant correlation; the only exception is *A. alba* (table 4.29).

This significant correlation can be explained by definition of vitality, which includes mechanical damage and unreliable/ uncertain growth, which are mainly caused by browsing at the study site (visual assessment).

Table 4.30: Correlation (Spearman-Rho) shows the very significant relationship between vitality and level of shading of regeneration. ** Correlation is significant at 0.01 (2-tailed), * Correlation is significant at 0.05 (2-tailed). Regeneration with less than five plants is excluded from analysis.

<i>Level of shading</i>	<i>Vitality</i>	
<i>F. sylvatica</i>	Coefficient of correlation	-.153
	Sig. (2-tailed)	.225
	N	65
<i>A. pseudoplatanus</i>	Coefficient of correlation	-.237(**)
	Sig. (2-tailed)	.007
	N	127
<i>S. aucuparia</i>	Coefficient of correlation	-.150
	Sig. (2-tailed)	.166
	N	87
<i>S. austriaca</i>	Coefficient of correlation	.390(*)
	Sig. (2-tailed)	.027
	N	32
<i>A. alba</i>	Coefficient of correlation	-.191
	Sig. (2-tailed)	.533
	N	13
<i>P. mugo</i>	Coefficient of correlation	-.150
	Sig. (2-tailed)	.166
	N	87

Vitality is not as clearly correlated with shading as it is with browsing (table 4.30). *A. pseudoplatanus* has a very significant negative correlation with shading, implying less abundance the more shade there is. Interestingly, *S. austriaca* shows significant positive correlation, which means it is more abundant under closed canopy. This result cannot be proven with site factors; there is no significant correlation between abundance of *S. austriaca* regeneration and GSF, DSF or ISF.

Release events

To see if and how regeneration reacts on disturbances and, hence, on release events, release events of the 1990's were analyzed plot-wise (fig 4.23).

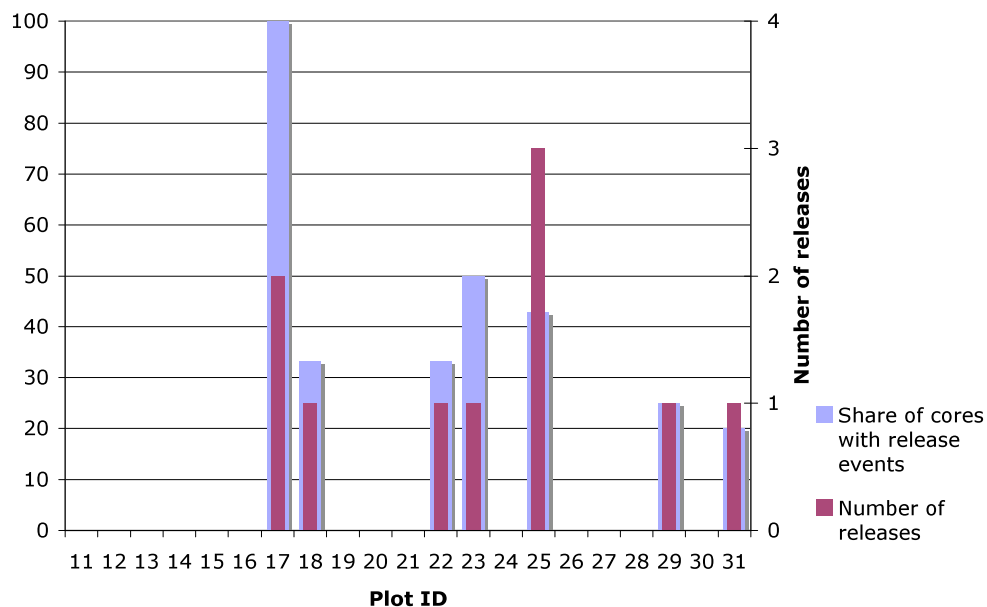


Fig. 4.23: Disturbance regime of each plot in the 1990's. Blue bars give the share of cores with release events on each plot, the violet bar gives the number of release events.

Data of fig 4.23 were used to create a disturbance frequency classification for each plot. Two variables with two and three categories were formed (low/ high frequency; no release event/medium/ high frequency). Both variables are correlated with abundance of regeneration (table 4.31). No significant results were gained using both variants.

Table 4.31: Correlation (Spearman-Rho) between disturbance frequency and abundance of regeneration per plot. Disturbance frequency was calculated with number of release events and share of cores with release events.

		<i>A. pseudo platanu s [n]</i>	<i>F. sylvati ca[n]</i>	<i>S. aucup aria [n]</i>	<i>F. excel sior [n]</i>	<i>L. decid ua [n]</i>	<i>P. mugo [n]</i>	<i>S. austri aca [n]</i>	<i>A. alba [n]</i>	<i>Salix sp. [n]</i>
Disturba nce frequen cy (3 categori es)	Coeffici ent of correlati on	.167	.170	-.219	.323	-.294	-.153	.151	-.432	.166
	Sig. (2- tailed)	.584	.579	.472	.281	.330	.619	.622	.140	.589
	N	13	13	13	13	13	13	13	13	13

Further on, height distribution of *F. sylvatica* was correlated with both variants. This test was repeated for each species abundant in regeneration; especially beech, *A. alba* and *P. mugo* were observed, which have continuous height distribution. No significant correlations were detected.

Vegetative regeneration of *P. mugo* and *F. sylvatica*

Vegetative regeneration of *P. mugo* was estimated by using the following parameters: share of branching points and share of vegetative connections on total number of adult *P. mugo* (table 4.32).

Table 4.32: Share of branching points and vegetative connections between individuals of *P. mugo* on total number of *P. mugo* on each plot. There is no *P. mugo* on plots 25 and 31.

<i>Plot ID</i>	<i>Branching point [%]</i>	<i>Vegetative connection [%]</i>
11	0	0
12	31	15
13	30	15
14	22	17
15	46	8
16	0	10
17	0	13
18	5	0
19	0	3
20	28	0
21	11	0
22	0	0
23	0	11
24	0	0
25	---	---
26	0	0
27	5	18
28	0	0
29	0	0
30	0	36
31	---	---

To test if there is a relationship between vegetative regeneration and avalanche hazard category, correlations were carried out. Results did not show significant correlations (table 4.33). Interestingly, a share of branching points have a negative trend; there are less branching points with increasing avalanche hazard.

Table 4.33: Correlation (Spearman-Rho) between vegetatively regenerated *P. mugo* and avalanche hazard category.

		<i>Avalanche class</i> (3 categories)	<i>Avalanche class</i> (2 categories)
Branching point [%]	Coefficient of correlation	-.421	-.282
	Sig. (2-tailed)	.072	.243
	N	19	19
Vegetative connection [%]	Coefficient of correlation	.202	.021
	Sig. (2-tailed)	.407	.933
	N	19	19

Vegetative regeneration of *F. sylvatica* is estimated by the share of established root suckers (diameter > 5 cm) on the total number of trees. The highest share is gained with 75% vegetatively regenerated *F. sylvatica* on plot 19 (table 4.34). On average, *F. sylvatica* trees emanated from root suckers account for 13% of the total *F. sylvatica* population.

Table 4.34: Total number and share of root suckers on total number of adult *F. sylvatica*.

<i>Plot ID</i>	<i>Shoot [n]</i>	<i>Shoot [%]</i>
11	---	---
12	0	0
13	0	0
14	---	---
15	---	---
16	---	---
17	0	0
18	3	38
19	3	75
20	0	0
21	2	20
22	0	0
23	0	0
24	16	32
25	0	0
26	---	---
27	---	---
28	0	0
29	0	0
30	0	0
31	5	29

4.3 Performance of adult tree species

Only two plots are without dwarf pine and six plots are without *F. sylvatica* (fig. 4.24). The category “other conifers” is formed by *L. decidua* (27% species abundance of the category “other conifers”) and *A. alba* (73%). *S. aucuparia* (35% species abundance of the category “other broad leaves”), *A. pseudoplatanus* (25%), *Alnus viridis* (20%), *S. austriaca* (10%) and *Salix* sp. (10%) form the category “other broad leaves”.

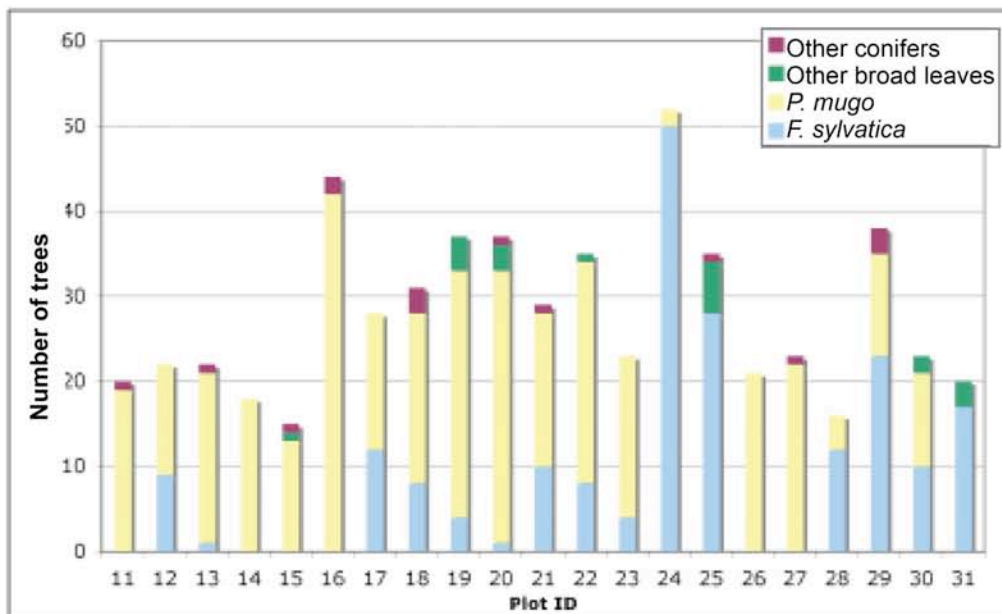


Fig. 4.24: Total amount of tree species per plot.

Figure 4.25 shows that absolute numbers of *F. sylvatica* density decrease with altitude, density of *P. mugo* increases up until an altitude of 1200 m and declines at 1250 m.

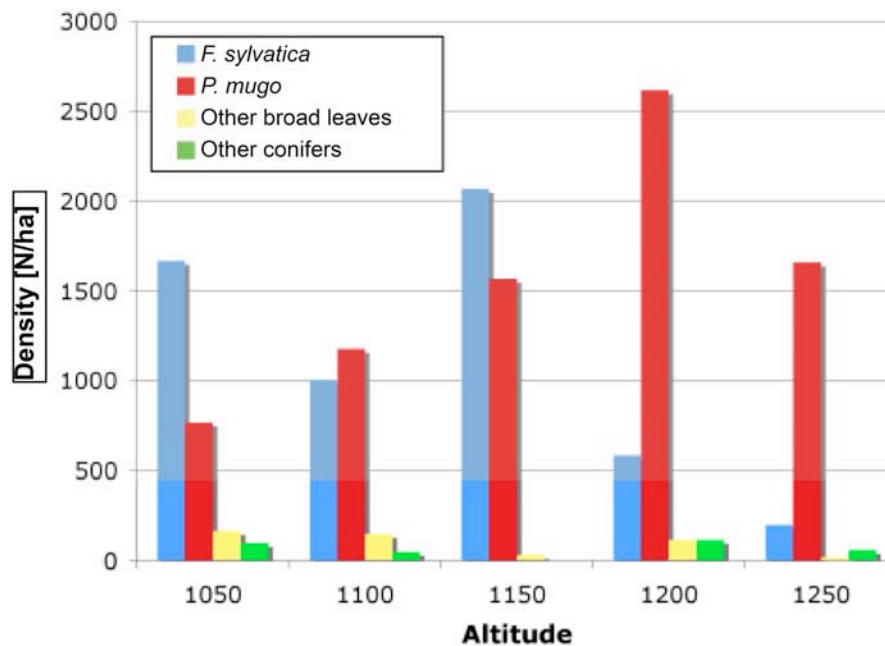


Fig. 4.25: Density distribution of adult trees in different altitudes.

Calculating species' densities for each altitudinal step, no significant correlations were detected (table 4.35). Only *P. mugo* has a positive tendency, thus an increasing density with increasing altitude.

Table 4.35: Correlation (Pearson) between altitude and density of adult tree species.

	Altitude [m]	
<i>F. sylvatica</i> adult [N/ha]	Correlation (Pearson)	-.692
	Significance (2-tailed)	.195
	N	5
<i>P. mugo</i> adult [N/ha]	Correlation (Pearson)	.740
	Significance (2-tailed)	.153
	N	5
Other broad leaves adult [N/ha]	Correlation (Pearson)	-.769
	Significance (2-tailed)	.128
	N	5
Other conifers adult [N/ha]	Correlation (Pearson)	-.046
	Significance (2-tailed)	.941
	N	5

Growth

F. sylvatica, other broad leaf species and other conifers have their highest total frequency at 4 m. With more than 10 m, *F. sylvatica* gains the greatest heights of all species. As expected, tree density decreases with size (fig. 4.26).

The biggest share of *P. mugo* (86% of all sampled individuals) is up to 3 m in height. Less than five individuals of *P. mugo* are more than 4 m in height.

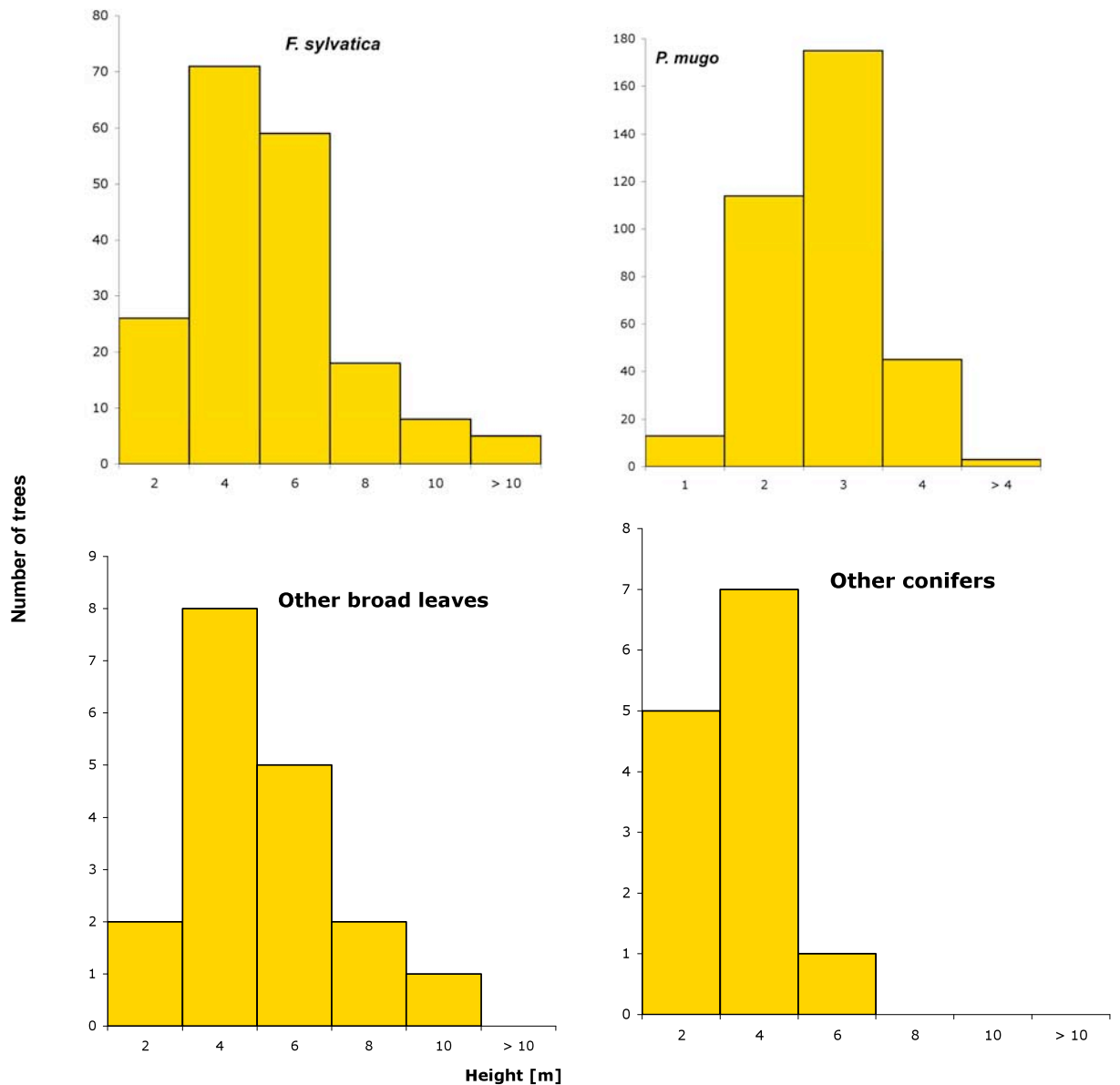


Fig. 4.26: Height distribution of adult trees in 2 m steps or 1 m steps for *P. mugo* respectively. Take into account different labelling of y-axis.

The average height of *F. sylvatica* is decreasing slightly with increasing altitude. The height difference between the lowest and the highest transect is 1.7 m. The height of *P. mugo* shows low variations without a clear trend at different altitude (fig. 4.27).

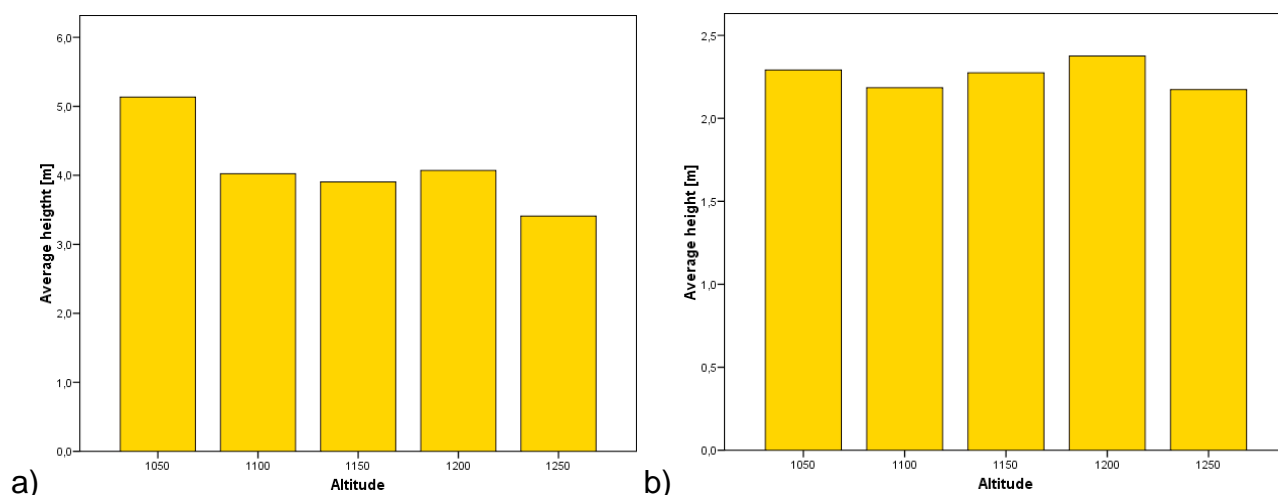


Fig. 4.27: Average height of trees given for increasing altitude. a) Average height of *F. sylvatica*, b) average height of *P. mugo*.

A diameter of ≤ 5 cm is counted as regeneration for trees. *P. mugo* individuals, which had a diameter of ≤ 5 cm but were obviously vegetatively regenerated, were counted as trees; therefore a diameter smaller than 5 cm is represented in fig. 4.28.

F. sylvatica is the dominating species gaining a diameter greater than 30 cm. The abundance of *F. sylvatica* and other broad leaf species decreases with an increasing diameter. Also, within the category “other broad leaves”, diameters up to 30 cm occur. Conifers other than *P. mugo* reach only diameters of maximum 15 cm.

Diameters of *P. mugo* were measured at the point where the stem left the soil. The stems are often creeping along the soil before starting to erect. Around half of stems of *P. mugo* have diameters between 5 and 10 cm. The greatest diameters gained are 20 cm.

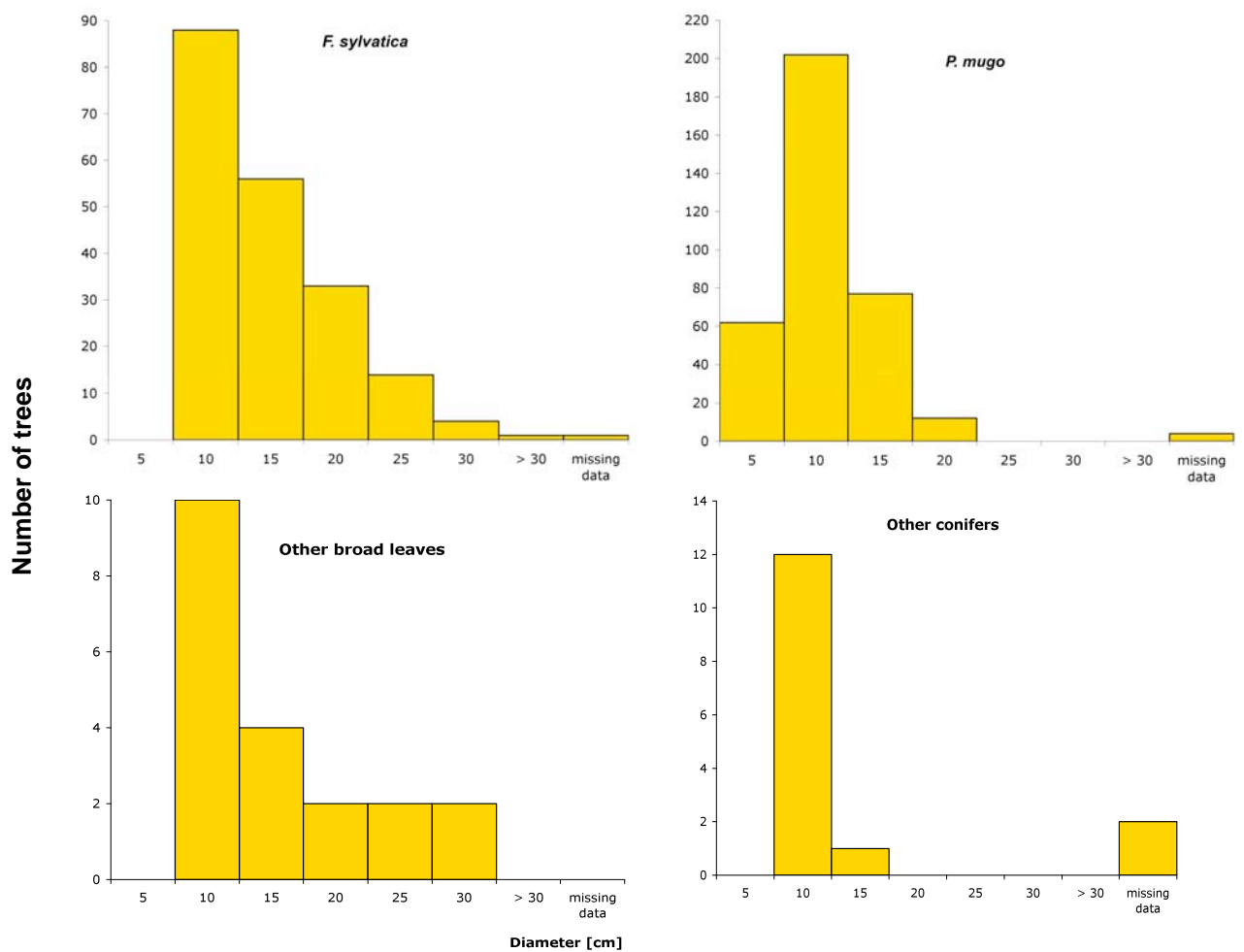


Fig. 4.28: Diameter distribution of adult trees in 5 cm steps. Take into account different labeling of y-axis.

Age structure

The age is given for each species at coring height; trees were cored at 1 m height, *P. mugo* at the point where the stem leaves the soil. No correction factor was calculated for tree species. High browsing pressure (including terminal shoot) makes it very difficult to estimate the real age.

P. mugo shows higher average and maximum ages on all but one plot (plot 12) where *F. sylvatica* had lightly higher average (but not maximum) ages (table 8.1 see Annex). *P. mugo* is on average 24 years older than *F. sylvatica*, calculated using mean age values per plot.

The average age of *F. sylvatica* is 51 years, of *P. mugo* 80 years, other conifers 23 years and of other broad leaf species 51 years.

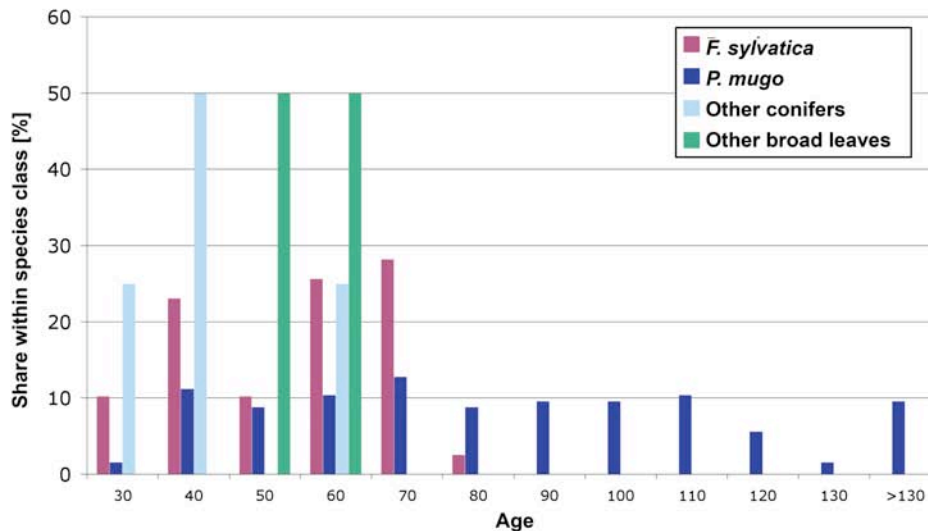


Fig. 4.29: Age distribution of *P. mugo* (125 cores; 36% of total abundance of *P. mugo*), *F. sylvatica* (39 cores; 21% of total abundance of *F. Sylvatica*), other broad leaf species (4 cores; 20% of other broad leaves) and other conifers (4 cores; 31% of other conifers) in 10-year age classes.

The age distribution of *P. mugo* shows the highest share in age classes 40, 70 and 110 (fig. 4.29). In general, *P. mugo* is distributed very regularly along all age classes. No core up to 20 years old was contained in samples; the age of regeneration is up to 8 years old. The highest age counted is 177 years. The maximum age of *F. sylvatica* is 77 years. *F. sylvatica* has a high abundance in age classes 40, 60 and 70 and in between, a sharp decline in age class 50. Dendroecological analysis showed that in the 1970's and 1950's many release events occurred, this is corresponding to the low abundance of beech. No *F. sylvatica* younger than 20 years old was cored. The maximum age of *F. sylvatica* regeneration is 8 years old; especially for higher and older *F. sylvatica* in regeneration, it was not possible to determine the age. The number of cores of other broad leaf and conifer species is very low (four cores each). The age of other conifers ranges from up to 30 to up to 60 years. All cored broad leaf trees are between 41 and 60 years old.

Apart from the real age of *P. mugo*, the age of the erected branches was determined (table 4.36).

Table 4.36: Age-related growth characteristics of *P. mugo*.

		Age of erecting branches	
		Average age	Stdev age
Total	108	47.0	15.9
Per plot			
11	3	41.0	1.7
12	3	34.0	3.6

13	11	58.0	14.9
14	11	38.9	17.2
15	8	46.0	11.8
16	8	43.6	10.1
17	4	34.3	10.4
18	3	38.3	11.5
19	7	36.3	5.5
20	8	48.1	17.1
21	8	37.8	5.9
22	5	46.0	6.3
23	1	46.0	---
24	1	45.0	---
25	0		
26	9	66.3	16.7
27	8	61.8	14.9
28	2	57.0	25.5
29	2	44.0	4.2
30	6	44.3	20.1
31	0		

The age of erecting branches ranges from 34 to 66 years (average 47.0 +/- 15.9 years). The average age of *P. mugo* when branches start erecting is 47.2 +/- 27.5 years.

Other damages

Nearly half of all *F. sylvatica* trees are forked, which can indicate disturbances (wind breakage, insects, etc.) but can also be a result of the genotype as well. Forked trees show a higher potential of being damaged. *P. mugo* has forked growth as well (table 4.37).

More than a quarter of *F. sylvatica* have broken treetops whereas only 2% of *P. mugo* has broken tops.

The most frequent trunk abnormality of *F. sylvatica*, *P. mugo* and other broad leaves is a wounded bark. 2% of *F. sylvatica* show signs of browsing and have a "Kollerbusch"-like growth.

Within all species, injuries hardly occur and wounds affect only small parts of trunks.

Table 4.37: Types of injuries caused by mechanical impacts. Share is given for each species.

	<i>F. sylvatica</i> [%]	<i>P. mugo</i> [%]	<i>Other conifers</i> [%]	<i>Other broad leaves</i> [%]
Forking				
No	55	10	73	21
One fork	25	1	20	47
More forks	20	89	7	32
Curved trunk (sweep)				
No	27	3	20	11
Yes	73	97	80	89
Breakage of tree top				
No breakage	73	98	100	83

Moderate (< 3m)	1	1	0	6
Moderate (< 3m), side branch erected	13	1	0	6
Severe (> 3m), side branch erected	14	0	0	6
Trunk abnormality				
None	80	91	0	84
Resin flow	1	0	0	0
Lightning strike	0	0	0	5
Crack caused by frost	2	0	0	0
“Kollerbusch”	2	0	0	0
Wounded bark at stem base	17	9	0	11
Injuries				
None	73	93	80	74
Slight	17	5	20	16
Moderate	7	2	0	11
Severe	2	0	0	0
Very severe	2	0	0	0

Damage by game occurs less in adult trees than in regeneration. No damage caused by bark peeling was observed. Only 16% of *F. sylvatica* are slightly browsed. *P. mugo* shows no browsing damage at all (table 4.38).

A high share of *P. mugo* is infected by pests. The dominating pests of *P. mugo* are snow mould (*Herpotrichia*) and needle blight. Severe infection by snow mould can cause death of *P. mugo*. Pests of *F. sylvatica* are mainly insects. On adult *F. sylvatica* trees, the same larvae were found as on *F. sylvatica* regeneration. The species was quite likely *Phyllaphis fagi*. The leaves of *F. sylvatica* trees are covered by it to a great extent; but as for regeneration, a direct disadvantage could not be observed.

Table 4.38: Share of individual trees within species with damages caused by ungulates and insects.

	<i>F. sylvatica</i> [%]	<i>P. mugo</i> [%]	<i>Other broad</i> <i>leaves</i> [%]	<i>Other conifers</i> [%]
Bark peeling				
None	100	100	100	100
Browsing				
None	85	100	100	87
Up to 50% of side branches	16	0	0	0
Terminal shoot and up to 50% of side branches	0	0	0	7
Terminal shoot and > 90% of side branches	0	0	0	7
Tree canker				
No	0	99	31	27
Yes	100	1	68	73
Level of pest infection				
None	15	33	63	87
Slight	4	25	0	0
Moderate	76	41	37	13
Severe	5	1	0	0

The cause of death could not be determined in most cases (table 4.39). Dead *P. mugo* was killed through competition with other trees and by severe snow mould infections.

Table 4.39: Share of dead trees, cause of death and level of rotting.

	<i>F. sylvatica</i> [%]	<i>P. mugo</i> [%]	Other broad leaves [%]	Other conifers [%]
Cause of death				
Not dead	98	97	95	95
Competition	0	1	0	0
Snow or wind breakage	0	0	0	0
Snow mould	0	1	0	0
Not to be determined	2	1	5	5
Level of rotting				
Alive	94	92	90	87
Declining	5	5	5	7
Dead	0	1	0	7
Loose bark	1	2	5	0
Decomposed	1	0	0	0

Table 4.40 gives the extent of trees being shaded and by which species they are shaded. Whereas *F. sylvatica* is present under open to totally closed canopy, there is hardly any *P. mugo* that is totally covered. *P. mugo* and *F. sylvatica* cause shade mainly within the species.

Table 4.40: Extent of shading and shade causing species. Marginal: only the very borders of trees are shaded; partial: the bigger parts of the trees are shaded; total: the whole tree crown is under canopy, direct sunlight can be gained through gaps in the canopy above

	<i>F. sylvatica</i> [%]	<i>P. mugo</i> [%]	Other conifers [%]	Other broad leaves [%]
Shading				
None (0% of shading)	28	30	53	11
Marginal (1-10%)	23	44	13	37
Partial (11-80%)	36	24	33	42
Total (81-100%)	14	2	0	11
Canopy covered by				
<i>F. sylvatica</i>	89	13	43	47
<i>P. mugo</i>	3	77	43	24
Others	8	10	14	29

During fieldwork, signs of this year's fruits were sought, either on the tree or on the ground. The majority of *P. mugo* has cones of previous years or of this year (table 4.41). During fieldwork, which was carried out in late summer, beechnuts were only found on one tree, leading to the assumption that there was no mast year of *F. sylvatica* in 2008. The conifers within the plots are mainly younger trees, where it is unlikely that they have already started fruiting.

Table 4.41: Vitality as defined by Kraft and occurrence of fruits. Share is given within species abundance.

	<i>F. sylvatica</i> [%]	<i>P. mugo</i> [%]	Other conifers [%]	Other broad leaves [%]
Vitality (Kraft)				
Predominating – widely branched crown	16	29	7	10
Predominating – smaller diameter	24	33	0	40
Predominating – smaller diameter and height	41	33	67	30
Suppressed - equally	2	0	0	0
Suppressed - secund	15	1	7	10
Dead – green top	0	0	13	0
Dead - totally	2	3	7	5
Not specified	2	0	0	5
Fruits				
No	99	35	93	93
Yes	1	65	7	7

The distribution of vitality of *F. sylvatica* and other broad leaf species corresponds, with slight deviations, to the definition by Kraft. Within the category other conifers 7% belong to the first class, the biggest share of 67% is still predominating but has a smaller diameter and height. 20% of other conifers belong to the lowest vitality class; 7% have already died and 13% have only some green branches remaining.

P. mugo is a krummholz, which does not gain the same maximum height and diameter as trees do. Therefore, to get an estimate about vitality of *P. mugo* it was only compared within the species. Information about shading is contained in table 4.40. 95% of *P. mugo* is predominating; only 1% is suppressed and 3% were found dead.

Response to soil

F. sylvatica and other broad leaf species are not abundant on plots with high share of relictic loam in soil. The informative value of this result has to be understated, as there is only one plot with more than two subplots with relictic loam. More than half of *F. sylvatica* grows on plots with an average share of relictic loam. *P. mugo* and other conifers are equally abundant on plots with high share of relictic loam in soil and with no relictic loam influence. The lowest abundance of *P. mugo* is on plots with an average share of relictic loam (fig 4.30).

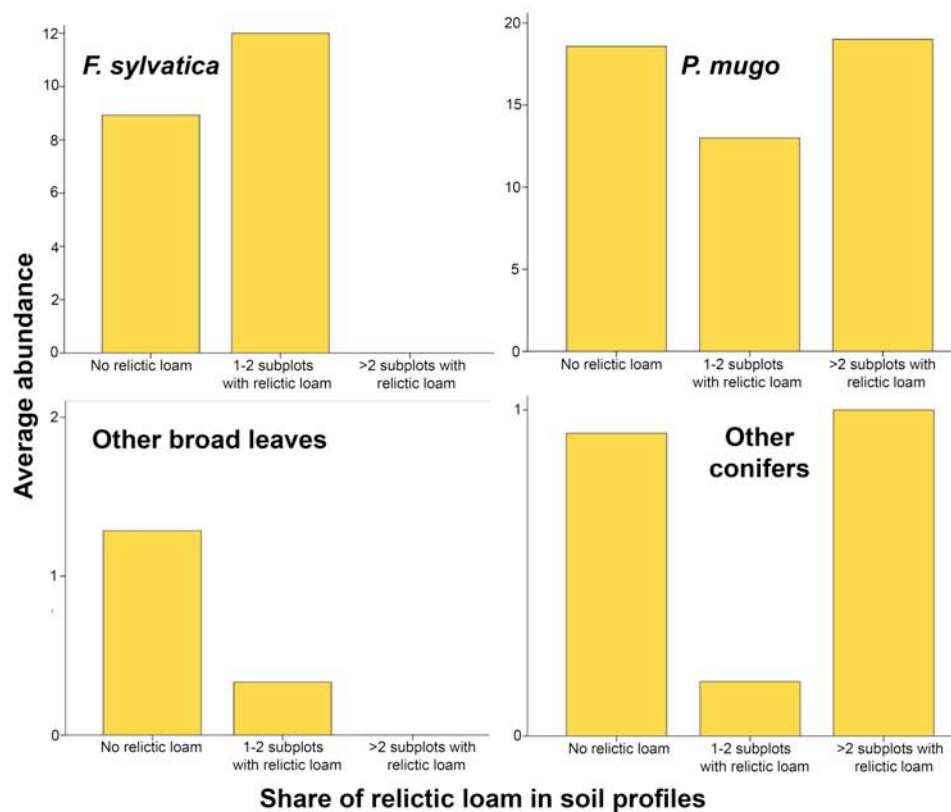


Fig. 4.30: Average abundance of tree species on different soil types.

Assuming a CI of 5%, no significant correlation between abundance of *F. sylvatica*/ *P. mugo* and the share of relictic loam in soil profiles could be found (table 4.42). This means that, from a statistical perspective, *F. sylvatica* and *P. mugo* are equally distributed on all types of soil.

Table 4.42: Test for dependence of species' abundance on share of brown loam in soil profiles using ANOVA.

		Sum of squares	df	Mean square	F	Significance
<i>P. mugo</i>	Between groups	1.586	2	.793	.260	.774
	Within groups	54.842	18	3.047		
	Total	56.428	20			
<i>F. sylvatica</i>	Between groups	6.029	2	3.014	.716	.502
	Within groups	75.744	18	4.208		
	Total	81.773	20			

Density of *F. sylvatica* shows an increasing, although not significant trend with increasing thickness of the A-horizon while the opposite is true for *P. mugo* (again not significant, $p < 0.05$) (fig. 4.31).

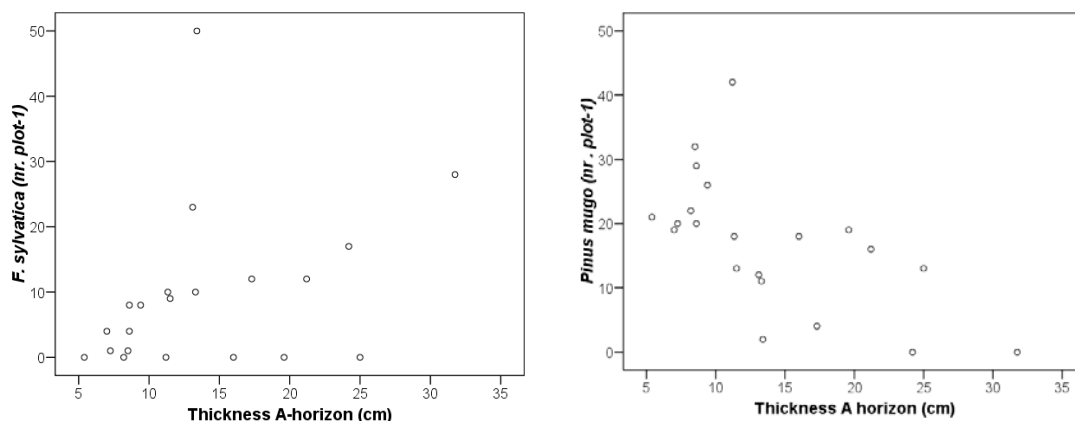


Fig. 4.31. Scattergram of the density of *F. sylvatica* trees and *P. mugo* on the average thickness of the A-horizon of soils (Ahb and Ahb-C horizons were lumped together).

Dominating type of humus

On plots with no *F. sylvatica* abundant, mull hardly forms. The more *F. sylvatica* on a site, the higher the share of mull formation. The formation of moder and alpenmoder is equal on plots where no or only a low amount of *F. sylvatica* grows. On plots with high abundance of *F. sylvatica*, no moder was built. The share of alpenmoder is 15% (fig. 4.32).

Moder is the dominating type of humus under high abundance of *P. mugo* and is not formed on plots with no *P. mugo*. At medium abundance of *P. mugo*, mull and alpenmoder have the same share with nearly 60% of humus types; the share of moder is a little bit lower.

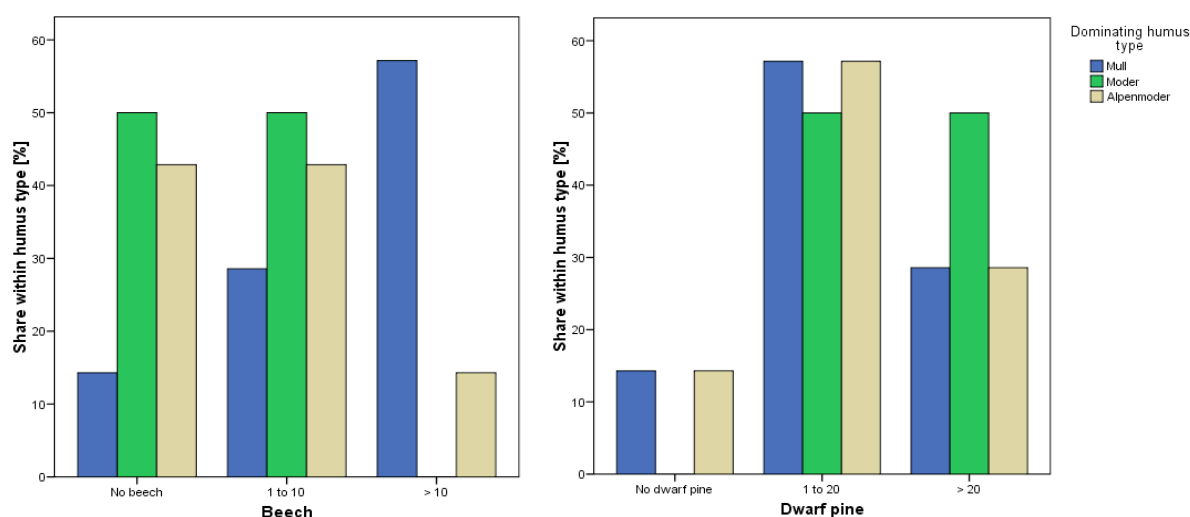


Fig. 4.32: Share of type of humus under various species abundance.

Table 4.43: Test for dependence of species' abundance on humus type using ANOVA.

		Sum of squares	df	Mean square	F	Significance
<i>P. mugo</i>	Between groups	10.065	2	5.032	1.652	.225
	Within groups	45.687	15	3.046		
	Total	55.752	17			
<i>F. sylvatica</i>	Between groups	22.034	2	11.017	2.871	.088
	Within groups	57.550	15	3.837		
	Total	79.583	17			

Assuming a CI of 5%, no correlation between abundance of *F. sylvatica*/ *P. mugo* and humus type could be found (table 4.43).

Response to multiple site parameters

Fig. 4.33 shows the average abundance of each species distributed in the clusters of cluster analysis 1.

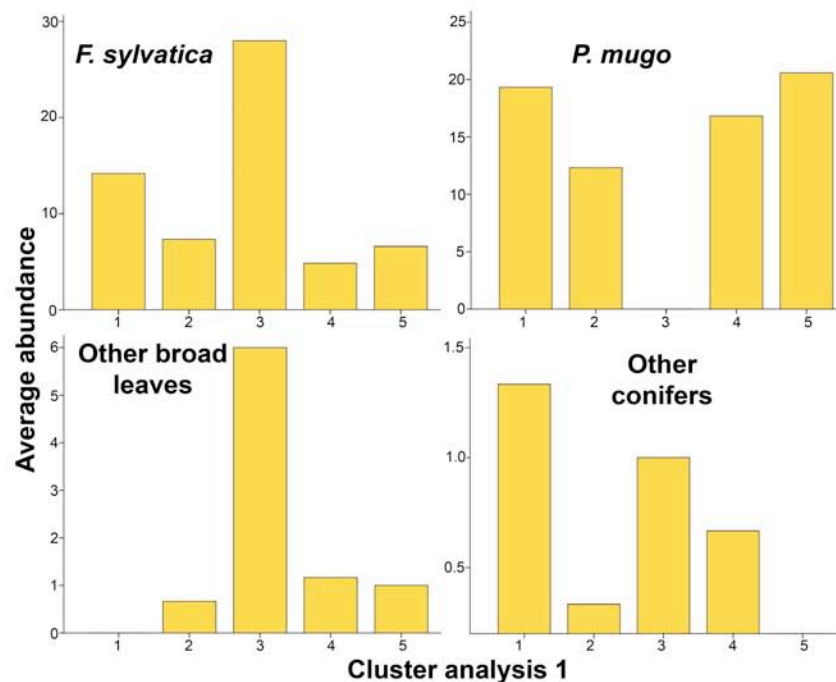


Fig. 4.33: Average abundance of tree species within clusters formed in cluster analysis 1 and 2. Take into account different labeling of x-axis.

Table 4.44: Analysis of variance to detect differences of species' abundance within clusters.

		Sum of squares	df	Mean square	F	Significance
<i>P. mugo</i>	Between groups	18.164	4	4.541	1.899	.160
	Within groups	38.264	16	2.391		
	Total	56.428	20			
<i>F. sylvatica</i>	Between groups	13.739	4	3.435	.808	.538
	Within groups	68.034	16	4.252		
	Total	81.773	20			

The clusters cannot be used to explain abundance of *F. sylvatica* or *P. mugo* at a 5% CI (table 4.44), but a tendency may be deduced: In cluster analysis 1, *F. sylvatica* has highest occurrence in cluster 3, where no *P. mugo* grows. The pattern of other broad leaf species corresponds to that of *F. sylvatica*. Summarized, *F. sylvatica* has the tendency to grow in lower altitudes, prefers deep soils and shows lowest performance in very steep terrain. *P. mugo* reacts indifferent to steepness of terrain and has higher abundance on shallow soils. Both species are neutral regarding potential avalanche release and influence of relictic loams.

The vitality distribution of *F. sylvatica* is quite uniform within the various clusters (fig. 4.34). In most of the clusters, the share of vitality classes corresponds to Kraft, with the highest share in category 3 (predominating – with smaller diameter and height). The only exception is cluster 4 in cluster analysis 1. Here, predominating trees with smaller diameter and suppressed trees have the highest share. In cluster analysis 2, only predominating trees with smaller diameter and height occur.

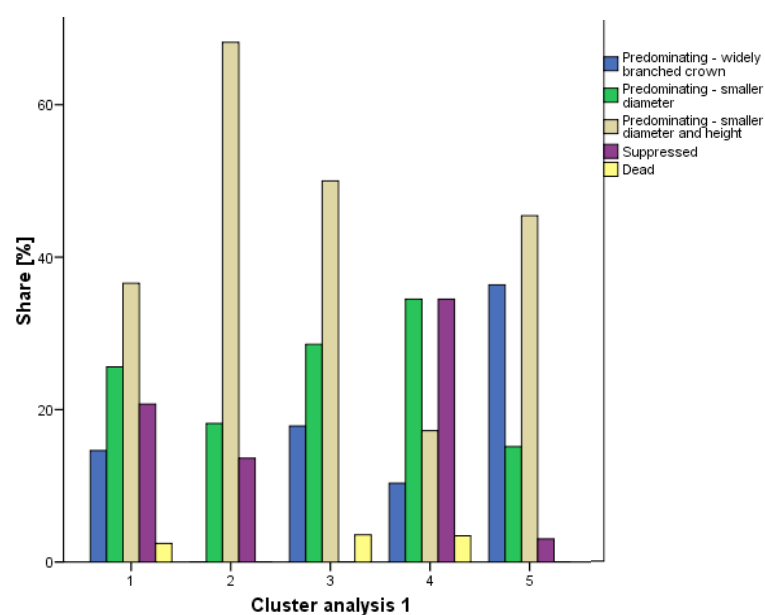


Fig. 4.34: Vitality distribution of *F. sylvatica* for cluster analysis 1.

In cluster analysis 1, *P. mugo* has higher vitality in clusters 2 and 4 (fig. 4.35). There is no *P. mugo* in cluster 3, which consists of one plot only.

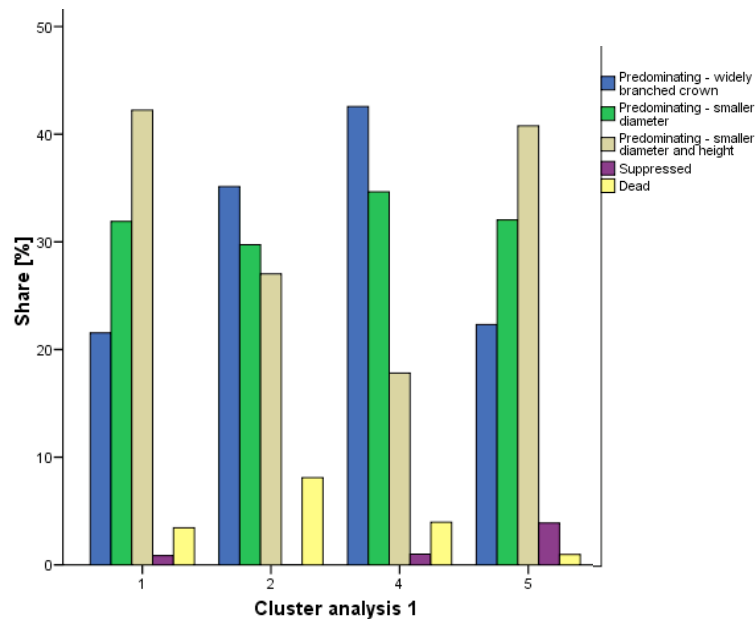


Fig. 4.35: Vitality distribution of *P. mugo* for cluster analysis 1. There was no *P. mugo* abundant in cluster 3.

When comparing species' vitality within the clusters (fig. 4.34 and fig. 4.35) we can observe that *P. mugo* has lower abundance in clusters with a high abundance of *F. sylvatica*. Vitality of *P. mugo* is lower on plots with higher abundance of *F. sylvatica*. In clusters with lower abundance and vitality of *F. sylvatica* *P. mugo* achieves highest share in the best vitality class (cluster 4). Vitality of *F. sylvatica* is corresponding to Kraft in nearly all clusters. This points out that on micro sites, favourable for *F. sylvatica*, it is able to out compete *P. mugo*.

Site factors (including inclination, exposition, soil and humus type and depth) do not explain the clusters formed in cluster analysis 2 (table 4.45)

Table 4.45: Discriminate analysis carried out to see if site factors influence the development of species composition.

Test of Function(s)	Wilks' Lambda	Chi-square	df	Sig.
1 through 4	.076	32.282	40	.802
2 through 4	.341	13.453	27	.986
3 through 4	.630	5.780	16	.990
4	.870	1.746	7	.973

4.4 Spatial distribution of adult *F. sylvatica* and *P. mugo*

The correlation between abundance of adult tree species shows a highly significant negative correlation between abundance of *F. sylvatica* and *P. mugo*. The higher the abundance of *F. sylvatica*, the lower the abundance of *P. mugo* (table 4.46).

Table 4.46: Correlation (Spearman-Rho) between abundance of adult tree species. ** Correlation significant at 0.01 (2-tailed).

		<i>F. sylvatica</i> [n]	<i>P. mugo</i> [n]	Other broad leaves [n]	Other conifers [n]
<i>F. sylvatica</i> [n]	Coefficient of correlation	1.000	-.715(**)	.186	-.185
	Sig. (2-tailed)	.	.000	.420	.422
	N	21	21	21	21
<i>P. mugo</i> [n]	Coefficient of correlation	-.715(**)	1.000	-.097	.240
	Sig. (2-tailed)	.000	.	.675	.296
	N	21	21	21	21
Other broad leaves [n]	Coefficient of correlation	.186	-.097	1.000	-.128
	Sig. (2-tailed)	.420	.675	.	.580
	N	21	21	21	21
Other conifers [n]	Coefficient of correlation	-.185	.240	-.128	1.000
	Sig. (2-tailed)	.422	.296	.580	.
	N	21	21	21	21

4.4.1 Intraspecific distribution

Fagus sylvatica

At small radii (up to 2 m), *F. sylvatica* shows a clumped growth, whereas it is distributed in a random up to a segregated manner when having a look on greater radii (table 4.47).

Table 4.47: Analysis of spatial distribution of *F. sylvatica* up to a radius of 5 cells. Plots with no *F. sylvatica* are excluded from the calculation. Percentages denote the ratio of plots showing the respective first order spatial structure.

	Radius = 1m [%]	Radius = 2 m [%]	Radius = 3 m [%]	Radius = 4 m [%]	Radius = 5 m [%]
Clumped	100	60	33	0	0
Random	0	40	53	80	60
Regular	0	0	13	20	40

Pinus mugo (alive)

At a radius of one cell, *P. mugo* shows a very strong aggregation with 89% of the plots (table 4.48). With an increasing radius, aggregation becomes less and random distribution of *P. mugo* increases. The share of segregation increases at a bigger distance.

Table 4.48: Analysis of spatial distribution of *P. mugo* up to a radius of 5 cells. Plots with no *P. mugo* or only contact of *P. mugo* per plot are excluded from the calculation. Percentages denote the ratio of plots showing the respective first order spatial structure.

	Radius = 1m [%]	Radius = 2 m [%]	Radius = 3 m [%]	Radius = 4 m [%]	Radius = 5 m [%]
Clumped	89	50	28	17	6
Random	11	50	61	61	61
Regular	0	0	11	22	33

Pinus mugo dead

In all distance classes of the analysis, dead *P. mugo* shows mainly a random distribution, reaching from 73 to 93 % of the plots (table 4.49).

Table 4.49: Analysis of spatial distribution of dead *P. mugo* up to a radius of 5 cells. Plots with no dead *P. mugo* and only one contact of dead *P. mugo* pine are excluded. Percentages denote the ratio of plots showing the respective first order spatial structure.

	Radius = 1 m [%]	Radius = 2 m [%]	Radius = 3 m [%]	Radius = 4 m [%]	Radius = 5 m [%]
Clumped	27	7	0	0	7
Random	73	87	80	93	87
Regular	0	7	20	7	7

4.4.2 Interspecific distribution

Fagus sylvatica – *Pinus mugo* (alive)

In close proximity, *F. sylvatica* and *P. mugo* are segregated, whereas when growing at a greater distance to each other, their distribution tends to be random (table 4.50).

Table 4.50: Spatial correlation between *F. sylvatica* and *P. mugo* (alive) up to a radius of 5 cells. Points with both categories, *F. sylvatica* and *P. mugo*, were assigned to that category, which touched at the greatest height. Percentages denote the ratio of plots showing the respective first order spatial structure.

	Radius = 1 m [%]	Radius = 2 m [%]	Radius = 3 m [%]	Radius = 4 m [%]	Radius = 5 m [%]
Aggregation	15	8	15	15	31
Random	23	46	46	85	54
Segregation	62	46	38	0	15

To test if the patterns with both categories could be assigned either to *F. sylvatica* or to *P. mugo*, the following analyses were made:

Fagus sylvatica – *Fagus sylvatica* & *Pinus mugo* mixed

Table 4.51: Spatial correlation between pure points (*F. sylvatica* only) and mixed points (*F. sylvatica* and *P. mugo*) up to a radius of 3 cells. Percentages denote the ratio of plots showing the respective first order spatial structure.

	Radius = 1 m [%]	Radius = 2 m [%]	Radius = 3 m [%]
Aggregation	46	31	8
Random	46	62	85
Segregation	0	0	0

Pinus mugo – *Fagus sylvatica* & *Pinus mugo* mixed

Table 4.52: Spatial correlation between pure points (*P. mugo* only) and mixed points (*F. sylvatica* and *P. mugo*) up to a radius of 3 cells. Percentages denote the ratio of plots showing the respective first order spatial structure.

	Radius = 1 m [%]	Radius = 2 m [%]	Radius = 3 m [%]
Aggregation	15	38	23
Random	69	46	62
Segregation	8	8	8

Tables 4.51 and 4.52 show that, except for small radii for *F. sylvatica* with *F. sylvatica* & *P. mugo*, the mixed points are mainly randomly distributed. *F. sylvatica* has a higher share of aggregation than *P. mugo* has. *P. mugo* shows constant segregation above all radii classes. This shows that the non-mixed components in the bivariate analysis show a stronger segregation.

Fagus sylvatica – dead *Pinus mugo*

At all radii, random distribution dominates (tab. 4.53)

Table 4.53: Spatial correlation between *F. sylvatica* and dead *P. mugo* up to a radius of 3 cells. Points with both patterns, *F. sylvatica* and dead *P. mugo*, were assigned to the pattern "dead *P. mugo*" for analysis. Percentages denote the ratio of plots showing the respective first order spatial structure.

	Radius = 1 m [%]	Radius = 2 m [%]	Radius = 3 m [%]
Aggregation	10	30	20
Random	90	70	80
Segregation	0	0	0

Pinus mugo (alive) – dead *Pinus mugo*

All three tests with variations of random labeling result in random distribution between *P. mugo* (alive) and dead *P. mugo* (tables 4.54 to 4.56).

Table 4.54: Spatial correlation between *P. mugo* and dead *P. mugo* up to a radius of 3 cells. Assumed 0-hypothesis is random labeling - variant 1. Percentages denote the ratio of plots showing the respective first order spatial structure.

<i>Spatial distribution</i>	Radius = 1 m [%]	Radius = 2 m [%]	Radius = 3 m [%]
Aggregation	0	0	13
Random	88	100	88
Segregation	13	0	0

Table 4.55: Spatial correlation between *P. mugo* and dead *P. mugo* up to a radius of 3 cells. Assumed 0-hypothesis is random labeling - variant 4. Percentages denote the ratio of plots showing the respective first order spatial structure.

Spatial distribution	Radius = 1 m [%]	Radius = 2 m [%]	Radius = 3 m [%]
Aggregation	25	13	0
Random	75	88	100
Segregation	0	0	0

Table 4.56: Spatial correlation between *P. mugo* and dead *P. mugo* up to a radius of 3 cells. Assumed 0-hypothesis is random labeling - variant 7. Percentages denote the ratio of plots showing the respective first order spatial structure.

Spatial distribution	Radius = 1 m [%]	Radius = 2 m [%]	Radius = 3 m [%]
Aggregation	0	6	6
Random	94	94	94
Segregation	6	0	0

4.5 Disturbance regime

Disturbances were analyzed using two methods; the dendroecological method, which allows to identify past disturbance events directly on the tree rings, and avalanche simulation, which makes it possible to point out the relative avalanche hazard which might affect a plot.

4.5.1 Results achieved using the dendroecological method

Fig. 4.36 gives an example of a *F. sylvatica* chronology. The highest value of radial growth increment in a series of values exceeding the threshold (25% or 50% change in radial growth increment) is counted as a release event.

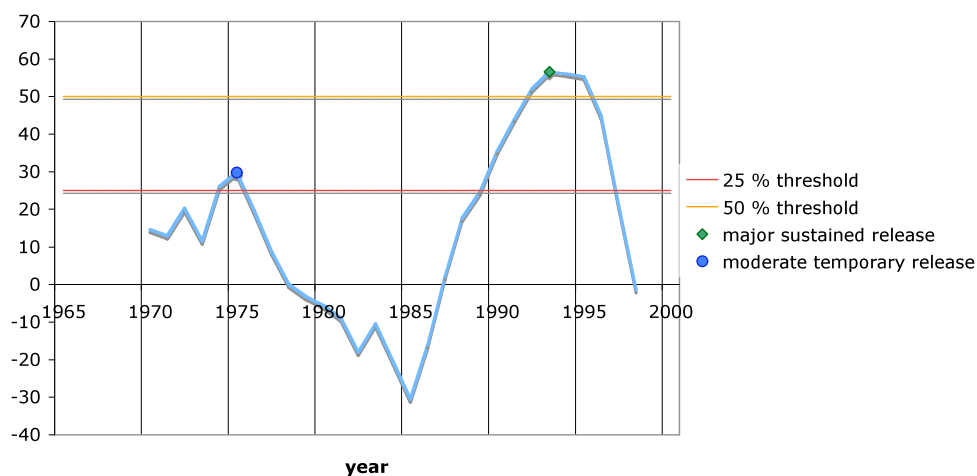


Fig. 4.36: Example of release events of a single *F. sylvatica* chronology.

A chronology was created including all synchronized *F. sylvatica* cores (fig. 4.37). The chronology starts in the 1940's. No release events could be identified in this decade. In all other decades, major sustained and moderate temporary release occurred, leading to an increased radial growth. The decade of 1970 to 1979 shows the highest share of *F. sylvatica* with release events; more than half of the *F. sylvatica* trees were affected by disturbances. In the following two decades, the share of release events declined even more than in the beginning of the series. In the 1980's and 1990's, only up to 14% of the cores showed a moderate temporary release and up to 6% a major sustained release.

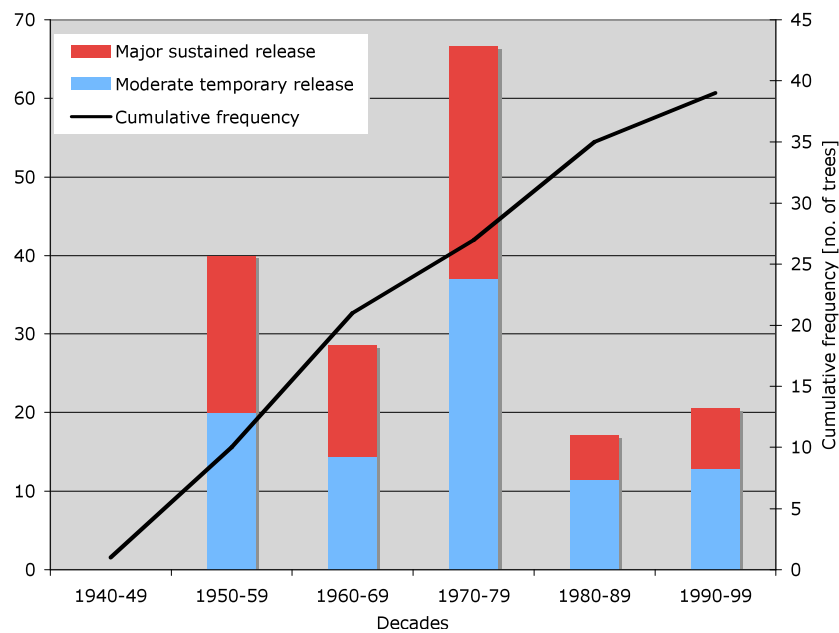


Fig. 4.37: Share of *F. sylvatica* cores with major sustained and moderate temporary release events split up into decades.

Release events (major sustained and moderate temporary release) were used to produce a disturbance classification for each plot. For calculation, number of releases and a share of cores with release events were used (fig. 4.38).

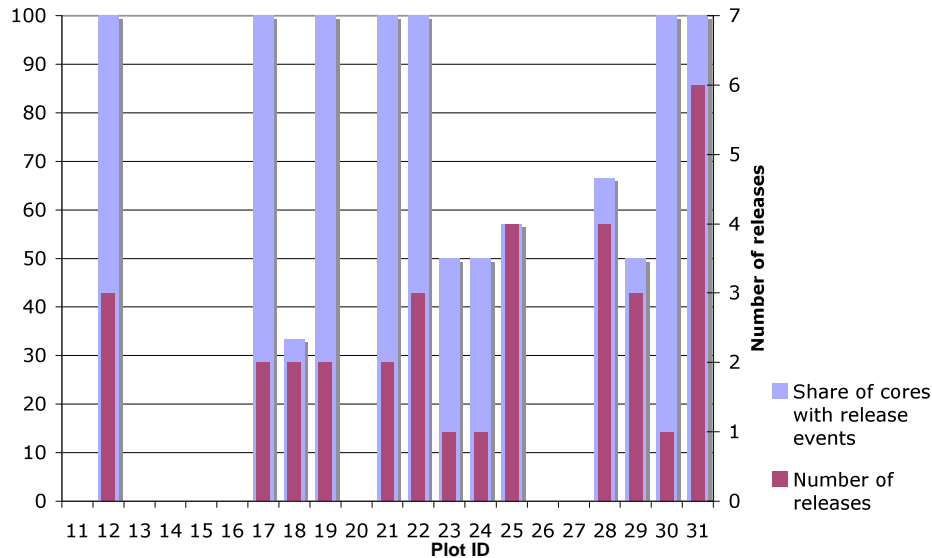


Fig. 4.38: Analysis of release events since 1970. The blue bar shows the share of cores with release events, the violet bar gives the total number of release events detected in the cores.

Boxplot was applied to identify a relationship between species' abundance and level of disturbances occurred since 1970.

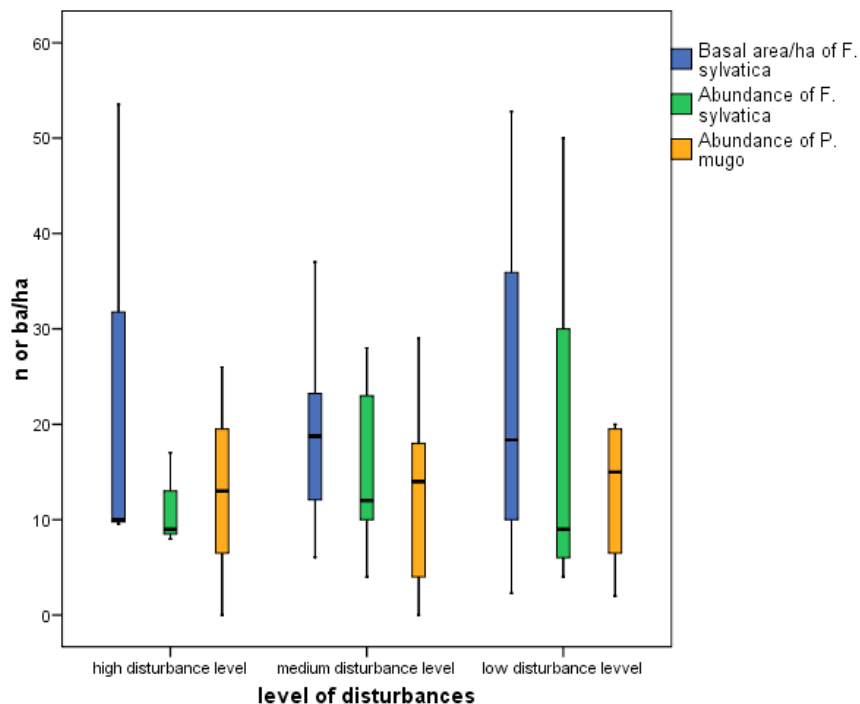


Fig. 4.39: Boxplot of abundance and basal area/ha of species and disturbance level since 1970.

The boxplot (fig. 4.39) indicates that the abundance of *P. mugo* is relatively homogenous distributed over all disturbance levels. The median of *F. sylvatica* shows highest basal area/ha on plots with low and medium

disturbance level. Abundance of *F. sylvatica* deviates from this picture: Abundance gained on plots with medium and high disturbance level is higher than on plots with low disturbance level. This may indicate that *F. sylvatica* is able to colonize also frequently disturbed areas but gains more biomass on less disturbed areas.

4.5.2 Results achieved applying an avalanche simulation

F. sylvatica shows no clear trend when comparing its basal area either to abundance of flow pressure affecting a plot or to relative avalanche hazard (3-level classification) (fig. 4.40 a and b).

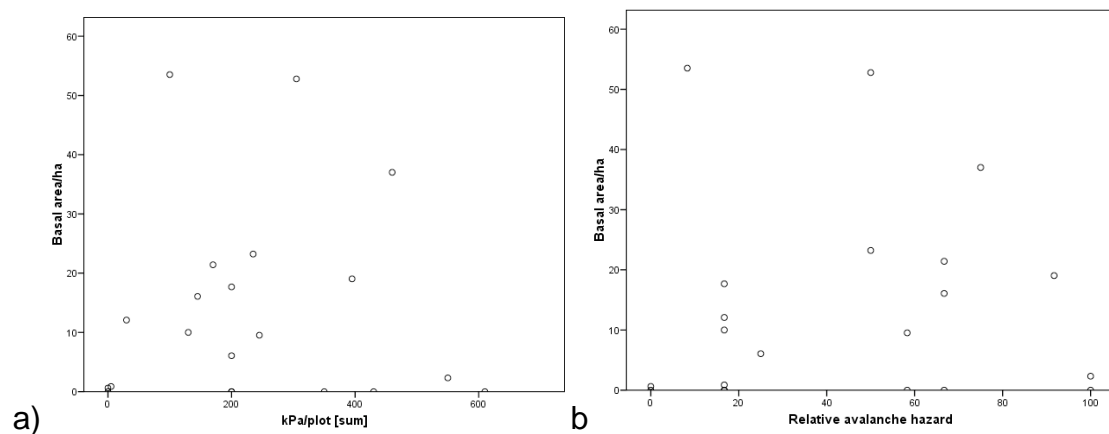


Fig. 4.40: Relation between basal area/ha of *F. sylvatica* and avalanches: a) Flow pressure (kPa) of all simulations affecting the plots were summed up, the values represent magnitude and occurrence b) Relative avalanche frequency within plots.

Also, the standardized density of *P. mugo* does not correlate to the relative avalanche hazard (fig. 4.41).

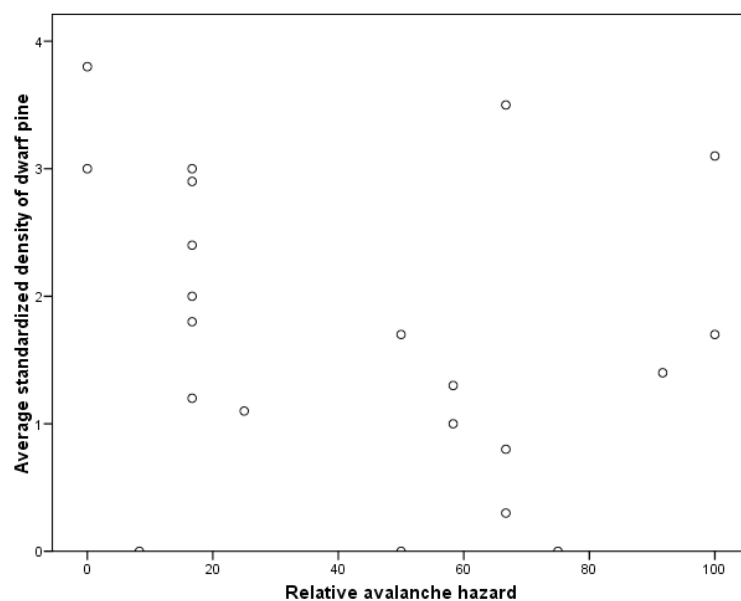


Fig. 4.41: Relationship between standardized density of *P. mugo* and the relative frequency of avalanches within the plots.

Correlation does not show any significant relationship between avalanche hazard and abundance of *F. sylvatica* or *P. mugo* (table 4.57).

Table 4.57: Correlation (Pearson) between avalanche hazard and abundance/ basal area of *F. sylvatica* and *P. mugo*.

		<i>Avalanche hazard</i> (3 levels)	<i>Avalanche hazard</i> (2 levels)
<i>F. sylvatica</i> [Basal area/ha]	Correlation	.146	-.092
	Significance (2-tailed)	.527	.691
	N	21	21
<i>F. sylvatica</i> [n]	Correlation	.233	.022
	Significance (2-tailed)	.309	.923
	N	21	21
<i>P. mugo</i> [n]	Correlation	-.298	-.172
	Significance (2-tailed)	.189	.456
	N	21	21

When using a 3-step characterisation of avalanche hazard, a uniform distribution of *P. mugo*/ *F. sylvatica* in different avalanche hazard zones cannot be precluded under assumption of a 5% CI. Also, when changing the scale of avalanche hazard into two levels (low/ high risk), null-hypothesis cannot be rejected (table 4.58).

Table 4.58: Analysis of variance for proving uniform distribution of abundance of *P. mugo*/ *F. sylvatica* in avalanche hazard categories (low/ high risk).

		<i>Sum of</i> <i>squares</i>	<i>df</i>	<i>Mean square</i>	<i>F</i>	<i>Significance</i>
<i>P. mugo</i> [n]	Between groups	1.672	1	1.672	.580	.456
	Within groups	54.756	19	2.882		
	Total	56.428	20			
<i>F. sylvatica</i> [n]	Between groups	.041	1	.041	.010	.923
	Within groups	81.732	19	4.302		
	Total	81.773	20			
<i>F. sylvatica</i> [basal area/ha]	Between groups	47.121	1	47.121	.163	.691
	Within groups	5492.647	19	289.087		
	Total	5539.768	20			

To assess the influence of avalanches on the frequency of release events, correlation was carried out (table 4.59).

Table 4.59: Correlation between number of release events and avalanche hazard category.

	<i>Number of releases</i>	
Avalanche hazard (2 levels)	Coefficient of correlation	.127
	Sig. (2-tailed)	.679
	N	13

The results show that release events do not correlate significantly with avalanche hazard classification; thus, avalanches may not be the main disturbances influencing stand dynamics.

Table 4.60: Significant correlation between the relative frequency of avalanches and the occurrence of snow mold.

	<i>Relative avalanche hazard</i>	
Snow mold [%]	Coefficient of correlation	.576(**)
	Sig. (2-tailed)	.010
	N	19

It seems that the share of infected *P. mugo* by snow mould is significantly positively associated with relative avalanche hazard (table 4.60).

Potential affects of avalanches on stand structure were assessed as well (fig. 4.42).

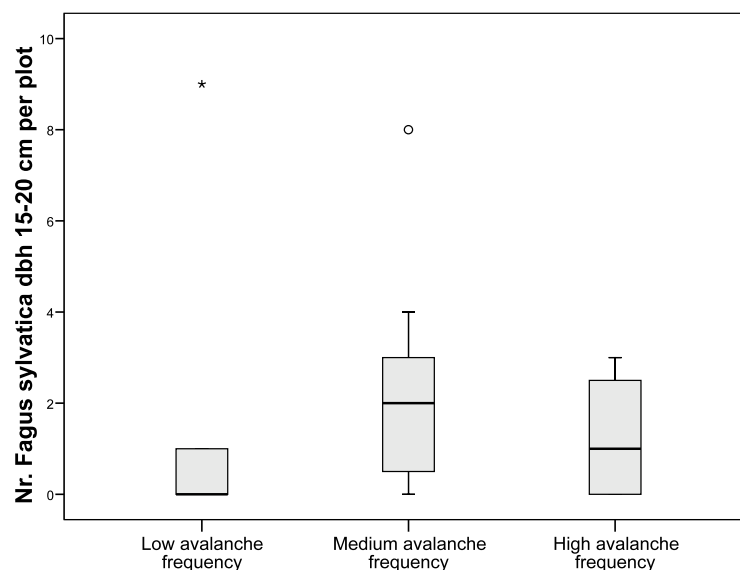


Fig. 4.42: Boxplot of frequency of *F. sylvatica* with a diameter between 15 to 20 cm on plots with low, medium or high potential avalanche frequency.

Fig. 4.42 shows that the frequency of *F. sylvatica* with a diameter of 15-20 cm is highest at a medium potential avalanche frequency and high potential avalanche frequency. Though on plots with low potential avalanche frequency, *F. sylvatica* is hardly abundant in low diameter class. This implies

that *F. sylvatica* is influenced by avalanches and results in a stand structure dominated by low diameter classes on plots more often affected. Trough the physical impacts of an avalanche release and lower elasticity of big trees, these may be removed more easily and trees with a lower diameter remain.

5. Discussion

5.1 Limitations of the field survey

The plots were set up by using GPS. Due to the location of the study area, which is located between high peaks, the GPS signal was very often weak and in one case even no signal was received at all. To improve the accuracy of plot locations, orthophotos were used. Significant points in landscape such as big rocks, gullies etc. helped with locating. Average accuracy using the GPS was +/- 10 m; improvements up to 3-5 m were achieved.

The stand structure in the study area is variable, and the number of plots was limited because of workability in the context of a diploma thesis. It was taken care, however, not to bias the location of plots towards any structural type.

After fixing the north-western corner of the plot, plot corners were fixed. For this work, compass and measuring tapes were used. The terrain of the study area and very dense stands of *P. mugo* made it difficult to set up a 10x10 m rectangle. To keep inaccuracy as low as possible, two persons carried out the setup and the angle of the rectangle as well as the length were rechecked.

Branching points and vegetative connections of *P. mugo* were used to estimate vegetative regeneration. On the other side, these growth patterns made it complicate to distinguish, which branches could be counted as an individual plant. Therefore it was tried to associate branches to plants as good as possible to a mother plant; in unclear situations the origin of a branch was followed, also below the soil if doable. During work, branch allocation was done according to a certain design so that results are comparable within all plots.

Due to the growth of *P. mugo* (creeping and ultimately erecting branches), its density and terrain, it was not possible to measure height from stem at root base to its top; instead, the distance from the highest branch top to soil was measured. If there were big branching points, an average value of three branches was noted. Thus, different inclination of the plots had an influence on the final results. With an average standard deviation of 11% of the meso relief, the measuring error is quite low and increases the further away the highest top of *P. mugo* is located from the root base.

Vitality assessment of *P. mugo* using Kraft is not a suitable method to be applied. Highest individuals do not necessarily have biggest diameters; variation in diameter classification is caused by soil covering of the stem, thus reducing the extent of diameter. As well, *P. mugo* is a krummholz and does not allow direct comparison with tree species. Without direct comparison, information about stand structure is lost; it was tried to compensate this drawback by introduction of the variables extent of shading and shade causing species.

To be able to detect relationship between regeneration and light regime hemispherical pictures were made. In average, these pictures were taken at a height of 60 cm. The use of the tripod and correct handling of the camera made it impossible to take the pictures at a lower height. In many cases, especially below *P. mugo*, some branches were below the lens of the camera. The values may reflect this to a certain extent, and are thus conservative estimates of shading of the ground.

5.2 Site differences: fine scaled spatial partitioning versus competition

5.2.1 Response to site parameters

The cluster analysis performed did not result in significant differences of species abundance and performance regarding response to site parameters. Nevertheless, differences and trends in species abundance become apparent. Svajda et al. (2011) name soil as an important factor for the presence of *P. mugo* as it segregates competing (shadow) trees. Also in this study it became apparent that *P. mugo* has higher abundances on shallow soils with decreasing thickness of the A-horizon. On plots with medium share of relictic loams, where abundance of *F. sylvatica* is highest, abundance of *P. mugo* is lowest. Also if statistical analysis showed no significant results, the tendency gained is comparable with Svajda et al. (2011). Thus, shallow soils are an environmental factor allowing for improved competitiveness of *P. mugo* at the study site.

Svajda et al. (2011) also stated that *P. mugo* shows better growth characteristics on steeper slopes in the Tatras, a result which is in accordance to the cluster analysis performed.

Other broad leaf and conifer species have only low abundance and are not growing densely. Their competition with *P. mugo* can be seen as negligible on stand scale.

P. mugo is on the boarder of its lower altitudinal distribution at the study site, which is caused by interspecific competition (Hafenscherer, 1985). The study site reaches with 2500 mm a high amount of precipitation and also high air humidity is given there (Wankonigg, 1978 & Carli, 2009a). These environmental factors and the carbonate parent material, which Hafenscherer (1985) distinguished as ecological optimum of *P. mugo*, may increase competitiveness of *P. mugo* at the study site.

5.2.2 Intraspecific and interspecific spatial distribution of adult trees

When having a look at abundances the strong negative correlation between abundance of *P. mugo* and *F. sylvatica* can be observed. This can be the result of two processes: *P. mugo* is suppressed by *F. sylvatica* due to competition and disappears or *F. sylvatica* has not managed to establish in dense stands of *P. mugo*.

Intraspecific interactions

Fagus sylvatica

At small radii (up to 2 m), *F. sylvatica* shows a clumped growth, whereas it is randomly up to regular distributed at bigger radii (3 to 5 m). On average, 13% of established *F. sylvatica* trees results from sprouting. On the schemes drawn, a tendency of clumped growth of *F. sylvatica* can be seen also.

Pinus mugo

The distribution of *P. mugo* shows similar tendency as *F. sylvatica* does. Clumped growth is stronger at small radii (up to 2 m), but already at a radius of 2 m 50% are distributed randomly. At bigger radii (>2 m), the share of regular distribution increases. *P. mugo* regenerates mainly vegetative (Hafenscherer, 1985), what causes a clumped growth. Its requirement of light can cause intraspecific competition and may lead to regular growth.

Dead Pinus mugo

Dead *P. mugo* is randomly distributed in all distance classes (1 to 5 m). This implies that there was not one main cause of death. As pointed out in the method, all contacts with dead branches or whole dead individuals were counted, thus including also dead branches of alive individuals. This is justified by the fact that vegetative regeneration has a strong importance for *P. mugo* and that live branches can become sources of vegetative regeneration (comp. Hafenscherer, 1985). During fieldwork, I observed that dead branches were mainly killed by snow mould; 25% of alive *P. mugo* had slight, 41% showed moderate infection. In dense stands the lower branches were dead, a result of self-shading. 54% of shaded *P. mugo* was overtopped by other *P. mugo* individuals, thus showing high intraspecific competition for light.

Thickness of soil is a parameter allowing for explanation of growth patches. As results showed, soil depth is an important factor of species' abundance (comp. Svajda, 2011). Within the plots (10x10 m) soil depth was varying to a great extent and thus causes clumped growth at small radii within species. Vegetative regeneration and the lateral growth of *F. sylvatica* (Legbuchen) can lead to higher densities in close spatial neighborhood.

Kutter (2007) analysed seed dispersal of *F. sylvatica* and compared an empirical and mechanistic model of seed dispersal. The empirical model showed that seeds of *F. sylvatica* are mainly distributed below crown area (average crown radius is 2 m at study site) and further dispersal is unlikely or done by seed predators (comp. Dengler, 1990). This feature and the shade tolerance of regeneration can be another explanation for clumped growth at small radii.

Random growth patterns of the species are explainable by the heterogeneous parameters of micro site (see Wiegand, 2004).

These results suggest that growth patterns of *F. sylvatica* and *P. mugo* allow for coexistence, especially as it seems that *F. sylvatica* was not able to occupy all patterns yet.

Interspecific

Fagus sylvatica and *Pinus mugo* (alive)

The characteristics of the software Programita made it hard to evaluate bivariate distribution of *F. sylvatica* and *P. mugo* in a matrix mode. In order to test the reliability of the results, the correlation between pure and mixed points was separately proved. The results show that bivariate analysis of *F. sylvatica* and *P. mugo* is close to reality.

F. sylvatica and *P. mugo* show segregated dispersal at small radii (1 (to 2) m), what may be caused mainly by interspecific competition. *P. mugo* is less competitive than the late-successional species *F. sylvatica* (Hafenscherer, 1985; Ellenberg, 1996). At a radius of 4 to 5 m, random distribution is the dominant spatial pattern; *F. sylvatica* and *P. mugo* do not have any interaction at bigger radii, also root competition can be excluded.

Fagus sylvatica and dead *Pinus mugo*

F. sylvatica and dead *P. mugo* show random distribution above all radii. There is no evidence that dead *P. mugo* is in close neighborhood to *F. sylvatica* in particular.

As dead *P. mugo* does not especially imply that the whole individual was dead, results may be jagged. As observed, *P. mugo* (alive) and *F. sylvatica* are segregated especially at small radii, where *F. sylvatica* has the most power to influence growth of *P. mugo* by overtopping and shading. This coincides with the following result: only 13% of *P. mugo* is shaded by *F. sylvatica*, but more than three quarters are shaded by *P. mugo*; this indicates high intraspecific competition about light.

Thus, it is likely that *P. mugo* has already died some time ago and no standing dead wood has remained. Besides that, it was not possible to separate completely dead individuals out of database. Therefore, the results do not have best informative value for interpretation.

Pinus mugo (alive) and dead *Pinus mugo*

With all variants used, mainly the same results were achieved, namely spatial randomness.

Dead *P. mugo* is not stronger correlated than expected by the average aggregation of the two component patterns (variant 1). Neither is dead *P. mugo* more clustered than alive *P. mugo*, conditional on the structure of the joined patterns (variant 2). The plots analyzed with variant 7 are mainly randomly distributed. This allows the conclusion that dead *P. mugo* does not necessarily occur within dense alive *P. mugo* stands, where, due to a higher density of branches and less light penetrating to the floor, branches would die off because of low light regime.

These results imply that death of *P. mugo* is caused individually and a result of various influences (e.g. snow mould infection, competition, abiotic influence). But, as expected (e.g. Hafenschner, 1985 & Ellenberg, 1996), it is also becomes apparent that *F. sylvatica* is able to outcompete *P. mugo* in direct neighborhood.

The low share of aggregation in direct neighborhood (15%) may be explained by regeneration of *F. sylvatica*. Pioneer species as *P. mugo* promotes growth of later successional species by enhancing various site parameters (e.g. soil formulation) (e.g. Ellenberg, 1996). It was observed that much regeneration (especially broad leaf species) was found below *P. mugo*. It is likely that the *F. sylvatica* individuals belong to regeneration, as also these contacts were counted. To proof this conclusion the method of data collection would have to be adapted.

5.3 Disturbances: coarse scaled spatial partitioning

5.3.1 Disturbance regime

Response to disturbance events

Analysis of radial growth increment of *F. sylvatica* shows major sustained and moderate temporary release events in every decade of analysis. The threshold for the release events was set as in Nowacki & Abrams (1997). The threshold is an important parameter, which may influence results of the study (Rubino and McCarthy, 2004).

It is likely that absence of release events in the 1940's is a result of the low number of cores available. From 1950 to 1970, the relation between moderate temporary and major sustained release events is nearly 1:1. Highest share of cores with release events was achieved in the 1970's. In January 1976 a severe storm event took place in the eastern part of Austria, causing high damage in the forest (Weinfurter, 2005). Up to 20 days with wind speed higher than 100 km/h occurred in January (Tageszeitung Österreich, 2008).

This storm event may have caused the big increase in release events in the 1970's.

The share of release events (since 1970) on total number of cores was used to calculate a disturbance frequency for each plot. Correlation achieved no significant results between abundance of species and disturbance frequency. The disadvantage of this method is, that for plots, where no *F. sylvatica* grows (n=6) or where no *F. sylvatica* trees were cored (n=2), no information is available. Especially for *P. mugo*, information may be lost.

Wind damage

During fieldwork, wind damage was observed. Admont, where one of the weather closest stations to the study site is located, faces mainly wind coming from the east; the main aspect of the caldera Hinterwinkel. No dead tree could be clearly allocated to wind throw. Impact of wind can be estimated by the extent of broken treetops. More than 25% of *F. sylvatica* and 20% of other broad leaf trees had broken treetops. It is likely, that at least a certain share of breakage was caused by wind. Splachtna et al. (2005) distinguished wind as the primary coarse-scale disturbance agent in mixed forests in Central Europe.

Snow fall events

Another potential causing factor may be snowfall events in early autumn, when snow is very heavy and when trees still have their foliage. Such events may lead to breakages of crowns. In the last days of fieldwork (middle of September) snowfall occurred. The snow was very wet and heavy so that branches bowed under the weight of the snow. This type of disturbance may slow down succession and thus, distribution and establishment of *F. sylvatica* as the main competitor of *P. mugo* at the study site. But it is doubtful that is a driving agent in the system.

Browsing

High densities of ungulates and fencing in winter may increase pressure especially on tree regeneration. Regeneration of *A. pseudoplatanus* and *S. aucuparia* face the highest browsing pressure of all species at the study site. More than half of regeneration had browsed terminal shoots, affecting their vitality and further development to a high extent (Motta, 2003). Data of browsing pressure on regeneration correlates with height distribution; *A. pseudoplatanus*, *S. austriaca* and *S. aucuparia*, a very appetizing species (Motta, 2003), are hardly able to establish and disappear at higher heights. Reliable conclusion of *A. viridis*, *Salix* sp. and *L. decidua* can hardly be drawn as their abundance is very low (two to three plants per species). Regeneration of *P. mugo* was not browsed at all. Cermak et al. (2009) analyzed relationship between species dominance and damage of browsing in Czech forests. They

state that browsing pressure was higher on species with low abundance and that it was possible to increase pressure on population.

Browsing has very significant impact on *F. sylvatica* regeneration and its vitality. A quarter of the regeneration has at least a browsed terminal shoot and another quarter shows no signs of being browsed. Regeneration is browsed in all height classes equally, showing a tendency to higher browsing effects in lower height classes.

Browsing is a disturbance factor, which mustn't be neglected at the study site. It seems that it slows down growth of *F. sylvatica* and may even influence species composition regarding species with low abundance.

Abiotic damages due to disturbances

Nearly half of *F. sylvatica* has forked growth, indicating that the individual was injured (wind break, browsing etc.). Besides of the previous injury, forked trees are more susceptible to decay or to anew breakage. Broken treetops, trunk abnormalities and injuries occur on up to 20% of *F. sylvatica* in each category. Damage makes the trees more susceptible to infection by pest agents and thus, has an impact on vitality and stability. 73% has a curved trunk. A curved trunk also includes individuals, which can be classified as "Legbuchen". "Legbuchen" form especially on sites influenced by avalanches or at the timberline (Fanta, 1981 & Kölling et al., 2004). Despite these features, *F. sylvatica* shows viable growth; its life span may be shortened due to potential infections and thus, because of reaching mature age late, result in lower reproduction rates.

5.3.2 Response to avalanche hazard

Under the assumption, that repeated avalanches allow *P. mugo* to grow and establish because of eliminating competing trees (Ellenberg, 1996), a high avalanche hazard should have neutral or slight positive effects on *P. mugo* abundance. At the study site, *P. mugo*, which is not susceptible to avalanches (Ellenberg, 1996), even shows a negative tendency in abundance with higher avalanche hazard; a result, contrary to the assumption stated above. Summed up, neither *F. sylvatica* nor *P. mugo* show any significant correlation in abundance or basal area with avalanche hazard affecting a plot. No significant relationship could be achieved if changing classification of avalanche hazards from three to two levels.

To identify a relationship between avalanche hazard and release events of *F. sylvatica*, correlation analysis was carried out. A positive, but no significant relation was calculated. Thus, avalanches don't seem to be the type of disturbance with the highest impact on *F. sylvatica*.

These results lead to the conclusion, that avalanche hazard is not a main factor explaining the abundance and coexistence of *F. sylvatica* and *P. mugo* in the studied area.

Avalanche release events as calculated with ELBA can only delineate the potentially affected areas and, to some extent, give the probability and intensity of an avalanche release. But as we have no real data about avalanche releases in the study area and no field data were collected, it is also possible, that this is not the appropriate method to be applied to detect the impact of avalanche releases.

5.4. Temporal partitioning and seed limitation: life histories

5.4.1 Seed limitation

The close spatial neighbourhood between adult and juvenile *F. sylvatica* indicate the low dispersal distance. 99% of regeneration found grows on plots where adult *F. sylvatica* trees occur. The range of dispersal of beechnuts is limited, most seeds are found within 20 m to the mother tree or even closer, right under the canopy (Dengler, 1990 & Kutter, 2007). The clumped growth of *F. sylvatica* at a small scale and its observed irregular distribution (no individuals on some plots) suggest that characteristics of seed dispersal result in seed limitation and thus, allowing *P. mugo* to grow without competitive pressure.

There cannot be drawn any conclusions about seed limitation of other broad leaf and conifer species as the quantity and quality of data was too low. *P. mugo*, which reproduces mainly vegetatively, seed limitation is no limiting factor at the study site.

5.4.2 Life histories

Tree regeneration

Species composition

F. sylvatica is the second most dominant species within regeneration >1 year and shows a slight, but not significant decrease within altitude. Korpel (1995) observed in spruce-fir-beech forests that the existence of a dominating *F. sylvatica* regeneration gives the impression that the species is expanding. This is not necessarily the case as beech has a shorter life span and a faster change in generation as coniferous species and here especially *A. alba*.

On the whole study site less than 50 generatively regenerated *P. mugo* plants were found. *P. mugo* is the dominant species with 1560 adult plants/ha but has less than 3% of total regeneration. This implies the low importance of

generative regeneration for successful stand establishment according to Hafenscherer (1986).

Conifer regeneration other than *P. mugo* is *L. decidua* and *A. alba* (seedlings < 1 year and > 1 year). *L. decidua* is hardly abundant with less than five individuals per ha (equals one individual on all plots) in regeneration > 1 year. Due to its low abundance, no statistical tests were made for *L. decidua*. *A. alba* is more frequent, reaching a density of 230 individuals per ha and its abundance is decreasing significantly with increasing altitude. Due to a lack in knowledge about potential mother trees (for more than the half it could not be identified) it seems that *A. alba* reaches the highest potential distribution distance. According to Kutter (2007) highest seedling densities are found within 50 m of a potential mother tree.

Other broad leaf species occurring in regeneration are *A. pseudoplatanus*, *S. aucuparia*, *S. austriaca*, *Salix* sp., *F. excelsior* and *A. viridis*. *F. excelsior*, of which low number of regeneration is abundant, was not found within adult trees.

A. pseudoplatanus and *S. aucuparia* have one of the highest abundance in regeneration totally, but when having a look in height distribution it becomes obvious that they are hardly able to establish and reach mature age. Also *S. austriaca* does not grow higher than 1 m. Analysis of regeneration has already shown that other broad leaf species are very present in regeneration, but do not manage to establish successfully. Densities of adult trees reflect this result. By reducing browsing pressure, it is likely that more individuals of broad leaf species would be able to establish successfully and achieve higher abundance.

Vegetative regeneration

Vegetative regeneration was assessed by the share of branching points and vegetative connections on the total number of *P. mugo* on each plot. On six out of 21 plots, no signs of vegetative regeneration were obvious. On most other plots grows *P. mugo*, which emerge from a branching point or still have connection to its mother plant. The numbers gained by using this method can only be seen as an approximation of the share on total regeneration: If possible, vegetative connections were followed back to the “mother” plant and the unity between branches of branching points was proved. Soil coverage made it impossible to proof each connection under efficient use of time. Besides that, it was observed that connections had started rotting. Thus, rotten and already missing connections are not included in the results.

F. sylvatica trees regenerate vegetatively as well. Root suckers make up 13% of total adult *F. sylvatica* abundance. Root suckers with a diameter smaller than 5 cm were not counted; thus, just information about established root suckers is available. Fanta (1981) observed that vegetative regeneration of *F. sylvatica* is increasing on sites prone to disturbances. Especially when it forms

the alpine timberline as certain sites on the Balkans, importance of vegetative reproduction increases. Also this way *F. sylvatica* is able to form dense stand, a quite unique feature and once more presenting its potential for dominance within European forests.

Establishment of regeneration

Height distribution of *F. sylvatica* regeneration gives evidence that it can establish and reach maturity. *F. sylvatica* is the only successful broad leaf species therein; especially *A. pseudoplatanus* and *S. aucuparia* have higher abundances at low height (< 50 cm), but hardly any grow higher than that. All diameter classes up to 5 cm are abundant. Also growth of terminal shoot of the previous year shows best performance out of all species' regeneration.

F. sylvatica gains best increment under open canopy, but performs similar under closed one (Nicolini, 1997; Kunstler et al., 2005). The regeneration (seedlings and > 1year) is not limited by light and no significant correlation between vitality and level of shading was identified. *F. sylvatica* has high plastic morphology (Nicolini, 1997; Kunstler et al., 2005) and can withstand unfavorable conditions well.

Height distribution of generative *P. mugo* regeneration allows the conclusion that plants are able to establish. The abundance of plants is decreasing with increasing height. Some plants reach heights bigger than 1 m and escape from competition with ground vegetation. There were no significant indications that dense grass cover and high humus layer lead to a lower abundance of generative regeneration of *P. mugo* and bare and wounded soil as well as moist sites favour it as described by Grembichl (1893).

Height classes of *A. alba* show, that it is able to establish and reach heights bigger than 2 m. Average age is 15 years. The span of age distribution is wide. Nearly 50% of *A. alba* regeneration is covered in this result.

The average age of regeneration was quite low, this is a result of the data collection; for many individuals it was not possible to count age as the regeneration showed mechanical defects (*F. sylvatica* 28% determined, *A. pseudoplatanus* 11%). Thus, with the data received it is not possible to draw reliable conclusions of regeneration reaching mature age.

Performance of adult trees

Species composition

P. mugo is the most dominant "tree" species at the study site, reaching a density of 1560 N/ha on average. Its density is increasing with increasing altitude, but not significantly. *F. sylvatica* is the second most important tree species at the study site. On average, it has a density of 1100 trees/ha. It reaches highest densities up to 1150 m altitude; analysis of variance showed

no significant results. *A. alba* (73%) and *L. decidua* (27%) are the only conifer species found beside *P. mugo*. They achieve lowest average density with 65 trees/ha within all species/ species cluster. Their density nearly stays constant within the altitudinal range of the study site. *S. aucuparia*, *A. pseudoplatanus*, *A. viridis*, *S. austriaca* and *Salix* sp. represent other broad leaf species at the study area. These species are typical elements in the montane zone (Ellenberg, 1996). Together, they reach a low average density with 97 N/ha. They show a strong negative, but not significant, tendency of decreasing density in increasing altitude. The species composition is typically in montane areas (Zukrigl, 1961 & Neumann, 1978). A missing element is *P. abies*, which was observed below the study area. Species other than *P. mugo* and *F. sylvatica* are important in terms of biodiversity but due to their low abundance they are no relevant competitors for the well performing *F. sylvatica* and also the low competitive, but highly abundant *P. mugo*.

Growth characteristics

The average height of *P. mugo* reached is 3 m, which corresponds to Ellenberg (1996). Some *P. mugo* with an erect growth even reach heights up to 4 m and more. Its diameter ranges between 5 to 20 cm, with a peak in the 10 cm class. *P. mugo* with a diameter lower than 5 cm were counted as adult plants in case that it was obvious that their stem was covered by soil for a longer distance or they originated obviously from vegetative regeneration.

F. sylvatica achieves the biggest heights of all species and some trees are more than 10 m high. Most trees are up to 4 m high. Abundance is steadily declining with increasing height. Due to the inclined growth of *F. sylvatica*, it was difficult to take height measurements. Height is decreasing slightly with altitude. On the margins of the study area, which are more protected from erosion or other disturbances, grow erect, well-developed *F. sylvatica* trees also in higher altitudes. This result may therefore not be a cause of altitudinal effects but a result of site parameter and other agents. Besides that, *F. sylvatica* is not at its distribution limit at an altitude of 1250 m (Mayer, 1986).

The diameter of adult *F. sylvatica* trees range from up to 10 cm to more than 30 cm. The abundance of *F. sylvatica* is decreasing steadily with an increasing diameter (reverse J-curve). This indicates that there is continuous regeneration and that coarse scale disturbances leading to single cohort stands do either not occur on the site or do not lead to regeneration pulses of *F. sylvatica*.

Other coniferous species are the youngest component with an average age of 23 years, representing 31% of all other coniferous trees. Thus, they also have lowest height reached with 6 m and a maximal diameter up to 15 cm.

In the category other broad leaf species trees with heights up to 10 m occur (*S. aucuparia*, *A. pseudoplatanus*), but having their maximum in the 4 m height class. The curve is reverse-J like. Biggest diameter reached is up to 30

cm. Other broad leaf species reach similar extent in height and diameter as *F. sylvatica*.

In comparison, analysis taken in the close, natural forest Rothwald show that also there *F. sylvatica* is the dominating species but *A. alba* and *P. abies* gain bigger heights than this one (Zukrigl et al., 1963). As we have seen, conifers other than *P. mugo* are the youngest elements in the system, so they haven't reached their mature age yet.

Life span

P. mugo is on average the oldest tree species present at the study site. The oldest *P. mugo* is 177 years old; it is likely, that much older individuals grow there. Especially when originating from vegetative connection or when covered by soil, the heartwood was very often rotten and it was impossible to estimate the amount of missing tree rings (cf. Hafenscherer, 1985). The age distribution of *P. mugo* is very even. The youngest plants counted are up to 30 years. The abundance in this class is low, implying that it needs up to 30 years to reach mature age. The abundance of *P. mugo* older than 110 years is slightly decreasing, the peak of the class "> 130" can be explained by the summation of age classes. The even age distribution leads to the conclusion that there are no phases of development within *P. mugo* stands; this corresponds to results gained by Gallmetzer (1994).

Age distribution of *F. sylvatica* at 1 m height has three main peaks in the age classes 40, 60 and 70. Sample number per plot is too small to make inferences to peaks in establishment, however.

Other conifers and broad leaf species are younger elements in the system (30-60 and 50-60 years). Due to a low number of cores it is not possible to draw reliable conclusions and results were not used for further analyses.

Interestingly, *P. mugo* is the oldest woody species abundant at the study site, *F. sylvatica* penetrated into the system only 80 to 100 years ago. Regarding Kilian et al. (1994), the potential forest community of the study site is a spruce-beech-fir forest. Carli (2009a) classified the study site as an azonal site, namely a "talus fen of higher altitudes". The absence of old individuals of *F. sylvatica* may indicate the very old age of the system.

6. Conclusions

Site differences: fine scaled spatial partitioning versus competition

- *Are there parameters of micro site which allow for coexistence and which parameters do so?*

The growth of *F. sylvatica* is favoured by climatic conditions (humid climate), altitudinal range within, the calcerous bedrock and depth of soil.

The cluster analysis performed showed differences in abundance of *P. mugo* and *F. sylvatica* within clusters. *P. mugo* achieved mainly high abundance in clusters with a low abundance of *F. sylvatica*. When having a look at the characteristics of clusters, *F. sylvatica* performs well on deep and shallow soils. Lowest performance of *F. sylvatica* was obtained in steep terrain, in higher altitude and under low avalanche hazard. In contrast, *P. mugo* has higher abundance in increasing altitude, in shallow soils without relictic loam and shows relative indifferent behaviour against inclination.

Thus, the main parameters of micro site allowing for coexistence are altitude and steepness of terrain, where *F. sylvatica* is performing worse than *P. mugo*.

- *Is *F. sylvatica* able to outcompete *P. mugo* on specific sites?*

It is not negligible that *F. sylvatica* has an impact on *P. mugo* if growing in close spatial neighborhood. Bivariate analysis of spatial distribution showed segregated growth at small radii. *P. mugo* cannot withstand long periods of shading; but death of *P. mugo* cannot be associated to suppression by *F. sylvatica* only.

F. sylvatica shows a good performance at the study site. It is the most abundant, predominating tree species, and the only broad leaf species, which is able to reproduce continuously. Regeneration does not show worse performance under closed canopy or at higher altitude. Only browsing impacts on *F. sylvatica* regeneration have to be taken into account; but also when browsed, the highest share of its regeneration shows is still well growing (vitality class 2). Nevertheless, it is likely that it slows down the establishment of *F. sylvatica* regeneration. Besides that, browsing is a selective agent, which favours *P. mugo* at the study site.

Adult *F. sylvatica* trees are missing on plots with a high share of relictic loam, a soil type, favourable for growth of *F. sylvatica*. That *F. sylvatica* is missing on these plots indicates that it has not yet reached its maximum distribution at the study site. All regeneration of *F. sylvatica* was found on plots with adult trees as well, demonstrating its low dispersal ability and allowing the conclusion, that distribution of *F. sylvatica* is seed-limited at the study site. Thus, as long, as *F. sylvatica* will not have dispersed into

and established in all parts of the study area, it will be able to outcompete *P. mugo* only locally and in absence of severe disturbances.

Disturbances: coarse scaled spatial partitioning

- *Does a correlation between the spatial pattern of tree species and the occurrence of avalanches exist?*

No significant correlation between avalanche hazard, as created with ELBA, and the abundance of tree species could be identified. Avalanches are a disturbance agent in the Hinterwinkel. The high share of “Legbuchen” may indicate that *F. sylvatica* is able to react properly to this type of disturbance and does not get excluded by it.

High avalanche hazard correlates significantly with snow mould infection of *P. mugo*. Snow deposit and snow compaction may increase the duration of snow coverage of *P. mugo* and thus, favour infections. To verify this hypothesis, more data about avalanche deposit would be required.

However, there are some indications that avalanches/disturbances shape the stand structure. On plots with differing potential avalanche release the composition of diameter classes of *F. sylvatica* looks differently. Plots with medium to high avalanche frequency have a higher number of trees with low diameter.

Seed limitation

- *Does seed limitation of *F. sylvatica* allow for coexistence of the two species?*

The range of dispersal of beechnuts is limited, most seeds are found within 20 m to the mother tree (Kutter, 2007). Thus, seed limitation of *F. sylvatica* does not allow for fast dispersal and slows succession.

It is likely that *F. sylvatica* has spread from the entry of the valley head and is in stage of further dispersion. The minor differences in niche occupation (altitude) between *F. sylvatica* and *P. mugo* may result from seed limitation. *F. sylvatica* is abundant within the whole altitudinal range of the study area and there are no or only slight signs of differing seedling establishment in different niches. Nevertheless, *F. sylvatica* does not grow in all potential habitats. This implies that seeds of *F. sylvatica* haven't reached these yet. This way competition between *F. sylvatica* and *P. mugo* is avoided and seed limitation of *F. sylvatica* can contribute to coexistence of the two species.

7. Indexes

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7.4 List of abbreviations

ANOVA	Analysis of variance
ASCII	
CI	Confidence interval
CSR	Complete spatial randomness
DEM	Digital elevation model
DSF	Direct site factor
ELBA	Energy line based avalanche model
GC%	Percentage growth change between preceding and subsequent 10-yr means
GSF	Global site factor
ISF	Indirect site factor
WRB	World resource base of soils

8. Annexes

8.1 Table of age distribution of adult tree species

Table 8.1: Summary of age characteristics on each plot. "---" indicates species abundance on a plot with no cores taken. For trees, age is given for a height of 1 m.

Plot ID	Age mean	Age min	Age max	Age stdev	Total no. of cores	Total no. of trees within species
11						
<i>P. mugo</i>	65.0	48	75	10.1	6	19
Other conifers	39	39	39	0	1	1
12						
<i>P. mugo</i>	47.4	37	64	8.3	8	13
<i>F. sylvatica</i>	49.3	39	57	9.3	3	9
13						
<i>P. mugo</i>	131.6	85	177	36.0	5	20
<i>F. sylvatica</i>	---	---	---	---	---	1
14						
<i>P. mugo</i>	88.6	37	147	37.5	8	18
15						
<i>P. mugo</i>	72.1	34	96	24.9	8	13
<i>F. sylvatica</i>	---	---	---	---	---	1
Other broad leaves	---	---	---	---	---	1
16						
<i>P. mugo</i>	77.5	39	114	27.4	12	42
Other conifers	54.0	54	54	0	1	2
17						
<i>P. mugo</i>	70.1	31	111	31.5	7	16
Beech	44.5	35	54	13.4	2	12
18						
<i>P. mugo</i>	39.6	27	59	12.5	7	20
<i>F. sylvatica</i>	39.3	35	48	7.5	3	8
Other conifers	---	---	---	---	---	3
19						
<i>P. mugo</i>	92.0	60	166	35.3	8	29
<i>F. sylvatica</i>	66.0	66	66	0	1	4
Other broad leaves	---	---	---	---	---	4
20						
<i>P. mugo</i>	92.0	65	128	23.0	6	32
<i>F. sylvatica</i>	---	---	---	---	---	1

Other broad leaves	48	48	48	0	1	3
Other conifers	---	---	---	---	---	1
21						
<i>P. mugo</i>	87.6	37	159	35.2	8	18
<i>F. sylvatica</i>	58	58	58	0	1	10
Other conifers	---	---	---	---	---	1
22						
<i>P. mugo</i>	64.5	38	91	16.7	8	26
<i>F. sylvatica</i>	53.3	52	56	2.3	3	8
Other broad leaves	---	---	---	---	---	1
23						
<i>P. mugo</i>	96.3	53	173	66.6	3	19
<i>F. sylvatica</i>	59	53	65	8.5	2	4
24						
<i>P. mugo</i>	88	88	88	0	1	2
<i>F. sylvatica</i>	44.3	30	63	16.9	3	50
25						
<i>F. sylvatica</i>	38.1	23	67	16.1	7	28
Other broad leaves	---	---	---	---	---	6
Other conifers	---	---	---	---	---	1
26						
<i>P. mugo</i>	104.1	38	149	38.4	8	21
27						
<i>P. mugo</i>	101.0	32	177	42.5	9	22
Other conifers	---	---	---	---	---	1
28						
<i>P. mugo</i>	62.7	31	86	28.4	3	4
<i>F. sylvatica</i>	50.3	15	74	20.2	7	12
29						
<i>P. mugo</i>	100.3	73	127	27.0	3	12
<i>F. sylvatica</i>	61	56	65	4.6	3	23
Other conifers	29	25	33	5.7	2	3
30						
<i>P. mugo</i>	75.1	48	112	24.0	7	11
<i>F. sylvatica</i>	34	34	34	0	1	10
Other broad leaves	47	47	47	0	1	2
31						
<i>F. sylvatica</i>	63.2	57	70	4.8	6	17
Other broad leaves	54.5	50	59	6.4	2	3

8.2 Photographs of the study area



Fig. 8.1: View of the study area from northwest.



Fig. 8.2: A very dense branching point of *P. mugo*.



Fig. 8.3: Snow mould infection of *P. mugo*.



Fig. 8.4: Contact zone of *P. mugo* and *F. sylvatica*. Below the canopy cover of *F. sylvatica* *P. mugo* has already died off.

8.3 Photograph of an avalanche release in the study area



Fig. 8.5: Google image of the study site. In the left part of the picture an avalanche release can be seen.