”Natural regeneration and protection efficiency of the upper montane forests in the Natural Forest Reserve Goldeck, Carinthia”

MASTER THESIS

submitted by

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ABSTRACT

Many mountain forests growing in the European Alps protect the site, subjacent infrastructure and settlements against the impact of natural disasters. Natural regeneration is of prime importance for a permanent forest cover and continuous protection. The regeneration preconditions of Norway spruce (*Picea abies* (L.) Karst.) in the upper montane zone of the Austrian southern inner Alps are however insufficiently understood. The aim of this study was therefore to characterise favourable conditions of site factors for germination and establishment of Norway spruce and to quantify the protection efficiency of unmanaged forest stands in this zone. The case study was conducted on the north facing slopes of the Natural Forest Reserve (NFR) *Goldeck* in Carinthia in the forest communities *Larici-Piceetum* and *Galio rotundifolii-Abietum* at an altitude of 1 000 to 1 600 m. Forest structure was investigated on 30 regular sample plots 300 m^2 in size, including 480 subplots of 0.25 m^2 and 1 m^2 where seedlings and saplings were recorded respectively. Binary logistic regression models were used to examine the importance of micro site characteristics on the occurrence of Norway spruce regeneration.The potential current and future protection efficiency under natural development was assessed following the NaiS-Guidelines of the Swiss Federal Office of the Environment. The mean volume of the mixed spruce-larch-fir stands was 726 ± 308 m^3/ha for living trees and 62 ± 70 m^3/ha for deadwood. Regeneration density of Norway spruce was 1.52 ± 3.34 per m^2 for seedlings and 0.88 ± 2.15 per m^2 for saplings (annual till 15 cm in height). Strongly decomposed deadwood was especially favoured by spruce regeneration. The existence of regeneration was significantly related to the amount of direct and indirect radiation at the position of the individual plant. Spruce germination decreased on thin humus layers. Spruce saplings were negatively linked to soil humidity and slope gradient but positively influenced by the dominance of mosses. The results of the protection efficiency assessment prove a satisfactory stability of the forest stands and good conditions for germination. Long, permanently unstocked gullies crossing the reserve and the absence of Silver fir (*Abies alba* Mill.) regeneration which would be part of the natural vegetation in the *Galio rotundifolii-Abietum* led however to deficiencies in protection performance. The forest stands of the reserve are characterised by a strong heterogeneity and un-even structure with groups of old trees next to regeneration patches. This will reduce the length of critical periods with low protection efficiency.

Keywords: *Picea abies*; Protection forest; Natural regeneration; Natural Forest Reserve; southern central Alps; Austria

ZUSAMMENFASSUNG

Zahlreiche Gebirgswälder der Europäischen Alpen schützen den Standort, darunterliegende Siedlungen, Infrastruktur und Menschenleben gegen die negativen Einflüsse von Naturgefahren. Naturverjüngung ist eine essentielle Voraussetzung für eine dauerhafte Waldbestockung und ununterbrochene Schutzerfüllung. Die Bedingungen für eine erfolgreiche Verjüngung der Gemeinen Fichte (*Picea abies* (l.) Karst.) in der hochmontanen Zone der südlichen Zwischenalpen Österreichs sind allerdings noch weitgehend unbekannt. Ziel dieser Studie war es darum den Schutzerfüllungsgrad unbewirtschafteter Waldbestände zu quantifizieren und die verjüngungsfördernden Standortsfaktoren für eine erfolgreiche Keimung und Etablierung von Fichte zu untersuchen und zu beschreiben. Die Untersuchungen wurden als Fallstudie an den nordexponierten Hängen des Naturwaldreservates *Goldeck* in Kärnten in den Waldgesellschaften *Larici-Piceetum* und *Galio rotundifolii-Abietum* auf einer Höhe von 1 000 bis 1 600 m ü.NN durchgeführt. Waldstrukturelemente wurden auf 30 systematisch angelegten 300 m^2 großen Probeflächen aufgenommen, innerhalb deren insgesamt 480 Teilflächen für die Untersuchung von Keimlingen (0.25 m^2) und mehrjähriger Fichtenverjüngung (1 m^2) ausgeschieden wurden. Der aktuelle und zukünftige Schutzerfüllungsgrad wurde unter Annahme einer natürlichen Entwicklung innert der nächsten 50 Jahre anhand der NaiS-Richtlinien des Schweizer Bundesamtes für Umwelt, Wald und Landschaft (BUWAL) aufgenommen. Das mittlere Volumen der Fichten-Lärchen-Tannenwälder betrug 726 ± 308 m^3/ha für den lebenden Baumbestand und 62 ± 70 m^3/ha für Totholz. Im Durchschnitt fanden sich 1.52 ± 3.34 Fichtenkeimlinge und 0.88 ± 2.15 mehrjährige Fichten (< 15 cm) pro m^2. Stark zersetztes Totholz war auffällig häufig besiedelt. Binäre logistische Regressionsmodele wurden erstellt um den Einfluss kleinstandörtlicher Parameter auf die Fichtenverjüngung zu untersuchen. Das Vorhandensein von Verjüngung war signifikant an die direkte und indirekte Strahlungsintensität am Verjüngungsstandort gebunden. Geringe Humusauflagen waren mit niedrigen Keimlingszahlen verbunden. Bodenfeuchte und Hangneigung hatten eine signifikant negative Auswirkung auf das Vorhandensein von mehrjährigen Verjüngungspflanzen. Wohingegen der Deckungsgrad von Moosen einen signifikant positiven Einfluss auf das Vorhandensein mehrjähriger Fichtenpflanzen aufwies. Bezüglich des Schutzerfüllungsgrades sind die Waldbestände von ausreichender Stabilität und guten Keimbedingungen geprägt. Dauerhaft unbestockte Runsen, die das Reservat durchziehen und die fehlende Verjüngung der Weißtanne, die Teil der natürlichen Vegetation des *Galio rotundifolii-Abietums* darstellt, führen jedoch zu Mängeln bei der Schutzerfüllung. Die starke

Heterogenität der Waldbestände in denen Baumgruppen mit starkem Baumholz in unmittelbarer Nähe zu Verjüngungsinseln zu finden sind, setzt die Länge kritischer Perioden der Bestandeserneuerung mit geringem Schutzerfüllungsgrad herab.

Schlagwörter: *Picea abies*; Schutzwald; Naturverjüngung; Naturwaldreservat; Südliche Zwischenalpen; Österreich

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1 INTRODUCTION

Many mountain forests growing in the European Alps protect the site, subjacent infrastructure and settlements against the impact of natural disasters such as avalanches, rock fall, erosion or land slides (e.g., Brang 2001). The Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management (BMLFUW 2007) defines the primary function of 19.3% of the forested area in Austria as protection function. By increasing the roughness of the land, stabilising the ground through widely ramified root systems and the snow cover through natural barriers formed by the stems, forest cover reduces the frequency and magnitude of natural hazards more than any other land cover or land use (Hamilton et al. 1997, van Steijn 1996). Stöckli et al. (2007) estimate that the replacement of forest protective functions against avalanches by technical constructions would increase costs by a factor of 10. It is however uncertain whether all forests types can fulfil these protective functions continuously on a long run without management, or if the natural succession will lead to temporal standwise break-down before the next forest generation can take over the protection (Dorren et al. 2004). The BMLFUW reports for 2005 a total of 172 000 ha (4.4%) of Austrian forest with direct protective function for settlements and other infrastructure with urgent need of restoration.

The continuous provision of protective functions is strongly linked with the existence of natural regeneration (Baier et al. 2007). One of the main problems in mountain forest management is the lack of sufficient regeneration (e.g., Ammer et al. 2004) and that the processes related to regeneration ecology are not sufficiently understood (Kräuchi et al. 2000). Schodterer (2004) interprets the missing or insufficient regeneration in the results of the Austrian National Forest Inventory (ANFI) as 23% and 21% the consequence of deer browsing and cattle grazing respectively. On 56% of the inventory plots Schodterer mentions limiting factors as light conditions or competing ground vegetation. The importance of the single micro site conditions (e.g., light, humus type, micro relief) may vary during early growth (Diaci 1997, Brang 2005).

As a direct outcome of the Helsinki Resolution H2 "General Guidelines for the Conservation of the Biodiversity of the European Forests" (1993), the "Austrian Natural Forest Reserves Programme" is implemented since 1995. The program aims at systematically establishing a representative network of natural forest reserves (NFR) (Frank, Koch 1999). At the end of

2006, Austria had made 188 contracts with forest owners for voluntary participation within the natural forest reserves programme, covering a forest area of 8 470ha or 0.15% of the country‘s total forest area (Frank 2006).

The primary target of natural forest reserves, where the forests are excluded from active management, is the maintenance of biological diversity characteristic of the different forest communities in Austria (Frank 2006). It is not that particular forest conditions shall be conserved, but that the dynamics of natural processes shall develop without intervention (Frank, Koch 1999). The majority of the NFRs can not be seen as true remnants of virgin forests, but most of them had far less intensive management over the past decades or even centuries. This was mostly caused by inaccessibility or low suitability for agricultural use of the areas due to difficult terrain and soil conditions. The historical landuse patterns explain why most of the reserves were formerly established in the montane and subalpine belts of the Austrian Alps (Frank, Koch 1999). The minor anthropogenic interferences in these areas enable however promising research studies on natural forest structure and undisturbed forest development.

The University of Natural Resources and Applied Life Sciences, Vienna started in 2008 in cooperation with the Austrian Federal Research and Training Centre for Forests, Natural Hazards and Landscape (BFW) the ELENA project (in German: *EmpfehLungEn für die NAturverjüngung von Gebirgswäldern*) to address the above mentioned issues and to develop recommendations for the natural regeneration methods in mountain forests. The research project aims to study the dynamics of natural regeneration in unmanaged mountain forests and to apply the findings subsequently for the development of a minimal management concept. Light ecology, competitive factors, site and stand conditions as well as the degree of human influence shall be analysed for the phases of germination, seedling establishment and sapling growth. Additionally the role of deadwood and woody debris, which has been proved to be of special importance for the natural regeneration in some forest communities already in previous studies (e.g., Eichrodt 1969, Stöckli 1995), shall be considered within the study.

This Master thesis is imbedded in the ELENA project. The aspects of protection efficiency and natural regeneration of Norway spruce (*Picea abies* (L.) Karst.) are examined using the example of the NFR *Goldeck* in Carinthia in Southern Austria. With an average slope gradient of 80 % in the upper part of the reserve, a long and deep snow cover, rock falls, heavy rainfall events and the location within the water protection zone, the forests at the northern slope of the *Goldeck* massif are very important for protection against natural hazards. Debris flows at the mountain torrent *Schwaigerbach* running mainly through the NFR, caused severe damages at the lower settlements and several fatalities during the last century (WLV 2000). A lime marble layers crossing the reserve at an altitude of approximately 1600 m a.s.l. is characterised by irregular break-offs and rock falls.

1.1 Objectives

The aim of this thesis is to analyse

(1) the primary influencing factors for the initiation of natural Norway spruce regeneration in the present forest communities (*Larici-Piceetum & Galio rotundifolii-Abietum*);

(2) the factors determining the establishment of Norway spruce saplings in the present forest communities (*Larici-Piceetum & Galio rotundifolii-Abietum*);

(3) whether the protective functions of the NFR *Goldeck* can be fulfilled continuously over the long run without management, and

(4) possible challenges of natural maintenance of protection forest functions in the NFR *Goldeck.*

2 MATERIAL AND METHODS

2.1 Site description

2.1.1 Location

The NFR *Goldeck* is located at the northern hillside of the *Goldeck* massif (2 142 m a.s.l.) (46°47´N, 13°28´E) in the municipality *Baldramsdorf* of the district *Spittal/Drau* in *Carinthia* (Austria) (Fig.1). The NFR is a privately owned forest of 58.27 ha ranging from 1 040 m to 1 620 m a.s.l. with an average slope gradient of 40 % (Hauk 1997) (Fig. 2).
A 50 m wide corridor extending from the SSW to the NNE, owned by the operating company of the *Goldeck* mountain railway, separates the NFR into two parts. Managed forests are close to the protected area and border in the North, East and West. In the South the reserve reaches the subalpine meadows and settlements of the *Krendelmar-Alpe* and the village *Goldeck*.

The NFR *Goldeck* is part of the upper montane zone in the forest ecoregion *southern central Alps* (3.3) (Kilian et al 2004). The following potential natural forest communities comprise the forest stands of the NFR (Hauk 1997):

- *Larici-Piceetum* (Ellenberg et Klötzli 1972)
- *Galio rotundifolii-Abietum* (Wraber 1955)
- *Luzulo nemorosae-Fagetum* (montane Abies variation, Meusel 1937)
- *Alnetum incanae* (Lüdi 1921)

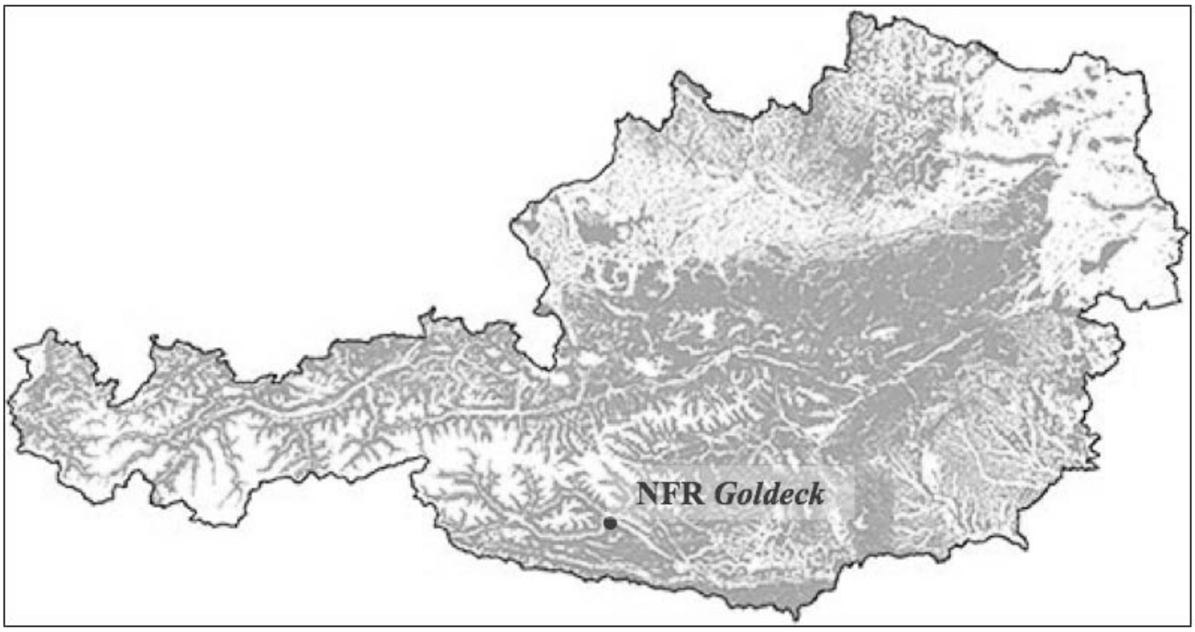

Fig. 1 Forest cover in Austria and location of the Natural Forest Reserve (NFR) *Goldeck* (Source: Bauerhansel et al. 2007; modified)

The main tree species are Norway spruce (*Picea abies* (L.) Karst.), European larch (*Larix decidua* Mill.) and Silver fir (*Abies alba* Mill.). Mountain ash (*Sorbus aucuparia* L.), Sycamore maple (*Acer pseudoplatanus* L.), European beech (*Fagus sylvatica* L.), Silver birch (*Betula pendula* L.), Grey alder (*Alnus incana* (L.) Moench), Green alder (*Alnus viridis* (Chaix) DC.) and willow (*Salix* sp.) are admixed in parts of the reserve.

Fig. 2 The northern slope and the summit of Goldeck (2 142m a.s.l.) with approximate location of the natural forest reserve (dotted line) (Photo: M.B.Winter)

2.1.2 Climate

The predominantly westerly wind directions lead to increased precipitation in the Northern and Western Alps while the inner Alps are characterised by lower amounts of precipitation. The Upper Tauern represent a meteorological divide. The lower summits of the mountain ranges in the south enable a great influence of Adriatic depressions in the study area (Rauter 1993), which is at the border of the continental climate.

Climate data for the site were interpolated from data of the nearby meteorological stations *Goldeck Bergstation* (1885 m a.s.l.) (Hydrographischer Dienst Kärnten, 1984-2007) and *Spittal/Drau* (524 m a.s.l.) (ZAMG-ZentralAnstalt für Meteorologie und Geodynamik, 1971-

2000). For this purpose a linear relationship between altitude and the climatic parameters temperature and precipitation was assumed between the two meteorological stations. The climatic values were calculated for the mean altitude of the NFR at 1300 m a.s.l. with an average annual temperature of 4.6 °C and an annual precipitation of 1174 mm. The precipitation peaks during the growing season (Fig. 3). Snow covers the north facing slopes from October/November until April/May with depths of up to two metres (Hydrographischer Dienst Kärnten 2007).

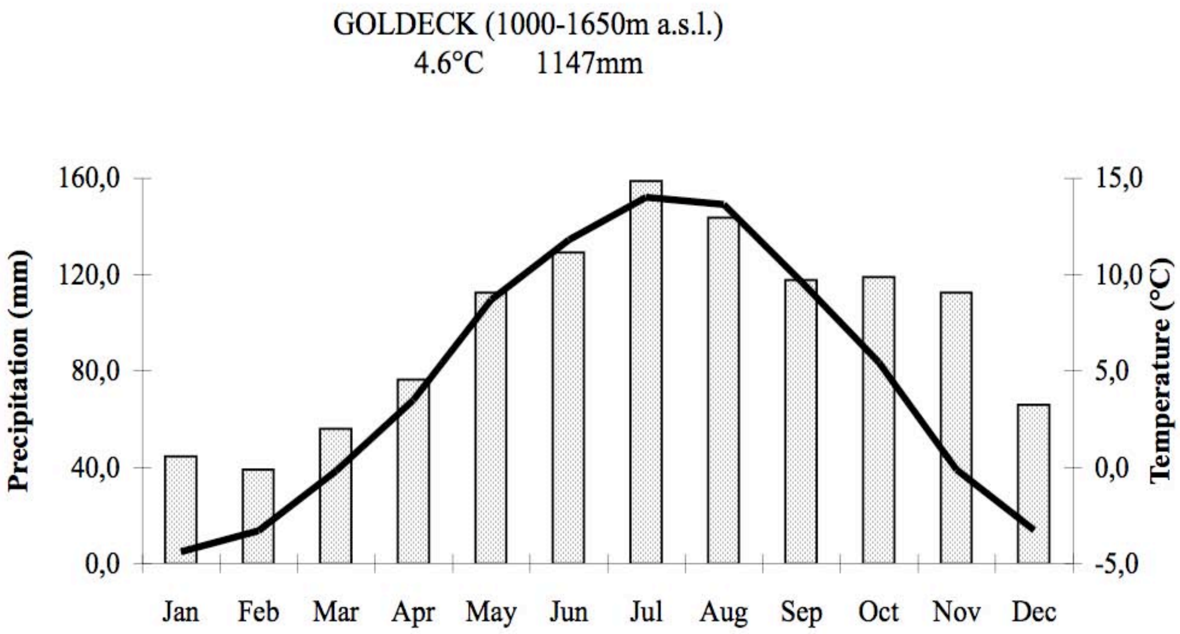

Fig. 3 Climate diagram of NFR *Goldeck* with mean monthly temperature and precipitation sums (1984-2007), interpolated from the meteorological stations Spittal/Drau (524m a.s.l.) and Goldeck Bergstation (1885m a.s.l.)

Thunder fronts ascending at the *Goldeck* massif due to the run of the *Drau* riverbed lead to unpredictable local and heavy rainfall during the summer months (WLV 2000).

2.1.3 Geology and Soil

The bedrock of the NFR *Goldeck* is rather inhomogeneous and consists of acid as well as alkaline rocks. In the upper part the quartz phyllite strata borders the bed of garnet mica schist in the north. Lime marble layers cross in the middle of the reserve, partly above ground with irregular break-offs and rock falls. At the lower border garnet mica schist can be found in island like deposits of amphibolites and boulders from the late glacial period (Fig. 4) (Geologische Bundesanstalt 2006).

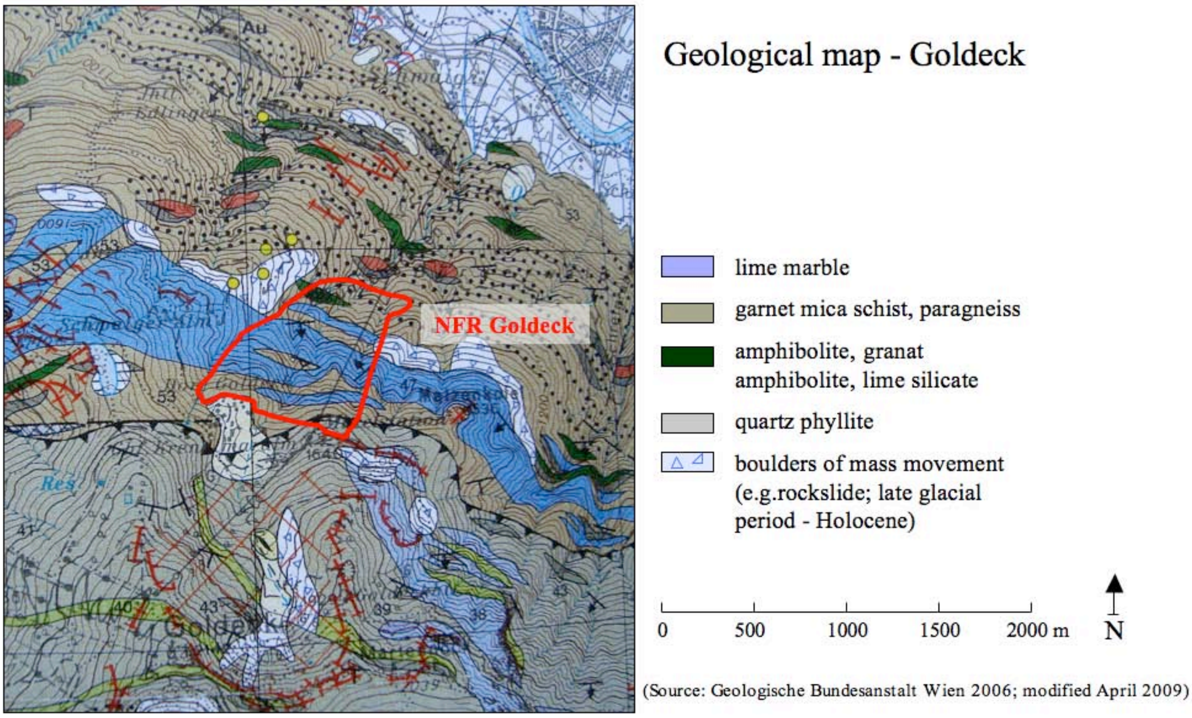

Fig. 4 Geological map of the northern slope of the *Goldeck* massif and location of the NFR

Different bedrocks and humidity conditions have resulted in distinct forest soils, namely cambisols, semi-podsols, podsols and leptosols. All three humus forms (mull, moder and mor), can be found in the study area depending on the particular soil and forest stand conditions.

2.1.4 Historical and present use

The forest area covering the northern slopes of the *Goldeck* massif was the property of the *Shire Lurn* and *Prince of Porcia* for several centuries. There are no reliable references of management from that time (Rauter 1993). It is however probable that the more plain areas were utilised by the farmers of the valley, while the upper parts have remained without larger anthropogenic interventions (Rauter 1993). During the 20th century parts of the forest were sold to private owners. The Natural Forest Reserve was established in 1998 on the initiation of the forest owner and the BFW. Since that time no cuttings have been implemented. The last management activities were carried out in 1954 (a minor selection cut) and 1993 (removal of snow damaged wood) (Hauk 1997). No thinnings have been conducted in the forest stands. Parts of the forest stands of the NFR are declared as gene conservation forests (Hauk 1997).

The northern slope of the *Goldeck* massif, including the NFR, is included in the water protection zone l and ll (Uggowitzer, B. pers.com. 30/09/2008), where groundwater contaminating activities are interdicted.

2.1.5 Game management

The NFR *Goldeck* is embedded in the 1 455 ha large collective hunting district Baldramsdorf. Although forest management is excluded in the natural forest reserves hunting is still an important intervention in the protected area to enable natural development where the natural predators of deer can not carry out a regulation of the population. During the last 8 years (2000-2007) 25 roe deer (*Capreolus capreolus* L.), 12 red deer (*Cervus elaphus* L.) and 1-2 chamois (*Rupicapra rupicapra* L.) have been hunted on an average per year (BFI 2008). Some hunting facilities as stands or salt-licks are present in the NFR, they are however degenerated and unused for several years. The difficult topography and poor accessibility within the hunting district where parts are located close to the *Drau* river and the village *Baldramsdorf* make it unlikely that regulative hunting is taking place within the steep protected areas of the NFR with difficult access. This impression was confirmed by Gerhard Walter (pers. com. 03/10/08), the chief officer of the municipality *Baldramsdorf* and member of the hunting association.

2.1.6 Seed availability

In addition to the micro site conditions that will be analysed in this study seed availability plays a major role in seedling establishment of natural forest regeneration. The BFW collects within the scope of forest decline studies annually pollen and seeds of the main tree species at several research plots in Austria since 1988 to calculate the potential seed production of these species (Litschauer 2004). The following figures have been taken from the European Aerobiological Network stations in Spittal/Drau (560m a.s.l.) and Lienz (680m a.s.l.) and represent the potential seed production of spruce, larch and fir from 2000-2007 (Tab. 1). High values are shown for spruce in 2006 and 2003, while the years between attest only low to moderate values of potential seed production in relation to mast years.

Tab. 1 Potential seed production of the main tree species [%] in relation to mast year (=100%) (Litschauer 2004)

	2000	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
Picea abies *	< 30%	late frost	< 30%	> 85%	< 30%	< 30%	> 85%	30-50%
Larix decidua *	< 30%	50-70%	< 30%	> 85%	30-50%	< 30%	50-70%	< 30%
Abies alba **	< 30%	70-85%	< 30%	< 30%	50-70%	< 30%	70-85%	< 30%

* European Aerobiological Network – Austria: Spittal/Drau – 560m

** European Aerobiological Network – Austria: Lienz – 680m

2.1.7 Natural disasters and protective effects of mountain forest

With an average slope gradient of 80 % in the upper part of the reserve, a long and deep snow cover, rock falls, heavy rainfall events and the location within the water protection zone the forests at the northern slope of the *Goldeck* massif play an important role for protecting the site itself, people and the subjacent assets. Most of the area, including the zone of the NFR is classified as primary protection forest in the forest development plan of *Carinthia* 2006 (KAGIS 2009).

Thunder fronts ascending the *Goldeck* massif due to the run of the *Drau* riverbed lead to unpredictable local and strong rainfalls during the summer months (WLV 2000). As a consequence the risk of natural disasters like flooding or debris flows is increasing. After heavy rainfalls massive debris flows at the mountain torrent *Schwaigerbach* (*Raunachgraben*), running mainly through the NFR, caused severe damages at the lower settlements and several fatalities in 1903, 1924, 1951, 1966 and 1983 (WLV 2000). Subsequently, technical barriers have been installed at the underflows (WLV 2000). Healthy mountain forests provide an important protective function by retaining forest soils and buffering the general groundwater level (e.g., Rickli et al. 2002, Hegg et al. 2004), but the protective effects of mountain forests are limited in case of short but heavy rainfall events or deep land slides (Frehner at al. 2005).

Bordering the southern forest edge of the reserve, an approximately 15 ha large avalanche risk area is delineated by the Austrian service for Torrent and Avalanche Control (WLV 2005) in the subalpine part of the northern *Goldeck* slopes. Technical measures protect the settlements and the ski trail against avalanches; very seldom the snowslides reach the subjacent forest and phase out in the torrent *Raunachgraben* (WLV 2005). The influence of forests on avalanches starting high above the timber line is relatively low (Margreth 2004). The avalanche looses energy while breaking off trees, but partly the energy of the falling trees reinforces the avalanche in return (Salm et al. 1990). Healthy and stable forests provide however good prevention against starting avalanches due to snow interception from trees, an increased heterogeneity of the snow cover caused by snow packages falling off the branches (Imbeck 1987) and at the same time a stabilisation of the snow cover by the tree trunks overtopping the snow layer (Margreth 2004). The balanced forest micro climate reduces the risk for surface rime, which is often the initiator of snow slides (Margreth 2004).

Irregular break-offs and rock falls occurre at the lime marble layers crossing the reserve at an altitude of approximately 1600 m a.s.l. Rock fall is an unpredictable event. Nevertheless it mostly occurs in spring caused by alternate freezing and thawing and after heavy rain falls (Dorren et al. 2005). The effect of forest in the rock fall source area is mostly negative, as the roots accelerate chemical weathering and can act as wedges especially during wind (Dorren et al. 2005). There is however a positive protective effect of mountain forests against rock fall in the transition area that can be ascribed to ”(i) stem contact with adsorption of up to 80% of the boulders' kinetic energy, (ii) contact with shrubs or ground vegetation, (iii) high dampening capacity of forest soils due to bio-activity and vegetation detritus, and (iv) high surface roughness due to vegetation and dead wood” (Brauner et al. 2005). Simultaneously the rock fall events affect the forest, its structure and its protection efficiency. According to Vospernik (2002), who analysed a rock fall damaged sub data set of the Austrian National Forest Inventory rock fall events increased the mortality rate of the thick barked European larch by 23 %, while for Norway spruce the mortality rate intensified by 66 %. Rock fall protection forests depend therefore very much on a continuous forest cover with a sufficient number of vital trees (Frehner et al. 2005) and efficient regeneration processes replacing rapidly damaged trees or closing evolving gaps.

2.2 Sampling design

Due to the rarely existing forest road infrastructure at the time of the NFR establishment the NFR *Goldeck* is classified as protection forest without yield. Therefore no systematic sample plots for the assessment and calculation of the compensation payments for the potential losses in relation to the timber value have been set up. Only three permanent sample plots were installed in the forest community of *Luzulo nemorosae-Fagetum* at the lower border of the reserve during the establishment of the NFR in 1997. Determined by the research focus on subalpine and upper montane spruce and spruce-larch-fir forests the study area is limited to the upper forest communities of *Larici-Piceetum* and *Galio rotundifolii-Abietum*. The old plots have therefore not been sampled again. At the upper part, where the reserve borders the alpine meadows of the *Krendelmar-Alpe*, an influence of grazing cattle entering the reserve through damaged fences is obvious. These parts have been excluded from the study area.

2.2.1 Forest structure

30 circular permanent sample plots, $300m^2$ in size, were established systematically on a 100x100m grid in the upper forest communities *Larici-Piceetum* and *Galio rotundifolii-Abietum* (Fig. 5). The number of samples is comparable to the 36 plots Kramer and Akça (2002) suggest for forest inventories in very heterogeneous stands with tolerated error in basal area of 10% ($P \leq 0.05$). 12 of the sample plots are situated in the *Larici-Piceetum,* while 18 plots have been set up in the *Galio rotundifolii-Abietum.*

Trees taller than 1.3m were documented on the whole 300 m^2 plot measuring their accurate position, DBH, tree height, crown length, horizontal crown size (in 0, 100, 200, and 300gon direction of the stem). Additionally, damages were accessed. Standing and fallen deadwood > 10 cm DBH / mid diameter was recorded through full enumeration on the study plot (see appendix, Tab. 9). For fallen deadwood < 10 cm in mid diameter the total dominance was estimated for the sample plot.

In addition, general characteristics such as altitude, aspect, slope gradient, geology, micro and meso relief and canopy closure of the different tree layers have been assessed on each of the plots.

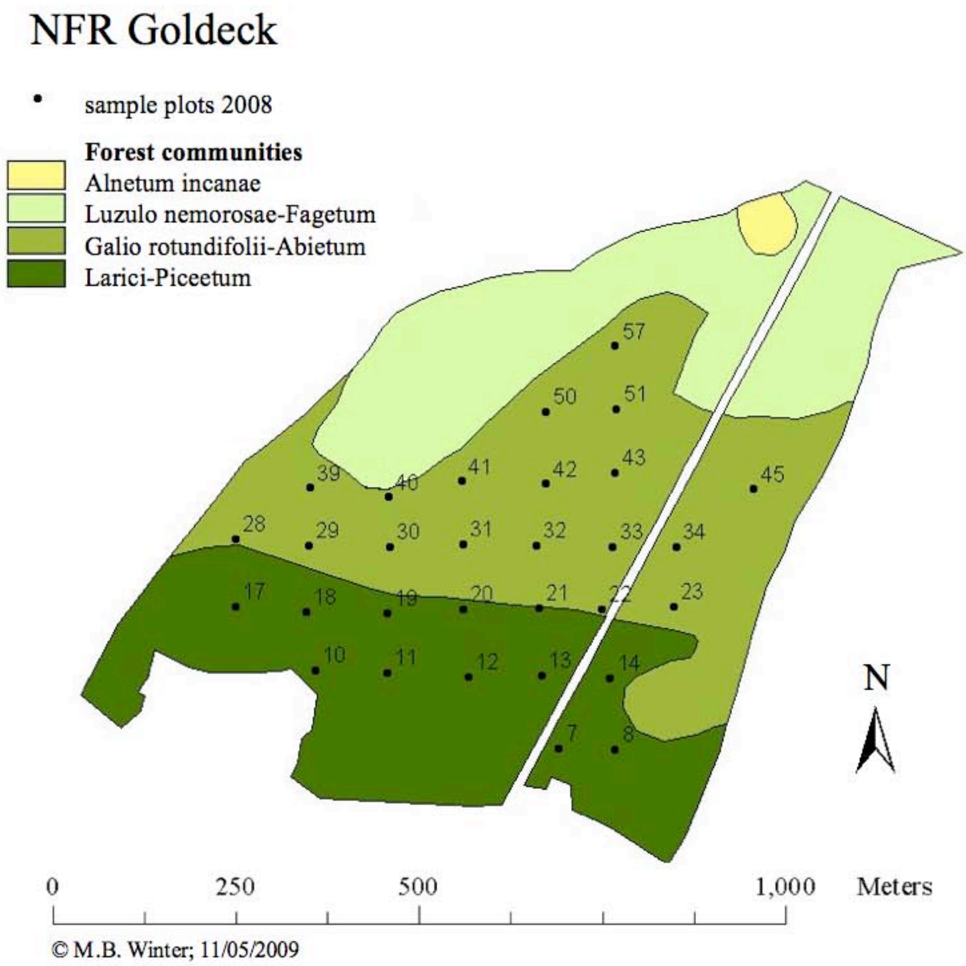

Fig. 5 Forest communities of the NFR *Goldeck* and sampling design of the plots of the inventory in September 2008

To assess the tree age of the different layers within the plot increment cores (∅ 5mm) were taken from 1-3 trees of different diameter classes of the main tree species spruce, fir and larch if present on the study plot. No cores were taken from trees with a DBH < 15 cm. To get the measure of the real seedling age, the cores were taken at the ground base (0.0 m), which was possible due to the high gradient of the slope. The samples were processed following Pilcher (1990). To assess pith age, where the mark was not reached, the missing years were estimated with a circle pattern (Bräker 1981). Ring width was measured using the measuring linear table Lintab (Rinn, Heidelberg, Germany) and the Time Series And Presentation Program TSAP (Rinn 1996). The raw ring widths of the single curves were first checked visually and then synchronized by tests (“Gleichläufigkeit” and “Student’s t-test” in the TSAP-program).

2.2.2 Regeneration

Within each of the 30 sample plots 16 subplots (category A), 0.25 m^2 in size (0.5 x 0.5 m), were placed systematically, with clusters of four subplots in 4m distance of the plot centre in direction of 0 gon, 100 gon, 200 gon and 300 gon respectively (Fig. 6). Within these small subplots the tree regeneration was counted (seedlings and saplings) separately for the different tree species. For the saplings > 15 cm in height the tree height, height increment of the preceding year and diameter at root collar were measured. Additionally the vitality, damages and micro relief of the sapling position was accessed.

The clusters of small subplots were surrounded by three 1 m^2 large subplots (category B) in 3, 5 and 6 m distance of the plot centre (Fig. 6). In the subplots of category B no seedlings were counted, but saplings were add up, and measured if larger than 15 cm. With this procedure 480 small seedling-subplots (category A) and 360 large subplots (category B) could be described. Assembling the subplot clusters of category A to subplots of category B offers information of saplings (annual till 15 cm in height) on 480 subplots 1 m^2 in size. Tree regeneration with heights larger than 30 cm was measured within the whole sample plot (same parameters as explained for the saplings > 15 cm in the small subplots) and their approximate location was documented on a sketch. The positions of the subplots were marked permanently with a spile at 5 m distance from the plot centre in each of the four directions. The plot centre was marked the same way and the closest large tree from the centre was labelled with the plot number.

In addition, natural regeneration of the four categories (seedlings, saplings < 15 cm, 15-30 cm, 30-130 cm) was assessed on standing and fallen deadwood.

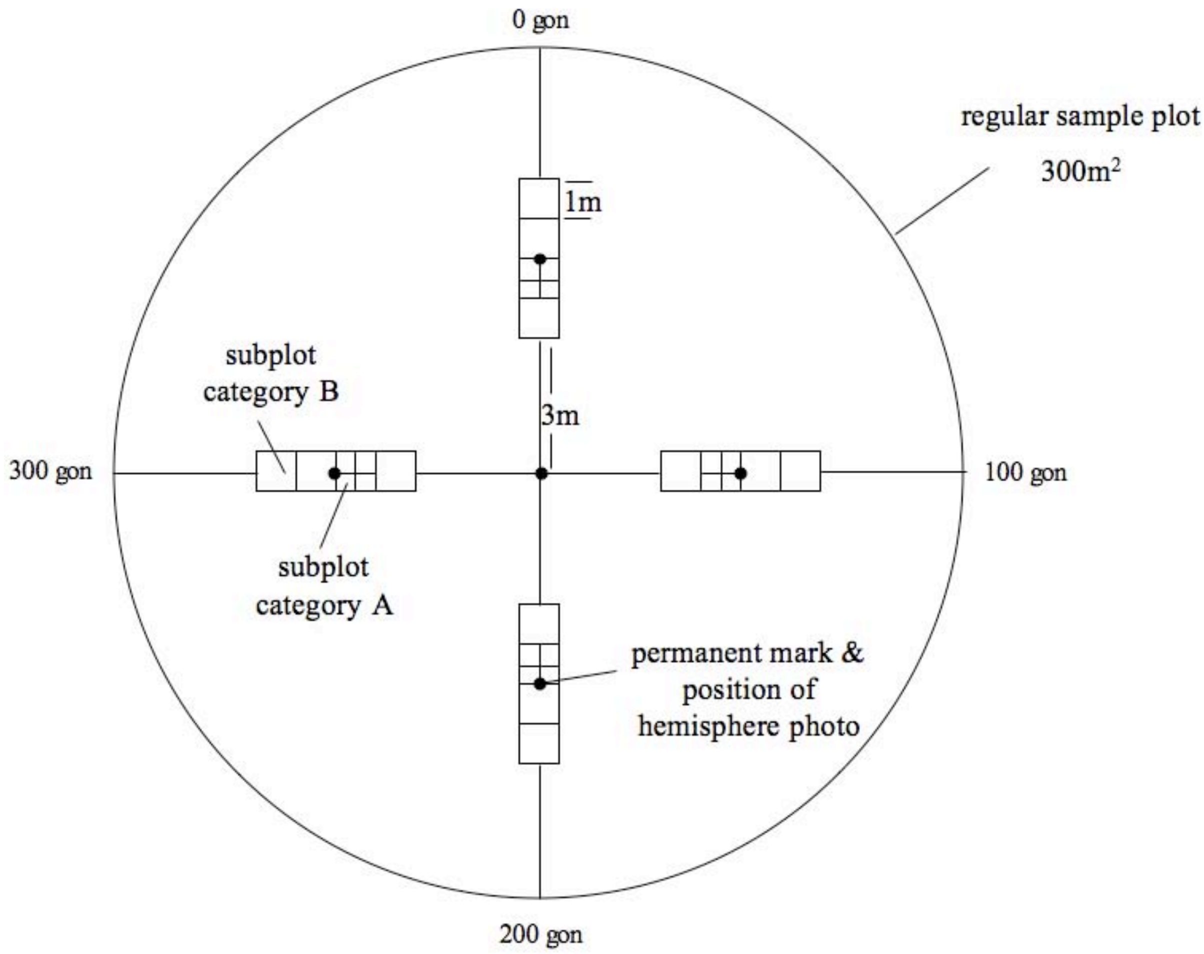

Fig. 6 Sampling design of the regular sample plots

2.2.3 Protection function

The assessment of the forest conditions for the fulfilment of the protective functions was carried out following the guidelines of the Swiss Federal Office of the Environment (FOEN) *Sustainability and efficiency control in protection forests* (NaiS, in German: *Nachhaltigkeit und Erfolgskontrolle im Schutzwald*) (Frehner et al. 2005).

The guidelines are based on the evaluation of the forest stands at current state (today) and on the estimation of the natural stand development without any intervention in the next 10 and 50 years respectively. The current conditions of the stands were compared with individual minimal and ideal requirements (profiles) according to the type of forest community and the natural disasters that are of relevance in the area.

Plots with a size of 300 m^2 are well suited for the investigation of regeneration ecology, but are rather small to study the stability of forest stands. Therefore the NaiS assessment was conducted on an area of approximately 0.75 ha at each grid point.

The present forest communities *Larici-Piceetum* and *Galio rotundifolii-Abietum* fall in the NaiS classifications 57c *Homogyno-Piceetum calamagrostietosum villosae* and 51 *Galio-Abieti-Piceetum typicum* respectively. The types of natural disasters present in the NFR Goldeck and applied for assessment are, with descending importance, rock fall, avalanches, and debris flow. The significance of the natural disasters was assessed on each plot for rock fall and avalanches, taking the site condititions as slope gradient and risk for break-off or transit of boulders into account. Assessment plots with an slope gradient <58% are defined as deposit areas for boulders and no-risk areas for the release of avalanches (Frehner et al. 2005). Plots that were not located in the trajectory of boulders were classified as not relevant for rock fall. Risk of debris flow was not assessed individually for each plot. As the risk of the natural disasters depends on geological conditions mainly (topography, geology), which are long term processes, the risk is assumed to stay constant over the next 50 years. The guidelines include prescriptions for each of the parameters: *tree species composition, horizontal* and *vertical structure, stand and tree stability,* and *germination, seedling* and *sapling conditions* for the assessment of minimal or optimal conditions. To quantify the forest condition, indices were built for each parameter and assessed per plot. The indices range from -3 (the parameters are not met at all), 0 (the parameters are fulfilled satisfactory) to +3 (the parameters are fulfilled optimally). See Tab. 2 and appendix, Tab. 10 and 11 for the requirements of the minimal profile for the different sites and the NaiS form.

Tab. 2 NaiS minimal profile for the forest communities *Larici-Piceetum* and *Galio rotundifolii-Abietum* including the requirements for the relevant natural hazards (rock fall, avalanche & debris flow)

Stand and tree attributes	**Larici-Piceetum**	**Galio rotundifolii-Abietum**
Mixture (species composition in %)	Spruce: 70-100 % Larch: 0-30 % Mountain ash: seedtrees-30 % some Green alders	Fir: 30-90 % Spruce: 10-70 % Larch: 0-60 % Mountain ash & Sycamore maple: seedtrees-30 %
Vertical structure (∅-distribution)	Enough vital trees with a high potential for future development in at least 2 diameter classes/ha	Enough vital trees with a high potential for future development in at least 2 diameter classes/ha
Horizontal structure (dominance, gap length, stem number)	At least 400 trees/ha with DBH > 12 cm, gaps in slope line < 20 m, lying wood and high stumps, canopy closure > 50 %, small groups or single trees	At least 400 trees/ha with DBH > 12 cm, gaps in slope line < 20 m, lying wood and high stumps, canopy closure > 50 %, small groups or single trees
Stability (crown development, ratio of slenderness, target diameter)	Crown ration at least 2/3, perpendicular stems, good anchoring, only single hanging trees	Crown ratio at least 1/2, perpendicular stems, good anchoring, only single hanging trees, h/d-ratio < 80
Regeneration (germination conditions)	Every 10 m deadwood or elevated micro sites with Mountain ash or mineral soil, protection against snow gliding	Area with intense competition through ground vegetation < 1/2
Regeneration (seedlings & saplings <40cm)	At least 30 % of the micro sites favourable for regeneration should have present spruce and Mountain ash regeneration	If canopy closure < 60 % at least 5-10 firs/a should be (every 3-4.5 m), single spruce and Mountain ash in gaps
Regeneration (40cm height – 12cm DBH)	At least 70 regeneration plots/ha should be present (every 12 m), species mixture as targeted	At least 30 regeneration plots/ha should be present (every 19 m), or a dominance of regeneration at least on 4 % of the area, species mixture as targeted

2.3 Description of site variables for regeneration

Within each of the subplots of category A and B, wheter seedlings or saplings were found on the subplots or not, the site parameters aspect, slope gradient and microclimate (e.g., cold or humid air, exposure to wind or snow accumulation) were recorded. To deduct the area not suited for regeneration (e.g., stones, living trees) and to record the dominance of the ground vegetation, the ground cover was estimated by a frame (0.5 x 0.5 m) with a rectangular grid for each of the subplots. The ground coverage [%] was recorded separately for vascular plants, mosses, lichens, deadwood (> 10 cm mid diameter), branches, living trees, litter, mineral soil, boulders and rocks. Additionally the mean height [cm] of the dominating ground vegetation was noted. The humus type, the mean thickness of the organic layer and the soil depth were measured and type, texture, hydrology and humidity of the soil were assessed (Tab. 3).

To measure the direct and indirect radiation available for germination and growth of the natural regeneration hemisphere photos were taken with a single lens reflex camera (SLR) during homogenously covered sky, in 0.9 m height over the category A subplot cluster and in 1.3m height at the plot centre (see Fig. 6 and 7).

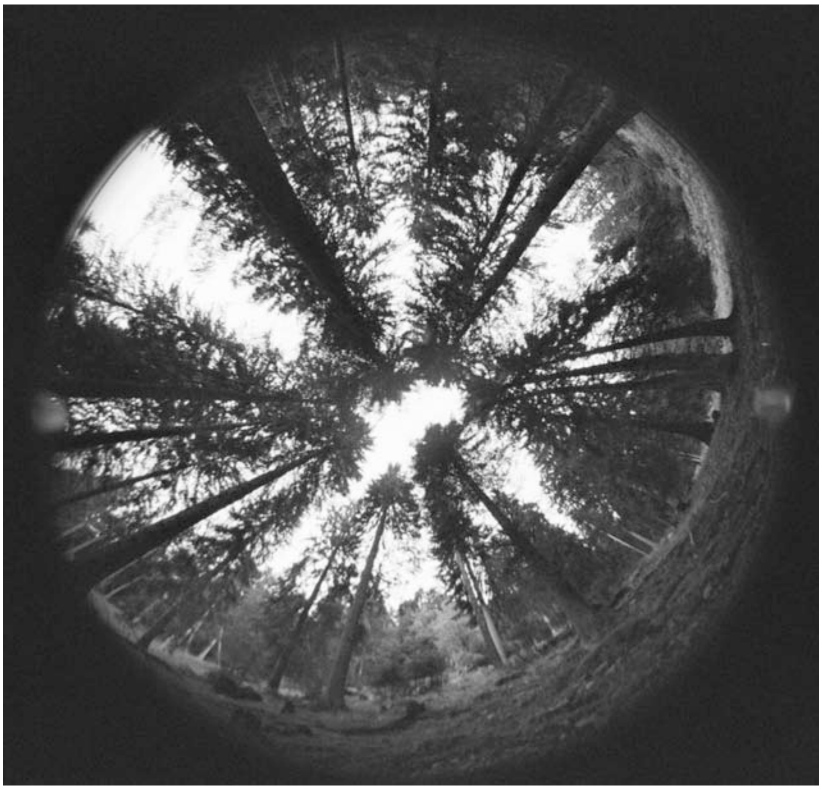

Fig. 7 Hemispheric photograph taken with a 180° lens at 0.9m height on plot no. 50

The camera position at a height of 0.9 m was the lowest position possible and was determined by the construction of the self-levelling tripod of the SLR and the steepness of the slope. At each position three photos (colour film, 400 ASA) were recorded with different settings for exposure time and aperture and the best one was selected for digitalisation and further analysis with the HemiView 2.1 software (Fig. 7). Each of the digitalised circular photographs consisted of pixel with grey scale values between 1 and 256 depending on the brightness of the sky, the slope and the forest stand components (HemiView 1996). The limit grey scale value separating sky and forest or slope pixel was defined manually for each picture by defining a threshold value. HemiView 2.1 calculated the radiation intensity at each measuring point separating between Direct-Site-Factor (DSF), Indirect-Site-Factor (ISF) and Global-Site-Factor (GSF). The DSF depicts the ratio of available direct solar radiation between forest stand and open area without sky cover, while the ISF computes the ratio of indirect radiation (reaching the earth surface after diffusion through molecules and aerosols) between forest stand and open area without sky cover. The GSF combines DSF and ISF reaching values between 0 (complete cover, no radiation) and 1 (open area and full available radiation) (Brunner 1994).

Tab. 3 Variables used in the binary logistic regression analysis.

Variable classes	Values in the binary logistics
Dependent variables	
One or more spruce seedling/sapling occurred in the subplot	1
No spruce seedling/sapling occured in the subplot	0
Independent variables	
Slope gradient [%]	metric
Coverage of vascular plants [%]	metric
Coverage of mosses [%]	metric
Mean height of dominant ground vegetation [cm]	metric
Proportion of mineral soil [%]	metric
Proportion of the subplot suitable for regeneration [%]	metric
Direct radiation (DSF) [%]	metric
Diffuse radiation (ISF) [%]	metric
Occurence of deadwood as obstacle	dummy variables
0 %	0/0
1-30 %	1/0
> 30 %	0/1
Humus type	dummy variables
mull	0/0
moder	1/0
mor	0/1
Humus thickness	dummy variables
< 3 cm	0/0
3-10 cm	1/0
> 10 cm	0/1
Soil type	dummy variables
leptosol	0/0/0
cambisol	1/0/0
semi-podsol	0/1/0
podsol	0/0/1
Soil texture	dummy variables
not determinable (leptosol)	0/0/0
sand	1/0/0
silt	0/1/0
loam	0/0/1
Soil humidity	dummy variables
moderately dry	0/0/0
slightly dry	1/0/0
fresh	0/1/0
moist	0/0/1

2.4 Statistical analyses

2.4.1 Analysis of forest structure

For the general description of the NFR *Goldeck* mean values of the volume of living trees and standing and lying deadwood were calculated per hectare for the two forest communities of *Larici-Piceetum* and *Galio rotundifolii-Abietum*. The volume of living trees was calculated using the form functions of Pollanschütz (1974). For volume calculations of standing deadwood a form factor of 0.5 was applied. Tree species mixture, age and diameter distribution were computed and presented graphically.

2.4.2 Analysis of regeneration

The seedling and sapling density was computed calculating the mean density and standard deviation per subplot or m^2 within SPSS (SPSS 13.0 for Windows 2004) for the main tree species spruce and larch. Additionally the seedling and sapling density was computed per m^2 of deadwood surface for the different degrees of decomposition, defining the upper half of the horizontal (lying) deadwood as potential area for regeneration. For the illustration of the growth, vitality and damage situation of the spruce regeneration > 30 cm frequencies of the parameters were calculated and presented graphically. Saplings showing browsing damages were excluded from the growth analyses.

To analyse the probability for natural regeneration of spruce to germinate and to reach the sapling phase two binary logistic regression models were used (one for the seedlings and one for the saplings). The binary logistic regression analysis calculates the likelihood of an occurrence of a spruce seedling and a sapling ≤15cm respectively as dependent variable being influenced by different independent variables (Tabachnick, Fidell 1989).

The logistic function to compute the probability for a seedling or sapling to be existent has the following general form:

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

Where P_{reg} is the probability for the existence of a seedling or sapling respectively and $variable_1$ to $varible_n$ are the independent variables that are used in the binary logistic regression model. The cut value whether regeneration does occur or not is 0.5. This method is not based on multivariate normal-distributed independent variables but uses both, metric and categorical variables (Tabachnick, Fidell 1989) and is simple and robust within SPSS. Table 3 shows the coding of the variables. Dummy coding was used for nominal scaled variables and to separate different groups of interval scaled independent variables. Interdependencies among the independent variables were tested by the existence of correlation. Variables with significant correlations >0.3 to other variables used were excluded from the analysis. The option stepwise forward LR (likelihood ratio) of SPSS was applied to introduce only significant variables into the model ($p \leq 0.05$). The improvement of the model was assessed by the calculation of the (decreasing) -2-log-likelihood-value (-2LL). To analyse the importance of the independent variables on the spruce seedling and sapling probability the odds ratios were calculated whereas the increase or decrease of the independent variables by one unit increases or decreases the seedling/sapling probability by the odds ratio (Tabachnick, Fidell 1989). The Hosmer-Lemeshow-test and the Nagelkerke R^2 were used to test the quality of the model. For the validation of the model the standardised residuals were calculated and compared with the optimal values of 0 for the mean and with 1 for the standard deviation of the residuals.

2.4.3 Calculation of the potential protection efficiency

Arithmetic means and standard deviation were calculated for each plot, parameter and date (today, in 10/50 years).

The graphical presentation of the natural hazard situation and the forest protection performance was accomplished in ESRI ArcGIS software 8.3 using the straight line allocation function in the spatial analyst.

The level of significance (p) for all statistical readings is defined as $p \leq 0.05$.

3 RESULTS

3.1 Describtion of forest structure

The main tree species of the upper forest communities in the NFR *Goldeck* by number of trees is Norway spruce which comprises 78% of the 489 trees assessed on the 30 study plots. European larch represents 10% of the tree species composition. In total 10 tree species have been identified. Compare Figure 8 for the share of the other species in the forest communities *Larici-Piceetum* and *Galio rotundifolii-Abietum.*

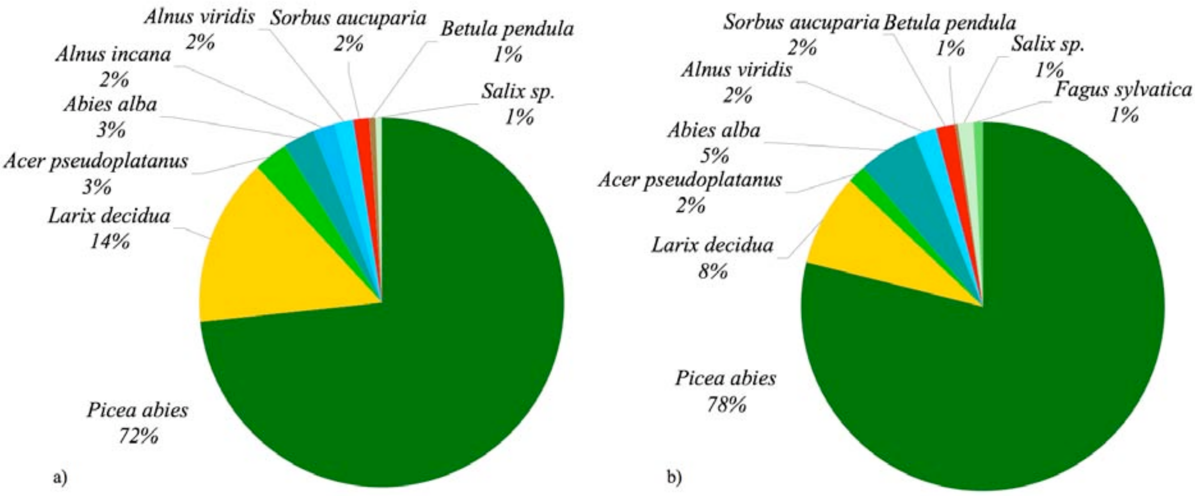

Fig. 8 Tree species composition in the forest communities a) *Larici-Piceetum* (n(trees)=194) and b) *Galio rotundifolii-Abietum* (n(trees)=380) in the NFR *Goldeck*

While the diameter distribution of the trees in the *Larici-Piceetum* is mostly even, the distribution shows a clear peak for trees with a DBH < 12 cm in the *Galio rotundifolii-Abietum* (Fig. 9).

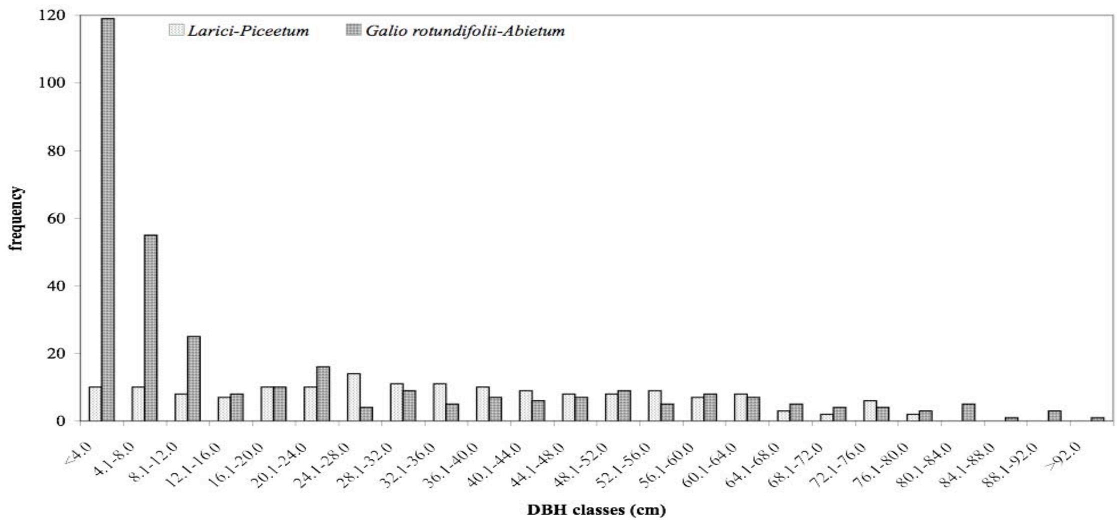

Fig. 9 DBH distribution in the forest communities *Larici-Piceetum* and *Galio rotundifolii Abietum* in the NFR *Goldeck*

The mean standing volume of living trees was calculated for the forest communities *Larici-Piceetum* and *Galio rotundifolii-Abietum* with 756 ± 256 m^3/ha and 700 ± 353 m^3/ha (mean ± standard deviation) respectively. The average stem number was found to be lower in the *Larici-Piceetum* (453 ± 158 trees/ha) than in the *Galio rotundifolii-Abietum*, where 604 ± 507 trees/ha were determined on average (Tab. 4). The high standard deviation indicates the high variability between the plots.

Tab. 4 Mean values of stem number (N), basal area (G) and volume (V) of living trees and volume of deadwood per hectare in the forest communities *Larici-Piceetum* and *Galio rotundifolii-Abietum* in the NFR *Goldeck* (mean ± standard deviation)

	Larici-Piceetum	*Galio rotundifolii-Abietum*
N/ha	453 ± 158	604 ± 507
G [m^2/ha]	58 ± 16	46 ± 20
V [m^3/ha]	756 ±256	700 ± 353
V (deadwood) [m^3/ha]	49 ± 51	70 ± 81

Within the *Larici-Piceetum* the following stability parameters were measured: a crown ratio of 67 ± 21 % and a ratio of slenderness (height/DBH) of 66 ± 42 (mean±standard deviation). The average canopy closure was calculated to be 62 ± 13 %. In the *Galio rotundifolii-Abietum* a mean crown ratio of 70 ± 25 %, a ratio of slenderness of 101 ± 102 and a canopy closure of 53 ± 13 % were recorded. Tree heights were measured up to heights of 46.5 m. See Table 5 for a summary of the values per sample plot.

Tab. 5 General information on sample plots of the investigation in September 2008 in the NFR *Goldeck* (the missing plot numbers refer to plots that are situated outside the study area)

	Forest community	Altitude [m a.s.l.]	Slope gradient [%]	Canopy closure [%]	Stem no. [N/ha]	Standing volume [m^3/ha]	deadwood volume [m^3/ha]	No. of saplings 30-130 cm [N/ha]
G_07	Larici-Picetum	1580	130	75	767	680	9	33
G_08	Larici-Picetum	1540	90	60	400	910	15	0
G_10	Larici-Picetum	1560	101	65	700	795	23	133
G_11	Larici-Picetum	1495	90	85	433	447	44	0
G_12	Larici-Picetum	1500	100	55	433	546	95	367
G_13	Larici-Picetum	1440	105	55	400	1121	5	0
G_14	Larici-Picetum	1440	98	40	267	860	58	33
G_17	Larici-Picetum	1475	85	45	267	441	33	33
G_18	Larici-Picetum	1520	95	60	533	841	5	0
G_19	Larici-Picetum	1460	95	85	533	927	124	0
G_20	Larici-Picetum	1440	40	40	400	525	18	33
G_21	Larici-Picetum	1440	72	80	300	1080	157	0
G_22	Galio Rot.-Abietum	1390	90	55	367	815	37	433
G_23	Galio Rot.-Abietum	1370	65	35	133	1	26	33
G_28	Galio Rot.-Abietum	1425	73	65	167	375	1	0
G_29	Galio Rot.-Abietum	1420	75	50	1433	339	219	3533
G_30	Galio Rot.-Abietum	1370	85	75	900	522	113	833
G_31	Galio Rot.-Abietum	1330	46	45	533	574	287	0
G_32	Galio Rot.-Abietum	1330	75	45	333	657	107	0
G_33	Galio Rot.-Abietum	1330	85	40	433	554	95	500
G_34	Galio Rot.-Abietum	1270	80	70	467	1367	22	1633
G_39	Galio Rot.-Abietum	1315	78	55	1300	883	131	1100
G_40	Galio Rot.-Abietum	1265	85	60	867	750	95	433
G_41	Galio Rot.-Abietum	1230	51	20	33	268	0	0
G_42	Galio Rot.-Abietum	1230	70	55	1367	832	14	2067
G_43	Galio Rot.-Abietum	1210	85	50	267	1300	85	167
G_45	Galio Rot.-Abietum	1200	75	55	1600	563	8	200
G_50	Galio Rot.-Abietum	1140	55	70	200	991	9	167
G_51	Galio Rot.-Abietum	1120	70	45	233	722	3	67
G_57	Galio Rot.-Abietum	1085	80	55	233	1095	11	33
mean values		1364 (135)	81 (19)	56 (15)	543 (407)	726 (308)	62 (70)	394 (778)

Either vertical (standing), horizontal (lying) or both types of deadwood were present on 29 of the 30 study plots. On average 49 ± 51 m^3/ha (mean ± standard deviation) were measured in the *Larici-Piceetum.* The forest stands of the *Galio rotundifolii-Abietum* showed mean deadwood volumes of 70 ± 81 m^3/ha (Tab. 4). The ratio between vertical and horizontal deadwood changed considerably among the plots (38 ± 38 % (mean ± standard deviation)). Highest amounts of deadwood were recorded in the middle part of the NFR (Fig. 10). Figure 11 presents the distribution of tree species, type of deadwood, cause of death and classes of decortication and decomposition of the deadwood assessed on the study plots. Norway spruce was mostly found. Some of the trees could not be identified, due to the strong degree of decomposition. Only few trees of recent death with needles or twigs were recorded, while stumps and stem parts were documented regularly. About half of the stumps showed signs of harvesting.

Other causes of death that could be identified were windthrow and competition from dominating neighbour trees. More than 50% of the deadwood had less than 25% of the bark left and a strong decomposition rate was identified most often.

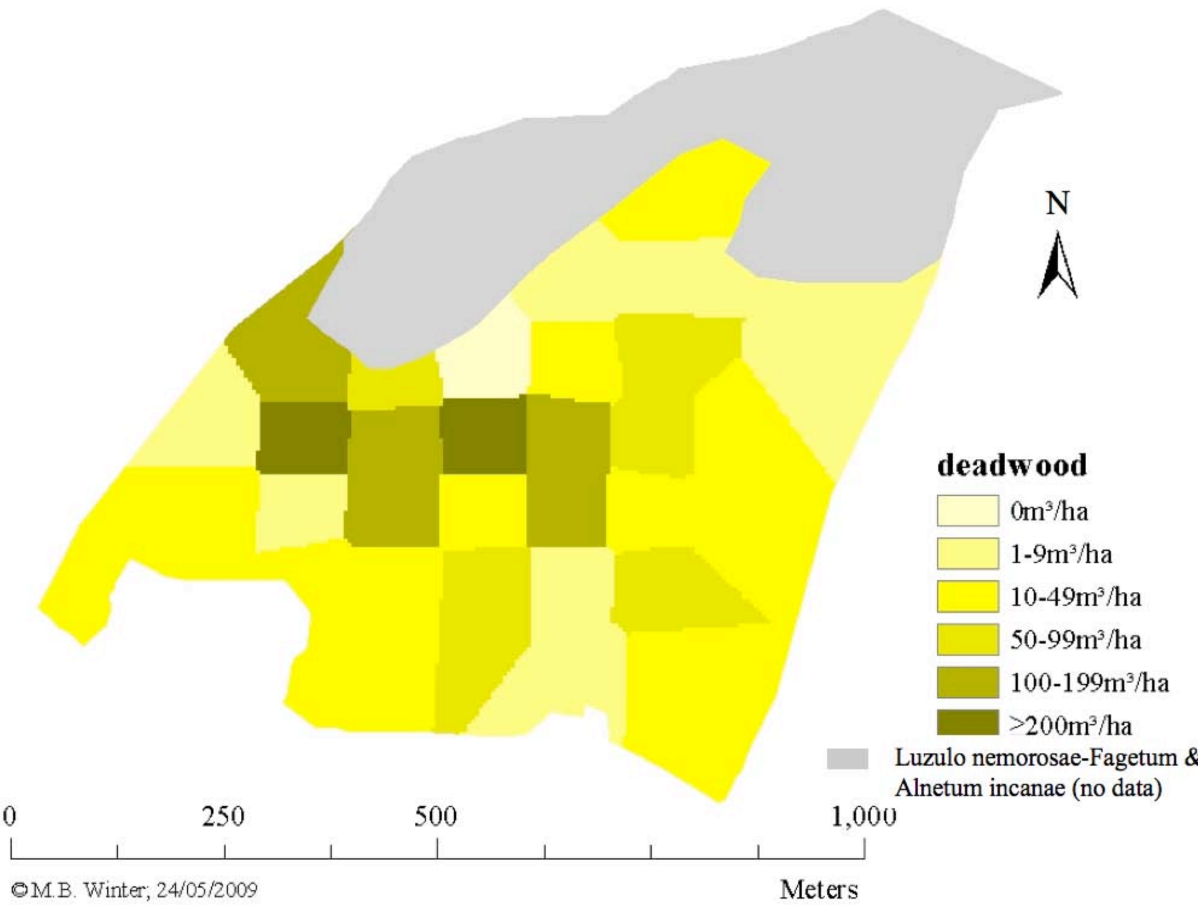

Fig. 10 Spatial distribution of standing and lying deadwood in the study area

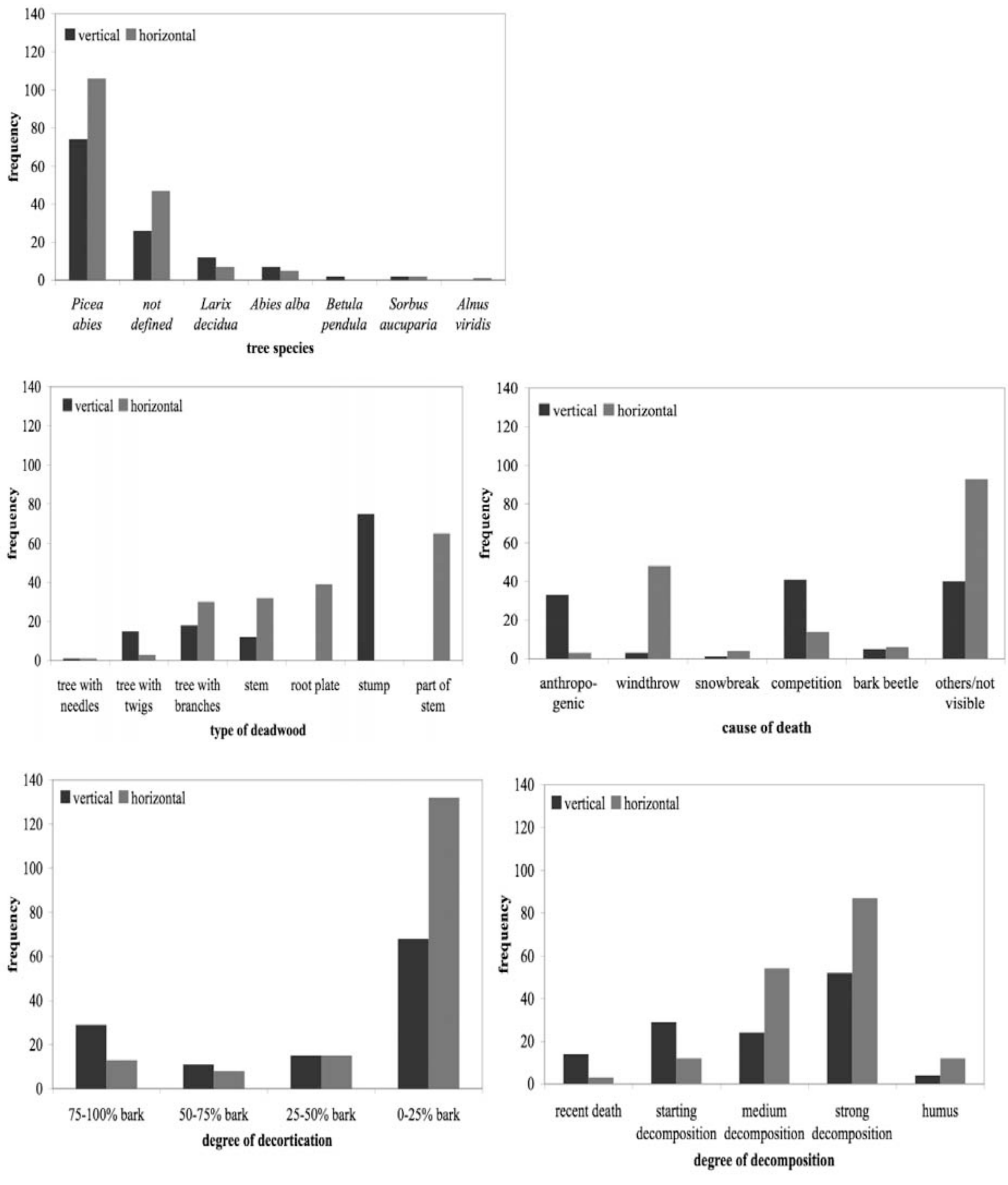

Fig. 11 Histograms of vertical deadwood (n=123) and horizontal deadwood (n=168) frequencies with respect to the parameters tree species composition, type of deadwood, cause of death, degree of decortication and degree of decomposition

Out of 93 increment cores 5 were sampled from Silver fir, 11 from European Larch and 77 from Norway spruce. The cross-dated increment curves (n=93) showed a mean Gleichläufigkeit (GLK) of 65 ± 8.28 (mean ± standard deviation). The average sampled tree age was 109 ± 39.34 with highest frequencies in the age classes 81-100, 101-120 and 121-140 years (Fig. 12). The oldest sampled tree, a Norway spruce, germinated in 1786.

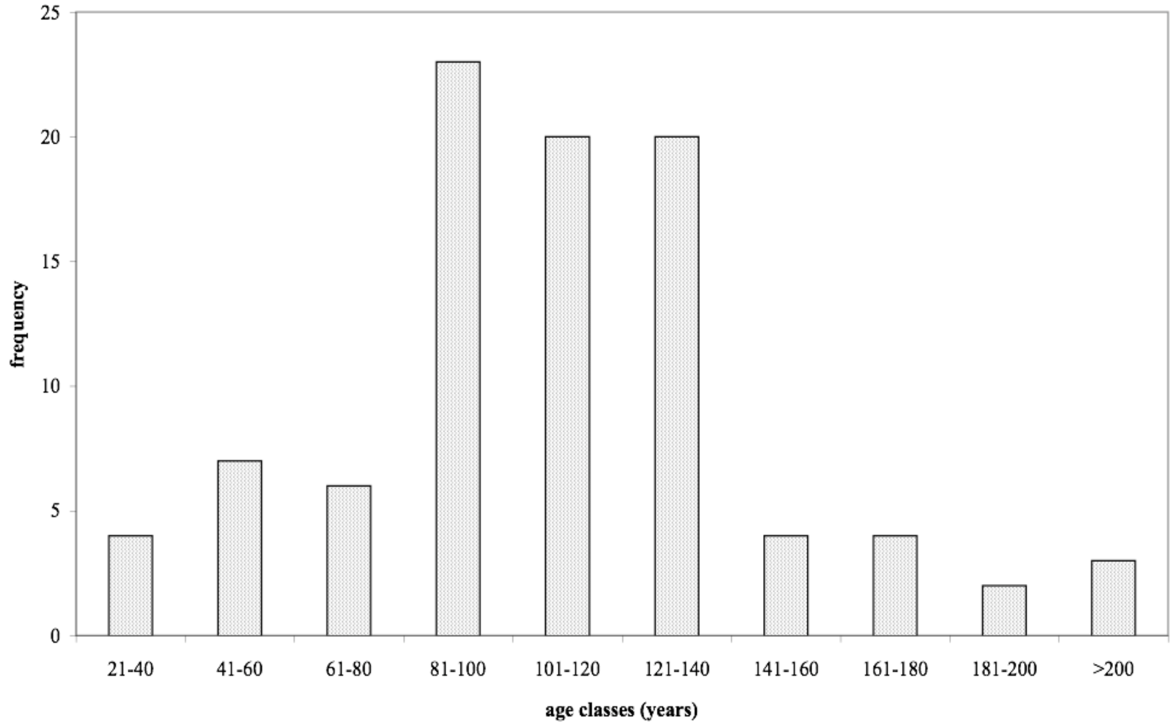

Fig. 12 Age distribution of sampled trees in the NFR *Goldeck*

3.2 Describtion of regeneration

Density of seedlings was 0.38 ± 0.83 per subplot (mean ± standard deviation) for Norway spruce (n = 183), which corresponds to 1.52 ± 3.34 spruce seedlings per m^2 or 15 250 ± 33 363 seedlings per hectare. 24 % of the subplots were occupied by at least one seedling. On these subplots 64 % had one seedling, 30 % showed two or three seedlings and four to five seedlings could be found only on 6 % of the subplots with regeneration (Fig. 13a). On the total of the 480 subplots (120 m^2) only four seedlings of European larch, three seedlings of Silver fir and one seedling of Mountain ash and Sycamore maple could be identified. See Figure 14 for the spatial distribution of seedling density.

Density of saplings (one year old till 15cm height) was 0.88 ± 2.15 per m^2 or 8 750 ± 21 532 per hectare for Norway spruce (n = 420). Both sapling density classes, 1 sapling and 2-3 saplings per subplot, were represented with 35 % (Fig.13b). Higher sapling densities were found on fewer subplots. Additionally, the following saplings have been counted on the 480 m^2 for the other species: 9 Silver fir, 3 European larch, 29 Mountain Ash, 17 Sycamore maple, 3 European Beech and each 2 of Green and Grey alder. Figure 15 presents the spatial distribution of sapling density.

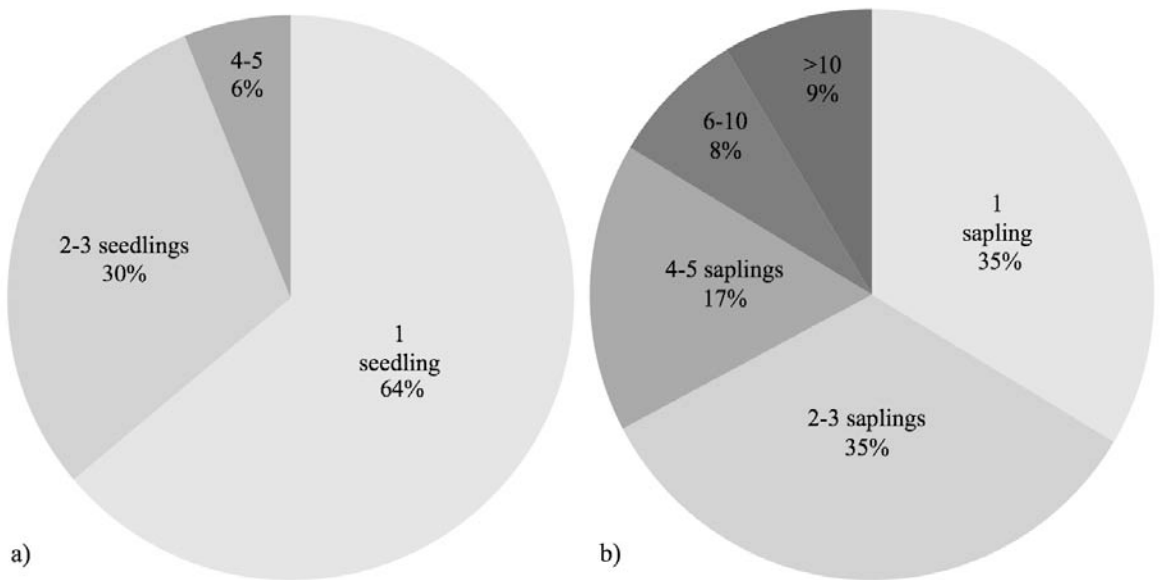

Fig. 13 Frequency of a) spruce seedlings (n = 115) found on subplots of category A and b) spruce saplings (n = 99) found on subplots of category B, excluding subplots without regeneration

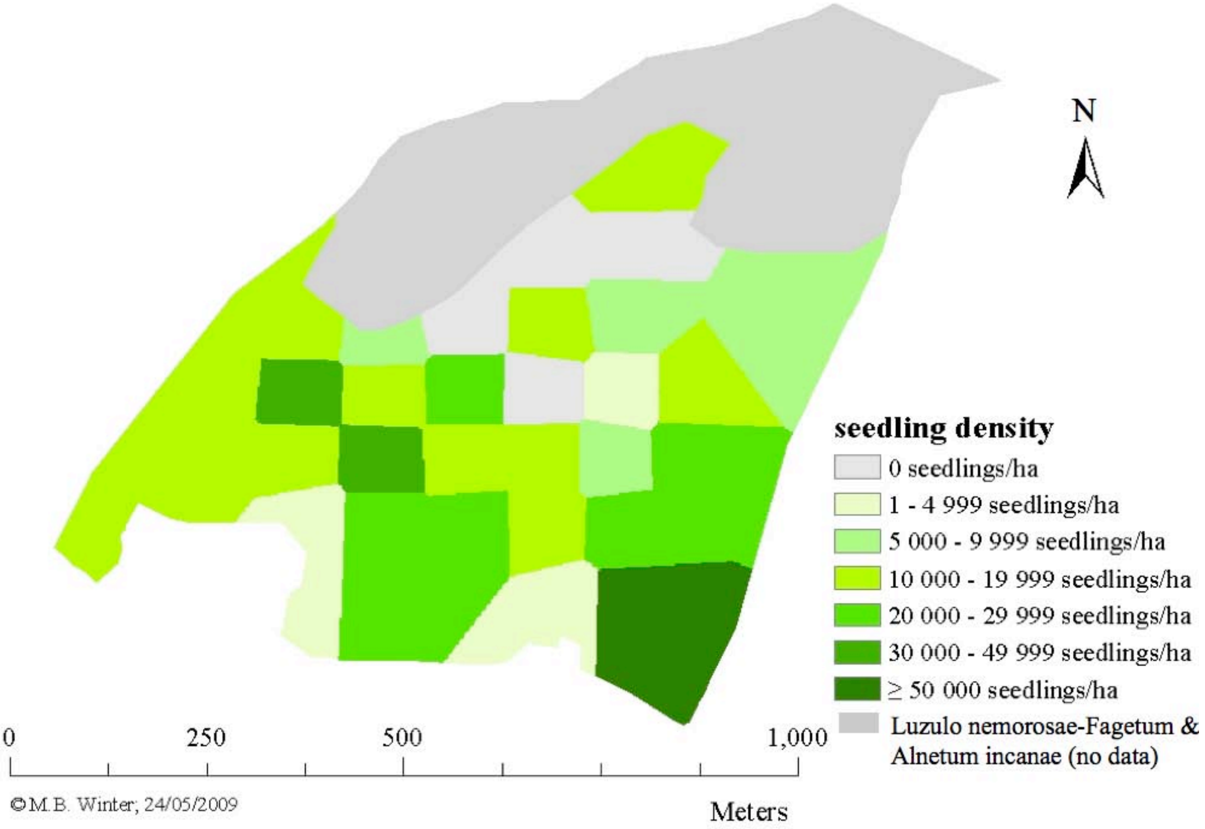

Fig. 14 Mean seedling density per hectare interpolated from the investigations of the sample plots

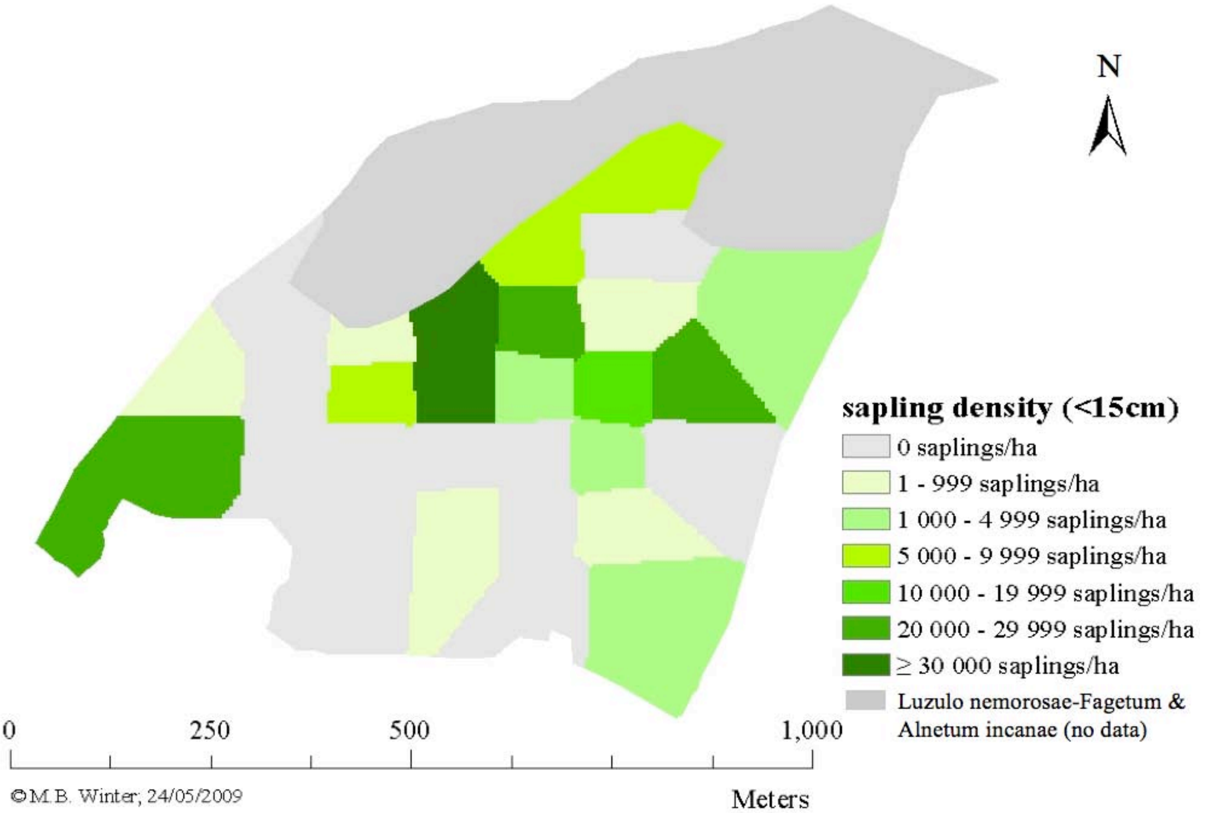

Fig. 15 Mean sapling (<15cm) density per hectare interpolated from the investigations of the sample plots

Figure 16 compares the independent variables of 115 subplots (category A) with spruce seedlings with 365 subplots without spruce seedlings scoring every column to 100%. This demonstrates the relative distribution of the site variables on spruce subplots compared to subplots without spruce. No clear trends are visible for the seedlings in regard to the variable characteristics.

Figure 17 shows the relation of 99 subplots (category B) with spruce saplings compared to 381 subplots without saplings. The proportion of subplots with spruce saplings increases with increasing direct light proportion (DSF) and humus thickness and decreasing soil humidity. Regarding the radiation, most saplings (relative proportion) were found on subplots receiving 25-29% of the direct radiation available above the canopy. A moderately dry soil humidity is linked with highest sapling proportions as well as humus depths > 10 cm .

The analysis of the correlation of the variables used in the logistic regression analysis showed some dependencies. The independent variables vascular plants, mean height of vascular plants, area suited for regeneration, deadwood as obstacle (against snow gliding and erosion), humus type and soil texture showed correlation values > 0.3 with the other variables used (Tab. 6) and were excluded from the logistic regression analysis.

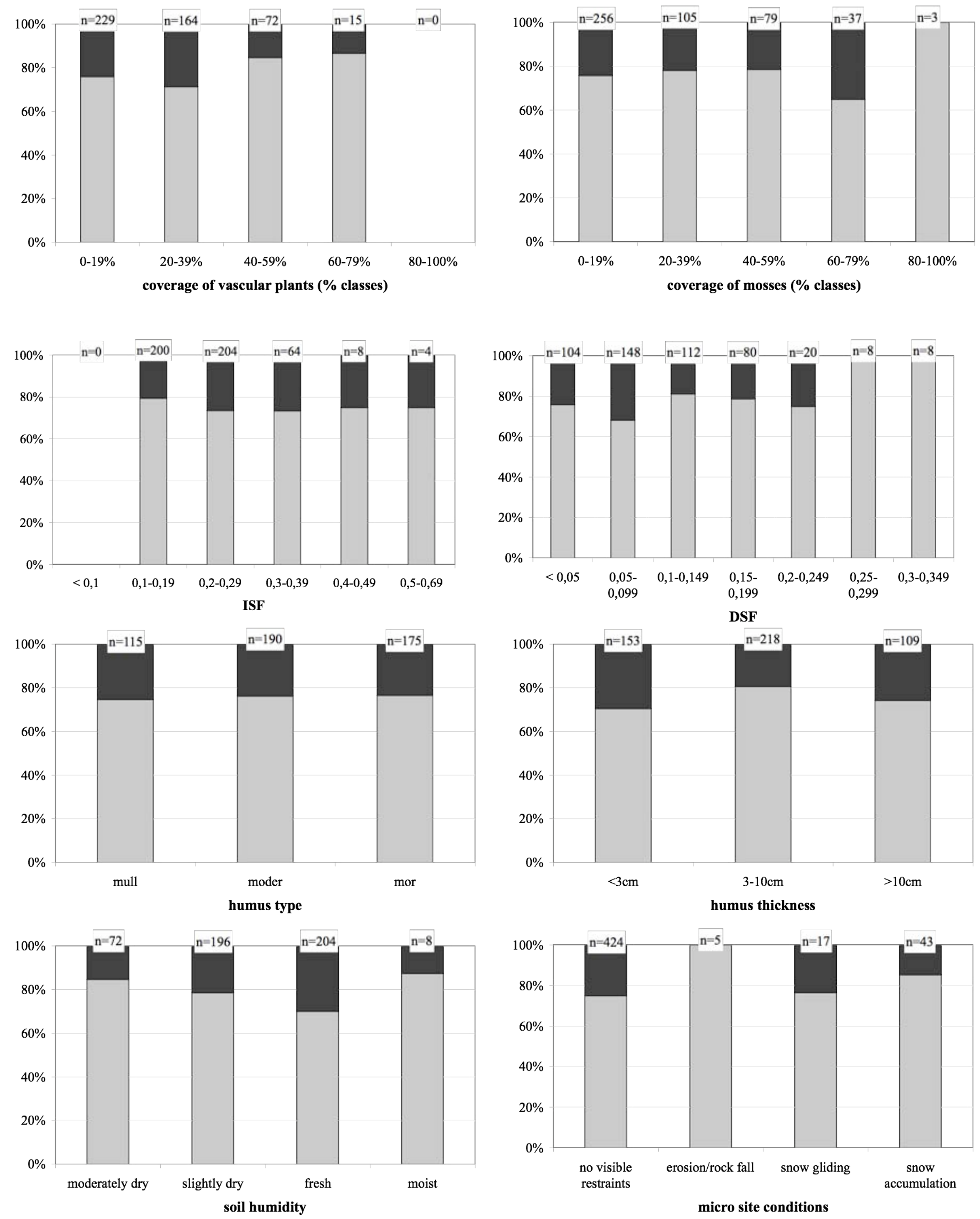

Fig. 16 Occurence of spruce seedlings (dark) in comparison with non-occurrence of spruce seedlings (light) on subplots with percent rates of total number within each class of independent variables (each independent variable is set up to 100%)

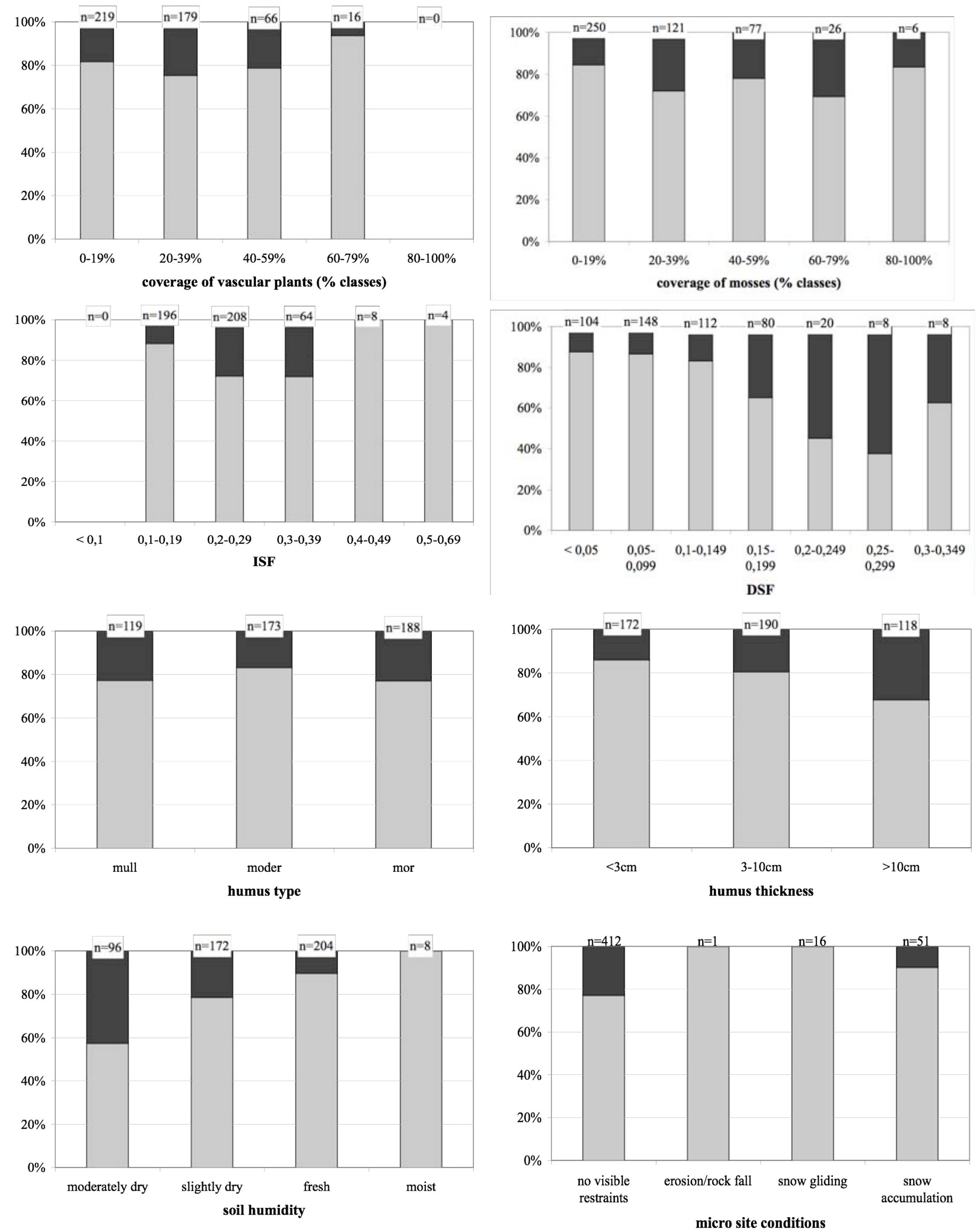

Fig. 17 Occurence of spruce saplings (dark) in comparison with non-occurrence of spruce saplings (light) on subplots with percent rates of total number within each class of independent variables (each independent variable is set up to 100%)

Tab. 6 Correlation matrix of the independent variables (2-tailed Pearson correlation; *$p<0.05$)

	soil humidity	soil texture	soil type	humus thickness	humus type	deadwood (obstacle)	DSF [%]	ISF [%]	suitable area [%]	slope gradient [%]	mineral soil [%]	mosses [%]	mean height (vp)	vascular plants (vp) [%]
vascular plants (vp)[%]	0.119*	0.213*	-0.015	-0.284*	-0.450*	-0.157*	0.148*	0.542*	0.280*	-0.082	-0.022	0.093*	0.685*	1
mean height [mm]	0.227*	0.274*	-0.038	-0.202*	-0.377*	-0.126*	0.292*	0.570*	0.202	0.002	-0.067	0.166*	1	
mosses [%]	0.133*	-0.034	0.002	-0.100*	-0.148*	-0.166*	-0.017	0.284*	0.349*	0.106*	-0.100*	1		
mineral soil [%]	0.033	0.086	0.023	-0.083	-0.118*	-0.014	-0.080	-0.075	0.096*	0.199*	1			
slope gradient [%]	-0.089	-0.074	-0.137*	-0.046	0.122*	-0.107*	-0.050	0.000	0.161*	1				
suitable area [%]	0.023	0.054	-0.023	-0.002	-0.046	-0.513*	0.058	0.189*	1					
ISF [%]	0.235*	0.129*	0.036	-0.125*	-0.289*	-0.058	0.281*	1						
DSF [%]	-0.220*	-0.160*	-0.006	0.148*	0.089	-0.074	1							
deadwood (obstacle)	-0.098*	-0.035	0.052	0.081	0.055	1								
humus type	-0.294*	-0.319*	-0.033	0.674*	1									
humus thickness	-0.290*	-0.267*	-0.186*	1										
soil type	0.070	0.362*	1											
soil texture	0.350*	1												
soil humidity	1													

Of the remaining variables DSF, ISF and humus thickness added significant explanatory value to the logistic regression model for the seedling occurrence (Tab. 7). The slightly decreasing -2LL value indicates only minor improvements when entering the variables. The factors coverage of moss and mineral soil, slope gradient, soil type and soil humidity were left out as a result of their non-significant influence on the probability of spruce seedlings occurrence.

76% of the cases were classified correctly in the model. A χ^2 value of 7.09 at p=0.53 in the Hosmer-Lemeshow-test indicates an adequate fit of this model. The Nagelkerkes R^2 of 0.057 is however an evidence that the model does not have much explanatory value. Same is implied by three out of the four odds ratio values of the factors that are close to 1 (Tab. 7).

A change in DSF, ISF or the existence of a humus layer >10cm would not change the probability of a spruce seedling occurrence considerably. Solely the presence of a medium humus layer (3-10cm) would almost halve the spruce seedling probability (odds ratio=0.575) in the model. The validity of the model was tested with standardised residuals, which had a mean of 0.000 and a standard deviation of 1.000.

Tab. 7 Results of the binary logistic regression analysis for predicting the occurrence of spruce seedlings

	-2 LL	parameter	SE of parameter	odds ratio	*p*-value
intercept	529	-1.049	0.416	0.350	0.012
DSF [%]	522	-0.060	0.020	0.942	0.003
ISF [%]	516	0.032	0.016	1.033	0.037
humus thickness *<3cm	510				0.046
humus thickness *3-10cm	510	-0.554	0.260	0.575	0.033
humus thickness *>10cm	510	-0.006	0.295	0.994	0.984 #

value not significant but parameter used in the model
Homer-Lemeshow-test: $\chi 2$= 7.09 p= 0.53
Nagelkerke R^2= 0.057
Success of classification: 76%

The logistic regression model for the sapling occurrence includes soil humidity, DSF, ISF, coverage of mosses and slope gradient as independent variables improving the explanatory value for predicting the spruce sapling occurrence significantly (Tab. 8). The factors coverage of mineral soil, humus thickness and soil type were excluded from the model due to *p*-values >0.05. Negative parameter values for soil humidity indicate a decreasing sapling probability with increasing soil humidity. In the same way the model predicts that steeper slopes minimize the sapling existence probability of spruce. In contrast, the parameters of direct and indirect light proportion (DSF, ISF) and of the coverage of mosses are positive. Their odds ratios are however only slightly larger than 1 and are therefore only of minor relevance to the model.

The Hosmer-Lemeshow-test computed a of χ^2 of 12.73 at p=0.12, the Nagelkerke R^2 of 0.295 shows a larger value than the required 0.2. Together with the 84% accurate classification the sapling model shows adequate quality parameters to accept the model. The standardised residuals indicating the validity of the model had a mean of 0.004 and a standard deviation of 0.969.

A substitution of the parameter measured indirect radiation (ISF) with total crown coverage (%) of the sample plot (two-tailed Pearson correlation: r= -0.489*) led to a decrease of correctly classified cases for both models and was therefore not applied in the final models.

Tab. 8 Results of the binary logistic regression analysis for predicting the occurrence of a spruce sapling (< 15 cm)

	-2 LL	parameter	SE of parameter	odds ratio	*p*-value
intercept	489	-1.156	0.546	0.315	0.034
Soil humidity *moderately dry	446				<0.001
Soil humidity *slightly dry	446	-1.064	0.327	0.345	0.001
Soil humidity *fresh	446	-2.474	0.401	0.084	<0.001
Soil humidity *moist	446	-22.422 +	13950.406	0.000	0.999
DSF [%]	425	0.061	0.019	1.063	0.002
Mosses [%]	412	0.023	0.006	1.023	<0.001
Slope gradient [%]	394	-0.016	0.004	0.984	<0.001
ISF [%]	388	0.046	0.019	1.047	0.017

+ value excluded in the model
Homer-Lemeshow-test: $\chi2$= 12.73 p= 0.12
Nagelkerke R^2= 0.295
Success of classification: 84%

Due to the low numbers of seedlings and saplings recorded per subplot no multiple logistic regression analysis could be carried out to determine the influencing factors for regeneration frequency. Figure 18 and 19 illustrate however the distribution of selected independent variables for classes of seedling and sapling density. Neither the seedlings nor the saplings show significant differences among the density classes, but for seedlings as well as for saplings slightly higher densities can be found on average at higher radiation intensities.

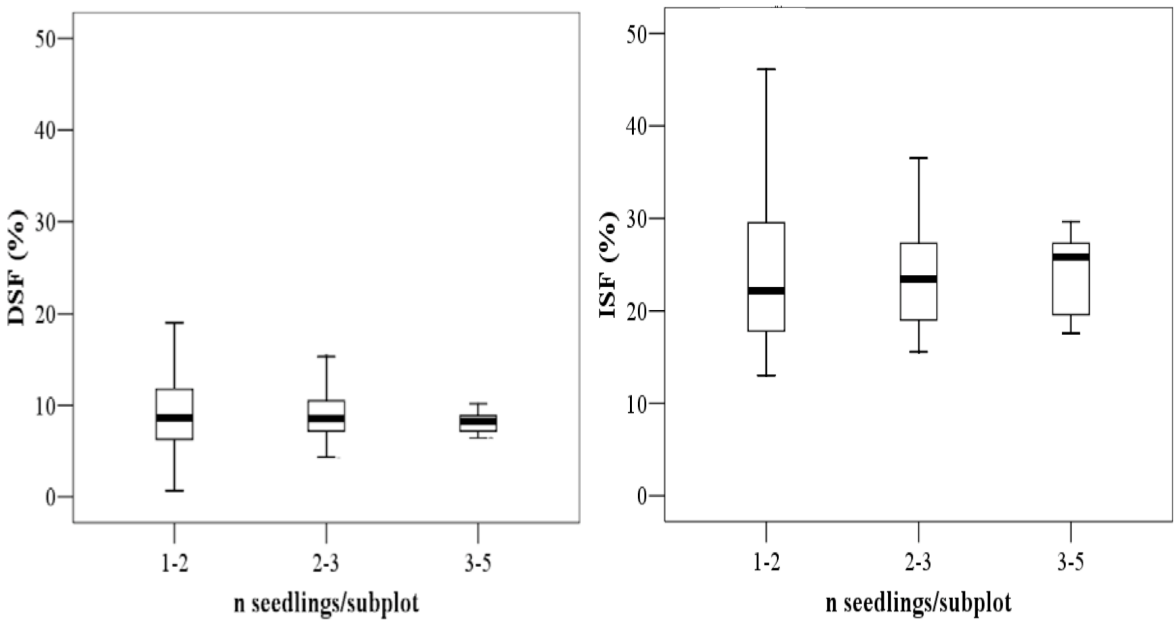

Fig. 18 Boxplots of direct (DSF) and indirect (ISF) radiation relative to values above the canopy for classes of spruce seedling density ($n_{1\text{-}2}$= 99, $n_{2\text{-}3}$= 34, $n_{3\text{-}5}$= 16)

More saplings are shown to be found in tendency with a decreasing coverage of vascular plants but an increasing share of moss cover. Sapling density does not indicate any clear trend in relation to slope gradient (Fig. 19).

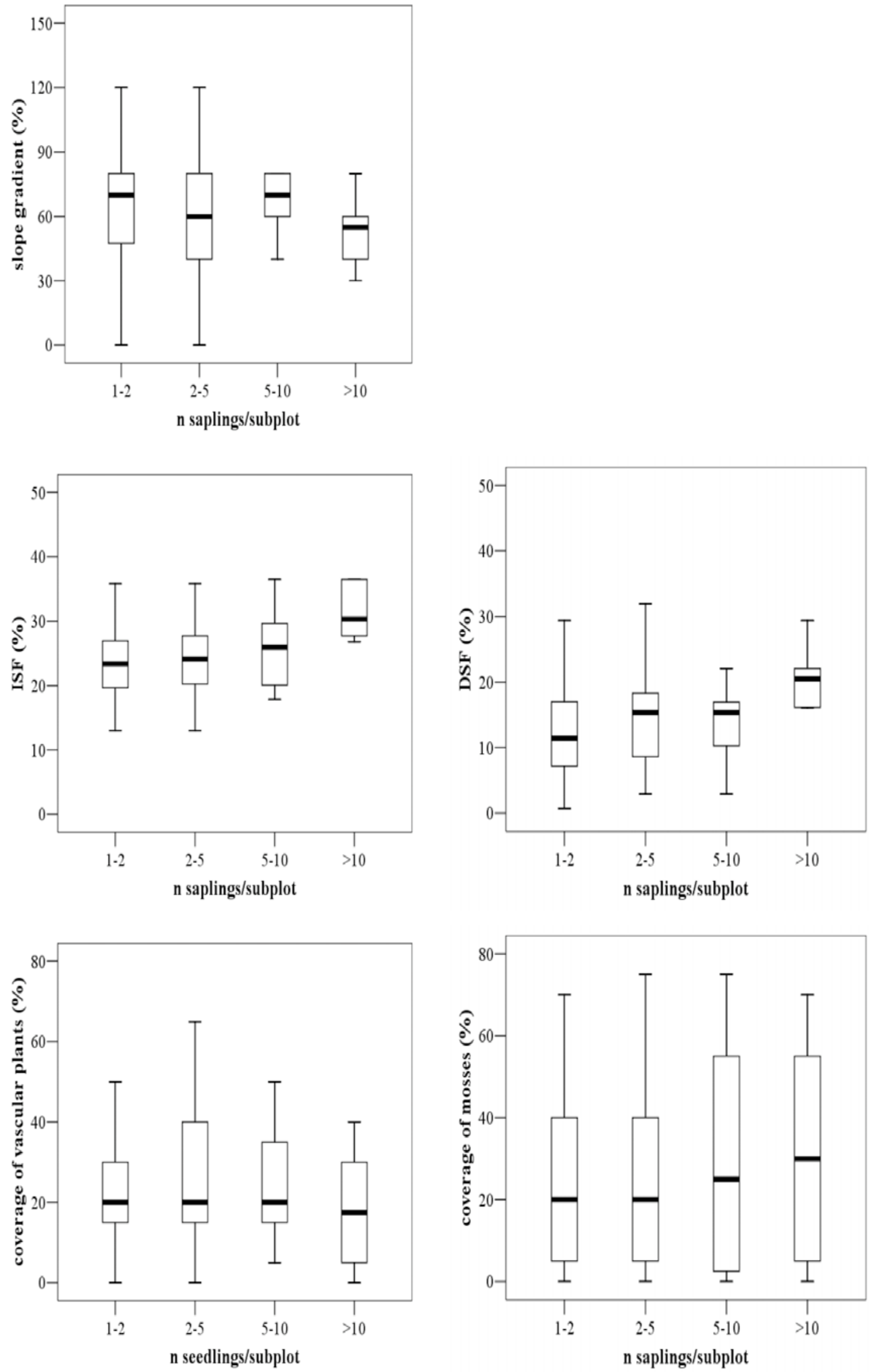

Fig. 19 Boxplots of slope gradient, direct (DSF) and indirect (ISF) radiation and coverage of vascular plants and mosses for different classes of sapling density ($n_{1\text{-}2}$= 56, $n_{2\text{-}5}$= 49, $n_{5\text{-}10}$= 15, $n_{>10}$= 10)

On 28 out of the 123 vertical deadwood objects (including stumps) spruce regeneration <15cm was recorded. The horizontal deadwood (n=168) showed spruce regeneration in 92 cases. In total 326 spruce seedlings have been recorded of which 15 were growing on vertical and 311 on horizontal deadwood. The 590 spruce saplings were portioned on 61 on vertical and 529 on horizontal deadwood. Taking only the regeneration on fallen deadwood into account 1.13 spruce seedlings and 1.55 spruce saplings occurred in average per m^2 of potentially regeneratable horizontal deadwood surface (upper half of horizontal deadwood surface) (Fig. 20). Deadwood with a degree of decomposition of E (humus like) were excluded for the comparison of Figure 20, because of the risk to detect and record this deadwood pieces only when regeneration is present, leading to a bias of seedling and sapling density. In comparing the average density per m^2 between spruce regeneration on the soil and on deadwood it was found that the proportion of seedlings was higher on soil (1.52) than on deadwood (1.13), while more saplings were assessed on deadwood (1.55) than on soil (0.88).

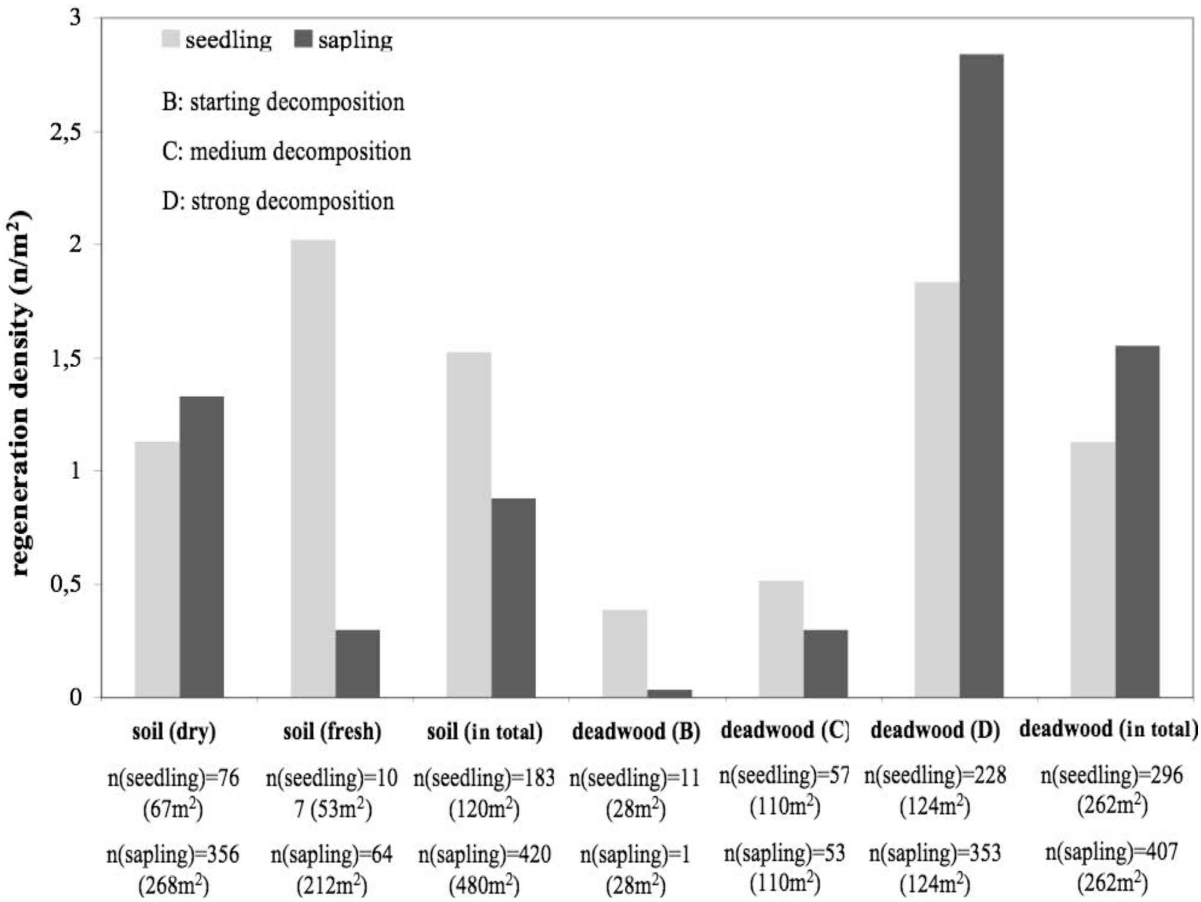

Fig. 20 Density of spruce seedlings and saplings on different growing substrates per m^2 recorded surface

The class of the 15-30 cm tall saplings was clearly underrepresented in the investigation, finding only 16 individuals within, of which 9 were Norway spruce, 4 green alder and 1 of Mountain ash and grey alder respectively. The measurements were therefore not included in any further analyses.

Density of large saplings (30-130cm) was 11.10 ± 22.43 per plot (mean ± standard deviation) or 370 ± 748 per hectare for Norway spruce and 0.67 ± 2.06 per plot (22 ± 49/ha) (Fig. 21) for European larch. No other species were found within this class.

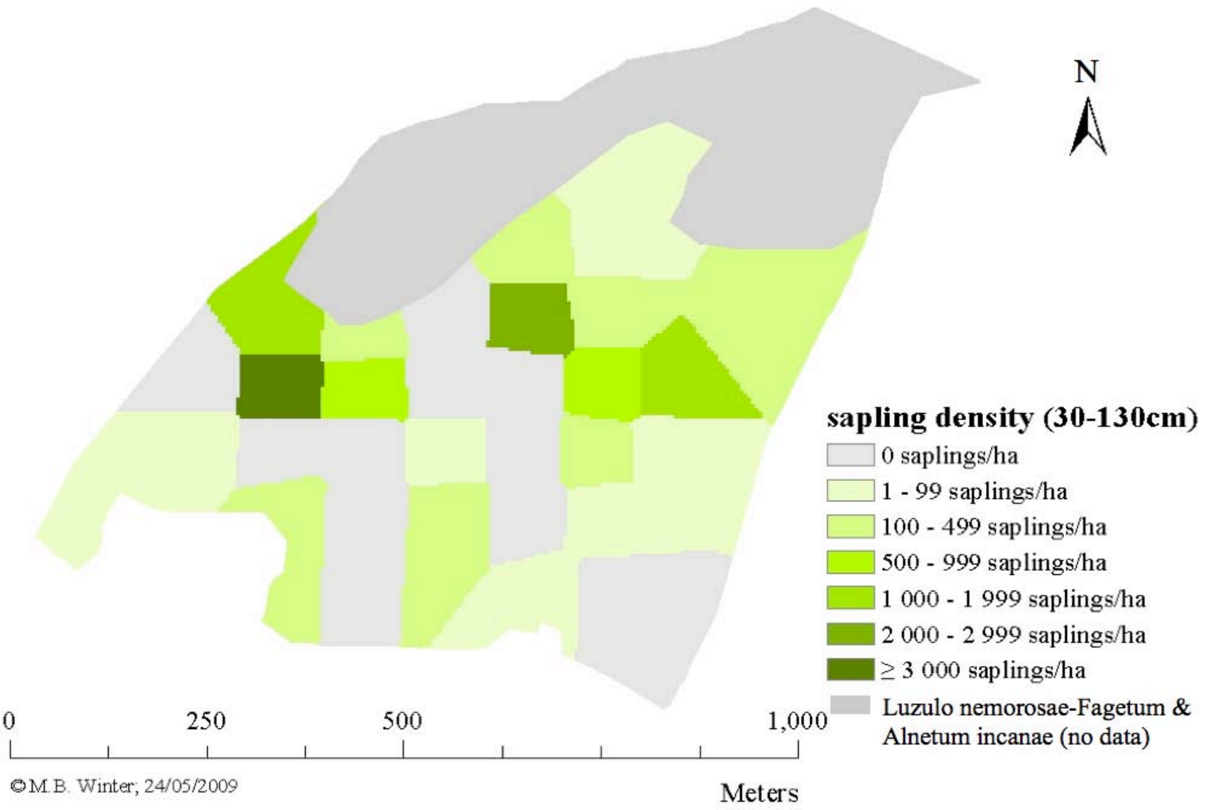

Fig. 21 Mean sapling (30-130cm) density per hectare interpolated from the investigations of the sample plots

The root collar diameter classes 6-10 mm and 11-15 mm show the highest frequency with 21 and 23 individuals respectively. The frequency is decreasing with increasing root collar (Fig. 22). A similar pattern is visible for the height distribution. Highest frequencies are found in the classes 30-40cm and 41-50cm. Increased height values are represented generally by fewer individuals (Fig. 23).

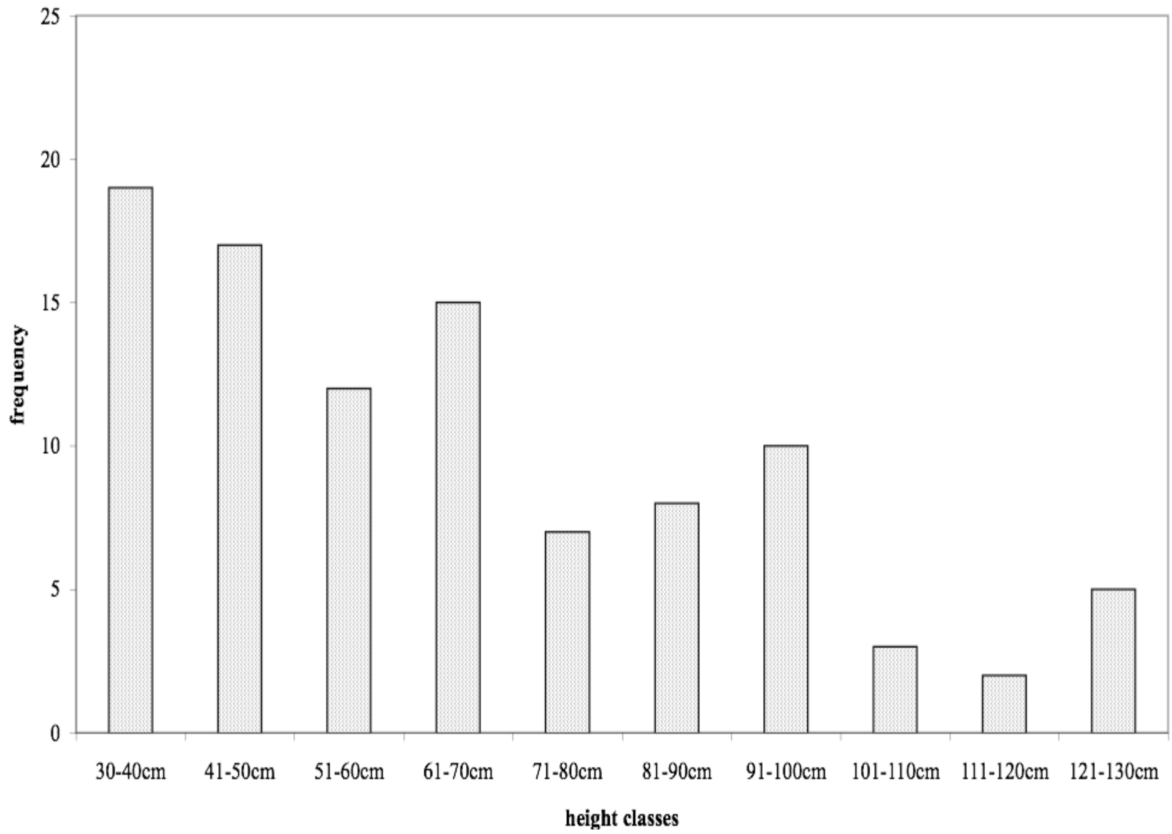

Fig. 22 Height distribution of large Norway spruce saplings (30-130cm) among height classes

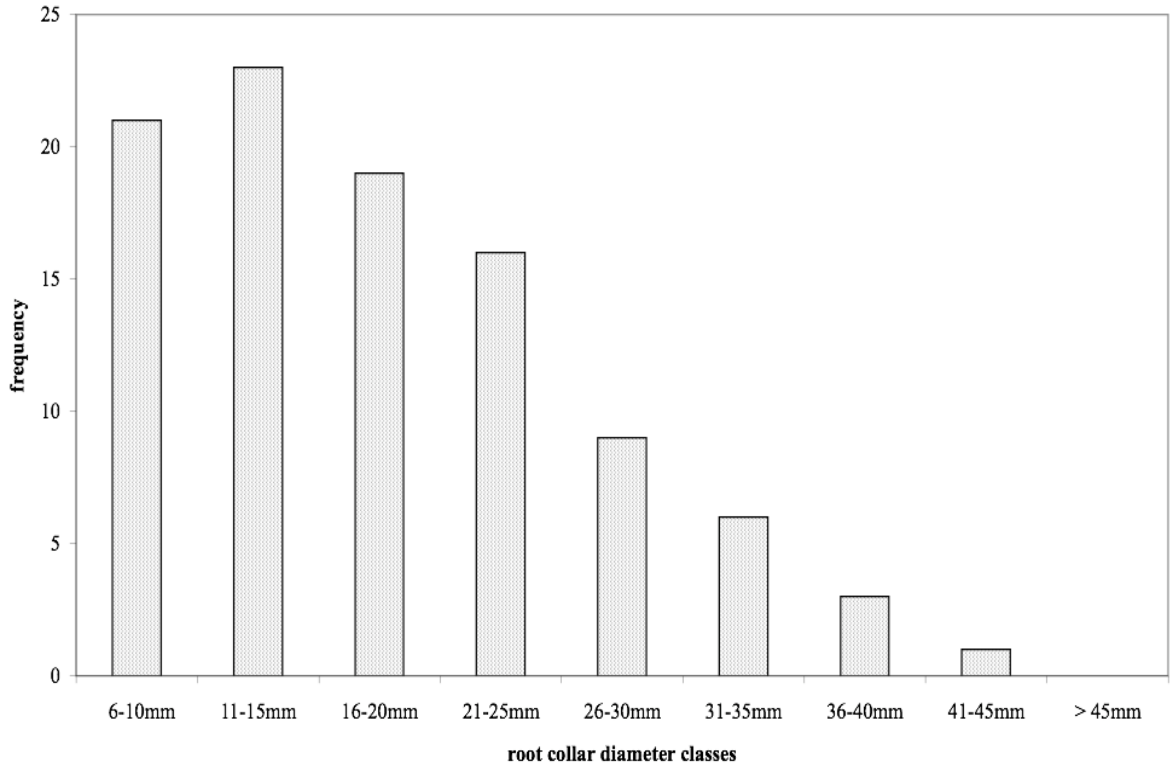

Fig. 23 Root collar diameter distribution of large Norway spruce saplings (30-130cm) among root collar classes

68 % of the large saplings (n = 331) occurred on an even micro-relief, 17 % grew on deadwood or woody debris. The last 15 % are distributed among the other classes (Fig. 24). The class *protected from hillside* includes saplings secured by boulders or stems in upper slope direction against erosion of the ground, rock fall or snow gliding, the category *elevated* describes micro positions higher than the average ground level (e.g., on stones, but excluding deadwood and root plate positions) reducing additionally the risk for browsing and late frost. 3 % of the large saplings were found on root plates (Fig. 25). Calculating the spruce sapling density per m^2 of potential growth area separating deadwood from the other classes, 0.03 saplings were recorded in average per m^2 investigated ground (summarizing even & elevated ground, protection from hillside and root plates), while 0.19 saplings occurred in average per m^2 deadwood.

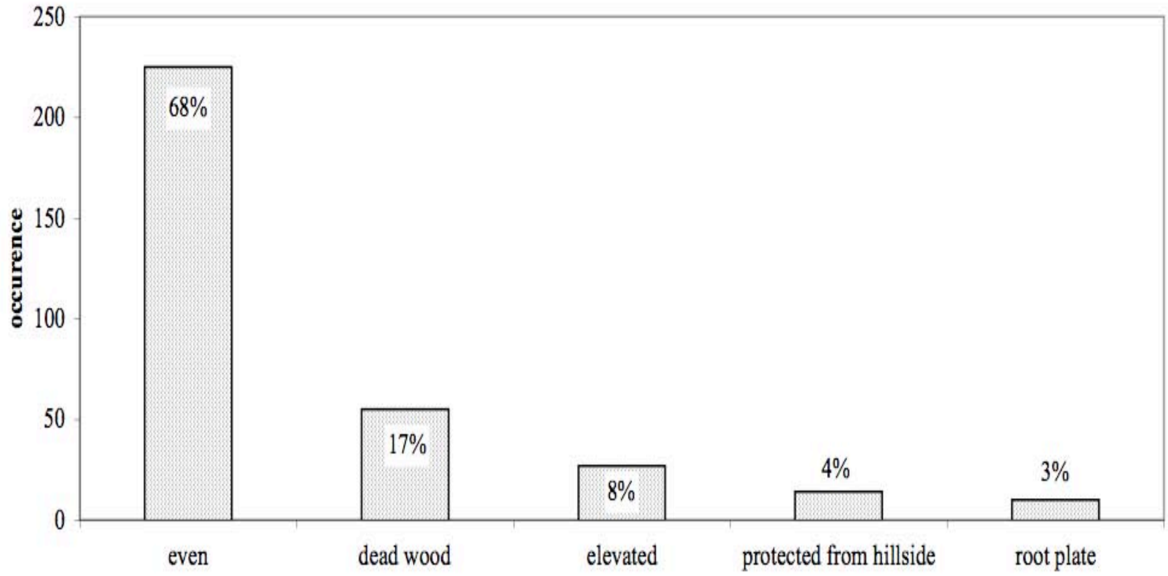

Fig. 24 Occurrence of large saplings (30-130cm) occurrence in relation to micro-site conditions

Fig. 25 Norway spruce regeneration on a root plate next to plot no. 10 in the *Larici-Piceetum* (Photo: M.B. Winter)

27 % of the large saplings showed browsing damages at their terminal shoot, the lateral shoots were browsed by deer at 69 % of the individuals. On average, browsed trees (n = 230) were damaged by game by 40 %. Browsing is the factor recorded leading to lethal damages most often. The highest frequencies of major damages not causing mortality were however found due to competing neighbouring saplings. Around half of the spruce regeneration showed infestation by insects, but a lethal damage was recorded in only one case (Fig. 26). Considering all kind of damages regardless of the damage intensity 98 % of the individuals show at least one damage. In total 717 damages have been recorded for 331 saplings.

In general, the plants with medium vigour dominated the parameter vitality with a frequency of 60%. 31% expressed a bad constitution, 8% had a very good vitality.

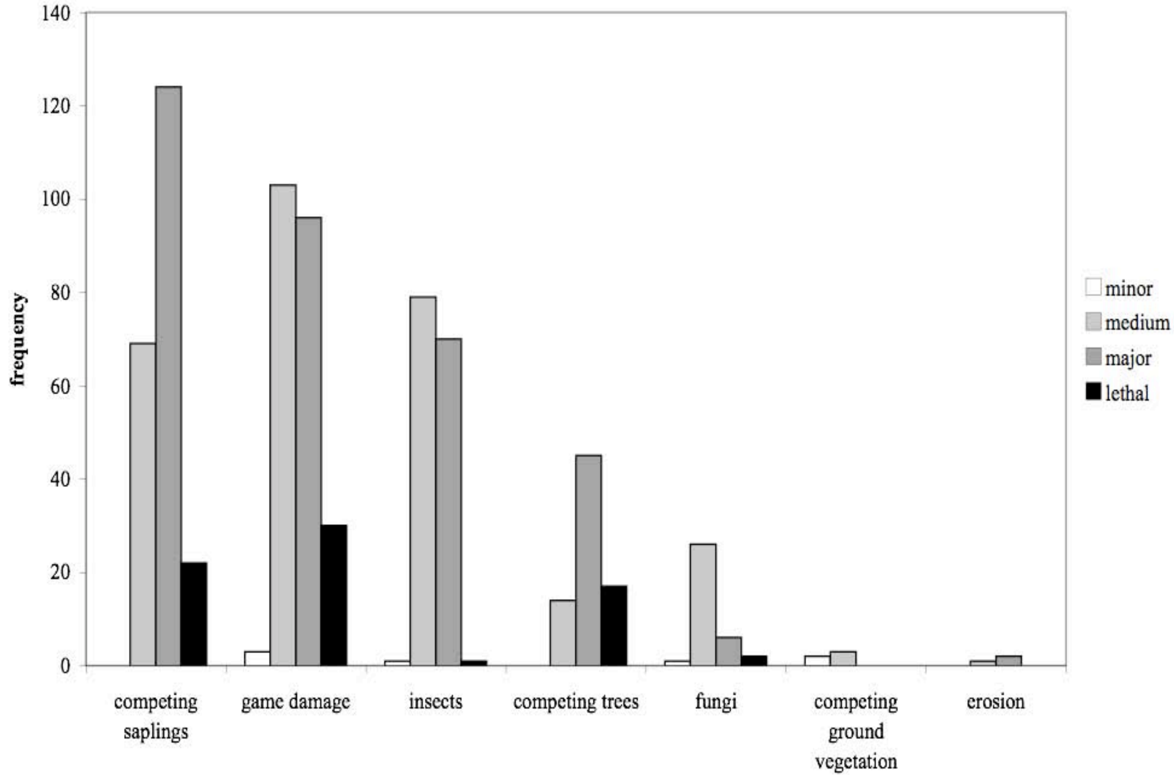

Fig. 26 Damaging parameters and damage intensities of large Norway spruce saplings (30 130cm)

3.3 Fullfillment of the potential protection function

The majority of the study area was assessed important for protection against rock fall and avalanches. Four plots had slope gradients <58% and were classified as deposit areas or no-risk areas respectively (see Tab. 4 and Fig. 27). Most boulders have their source area outside the study area and pass through the study area only. Two break-off areas are however situated in the middle of the study area at the location of the lime marble layer cliffs. Four assessment areas are not influenced by rock fall at all.

Eight out of the 30 assessment areas fulfil the minimum requirements of Frehner et al. (2005) of a protection forest with current conditions and show mean index values between 0.0 and 0.6 (mean 0.3). The other 22 plots perform with index values between -0.1 and -1.3 (mean -0.6) and do not fulfil the NaiS requirements for all parameters (see appendix, Tab. 12). All plots together (overall performance of the study area) show an arithmetic mean of -0.30 ± 1.2 (mean ± standard deviation). Considering the performance of the parameters, *stability* and *germination* score with 0.3 and 0.0 best, while the parameters *small saplings* (-1.2) and *horizontal structure* (-0.7) show major deficiencies (Fig. 28). The same situation with similar values gets visible for the estimated scenario in 10 and 50 years respectively (see appendix, Tab. 12-14 & Fig. 29). The potential performance of the parameters *horizontal structure, germination* and *saplings < 40 cm* is assessed to improve during the next 50 years, *stability* and *saplings > 40 cm* are estimated to perform worse in 2058, *species mixture* and *vertical structure* do not indicate a clear trend (Fig. 28). A slight improvement over the 50 years is rated for 14 plots, 13 plots are estimated to perform a little worse in 2058 and for 3 plots no change is calculated. The mean overall performance in 10 and 50 years respectively is still computed to be with -0.3 slightly below the requirements of the minimal profile.

Figure 27 shows the spatial and temporal variation of the forest protection performance compared to the risk situation for natural disasters. The fulfilment of the protection requirements is generally better in the southern *Larici-Piceetum*, than in the *Galio-rotundifolii-Abietum*.

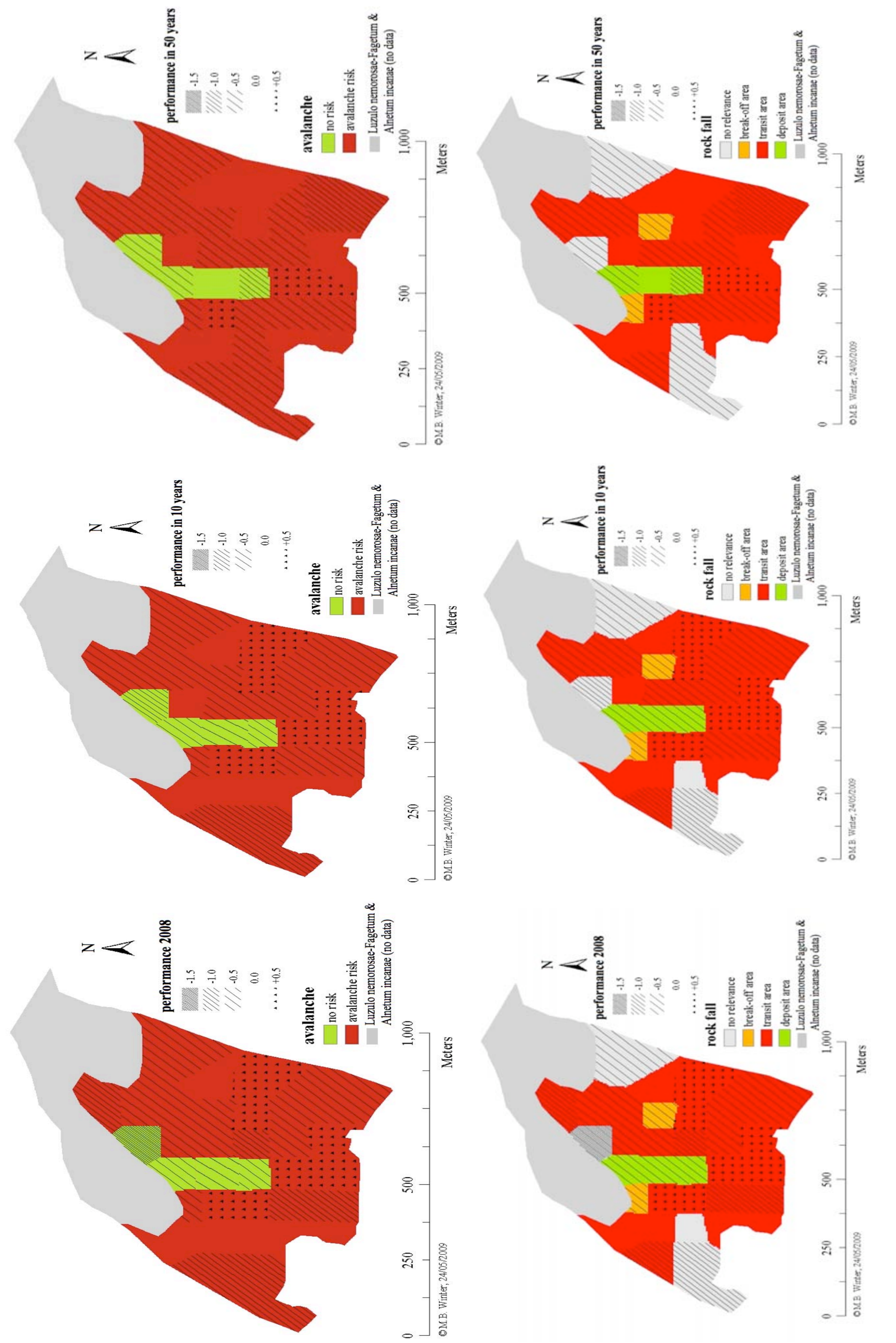

Fig. 27 Spatial presentation of natural disasters (avalanche and rock fall) in the study area and development of forest protection performance over the next 50 years

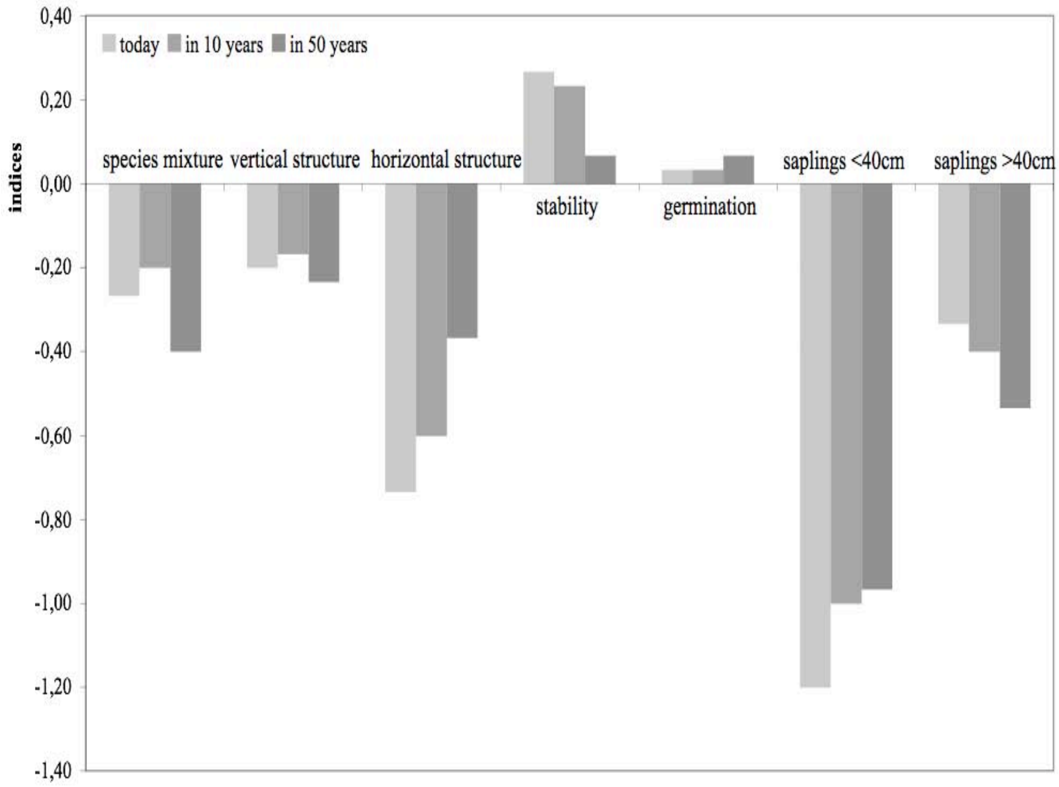

Fig. 28 Mean protection performance of the study area calculated for the different NaiS parameters 2008, 2018 and 2058

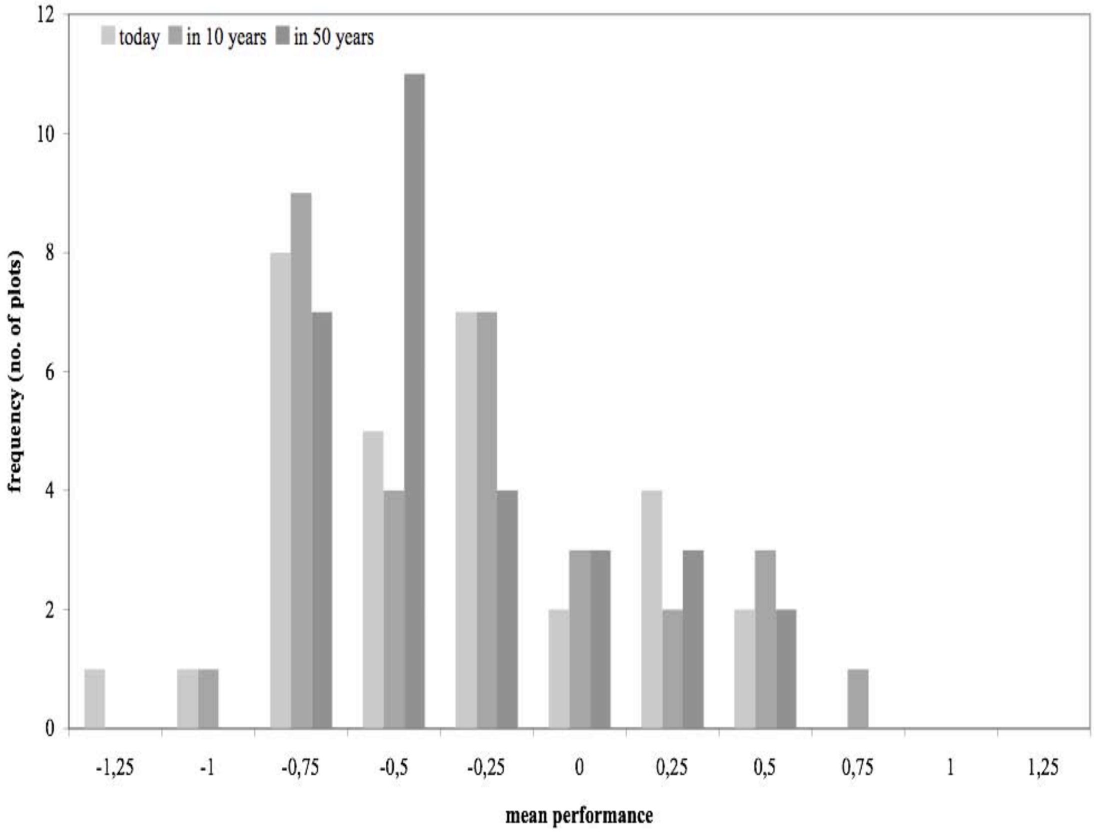

Fig. 29 Distribution of mean protection performance of study plots 2008, 2018 and 2058

4 DISCUSSION

4.1 Forest structure

Norway spruce is the main tree species of the study area. The share of 77% of the overall species composition is comparable to the 70-100% and 10-70% mentioned by Frehner et al. (2005) for constituting the potential natural vegetation (PNV) in the present forest communities *Larici-Piceetum (Homogyno-Piceetum calamagrostietosum villosae)* and *Galio rotundifolii-Abietum (Galio-Abieti-Piceetum typicum)* respectively. The other present tree species (see Fig. 8) are also part of the PNV and no other non-native tree species occur in the upper part of the NFR. The share of Silver fir, particularly in the younger stands, does not picture the natural situation. The NFR is situated within the natural distribution area of Silver fir (Schütt et al. 2002), which is a shade-tolerant species, well adapted to the conditions of continuous mixed mountain forests (Heuzé et al. 2005). The mechanical resistance of fir to rock fall is no smaller than those of spruce (Vospernik 2002). A negative selection of Silver fir caused by a higher vulnerability to natural disasters is therefore unlikely. Although Silver fir is known as shade tolerant species many studies have confirmed the negative impact of dominating spruce saplings on fir regeneration due to light competition (Ammer 1996a, Motta 1996, Heuzé et al. 2005, Stancioiu, Hara 2006). Together with limited nutrient availabilities caused by interspecific competition with spruce (Ammer 1996a), a higher susceptibility to late frost (Schweingruber, Müller 1992) and browsing (Ammer 1996b) this might have caused the almost complete lack of fir regeneration in the study area. The intense browsing damages at the studied spruce regeneration (see chapter 3.2 and 4.2) indicate that the underrepresented share of Silver fir could be partly caused by the ungulate population in this area. Ammer (1996b) explains the distinct effect of browsing on Silver fir regeneration firstly with the higher mortality to repeated game browsing and secondly with the indirect favouring of competitors by choosing significantly more often fir than other tree species for browsing. However, adult Silver fir trees were sparse in the NFR (3 and 5 % of the species composition in the forest communities) and were found on seven study plots only. A lack of seed trees might also be a partial explanation for the underrepresented share of Silver fir in the regeneration.

Highly structured continuous cover forests show characteristic diameter distributions, with high numbers of thin stems and decreasing frequencies with increasing diameter, in equilibrium over time (Schütz 2001). This secures that a sufficient number of trees can replace dying trees in all diameter classes continuously (Schütz 2001). A similar pattern can be observed in the *Galio rotundifolii-Abietum* where the DBH distribution follows roughly a negative exponential curve (see Fig. 9). This facilitates a constant forest cover and thus allows an efficient protection over time. The share of large trees (as required for rock fall protection) is however lower than in the *Larici-Piceetum* where the diameter distribution is almost even. See chapter 4.3 for a discussion of the spatial representation of protection status.

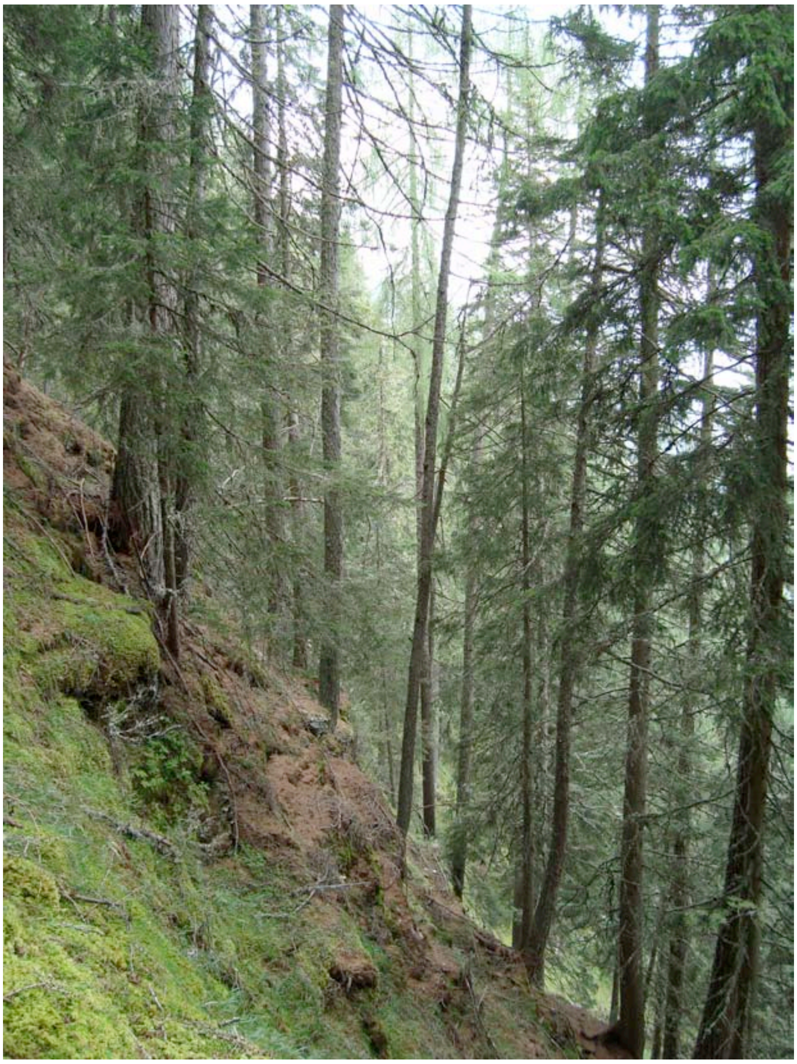

Fig. 30 Plot no. 8 in the *Larici-Piceetum* with Norway spruce and European Larch (Photo:M.B. Winter)

The mean standing volume of the upper part of the NFR *Goldeck* (*Larici-Piceetum* 756 ± 256 m^3/ha; *Galio rotundifolii-Abietum* 700 ± 353 m^3/ha (mean ± standard deviation)) is rather high compared to the results of the last ANFI (2000/2002) where an average volume of 299 m^3/ha was measured for managed protection forest in Carinthia (Schadauer 2004). The values are comparable with the average volume (738 m^3/ha) of commercial forest stands measured in the forest district *Spittal/Drau* in stands of the diameter class 35.5-50.4 cm (in

German: *starkes Baumholz*) only. However, the upper part of the NFR *Goldeck* is composed of stands in various diameter classes or respectively a mixture of those. The high values of mean volume could either indicate a very good site fertility or that the forest stands are over-aged. Considering the age structure (see Fig. 12) and the fact that tree heights up to 46m were measured at the steep slopes it is probably a result of both. Even aged over-mature forests pose the risk of large-scale breakdown of the stands and discontinuity of protective functions before regeneration can take over their position. Due to the heterogenic age structure and the existing smaller gaps there are already some regeneration patches in the reserve (see chapter 3.3 and 4.3). The good site fertility and a high growth rate might shorten the time of low protection during regeneration phases and can increase stability.

The importance of deadwood and woody debris includes its ecological value for biodiversity, its influence on the productivity (Motta et al. 2006) and its benefits for (temporary) protection against natural disasters (Frehner et al. 2005) are known. Compared to previous deadwood studies conducted in unmanaged Norway spruce forests of Central Europe as in *Panneveggio*/Italy (23.4 m^3/ha), *Wettersteinwald*/Germany (84 m^3/ha) and *Kosodrevina*/ Slovakia (50-200 m^3/ha) (reviewed by Motta et al. 2006) the 50-70 m^3 vertical and horizontal deadwood per hectare of the NFR *Goldeck* show medium values. Investigations in Austria indicate that large Norway spruce trees with a position parallel to the contour line can act as effective rock fall barriers for about 10 years (Dorren et al. 2004) (Fig. 31). During the decomposition process of the wood the stones get however released again. Additionally, stumps, root plates and lying stems reduce the risk for snow movement considerably (Frehner et al. 2005). Larger deadwood particles lying in slope direction without anchoring can cause log jams at bridges of mountain torrents in case of debris flow (Rickli et al. 2004). Chapter 4.2 has discussed regeneration conditions on deadwood.

High coefficients of variation of up to 100% for mean values of stem number, volume (see Tab. 5) and regeneration density (see chapter 3.2), and for the stability parameters crown ratio and ratio of slenderness, especially in the *Galio rotundifolii-Abietum* illustrate the substantial heterogeneity of the forest stands. The sampling intensity is considered to be large enough for the study area, since the results of the NaiS investigation, where about half of the entire study area was assessed show similar magnitudes of standard deviation.

Fig. 31 A Norway spruce trunk as effective temporal rock fall barrier in the NFR *Goldeck* (Photo: M.B. Winter)

The increment cores for the investigation of tree age were taken at the ground base of the trees (0.0m). Dendrochronological studies in lower elevations or of single layer forest stands regularly sample the trees in 1.3m height to avoid sampling irregular growth patterns at the stem base and to exclude reaction wood. Choosing the ground base as sampling height does not allow a regular growth analysis with the samples. It is however a good method to access the year of germination in highly structured forests, where the time the tree needs from germination till reaching a height of 1.3m varies from tree to tree due to heterogeneous stand and shading conditions and can not be as easily calculated as in homogenous stands. The oldest sampled tree, a Norway spruce, germinated in 1786. Under optimal growing conditions in the northern foothills of the Alps, Norway spruce can reach an age of up to 600 years (Schütt et al. 2002). The age class frequencies (see Fig. 12) represent the age structure of the upper NFR Goldeck. Probably the representation lacks validity in terms of frequency (stem number) per age class, because only one tree was sampled per diameter class and plot, no matter if 1 or 30 trees were present in one diameter class. But is still shows the trend that most of the study plots consist of medium to old trees (80-140 years), while younger trees and trees older than 140 years in age can be found only on some plots. This is consistent with the overall impression of the forest stands. The situation of the young growth, and trees in the thicket stage is however not observed, because no trees <15cm DBH were sampled to avoid damages to the small trees.

4.2 Regeneration

The occurrence of spruce seedlings depended significantly on the amount of solar radiation and humus layer conditions. For the saplings radiation, moss coverage, soil humidity and slope gradient had a minor but significant influence on their appearance. Various studies have already prooved the micro site effects on the occurrence of natural regeneration (Ott et al. 1997, Brang 1996, Hunziker, Brang 2005). Contrary to regeneration studies in the subalpine mountain forest that emphasise the importance of direct radiation for the seedling development (Ott et al. 1997, Brang 1996) seedlings in the montane zone seem to be able to survive with almost diffuse radiation only (Hunziker, Brang 2005). Table 7 and 8 show that this relation can be confirmed with the study in the NFR *Goldeck* similarly. Both binary logistic regression models include direct radiation as significant explanatory variable, but for the seedling model (-0.060) as well as for the sapling model (0.061) the parameter values are close to 0 and the importance for the probability for regeneration is therefore rather low. Indirect radiation proportions in the forest stand are higher than for those of direct radiation and are almost identical for seedlings and saplings (see Fig. 18 & 19). As the parameter values are very low (see Tab. 7 & 8) a change in diffuse radiation does not change the regeneration probability considerably. This indicates surprisingly that radiation generally is not a limiting factor for spruce seedlings and saplings on the mostly North and West facing slopes of the study area.

According to Mosandl and El Kateb (1998) a canopy closure of more than 75% decreases the probability of regeneration establishment in mountain forests of the Bavarian Alps. Only few study plots showed a crown closure above 75% in this investigation (see Tab. 4). Ammer (1998) concludes after long term regeneration studies in the Bavarian Forest that good site conditions might decrease the importance of radiation availability. Figure 15 and 16 demonstrate however that higher seedling and sapling densities could be found at intensified radiation levels. There is also a slight increase in the parameter values of radiation from the seedling to the sapling model and Figure 26 illustrates that most of the damages of the large saplings (30-130cm) are caused by competing saplings or in some cases by competing trees which can be explained as a competition for light (in regard to tree heights up to 46.5m and a therefore good site fertility, water and nutrients are considered to be not a limiting factor). Changing importances of requirements during the different phases of regeneration development are documented as well for other studies of spruce regeneration in the European Alps (Diaci 1997, Brang 1998).

Fig. 32 Norway spruce regeneration in a gap on plot no. 29 in the *Galio-rotundifolii-Abietum* (Photo: M.B. Winter)

Litter accumulation and thick humus layers are considered to diminish seedling probability in some investigations, because the root systems of the young spruce do not reach the mineral soil during the first years following germination (Brang 1996, Brang 1998). Diaci et al. (2002) prooved in their analysis the limiting effect of decreasing moisture availability for spruce regeneration due to drought in the upper humus layers of southern exposed mountain forests in the Slovenian Alps. Contrarily, Hanssen (2003) and Baier et al. (2007) show positive effects of an increasing humus depth on regeneration probability on alkaline soils due to improved nutrition uptake caused by the acid organic layers. The explanatory regression model for *Goldeck* showed as well a significant positive influence of thick humus layers on seedling occurrence.

The mean slope gradient of the study area in the NFR is 81% (minimum 40%, maximum 130%) (see Tab. 5). Caused by the horizontal measurement of the subplot size the effective surface size of the subplot, and therefore the potential area for regeneration, increased up to a slope gradient of 100%. Nevertheless the logistic regression model prooved the increasing slope gradient to be of significant negative importance for sapling growth. Rock fall, erosion and snow gliding are natural hazards that are strongly linked with higher slope gradients

(Ammer 1990, Frehner et al. 2005) threatening also the establishment and survival of the regeneration. Situations as shown in figure 33 were frequently found in the NFR. Erosion can lead to a washout of spruce seeds as well as to a float off of small spruce plants.

Many studies describe therefore the great importance of structural elements on natural regeneration on mountain forest slopes (Baier at al. 2005, Diaci et al. 2005, Rammig et al. 2006). The parameter *deadwood as obstacle* chosen for this study to describe structural elements on the subplots might have been to imprecise in spatial resolution to be valid as safety variable (e.g., against snow gliding or erosion) for the single seedling or sapling individuals.

Fig. 33 Small scale erosion on plot no. 29 in the NFR *Goldeck*

Ground cover, especially the proportion of mosses, had a significant influence on the probability of spruce occurrence in the sapling model. Due to an absence of larger disturbances over the last years in the study area it is assumed that the ground cover did not change considerably since the establishment of the saplings (<15cm). According to Brang (1996) the main factors affecting the degree of positive or negative influence of moss coverage on regeneration success are the present moss species, thickness of the moss mats and moisture. The moss mats in the study area with a mean height of around 3 to 5cm, mainly of *Hylocomium splendens* and *Pleurozium schreberi* allow therefore favourable conditions in maintaining a appropriate moisture condition for the saplings. The same trend is

indicated in Figure 19 where higher sapling densities are linked to greater shares of moss cover.
Mineral soil seedbeds influence Norway spruce regeneration positively (Brang 1998). The fact, that no significant relationship could be detected in this analysis might be a consequence of the small share of mineral soil (3.5% in average of the sample plots) in comparison to total ground cover in the study area.

The parameter *soil humidity* contributed significantly to the sapling model. Most of the spruce seedlings and saplings might not reach the mineral soil with their root system yet as the humus depth is larger than 3cm in most of the subplots (see Fig. 16 and 17). They are therefore not directly linked to the soil humidity. But due to the northern aspect of the study site, appropriate precipitation amounts and a consequently low probability for drought in this altitudes, the moisture conditions in the humus are assumed to be strongly related to the humidity in the soil. The negative influence of soil humidity shows that moisture is not a minimising factor for spruce saplings in the NFR *Goldeck*. On the other hand an increasing soil humidity might be linked with higher above ground and lateral water transport increasing as well the risk of erosion. A relation between soil humidity and the occurrence of small depressions at the slope leading to snow accumulation (and consequently shorter vegetation period and increased risk of *Herpotrichia juniperi* infestation) could explain the considerable difference between seedling and sapling density on fresh soil demonstrated with figure 18 and 19. The seedlings of this year have not yet been affected by any snow conditions, contrary to the saplings where already a selection might have taken place. However, there is only a slightly negative correlation (-0.1) between soil humidity and the slope gradient of the subplots of category A or B. This results suggest that it might be useful to record the micro relief in the direct surrounding of the single regeneration individuals in further studies and not as average value for the whole subplot of 0.25 or 1 m^2.

Missing regeneration is not considered to be a result of insufficient seed supply in this study. Table 1 depicts high potential seed production of Norway spruce in the years 2003 and 2006 and only 2001 is mentioned as year with missing seed production due to late frost. The altitudinal difference between Spittal/Drau (560m a.s.l.) and the NFR Goldeck (1 040-1 620m a.s.l.) might lead to minor variations in fructification patterns. But contrary to regeneration studies on large windthrow areas were the non-availability of seed trees can be a limiting factor (Rammig et al. 2006) the subplots of this study have all been in close distance to potential mother trees.

Regeneration density (seedlings & saplings <15 cm) of Norway spruce (2.40 ± 3.34 per m^2) (mean ± standard deviation) was comparable with the results of Hunziker and Brang (2005) (1.30 ± 4.25 per m^2) who investigated microsite patterns of conifer seedling (1-6 years old) establishment and growth on a north-facing slope in the upper montane zone of the Swiss southern central Alps. Baier at al. (2005) measured higher densities of large spruce saplings (20-200 cm) in small canopy gaps of southern exposed slopes (1 000 m a.s.l.) in the Bavarian Limestone Alps (4 200 stems/ha) than were investigated in this study (1 014 stems/ha). Higher densities can be found in general for seedlings than for saplings indicating that the survival of saplings seems to be more critical than the initial establishment (Streit et al. 2009). Figure 22 and 23 show a similar trend within in the class of large saplings (30-130 cm) with decreasing frequencies at increasing size (height and root collar diameter). The Austrian National Forest Inventory (ANFI) developed target values of sapling densities that should be reached to talk of an sucessfull regeneration (Schieler, Hauk 2001). The necessary densities decrease with increasing mean height of the regeneration (between 10 and 130 cm). For a mean sapling height of 70 cm 567 individuals have to be present per hectare, whereas one 80 cm tall sapling can be substituted by nine saplings with an average height of 10cm (Schieler, Hauk 2001). The average sapling (30-130 cm) density in the study area was 390 with a mean height of 70 cm. Adding the figures of the small saplings (1 year old till 30 cm) with an assumed mean height of 10 cm and calculating with the substitution factor of nine 1 400 saplings (∅70cm tall) were recorded in average per hectare. There was however a large heterogeneity among the single plots (see Fig 21). Target values for successful regeneration have to be specified for the primary forest function (Ammer 2004) and a rock fall protection forest in the upper montane zone in Carinthia might need other target values than the average Austrian forest assessed in the ANFI. The NaiS requirements (Frehner et al. 2005) concerning regeneration densities within the forest communities are hardly separable from their spatial context. The minimal profiles of the guideline recommend 70 regeneration plots per hectare in the *Larici-Piceetum* and 30 regeneration plots/ha in the *Galio rotundifolii-Abietum* (saplings with > 40 cm tree height till 12 cm DBH). The 529 spruce saplings of the required size that were measured on average per hectare would correspond to 8 and 18 individuals per regeneration plot respectively, considering a regular regeneration pattern. This would more or less match the NaiS requirements. The regeneration is however distributed very irregularly (see Fig. 21). Compare chapter 4.3 for the discussion of the spatial resolution of the regeneration. As the data collection was conducted in September it is possible that not all the germinated seedlings survived till the end of the vegetation period and were possibly excluded from the investigation. However, almost no dead seedlings very found during the field work.

Solely Norway spruce regeneration was recorded in considerable amount (see chapter 3.2). European Larch and Silver fir which constitute 10% and 4% of the tree layer respectively are clearly underrepresented in thetotal share of seedlings and saplings. Especially in the *Galio rotundifolii-Abietum*, where Silver fir is an essential part of the potential natural vegetation, the missing fir regeneration leads to major deficiencies in the fulfilment of the protection requirements (see chapter 3.3). European Larch is very susceptible to low radiation intensities and depends on open mineral soil for germination (Schütt et al. 2002). The adequate amount of adult trees mainly in the upper part of the NFR might be an indicator for lower rates of canopy closure at the time of their germination 100-200 years ago. Also spruce bark beetle calamities or windthrows might have caused the higher share of Larch.

The importance of deadwood and woody debris for natural regeneration of mountain forests is documented frequently in literature (e.g., Eichrodt 1969, Stöckli 1995, Diaci et al. 2002, Brang 2003, Baier et al. 2005, Motta et al. 2006). The higher position on the deadwood lowers the danger of late frost effects for the regeneration (Diaci et al. 2002), mitigates the competition with ground vegetation (Motta et al. 2006) and reduces the risk of damages due to rock fall, erosion or snow gliding. Additionally woody debris can increase water availability and nutrient uptake compared to mineral soil horizons (Baier et al. 2005). This is especially true in north-facing continuous cover mountain forests where the risk of rapid drought of the deadwood is minimized (Ott et al. 1997). While the first stages of decomposition are rarely covered with seedlings a proceeding decomposition improves the suitability of the woody debris for regeneration (Motta et al. 2006). Similar results have been found in the present investigation (see Fig. 20). The highest seedling and sapling density can be found on deadwood with strong decomposition. The relative regeneration densities on strongly decomposed deadwood were higher than on the regular subplots on the soil. Also the densities of large saplings was found to be six times higher on deadwood compared to potential growth areas on the ground (see chapter 3.2).

Medium vitality was documented for most of the large saplings (30-130cm). Only one third of the individuals expressed a bad constitution (see Fig. 22), mainly due to intraspecific competition and browsing (see Fig. 26). Healthy and vital regeneration is necessary for a continuous achievement of protective forest functions. Calculating only with saplings with good and medium vitality as effective regeneration would still fulfil the requirements of Schieler and Hauk (2001) for the ANFI.

Insect damages of larger saplings (30-130cm) (see Fig. 26) were mainly caused by *Sacchiphantes viridis* Ratzeburg and *Adelges laricis* Vallot. The infestations were found frequently, but were rarely leading to severe damages. Some of the older trees were infected as well, with the consequence of minor losses in increment (Amann 2003).

4.3 Protection efficiency

Forested hillslopes offer significantly higher protection effectiveness than non-vegetated slopes (e.g., van Steijn 1996, Margreth 2004, Brauner et al. 2005, Dorren et al. 2005). Nevertheless not all forest fulfil protection requirements to the same degree. According to Dorren et al. (2004) ecological stability, necessary for long-term continuous and effective protection in the European Alps, depends on (i) a diverse species composition, (ii) sufficient natural regeneration and (iii) optimal forest structure.

As discussed in chapter 4.1 the tree species of the study area in the NFR *Goldeck* are the species of the potential natural vegetation of the forest communities *Larici-Piceetum* and *Galio rotundifolii-Abietum*, but the share of Silver fir does not meet the optimal composition, especially in the middle part of the NFR. This is pictured as well by the results of the NaiS assessment. The parameter species mixture is characterised by slightly negative values on almost all the plots (see appendix, Tab. 12-14). Silver fir is with its deep roots and lower susceptibility for lethal beetle infestations an important species of the montane protection forests (Rickli et al. 2002). As forest management is excluded from the reserve and therefore intraspecific competition with spruce can not be influenced, strong emphasis should be put on effective regulation of the other, probably even more important, influencing factor – ungulate browsing – in order to maintain and improve the protective functions of the forest.

Slightly different results concerning the regeneration situation analysed on the study subplots and by the NaiS assessment can be partly explained by the lack of Silver fir on the subplot as well, as fir was not included in the regeneration analysis due to the low number of seedlings and saplings. Another reason is the dissimilar size of the two investigations. The study area is very heterogenic as demonstrated in large standard deviations of almost all calculations and the larger plot size in the NaiS assessment balances this heterogeneity more than the small subplots. A slight improvement in the situation of the small saplings is visible during the next 50 years (see Fig. 28), because some of the old tree groups are estimated to break down in near future, improving the light situation for the regeneration. The parameters *small and large saplings* are however still negative in 2058, as regulation of ungulate browsing was not considered to change in the assessment. A first step of an target oriented way to improve the regeneration situation of silver fir, would be to set up some small fences that can not be penetrated by deer to be able to quantify and demonstrate the impact of ungulate browsing and to develop and monitor a adapted regulation. The parameter *germination conditions* performed well due to satisfactory amounts of deadwood in the study area. The mainly mature to over-mature stand structure with old trees to fall in the next years indicate that the situation will not decline in near future.

The optimal forest structure for effective protection is often defined with minimum stand density (with required DBH), stable stands and a maximum gap size (Dorren et al. 2005, Brauner et al. 2005). Partly this targets are contradictory to the requirements (e.g., light) that are necessary for regeneration and consequently continuous protection fulfilment (Dorren et al. 2005, Cordonnier et al. 2008). Threshold values applied for the quantification of protection effectiveness have thus to find a compromise between the two aspects (Dorren at al. 2005). Experiences from rock fall experiments in France show that the number of trees is often more important for stopping boulders than the actual diameter of the trees (Dorren et al. 2004). For the NaiS assessment only trees with a DBH larger than 12cm were considered but a majority of the plots fulfilled or almost fulfilled the requirements of 400 trees per hectare. The study area is however characterised by several gullies that pass through the study area in slope direction. Most of them do not contain water most time of the year, but they are permanently without trees, covered by a intense layer of ground vegetation, represent a enlarged risk for snow gliding and starting avalanches and often act as transit line for rock fall. Due to there topography they are probably naturally without forest stock and even active management with planting or felling trees in contour line would not improve the situation considerably.
According to the French experiments rocks attain destructive velocities already after a distance of 40m (Dorren et al. 2005). Other studies mention 30m (Brauner et al. 2005) or 20m (Frehner et al. 2005) the gap size should not exceed in order to maximise effective protection against rock fall and avalanche release. Except of the gullies mentioned above no larger gaps were found in the study area.

Tree stability performed quite well in the study area (see chapter 3.1). The mean crown ratio of 67-70% and an average ratio of slenderness of 66 indicate a good tree stability and fulfil the minimal to optimal requirements of the NaiS guidelines (Frehner et al. 2005). Solely the younger stands with small diameters in the lower part of the study area worsen the mean ratio of slenderness in the *Galio rotundifolii-Abietum* up to 101. Hardly any hanging trees were found in the investigation, but some of the trees have very shallow root systems due to big boulders situated directly under the soil surface and therefore increase the risk for windthrow.

The forest stands of the study area are characterised by an intense heterogeneity and un-even structure. This leads to a spatially differentiated picture of the present protection performance (see Fig. 27). As shown in figure 27 there is no continuous line in slope direction of bad protection efficiency, neither under current conditions nor estimated for next future. Solely the northwestern part of the reserve, which is not relevant for rock fall, is characterised by an larger area of lower performance. Otherwise areas with lower protection efficiency are next to plots with better performance. This mosaic of small patches of different developmental phases improves the stand stability (Dorren et al. 2004, Brang 1998) and reduces the length of critical periods with low protection efficiency (Cordonnier et al. 2008).

Conclusion

The study offers new insight into microsite preconditions for germination and establishment of Norway spruce in the upper montane zone of the southern inner Alps. The binary logistic regression analysis proofs that seedlings and saplings are significantly influenced by micro site conditions. While radiation, humus depth and moss cover promote germination or establishment of spruce regeneration, an increasing slope gradient and soil humidity diminishes the probability of a successful regeneration process.
Due to the single case approach of the study the interpretation of results on a larger scale have to be dealt with caution. Nevertheless, comparable studies on regeneration processes of Norway spruce in mountain forests (Frehner 1989, Brang 1998, Hunziker, Hunziker, Brang 2005, Baier et al. 2005) show similar results. Different findings are however due on south facing slopes (Brang 1998).

Clear advantages of the microsite concept as approach for the regeneration studies are the rather easy assessability of the parameters and applicability of the results for planning silvicultural treatments (Hunziker, Brang 2005). Neglecting other parameters that are more difficult to assess, as mycorrhizal networks, nutrient supply or the intensity of pathogenic infestations as of *Herpotrichia juniperi* limits however the validity of the models if those parameters are important for spruce regeneration. This might be an explanation of the low R^2 especially in the seedling model of this study. Taking into account the substantial damages of larger saplings caused by browsing suggests a partial fencing of the study area for further studies to be able to quantify the effect of ungulates on small spruce regeneration in the upper montane zone of this region.

The forests stands of the NFR can develop since 1998 without human intervention by forest management. The signs of human influence (as the stumps of the selection cut in 1954) are however still present and partly shape the forest structure, especially the distribution of smaller regeneration gaps. The results of this study have therefore to be interpreted with caution in regard to their validity for real natural forest processes.

The study shows that the forest stands of the upper part of the NFR *Goldeck* can effectively contribute to the protection against rock fall and avalanches in most of the cases. Several natural gullies without permanent forest stock crossing the reserve and the absence of Silver fir regeneration restrict the protective functions to some extent. Windthrows, avalanches and snow breaks have the potential to impair effective protection of forests on large areas (Cordonnier et al. 2006). If large-scale disturbances will occur in the forest reserve and the forest owner and the responsible authorities agree on continuation of the original target, which means no intervention for timber harvesting or planting, it has to be evaluated whether the protective functions can still be fulfilled satisfactory by the forest in the reserve and the surrounding stands or if additional artificial devices are necessary.

Site characteristics as geology, topography and climate determine frequency and intensity of damaging events (Brang 2001). For the assessment of the protective forest functions in the NFR *Goldeck* the risk is assumed to stay constant over the next 50 years. In respect to the changing global climate (IPCC 2007), and possible alterations in the assumed development, the present assessment might need a thorough revision in future.

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REFERENCES

Amann G (2003) Kerfe des Waldes. Neumann-Neudamm AG, Melsungen

Ammer U (1990) Auswirkungen des Bestockungswandels und der Waldschäden auf die Schutzfunktion des Bergwaldes gegenüber Schneebewegungen. Beih. FwCbl 40:102-111

Ammer C (1996)a Konkurrenz um Licht – zur Entwicklung der Naturverjüngung im Bergmischwald. Forstl. Forschungsber. München Nr. 158, 211 S.

Ammer C (1996)b Impact of ungulates on structure and dynamics of natural regeneration of mixed mountain forests in the Bavarian Alps. For. Ecol. Manage. 88, 43–53.

Ammer C (1998) Die Fichte in der natürlichen Verjüngung des Bergmischwaldes. AFZ/Der Wald 8/1998

Ammer C, Weber M, Mosandl R (eds) (2004) Regenerating Mountain Forest. Series of Conference Proceedings, No. 1. 115 S.

Baier R, Meyer J, Göttlein A (2005) Regeneration niches of Norway Spruce (Picea abies (L.) Karst.) saplings in small canopy gaps in mixed mountain forests of the Bavarian Limestone Alps. Eur J Forest Res 126: 11-22.

Bauerhansl C, Koukal T, Schadauer K (2007) Erste österreichweite Waldkarte. Forstzeitung 12, 26 – 27. Available online: http://www.waldwissen.net/ (Accessed on 21/04/2009)

BFI (2008) Revier-Info 206021 Baldramsdorf 2000-2008. Interne Datenbank.

BMFLUW (2005) Impulse für die Schutzwaldstrategie. Online information: www.lebensministerium.at (Assessed on 21/04/2009)

BMFLUW (2008) Schutzwald – was ist das? Online information: http://forst.lebensministerium.at/article/archive/4947 (Assessed on 21/04/2009)

Bräker OU (1981) Der Alterstrend bei Jahrringdichten und Jahrringbreiten von Nadelhölzern und sein Ausgleich. In: Dickenwachstum der Bäume. Mitteilung der forstlichen Bundes-Versuchsanstalt Wien 142: 75-105

Brang P (1996) Experimentelle Untersuchungen zur Ansamungsökologie der Fichte im zwischenalpinen Gebirgswald. Beih. Nr. 77 Schweiz. Z. Forstwes.

Brang P (1998) Early seedling establishment of Picea abies in small forest gaps in the Swiss Alps. Can J. For Res 28: 626-639

Brang P (2001) Resistance and elasticity: promising concepts for the management of protection forests in the European Alps. For Ecol Manag 145: 107-119

Brauner M, Weinmeister W, Agner P, Vospernik S, Hoesele B (2005) Forest management decision support for evaluating forest protection effects against rock fall. For Ecol Manag 207: 75-85

Brunner A (1994) Ökologische Lichtmessungen im Wald. Forstarchiv 65: 133-138

Cordonnier T, Courbaud B, Berger F, Franc A (2008) Permanence of resilience and protection efficiency in mountain Norway spruce forest stands: A simulation study. For Ecol Manag 256: 347-354

Diaci J, Pisek R, Boncina A (1997) Regeneration in experimental gaps of subalpine Picea abies forests in the Slovenian Alps. Eur J Forest Res 124: 29-36

Dorren LKA, Berger F, Imeson AC, Maier B, Rey F (2004) Integrity, stability and management of protection forests in the European Alps. For Ecol Manag 195: 165-176

Dorren LKA, Berger F, le Hir C, Mermin E, Tardif P (2005) Mechanisms, effects and management implications of rock fall in forests. For Ecol Manag 215: 183-195

Eichrodt R (1969) Über die Bedeutung von Moderholz für die natürliche Verjüngung im subalpinen Fichtenwald. Beih Schweiz Z Forestw 45:122

Frank G, Koch G (1999) Country Reports for the COST Action E4: Forest Reserves Research Network. In: Parviainen, J. et al. (1999): Research in Forest Reserves and Natural Forests in European Countries. EFI Proceedings No. 16, 1999: p. 35-54

Frank G (2006) Naturwaldreservate-Programm in Österreich. Online publication: http://bfw.ac.at/rz/bfwcms.web?dok=4614. Accessed on 22/04/2009

Frehner M, Wasser B, Schwitter R (2005) Nachhaltigkeit und Erfolgskontrolle im Schutzwald. Wegleitung für Pflegemassnahmen in Wäldern mit Schutzfunktion, Vollzug Umwelt. Bundesamt für Umwelt, Wald und Landschaft, Bern

Geologische Bundesanstalt (2006) Geologische Karte der Republik Österreich. Blatt 182 Spittal an der Drau. Geologische Bundesanstalt, Wien

Hamilton LS, Gilmour DA, Cassells DS (1997) Montane forests and forestry. IN: Messerli B, Jves JD (Eds.) Mountains of the World: A Global Priority. A contribution to Chapter 13 of Agenda 21. Parthenon Publishing Group, New York, pp. 281-311

Hanssen KH (2003) Natural regeneration of Picea abies on small clear-cuts in SE Norway. For Ecol Manag 180: 199-213

Hauk E (1997) Gutachten über die Eignung des Waldbestandes ”Goldeck” als Naturwaldreservat. BFW, Wien

Hegg C, Badoux A, Lüscher P, Witzig J (2004) Zur Schutzwirkung des Waldes gegen Hochwasser. Conference proceedings. Forum für Wissen 2004: 15-20 Available online: http://www.wsl.ch/publikationen/reihen/forum/ (Accessed on 22/04/2009)

HemiView (1996) User Manual Version 2.1. Delta-T Devices Ltd, Cambridge

Heuzé P, Schnitzler A, Klein F (2005) Is browsing the major factor for Silver fir decline in the Voges Mountains of France? For Ecol Manag 217:219-228

Hunziker U, Brang P (2005) Microsite patterns of conifer seedling establishment and growth in a mixed stand in the southern Alps. For Ecol Manag 210:67-79

Hydrographischer Dienst Kärnten (2007) Langjährige meteorologische Kenngrößen: Goldeck. Archive Hydrographischer Dienst Kärnten, Klagenfurt.

Imbeck H, Ott E (1987) Verjüngungsökologische Untersuchungen in einem hochstaudenreichen subalpinen Fichtenwald, mit spezieller Berücksichtigung der Schneeablagerung und der Lawinenbildung. Mitt. Eidg. Schnee- und Lawinenforschung, Davos, 42 S.

IPCC (2007) Summary for Policymakers, In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York

KAGIS (2009) Kärntner Atlas – Das geographische Auskunftssystem der Kärntner Landesregierung. Avalable online: www.kagis.ktn.gv.at (Assessed on 14/05/2009)

Kilian W, Müller F, Starlinger F (2004) Die forstlichen Wuchsgebiete Österreichs. Eine Naturraumgliederung nach waldökologischen Gesichtspunkten. FBVA-Berichte 82/1994, 60 Seiten

Kramer H, Akça A (2002) Leitfaden zur Waldmesslehre. J.D. Sauerländer`s Verlag, Frankfurt am Main

Kräuchi N, Brang P, Schönenberger W (2000) Forests of mountainous regions: gaps in knowledge and research needs. For Ecol Manag 132:73–82

Litschauer R (2004) Pollenproduktion der Waldbäume. Online publication: http://bfw.ac.at/020/2259.html (Accessed on 21/04/09)

Margreth S (2004) Die Wirkung des Waldes bei Lawinen. . Conference proceedings. Forum für Wissen 2004: 21-26 Available online: http://www.wsl.ch/publikationen/reihen/forum/ (Accessed on 22/04/2009)

Motta R (1996) Impact of wild ungulates on forest regeneration and tree composition of mountain forests in the Western Italian Alps. For. Ecol. Manage. 88, 93–98.2004.

Motta R, Beretti R, Lingua E, Piussi P (2006) Coarse woody debris, forest structure and regeneration in the Valbona Forest Reserve, Paneveggio, Italian Alps. For Ecol Manag 235:155-163

Mosandl R, El Kateb H (1988) Die Verjüngung gemischter Bergwälder – Praktische Konsequenzen aus 10 jähriger Untersuchungsarbeit. Forstw. Cbl. 107:2-13

Ott E, Frehner M, Frey HU, Lüscher P (1997) Gebirgsnadelwälder: Ein praxisorientierter Leitfaden für eine standortgerechte Waldbehandlung. Haupt, Bern

Pilcher JR (1990) Sample preparation, cross-dating and measurement. In: Cook ER, Kairiukstis LA (eds) (1990) Methods of Dendrochronology. Kluwer Academic Publishers. Dordrecht, Boston, London

Pollanschütz J (1974) Formzahlfunktionen der Hauptbaumarten Österreichs. Allg. Forstzeitung Wien. 85:341-343.

Rammig A, Fahse L, Bugmann H, Bebi P (2006) Forest regeneration after disturbance: A modeling study for the Swiss Alps. For Ecol Manag 222: 123-136

Rauter A (1993) Waldbestände im Naturwaldreservat Goldeck bei Spittal/Drau. Diplomarbeit an der Universität für Bodenkultur, Wien

Rickli C, Zürcher K, Frey W, Lüscher P (2002) Wirkungen des Waldes auf oberflächennahe Rutschprozesse. Schweiz. Z. Forstwes. 153/11: 437-445

Rickli C, Graf F, Gerber W, Frei M, Böll A (2004) Der Wald und seine Bedeutung bei Naturgefahren geologischen Ursprungs. Conference proceedings. Forum für Wissen 2004: 27-34. Available online: http://www.wsl.ch/publikationen/reihen/forum/ (Accessed on 22/04/2009)

Rinn F (1996) TSAP-Reference Manual. Frank Rinn. Heidelberg

Salm B, Burkard A, Gubler H (1990) Berechnung von Fliesslawinen. Eine Anleitung für Praktiker mit Beispielen. Mitt. Eidgenöss. Inst. Schnee- Lawinenforschung Davos, Nr. 47

Schadauer K (2004) Ergebnisse der Österreichischen Waldinventur 2000-2002. Available online: http://web.bfw.ac.at/i7/oewi.oewi0002 (Assessed on 21/05/2009)

Schieler K, Hauk E (2001) Instruktion für die Feldarbeit - Österreichische Waldinventur 2000/2002. FBVA; Wien 2001, 199 S.

Schodterer H (2004) Verjüngung und Wildeinfluss – Inventurergebnisse richtig interpretieren. BFW Praxisinformation Nr. 4

Schütt P, Schuck HJ, Stimm B (2002) Lexikon der Baum- und Straucharten. Nikol Verlagsgesellschaft mbH & Co. KG, Hamburg

Schütz JP (2001) Der Plenterwald und weitere Formen strukturierter und gemischter Wälder. Parey Buchverlag, Berlin

Schweingruber FH, Müller M (1992) Dendrochronological evidence in fir and spruce of alternating frosts in Switzerland. Dendrochronologia 10, 23–28.

Stancioiu PT, O´Hara KL (2006) Regeneration growth in different light environments of mixed species, multiaged, mountainous forests of Romania. Eur J Forest Res 125:151-162

Stöckli B (1995) Moderholz für die Naturverjüngung im Bergwald. Merkblatt für die Praxis, Eidg. Forschungsanstalt für Wald, Schnee und Landschaft 26: 8-14

Stöckli V, Pfister R, Frey W (1997) Erforschung der Wechselwirkung zwischen Schutzwald und Lawinen. Schweizer Wald 11, 14-17

Streit K, Wunder J, Brang P (2009) Silt-shaped gaps are a successful silvicultural technique to promote Picea abies regeneration in mountain forests of the Swiss Alps. For Ecol Manag 257:1902-1909

Tabachnick BG, Fidell FS (1989) Using multivariate statistics. Harper & Row, New York

van Steijn H (1996) Debris-flow magnitude-frequency relationships for mountainous regions of Central and Northwest Europe. Geomorphology 15, 259-273

Uggowitzer B (2008) Pers. com. (30/09/2008). Municipality administration Spittal/Drau

Vospernik S (2002) Predicting forest growth against rock fall. Final report, Institute of Forest Growth and Yield, University of Agricultural Sciences, Vienna

Walter, G (2008) Pers. com. 03/10/2008. Municipality administration, Baldramsdorf

WLV (2000) Schwaigerbach – Technischer Bericht. Archiv Technischer Dienst für Wildbach und Lawinenverbauung, Sektion Kärnten, Gebietsbauleitung Oberes Drautal und Mölltal, Villach

WLV (2005) Schwaigerbach – Wildbachaufnahmeblatt & Lawinenaufnahmeblatt. Archiv Technischer Dienst für Wildbach und Lawinenverbauung, Sektion Kärnten, Gebietsbauleitung Oberes Drautal und Mölltal, Villach

STATUTORY DECLARATION

Hereby I assure that I wrote independently this present Master Thesis

”Natural regeneration and protection efficiency of the upper montane forests in the Natural Forest Reserve Goldeck, Carinthia”

and did not use other than indicated sources and aids.

Vienna, June 2009

Maria-Barbara Winter

APPENDIX

Tab. 9 Sampling design and recorded parameters of different plot types in the NFR *Goldeck*

NaiS plots ~ 0.75ha (n=30)	**Regular sample plots** 300m^2 (n=30)	**Subplots category A** 0.25m^2 (n=480)	**Subplots category B** 1m^2 (n=360)
Assessment of the parameters: • tree species composition • horizontal structure • vertical structure • stand and tree stability • germination • seedling conditions • sapling conditions Comparison with NaiS minimal and ideal profile depending on present forest community and relevant natural disaster.	Assessment of the parameters: • site description • altitude • aspect • slope gradient • geology • meso relief • micro relief • forest community • historical use • dominance of the tree layers Full enumeration of saplings 30-130cm height: • tree species • root collar • height • height increment of preceding year • vitality • browsing • damages (type and intensity) • micro relief of position Full enumeration of trees > 1.3m height: • tree species • location • DBH • height • crown height • horizontal crown size • damages • "neighbour trees" Full enumeration of standing and lying deadwood: • tree species • location • DBH/ mid diameter • height/ length • deadwood type • degree of	Assessment of the parameters: • aspect • soil type and texture • deepness of soil • soil hydrology • soil humidity • slope gradient • micro climate • potential regeneration restraints • mean height of ground vegetation • humus type • humus depth • ground cover • dominance of vascular plants and mosses Numeration of seedlings and saplings <15cm height seperated for different tree species. Full enumeration of saplings 15-30cm height: • tree species • root collar • height • height increment of preceding year • vitality • terminal and lateral browsing • damages (type and intensity) • micro relief of position	Assessment of the parameters: • aspect • soil type and texture • deepness of soil • soil hydrology • soil humidity • slope gradient • micro climate • potential regeneration restraints • mean height of ground vegetation • humus type • humus depth • ground cover • dominance of vascular plants and mosses Numeration of saplings <15cm height seperated for different tree species. No numeration of seedlings. Full enumeration of saplings 15-30cm height: • tree species • root collar • height • height increment of preceding year • vitality • terminal and lateral browsing • damages (type and intensity) • micro relief of position

	decomposition and decortication • cause of death • fungi and plant cover • regeneration Assessment of dominance of deadwood < 10cm diameter/plot. Sampling of increment cores of 1-3 trees per species of different diameter classes.

Tab. 10 NaiS protection requirements of *Larici-Piceetum* (*Homogyno-Piceetum calamagrostietosum villosae*) with the example of NaiS plot no. 7

NaiS form

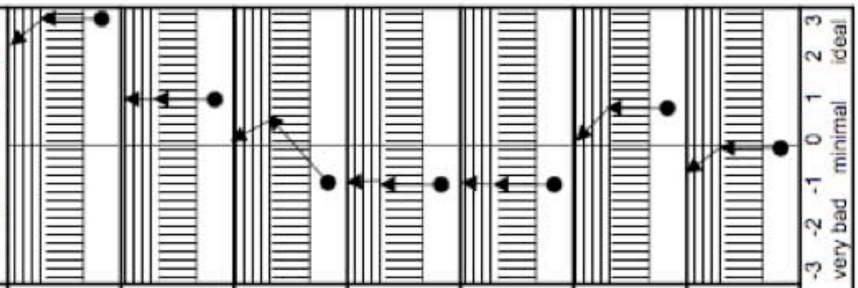
Municipality:	Baldramsdorf (Spittal/Drau)	**Location:**	NFR Goldeck	**Plot No.**	G_07	**Date:**	05.09.2008	**Editor:**	M.B. Winter

1. Forest community: 57C Homogyno-Piceetum calamagrostietosum villosae

2. Natural hazard: Rock fall, avalanche, debris flow

3. Forest condition and tendency of development:

Stand and tree attributes	Minimal profile (incl. natural hazard)	Today's condition	Today's condition, development in 10, 50 years
• **Mixture** (Species and %)	Spruce: 70-100% Larch: 0-30% Mountain ash: seedtrees-30% some Green alders	Spruce: 60% Larch: 40% Mountain ash: seedtrees	
• **Vertical structure** ∅-distribution	Enough developable trees in at least 2 diameter classes/ha	Enough developable trees in 3 diameter classes	
• **Horizontal structure** Dominance, gap length, stem number	At least 400 trees/ha with DBH >12cm, gap in slope line <20m, lying wood and high stumps, tree dominance >50%, small groups or single trees	Around 400 trees/ha with DBH >12cm, single small gaps in slope line <20m, tree dominance 70%, ingrowth of thinner trees but also break-down of old trees in the future	
• **Stability** crown development, h/d-ratio, target diameter	Crown ration at least 2/3, perpendicular stems, good anchoring, only single hanging trees	Crown ratio of spruce 1/3-2/3, of larch 1/3, perpendicular stems, good anchoring, no hanging trees	
• **Regeneration** germination condition	Every 10m deadwood or elevated micro sites with Mountain ash or mineral soil, protection against snow gliding	Deadwood available, but little protection against snow gliding	
• **Regeneration** seedlings & saplings <40cm	At least at 30% of the micro sites favourable for regeneration present spruce and Mountain ash regeneration	very good regeneration plots spreaded over the plot, probably increasing light deficiency in the future	
• **Regeneration** 40cm height - 12cm DBH	At least 70 regeneration plots/ha (every 12m), mixture as targeted	regeneration plots available, downgrading light conditions in the future	
			-3 -2 -1 0 1 2 3 very bad minimal ideal



Tab. 11 NaiS protection requirements of *Galio rotundifolii-Abietum* (*Galio-Abieti-Piceetum typicum*) with the example of NaiS plot no. 33

NaiS form			
Municipality: Baldramsdorf (Spittal/Drau)	**Location:** NFR Goldeck	**Plot No.** G_33 **Date:** 22.09.2008	**Editor:** M.B. Winter
1. Forest community:	51 Galio-Abieti-Piceetum typicum		
2. Natural hazard:	Rock fall, avalanche, debris flow		
3. Forest condition and tendency of development:			
Stand and tree attributes	Minimal profile (incl. natural hazard)	Today's condition	Today's condition, development in 10, 50 years
• **Mixture** (Species and %)	Fir: 30-90% Spruce: 10-70% Larch: 0-60% Mountain ash & Sycamore maple: seedtrees-30%	Fir: 5% Spruce: 75% Larch: 20% Mountain ash & Sycamore maple: seedtrees	
• **Vertical structure** ∅-distribution	Enough developable trees in at least 2 diameter classes/ha	Enough developable trees in 2 diameter classes, but in future trees of upper diameter class not developable any more, little ingrowth	
• **Horizontal structure** Dominance, gap length, stem number	At least 400 trees/ha with DBH >12cm, gap in slope line <20m, lying wood and high stumps, tree dominance >50%, small groups or single trees	Around 400 trees/ha with DBH >12cm, gap in slope line <20m, lying wood mostly in slope line, tree dominance 70%	
• **Stability** crown development, h/d-ratio, target diameter	Crown ration at least 1/2, perpendicular stems, good anchoring, only single hanging trees, h/d-ratio <80	Crown ration 1/2, perpendicular stems but shallow anchoring in leptosol, no hanging trees, h/d-ratio 80-100	
• **Regeneration** germination condition	Area with intense competition through ground vegetation < 1/2	No competition through ground vegetation	
• **Regeneration** seedlings & saplings <40cm	If tree dominance <60% at least 5-10 firs/a (every 3-4.5m), spruce and Mountain ash in gaps	Sruce and larch regeneration in gaps, no fir (browsing)	
• **Regeneration** 40cm height - 12cm DBH	At least 30 regeneration plots/ha (every 19m), or dominance of regeneration at least 4%, mixture as targeted	Every 30m good regeneration plots, but no fir (browsing)	
			-3 -2 -1 0 1 2 3 very bad minimal ideal

Tab. 12 Performance of NaiS plots in today's condition (2008) regarding NaiS requirements with means and standard deviations (in parenthesis)

	species mixture	**vertical structure**	**horizontal structure**	**stability**	**potential reg. sites**	**small saplings**	**large saplings**	**mean**
G_07	3	1	-1	-1	-1	1	0	**0.3** (1.5)
G_08	1	0	-1	-1	0	-3	0	**-0.6** (1.3)
G_10	0	1	-2	2	-2	0	0	**-0.1** (1.5)
G_11	0	0	-1	-1	0	-3	-1	**-0.9** (1.1)
G_12	1	1	-1	1	1	-1	0	**0.3** (1.0)
G_13	1	0	-1	0	-2	-1	-1	**-0.6** (1.0)
G_14	2	-1	-1	0	1	-3	-1	**-0.4** (1.6)
G_17	0	-1	-1	0	0	-2	-2	**-0.9** (0.9)
G_18	2	1	-2	0	-1	-2	1	**-0.1** (1.6)
G_19	0	1	-1	1	1	1	1	**0.6** (0.8)
G_20	-1	0	-1	0	-1	-2	0	**-0.7** (0.8)
G_21	-1	-1	-1	1	0	-3	-2	**-1.0** (1.3)
G_22	0	-1	-1	0	0	2	2	**0.3** (1.3)
G_23	1	-1	-1	0	0	2	1	**0.3** (1.1)
G_28	-1	0	-1	0	1	-3	-2	**-0.9** (1.3)
G_29	-1	-1	0	1	1	0	0	**0.0** (0.8)
G_30	-1	1	-1	1	3	-1	2	**0.6** (1.6)
G_31	-1	1	1	-1	1	-3	0	**-0.3** (1.5)
G_32	-1	0	0	-1	-1	-1	-1	**-0.7** (0.5)
G_33	-1	0	0	-1	2	-1	-1	**-0.3** (1.1)
G_34	0	0	-1	0	1	-1	1	**0.0** (0.8)
G_39	-1	1	1	1	-1	-1	-1	**-0.1** (1.1)
G_40	-1	0	0	0	1	-1	-1	**-0.3** (0.8)
G_41	-1	-1	-1	1	-1	-1	0	**-0.6** (0.8)
G_42	-2	0	0	0	1	-1	0	**-0.3** (1.0)
G_43	-1	-2	-1	3	-2	-2	0	**-0.7** (1.8)
G_45	-2	0	1	0	0	-1	-1	**-0.4** (1.0)
G_50	-1	-2	-2	0	0	-2	-2	**-1.3** (1.0)
G_51	-1	-1	-1	1	-1	-1	-1	**-0.7** (0.8)
G_57	-1	-2	-1	1	0	-2	-1	**-0.9** (1.1)
mean	**-0.3** (1.2)	**-0.2** (1.0)	**-0.7** (0.8)	**0.3** (0.9)	**0.0** (1.2)	**-1.2** (1.4)	**-0.3** (1.1)	**-0.3** (1.2)

Tab. 13 Probable performance of NaiS plots in 10 years (2018) regarding NaiS requirements with means and standard deviations (in parenthesis)

	species mixture	**vertical structure**	**horizontal structure**	**stability**	**potential reg. sites**	**small saplings**	**large saplings**	**mean**
G_07	3	1	1	-1	-1	1	-1	**0.4** (1.5)
G_08	1	0	0	-1	0	-3	0	**-0.4** (1.3)
G_10	0	1	-1	2	-2	0	0	**0.0** (1.3)
G_11	0	0	-1	-1	0	-2	-2	**-0.9** (0.9)
G_12	2	1	-1	1	1	1	0	**0.7** (1.0)
G_13	1	0	-1	0	-2	-1	-1	**-0.6** (1.0)
G_14	2	-1	-1	0	1	-2	-1	**-0.3** (1.4)
G_17	0	-1	-1	0	0	-2	-2	**-0.9** (0.9)
G_18	2	1	-2	0	-1	-2	1	**-0.1** (1.6)
G_19	0	1	-1	1	1	0	1	**0.4** (0.8)
G_20	-1	0	-1	0	-1	-2	-1	**-0.9** (0.7)
G_21	-1	-1	-1	1	0	-2	-2	**-0.9** (1.1)
G_22	0	-1	-1	0	0	2	2	**0.3** (1.3)
G_23	1	-1	-1	0	0	2	1	**0.3** (1.1)
G_28	-1	0	-1	0	1	-3	-2	**-0.9** (1.3)
G_29	-1	-1	0	1	1	0	0	**0.0** (0.8)
G_30	-1	1	-1	1	3	-1	2	**0.6** (1.6)
G_31	-1	1	1	-1	1	-3	0	**-0.3** (1.5)
G_32	-1	0	0	-1	-1	-1	-1	**-0.7** (0.5)
G_33	-1	0	0	-1	2	-1	-1	**0.3** (1.1)
G_34	0	0	-1	0	1	-1	1	**0.0** (0.8)
G_39	-1	1	1	1	-1	-1	-1	**-0.1** (1.1)
G_40	-1	0	0	0	1	-1	-1	**-0.3** (0.8)
G_41	-1	-1	-1	1	-1	-1	0	**-0.6** (0.8)
G_42	-1	0	0	0	1	-1	0	**-0.1** (0.7)
G_43	-1	-1	-1	2	-2	-2	0	**-0.7** (1.4)
G_45	-2	0	1	0	0	-1	-1	**-0.4** (1.0)
G_50	-1	-2	-2	0	0	-1	-1	**-1.0** (0.8)
G_51	-1	-1	-1	1	-1	-1	-1	**-0.7** (0.8)
G_57	-1	-2	-1	1	0	-1	-1	**-0.7** (1.0)
mean	**-0.2** (1.2)	**-0.2** (0.9)	**-0.6** (0.8)	**0.2** (0.9)	**0.0** (1.2)	**-1.0** (1.3)	**-0.4** (1.1)	**-0.3** (1.1)

Tab. 14 Probable performance of NaiS plots in 50 years (2058) regarding NaiS requirements with means and standard deviations (in parenthesis)

	species mixture	vertical structure	horizontal structure	stability	potential reg. sites	small saplings	large saplings	mean
G_07	2	1	0	-1	-1	0	-1	**0.0** (1.2)
G_08	1	-1	0	-1	-1	-3	-1	**-0.9** (1.2)
G_10	0	1	0	2	-1	0	-1	**0.1** (1.1)
G_11	0	0	0	-1	0	-2	-2	**-0.7** (1.0)
G_12	1	1	0	0	1	0	0	**0.4** (0.5)
G_13	0	-1	-1	-1	0	-1	-1	**-0.7** (0.5)
G_14	1	0	-1	0	-1	-3	0	**-0.6** (1.3)
G_17	0	-2	-1	0	0	-1	-1	**-0.7** (0.8)
G_18	1	1	-1	-1	-1	-1	0	**-0.3** (1.0)
G_19	0	-1	-1	0	1	-1	-1	**-0.4** (0.8)
G_20	-1	0	-1	-1	-1	-1	-1	**-0.9** (0.4)
G_21	0	-1	-1	1	0	-2	-2	**-0.7** (1.1)
G_22	0	0	-1	0	0	1	1	**0.1** (0.7)
G_23	0	-1	-1	0	0	1	1	**0.0** (0.8)
G_28	-1	-1	-1	0	1	-2	-1	**-0.7** (1.0)
G_29	0	0	0	1	0	0	0	**0.1** (0.4)
G_30	-1	2	-1	1	3	-2	1	**0.4** (1.8)
G_31	-1	0	1	0	1	-1	0	**0.0** (0.8)
G_32	-1	-1	0	0	-1	0	-1	**-0.6** (0.5)
G_33	-1	-1	0	-1	2	-1	-1	**-0.4** (1.1)
G_34	-1	0	-1	0	1	-1	1	**-0.1** (0.9)
G_39	-1	1	1	0	0	-1	-1	**-0.1** (0.9)
G_40	-1	-1	0	0	1	-1	-1	**-0.4** (0.8)
G_41	-1	-1	-1	1	-1	-1	0	**-0.6** (0.8)
G_42	-1	0	0	0	1	-1	0	**-0.1** (0.7)
G_43	-2	0	0	1	-1	-1	0	**-0.4** (1.0)
G_45	-2	0	1	0	0	-1	-1	**-0.4** (1.0)
G_50	-1	-1	0	0	0	-1	-1	**-0.6** (0.5)
G_51	-1	0	0	1	-1	-1	-1	**-0.4** (0.8)
G_57	-1	-1	-1	1	0	-1	-1	**-0.6** (0.8)
mean	**-0.4** (0.9)	**-0.2** (0.9)	**-0.4** (0.7)	**0.1** (0.8)	**0.1** (1.0)	**-1.0** (0.9)	**-0.5** (0.8)	**-0.3** (0.9)

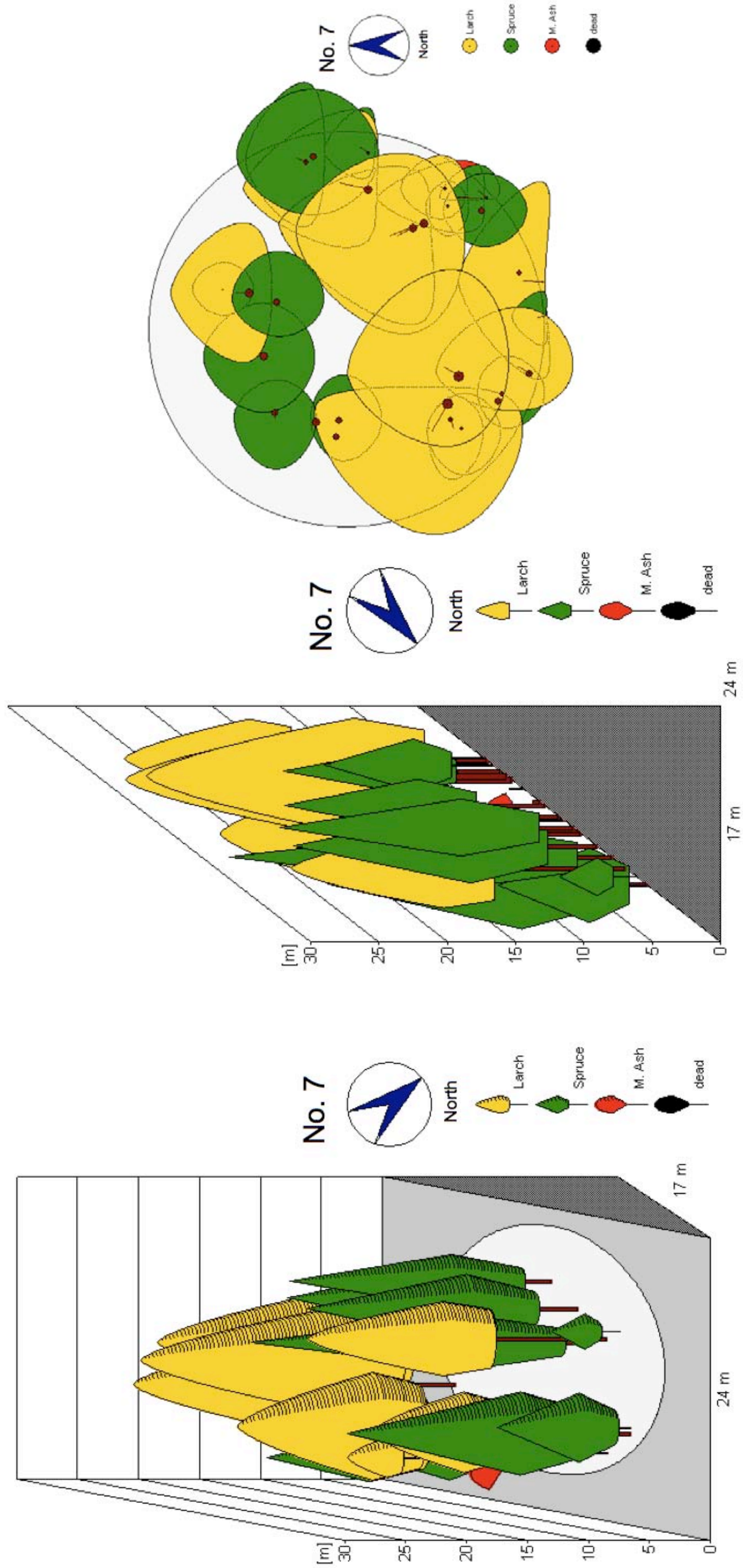


Fig. 34 Graphical presentation of sample plot no. 7 with cross-section and crown projection

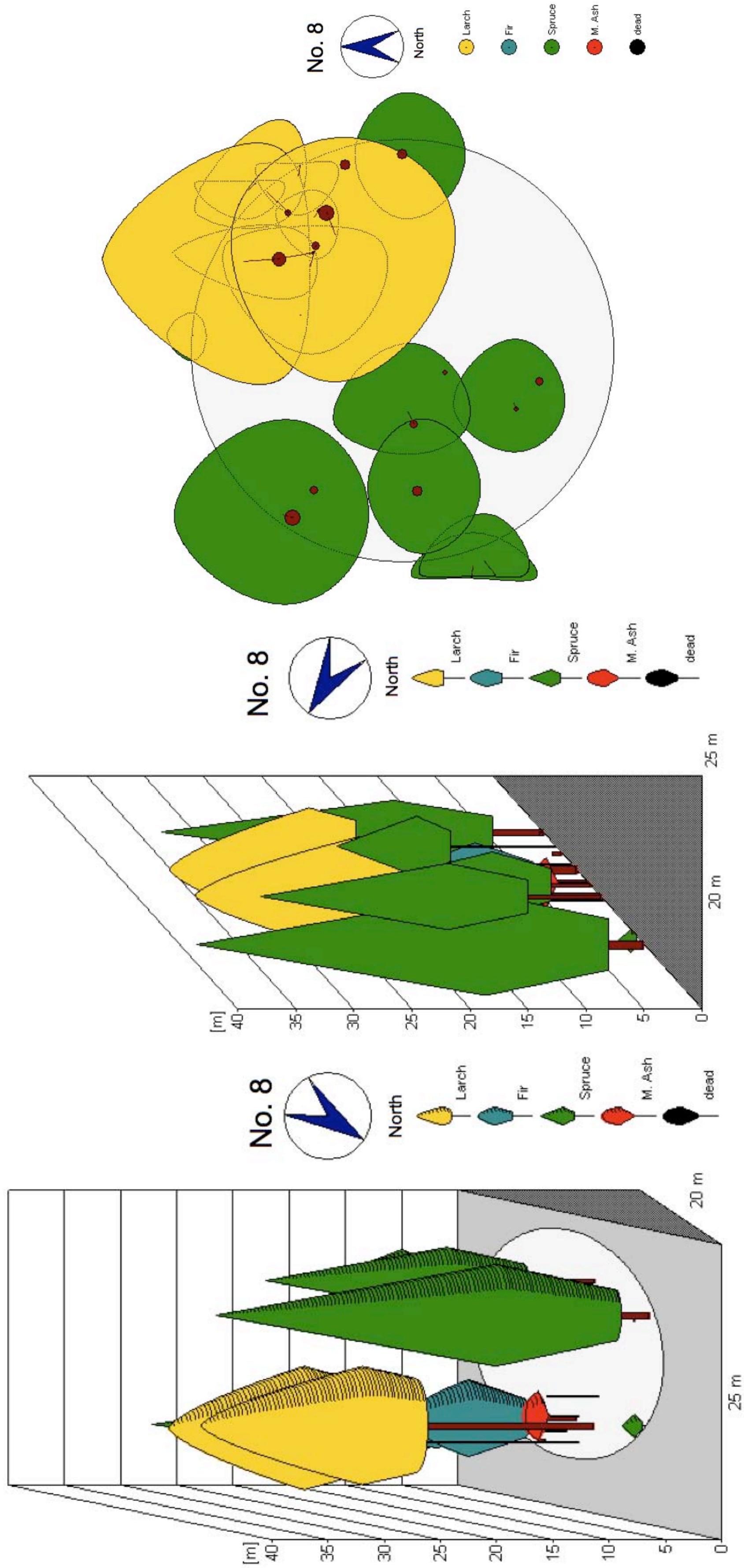


Fig. 35 Graphical presentation of sample plot no. 8 with cross-section and crown projection

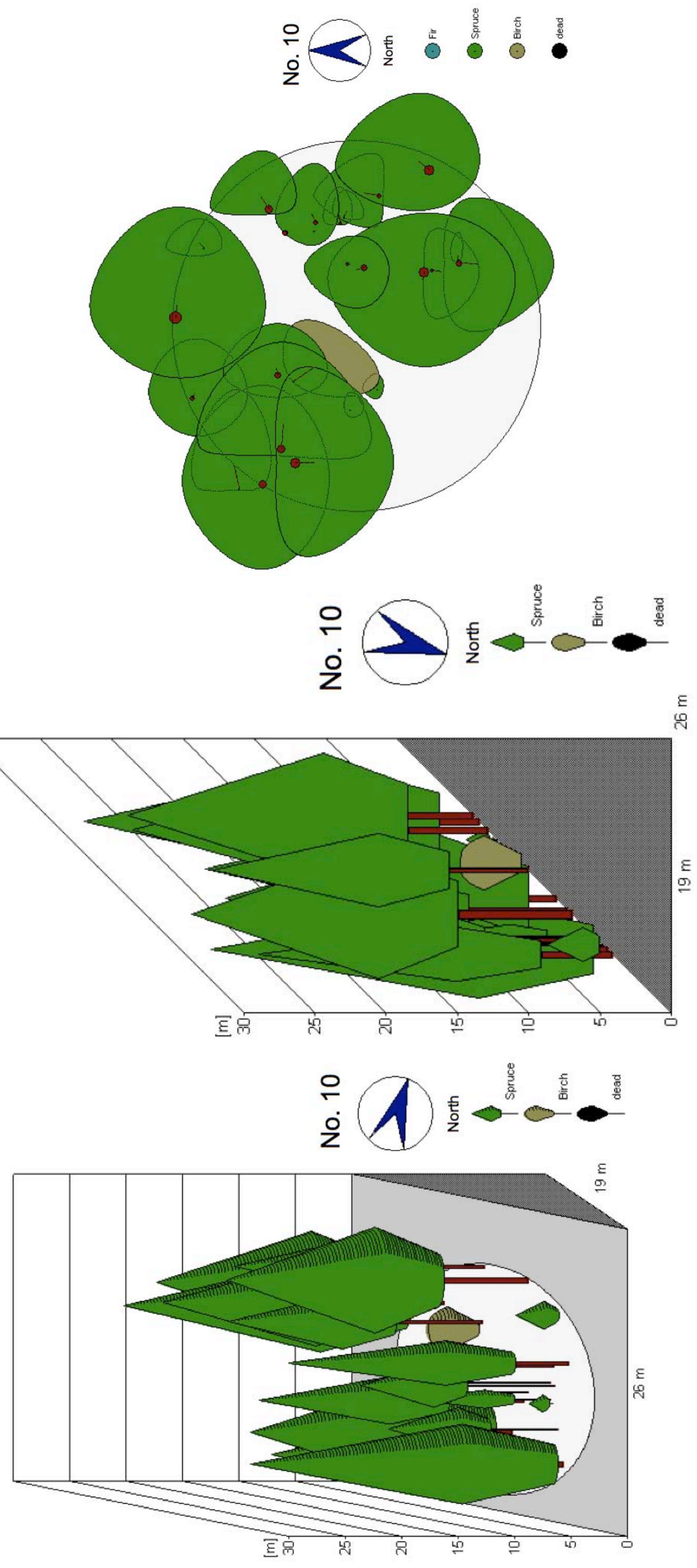


Fig. 36 Graphical presentation of sample plot no. 10 with cross-section and crown projection

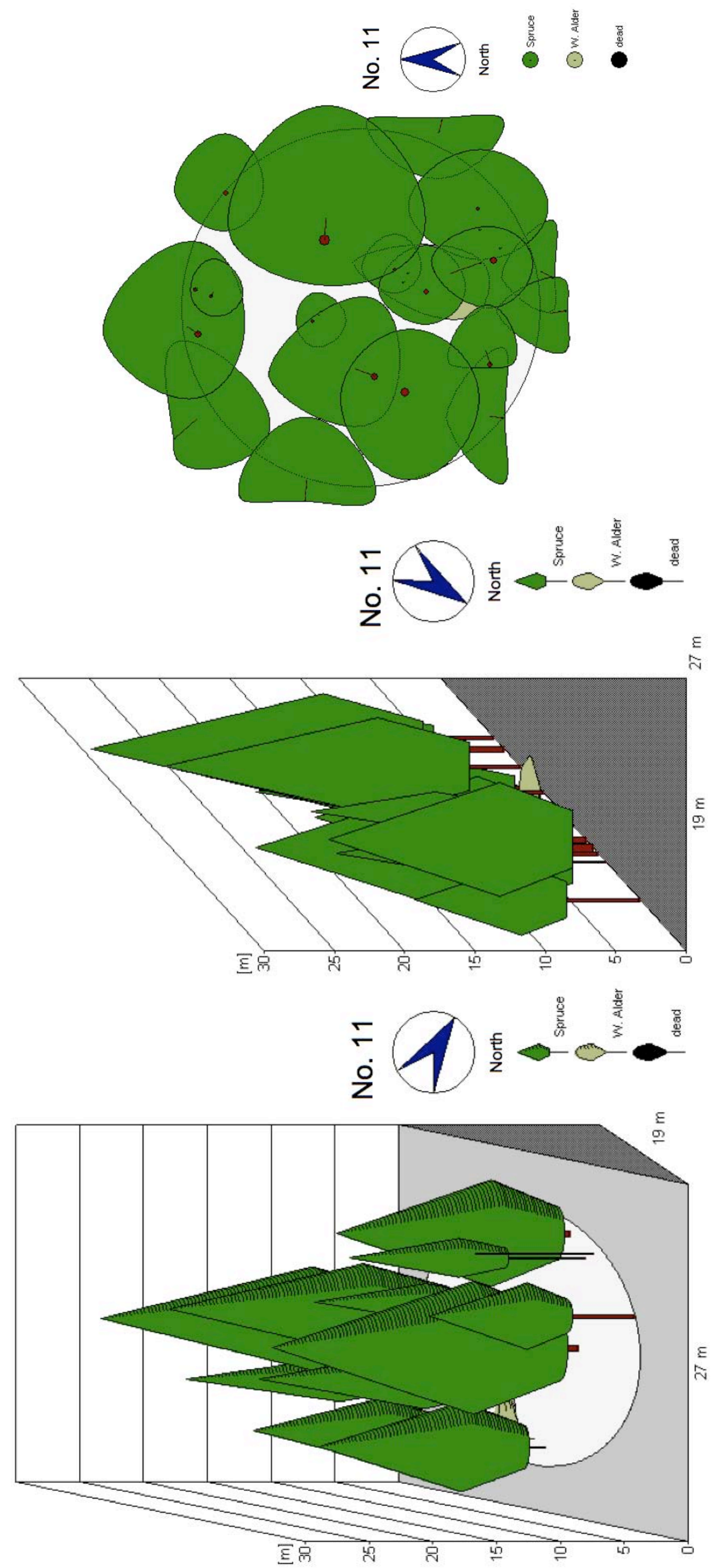


Fig. 37 Graphical presentation of sample plot no. 11 with cross-section and crown projection

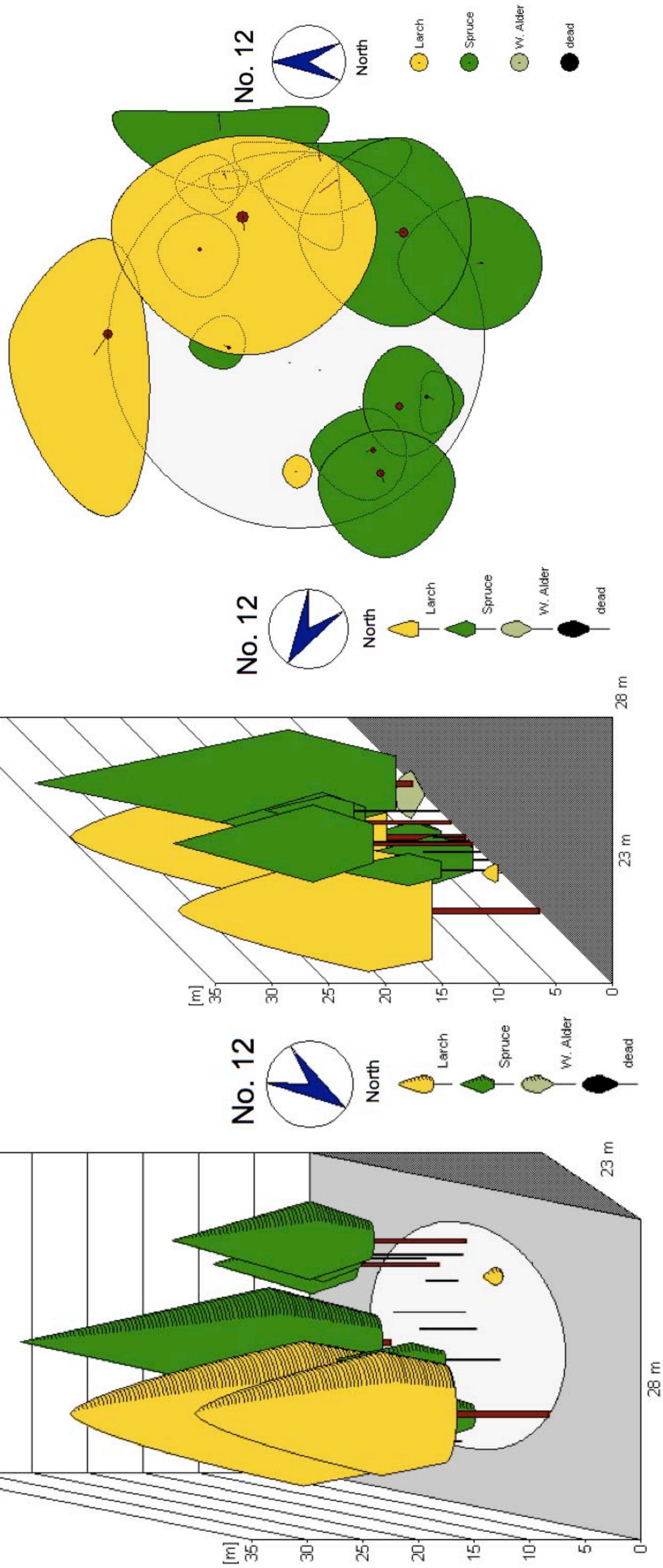


Fig. 38 Graphical presentation of sample plot no. 12 with cross-section and crown projection

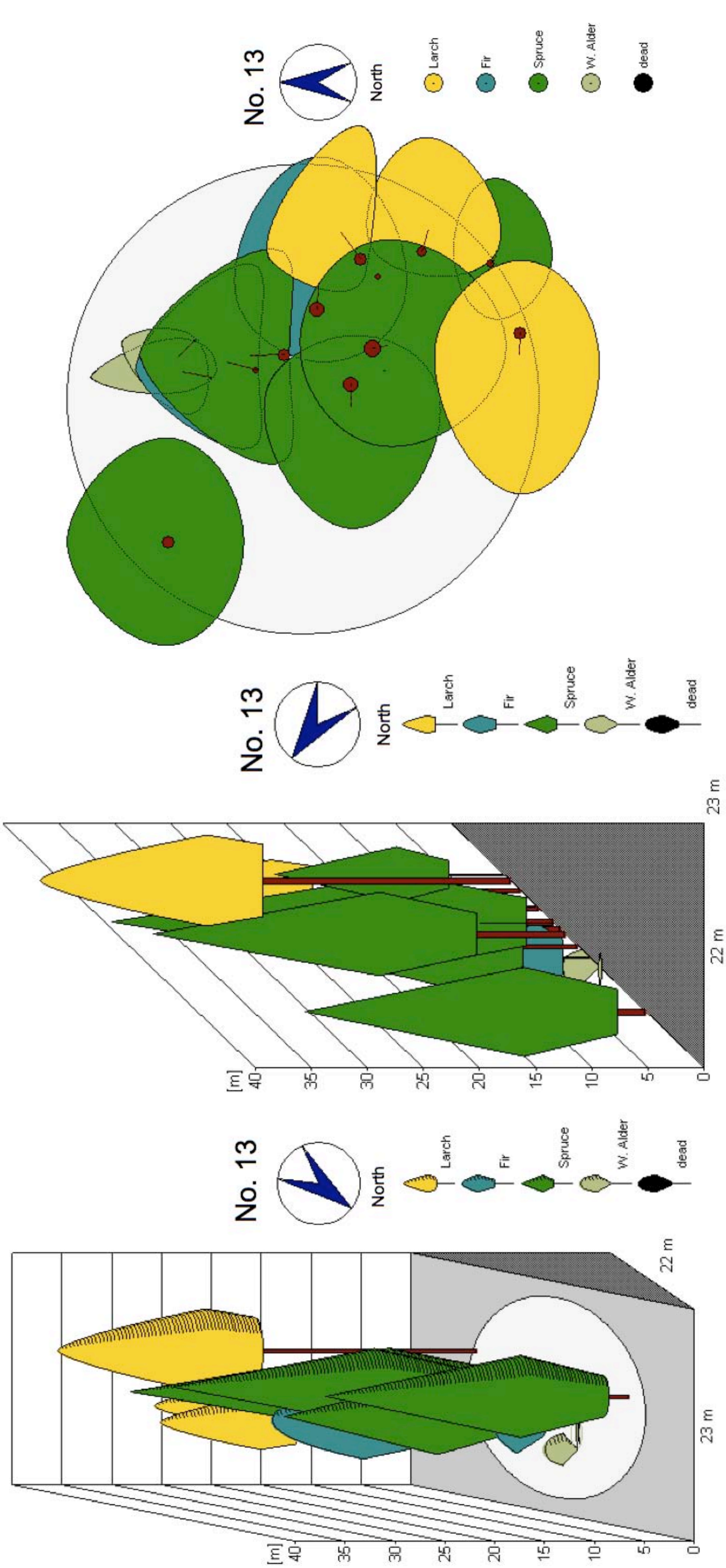


Fig. 39 Graphical presentation of sample plot no. 13 with cross-section and crown projection

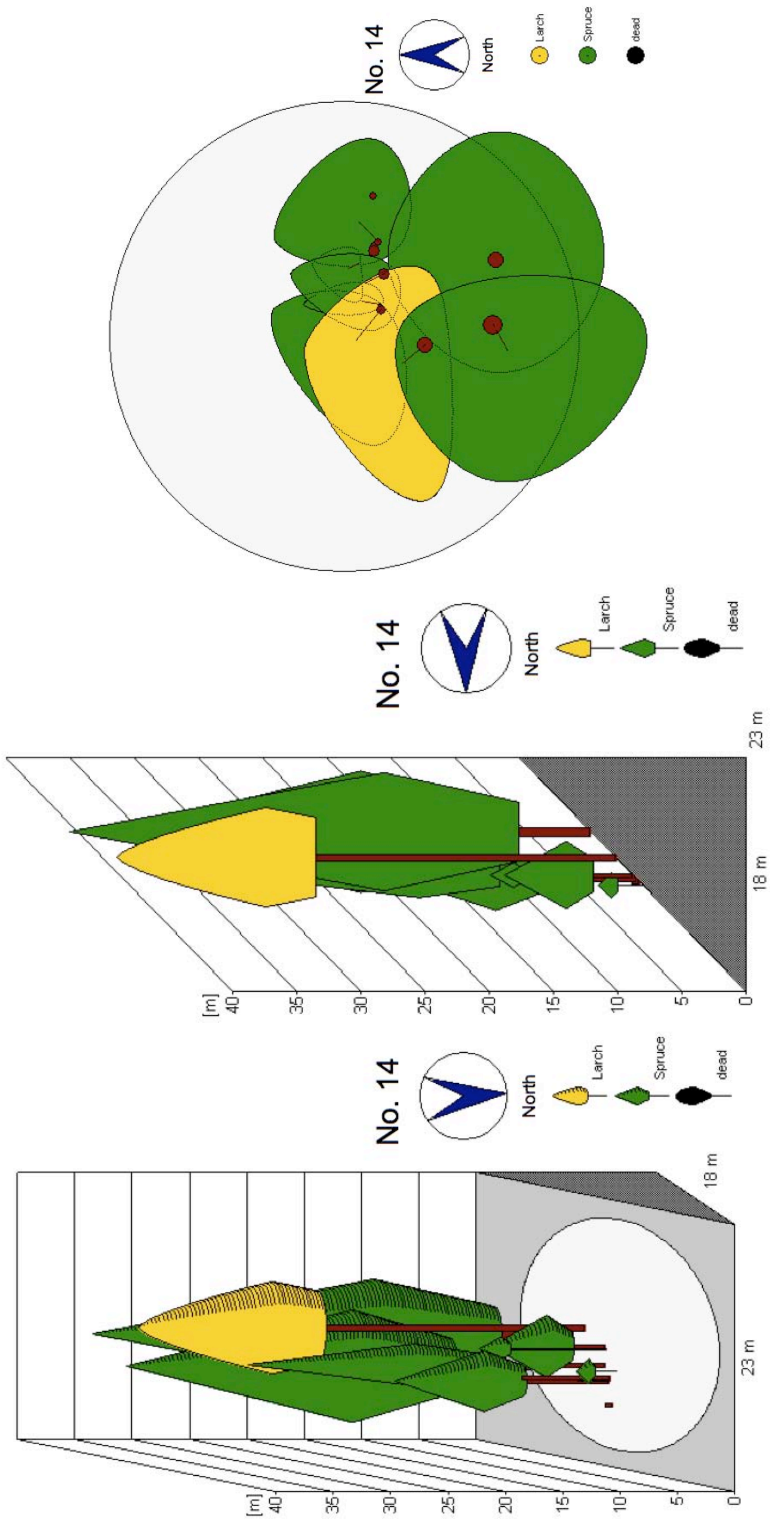


Fig. 40 Graphical presentation of sample plot no. 14 with cross-section and crown projection

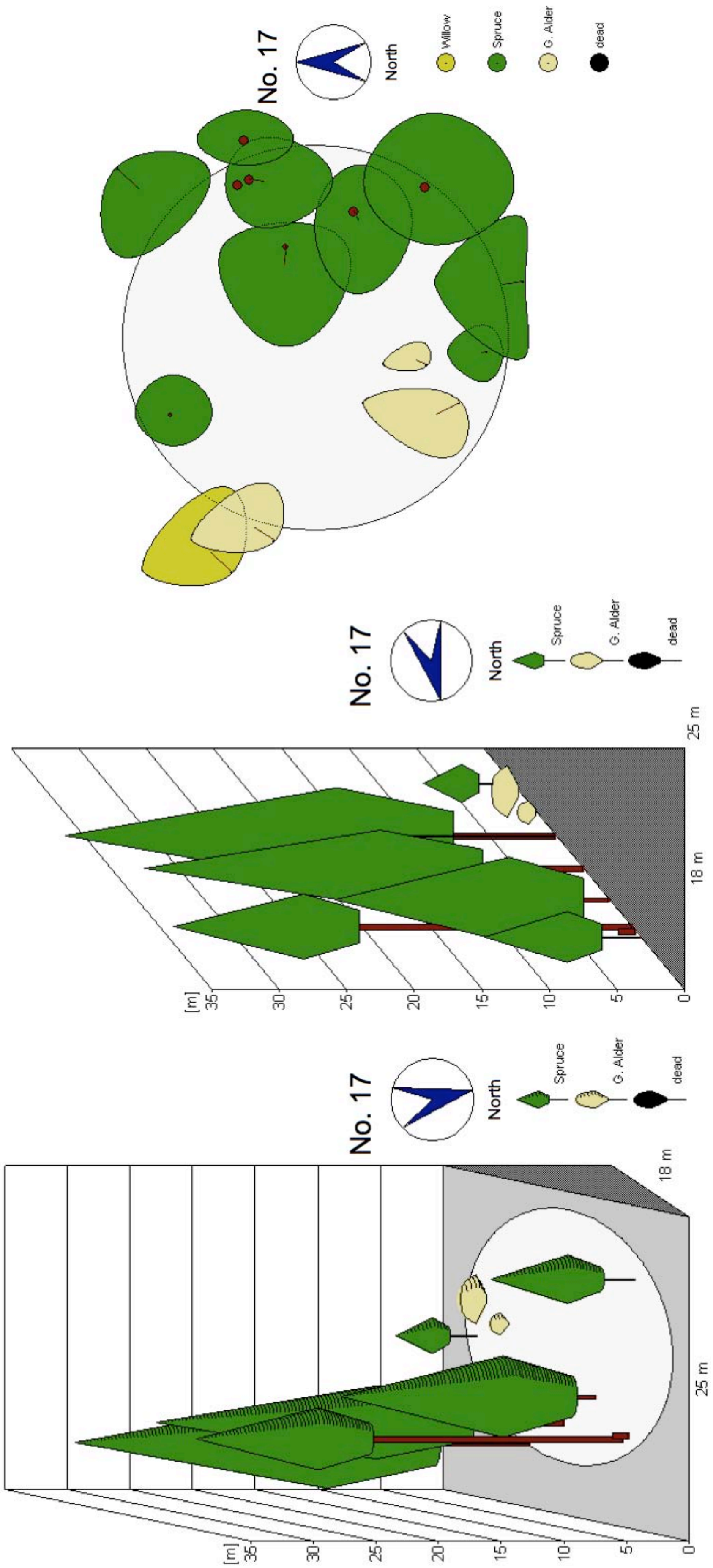


Fig. 41 Graphical presentation of sample plot no. 17 with cross-section and crown projection

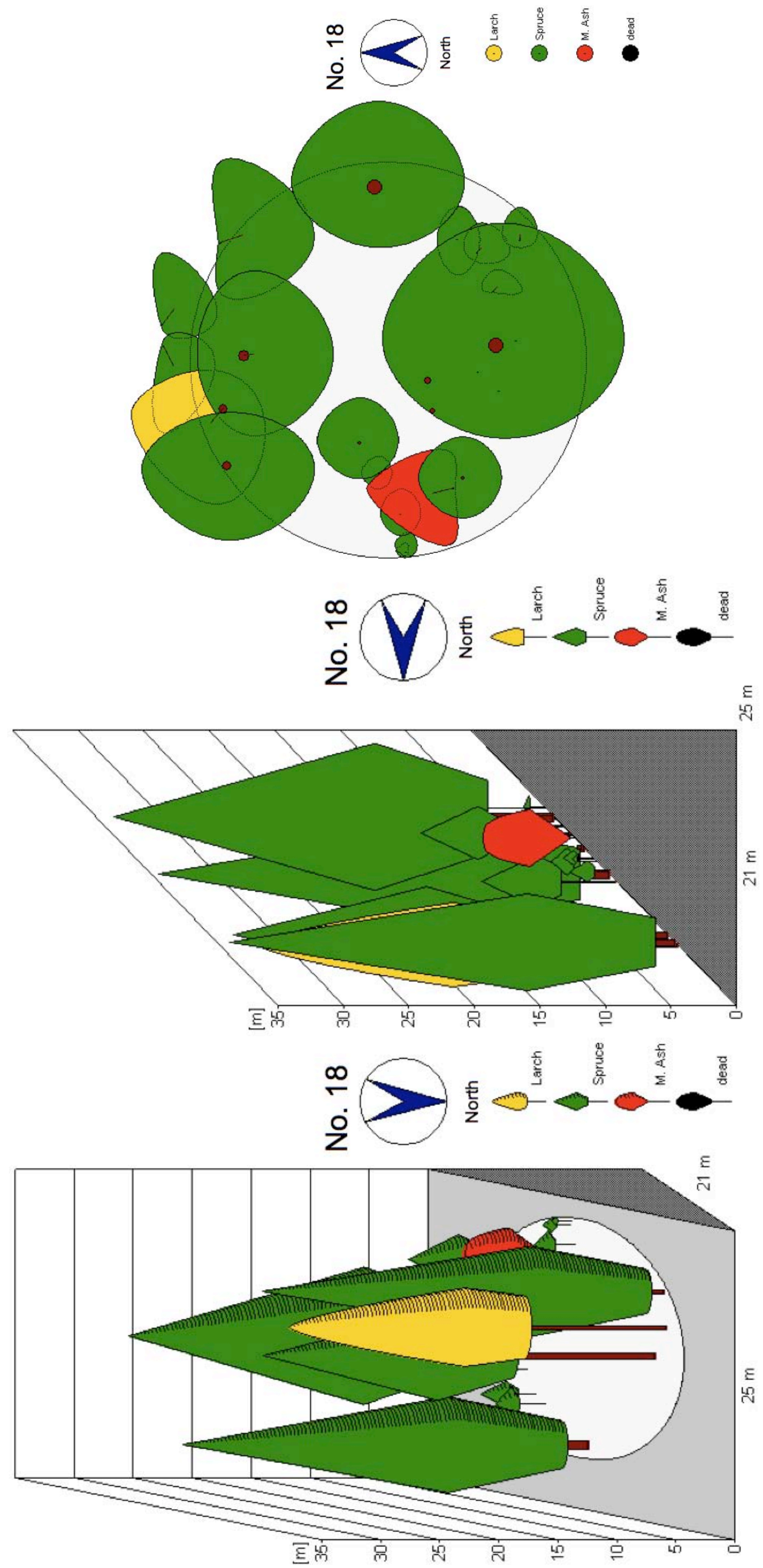


Fig. 42 Graphical presentation of sample plot no. 18 with cross-section and crown projection

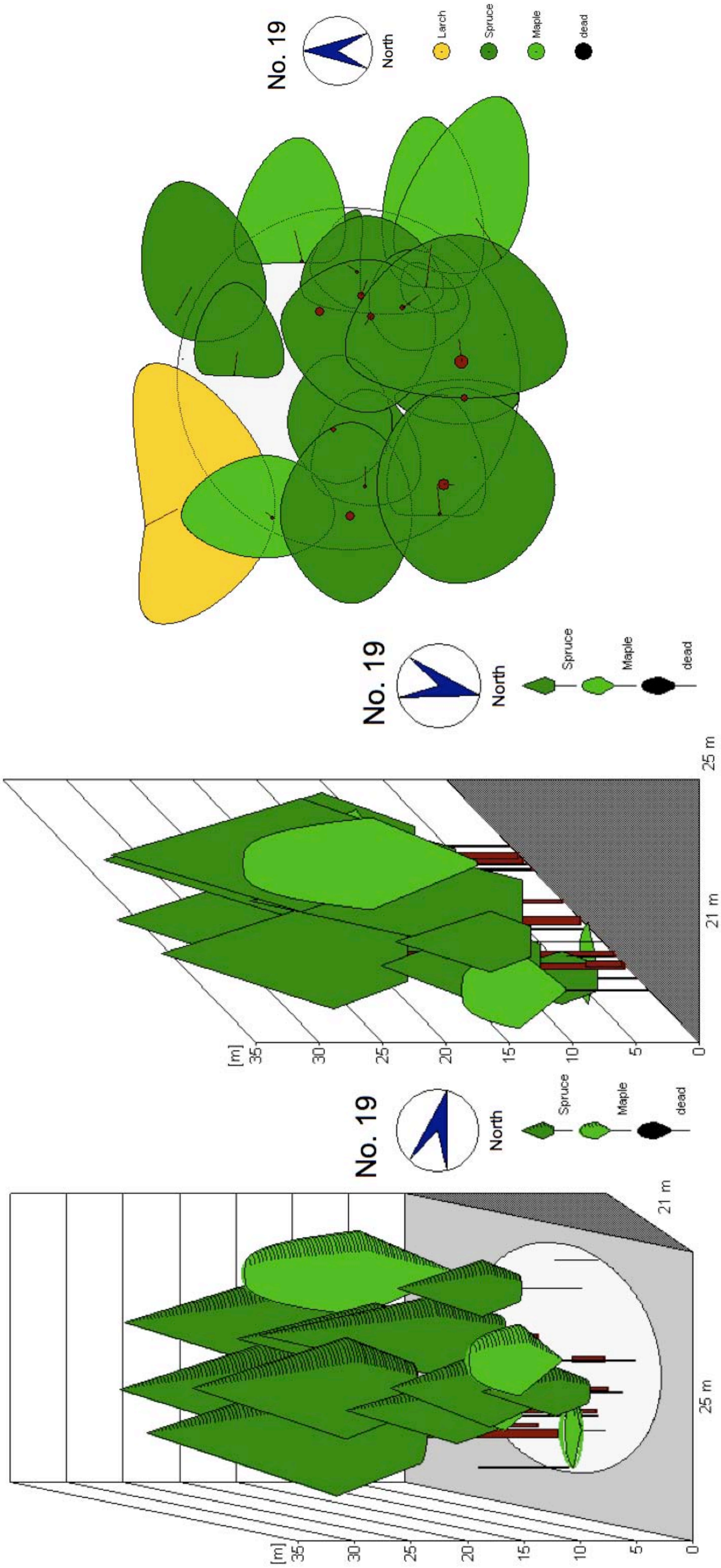


Fig. 43 Graphical presentation of sample plot no. 19 with cross-section and crown projection

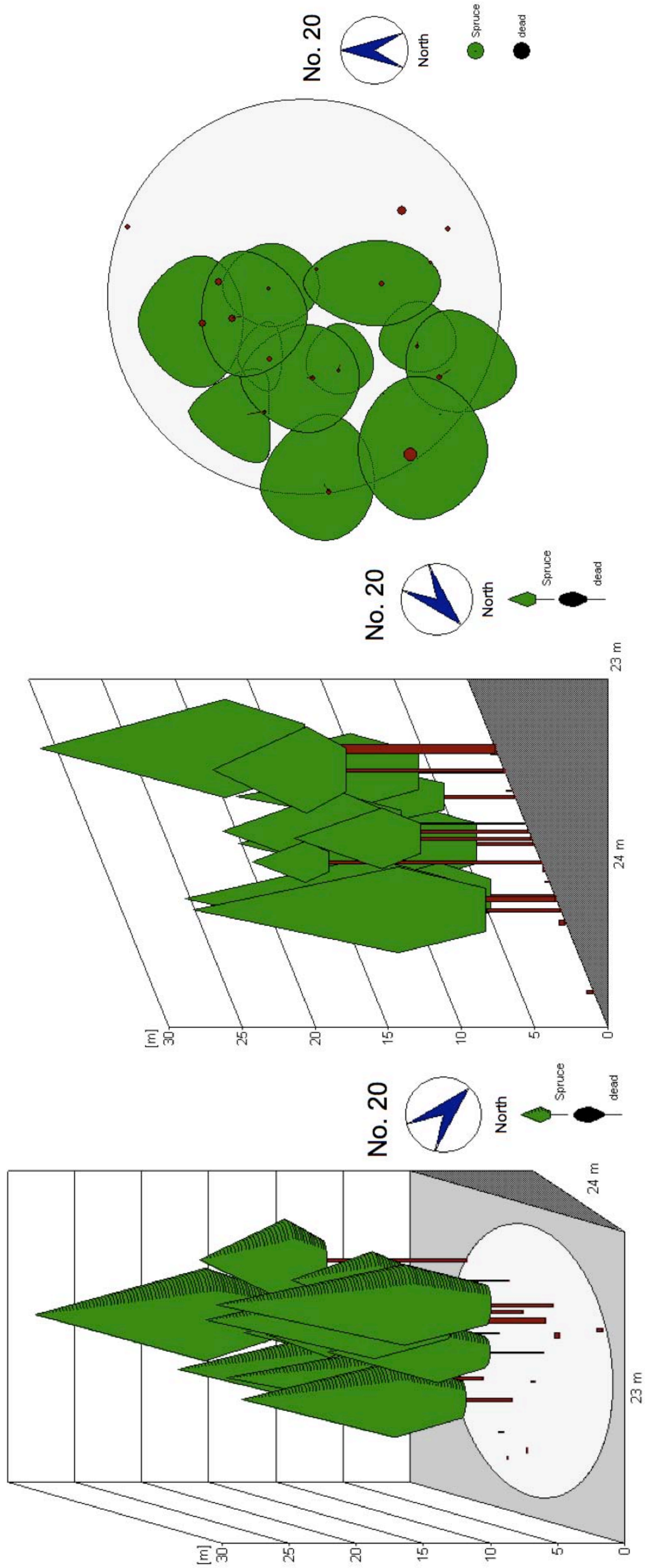


Fig. 44 Graphical presentation of sample plot no. 20 with cross-section and crown projection

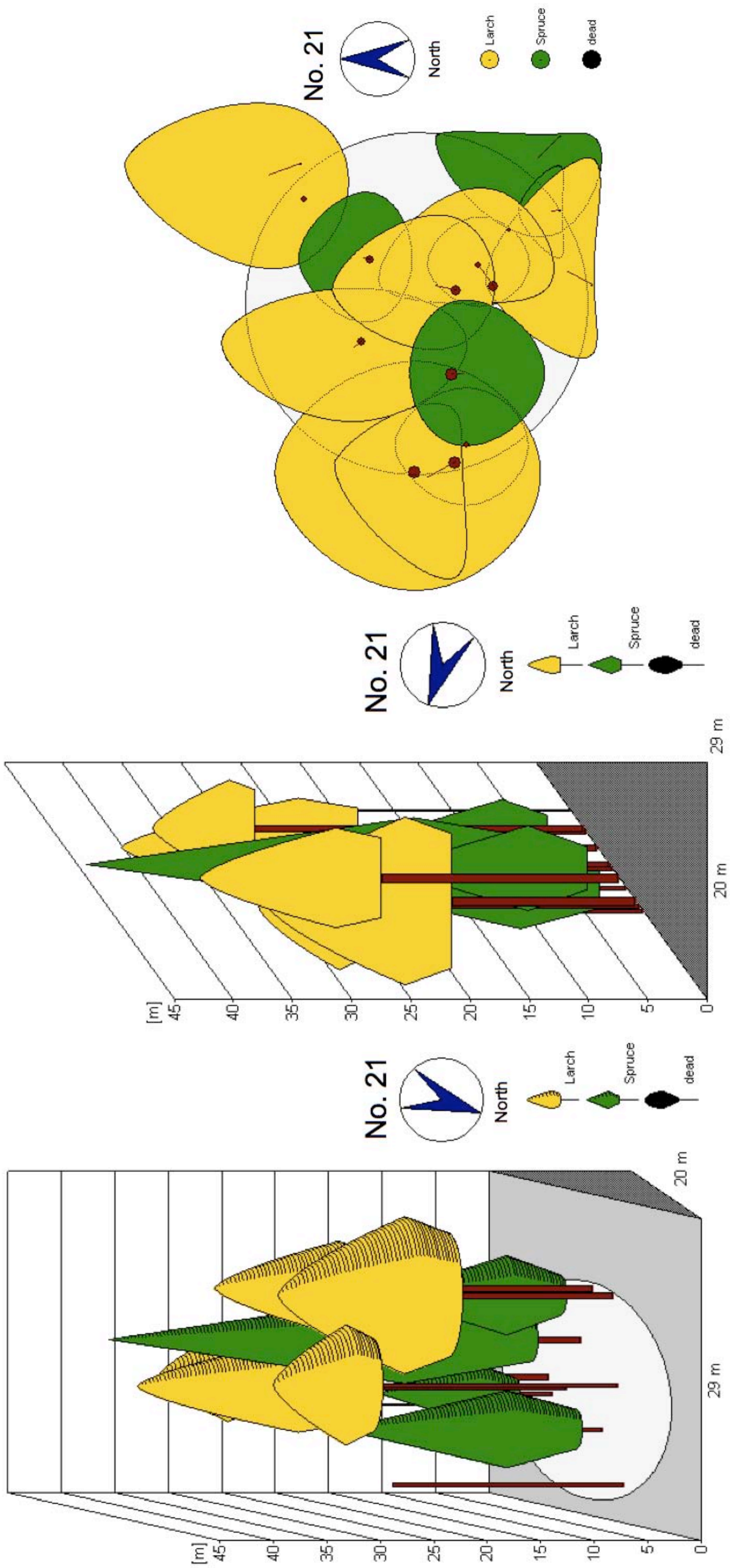


Fig. 45 Graphical presentation of sample plot no. 21 with cross-section and crown projection

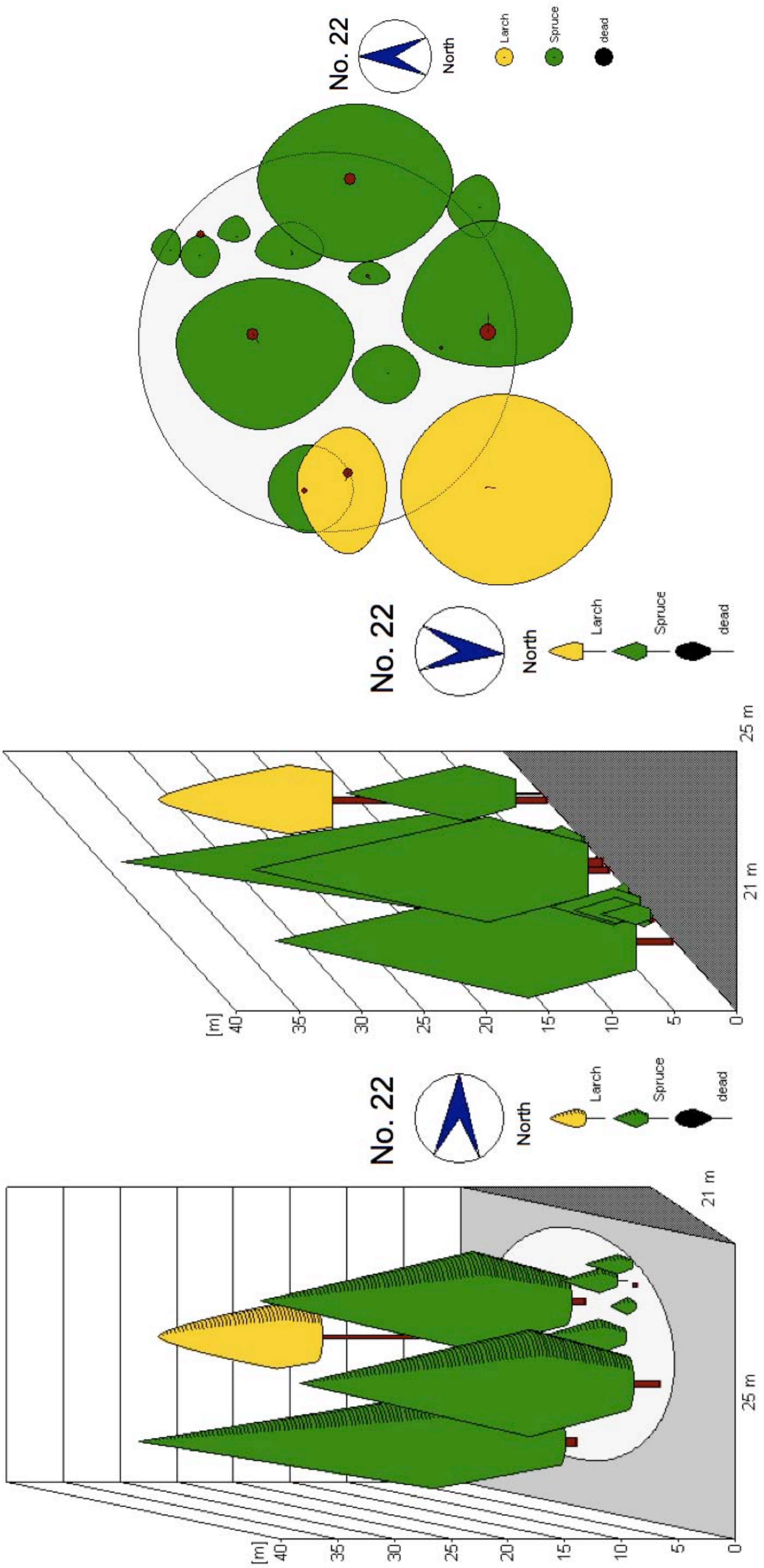


Fig. 46 Graphical presentation of sample plot no. 22 with cross-section and crown projection

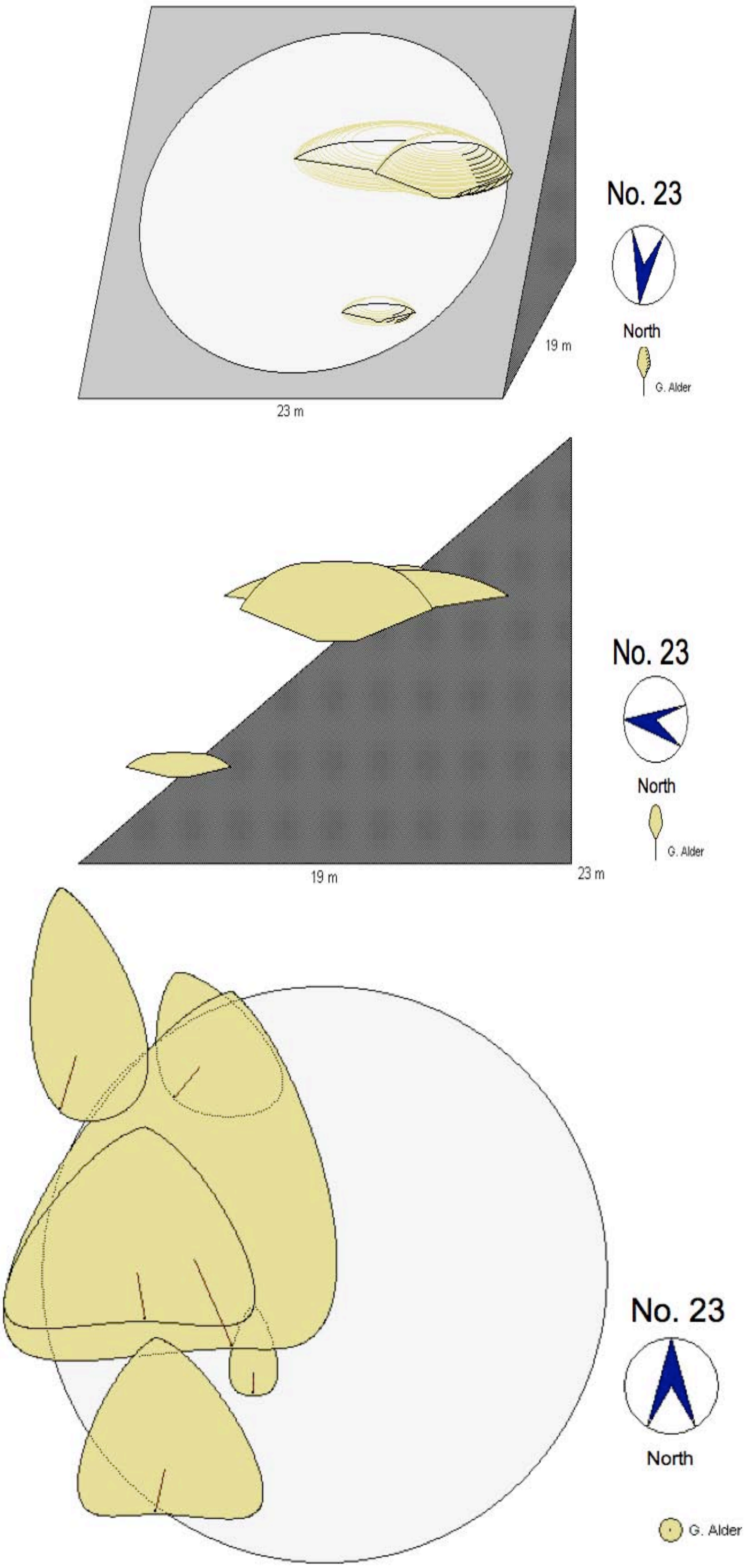


Fig. 47 Graphical presentation of sample plot no. 23 with cross-section and crown projection

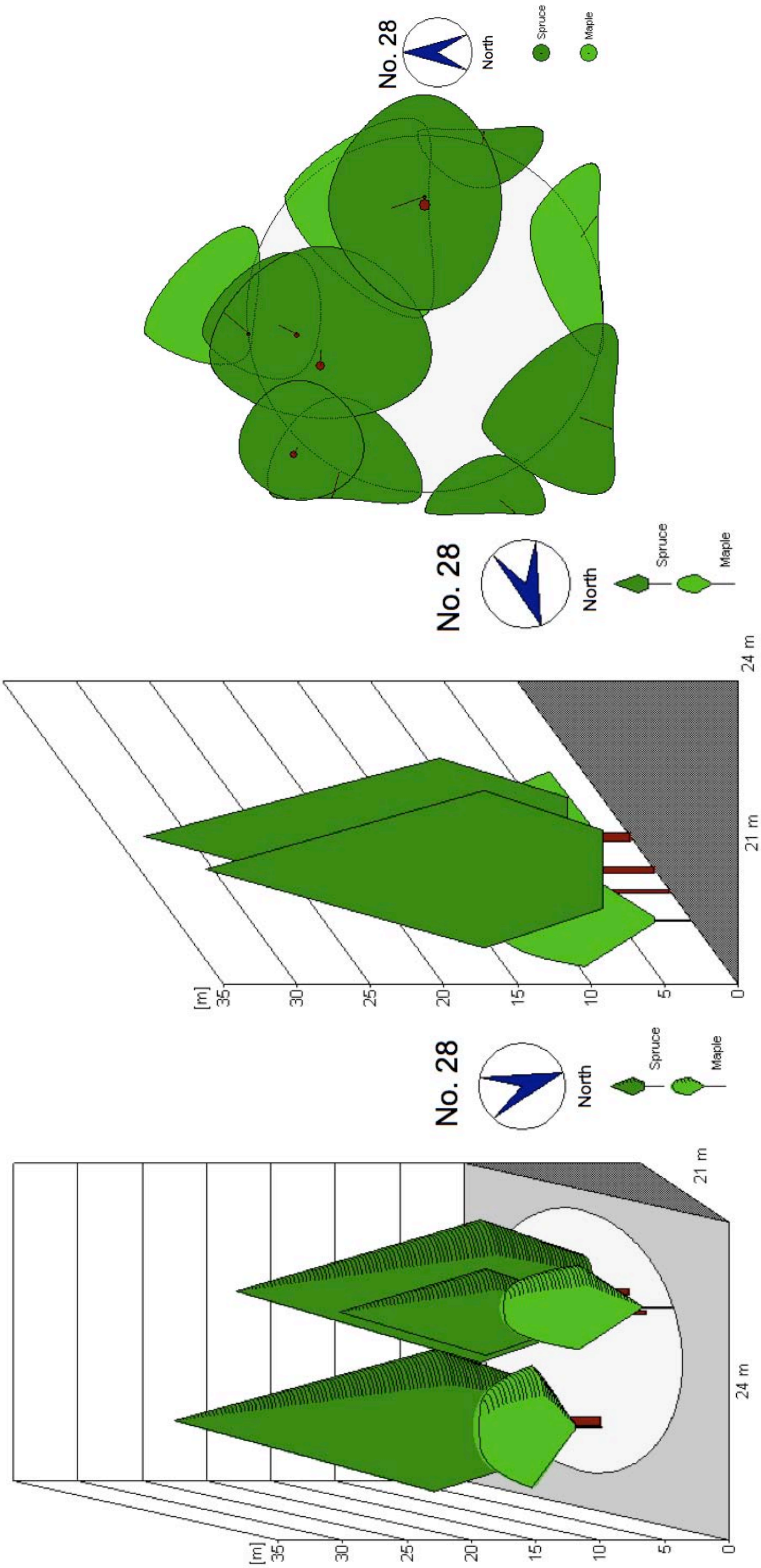


Fig. 48 Graphical presentation of sample plot no. 28 with cross-section and crown projection

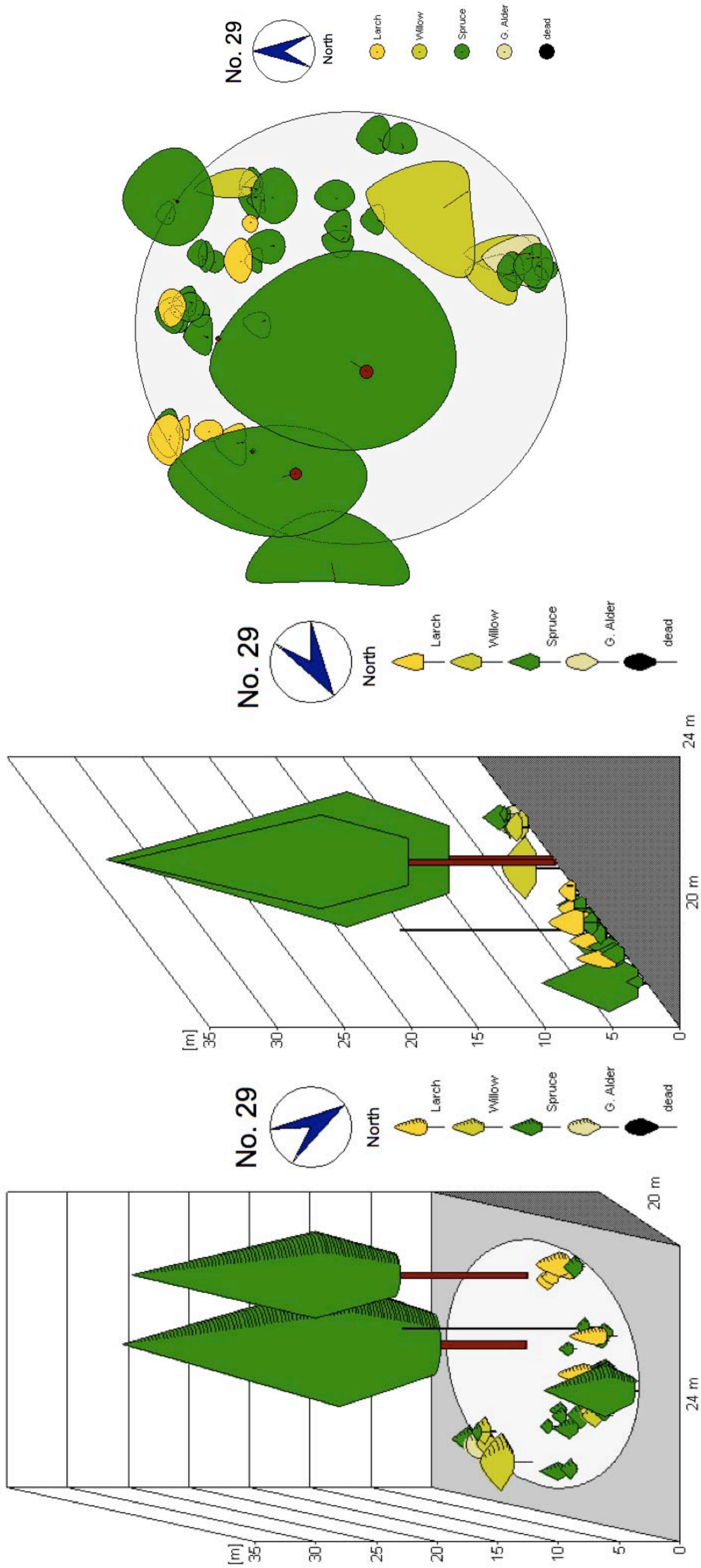


Fig. 49 Graphical presentation of sample plot no. 29 with cross-section and crown projection

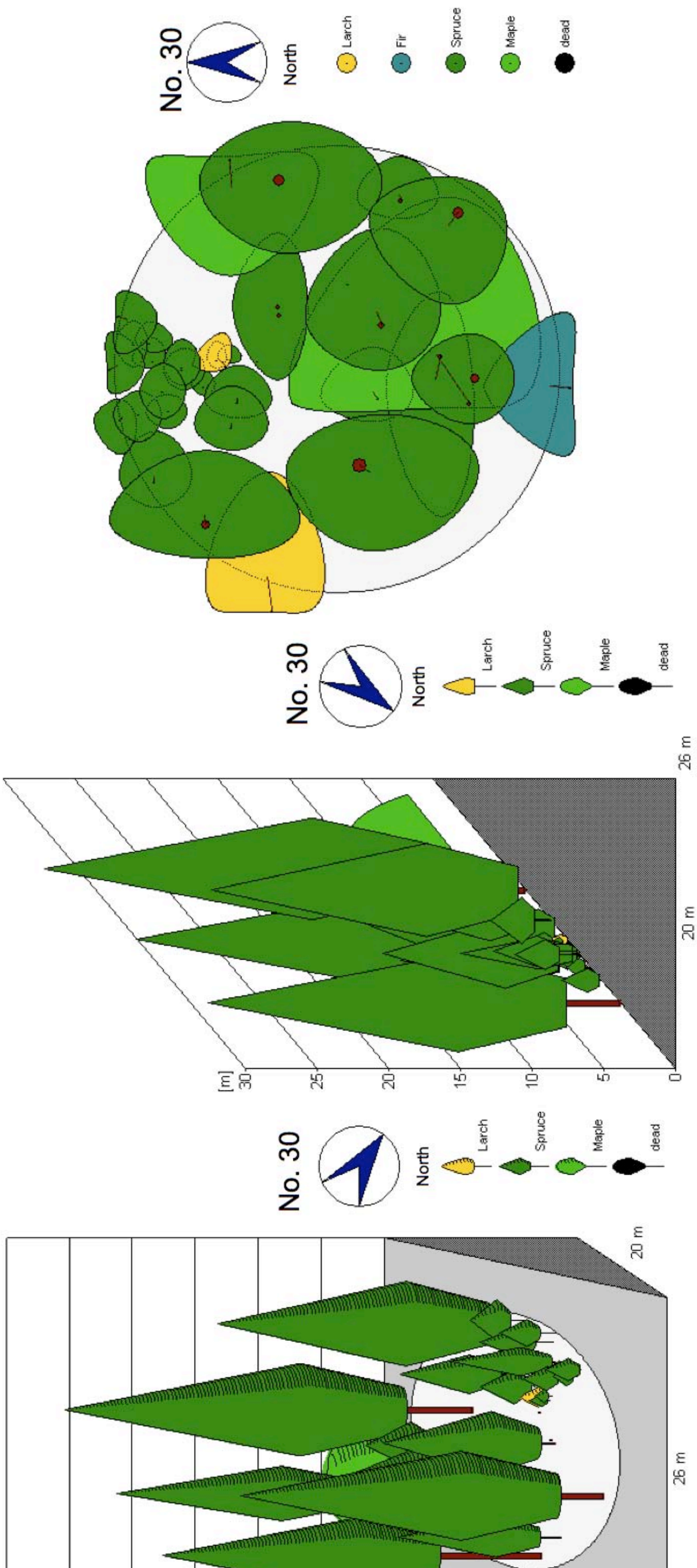


Fig. 50 Graphical presentation of sample plot no. 30 with cross-section and crown projection

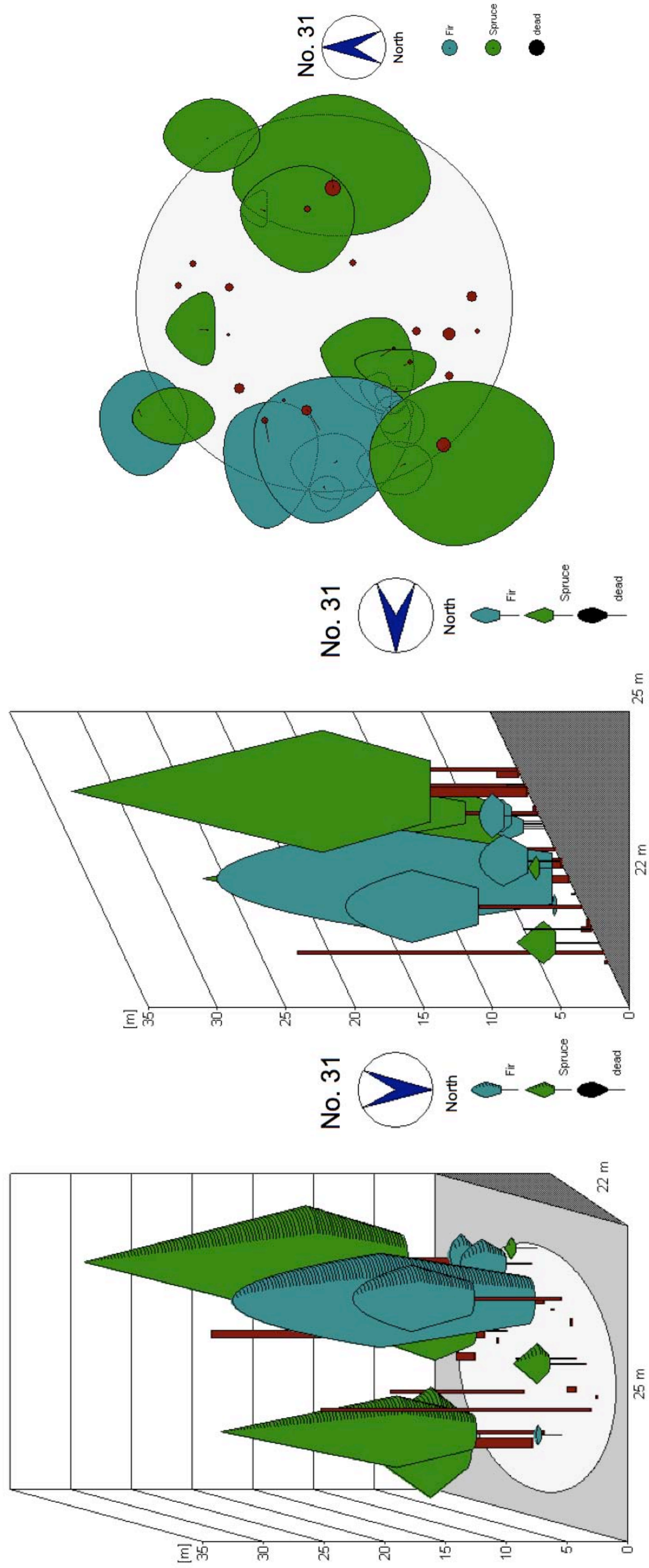


Fig. 51 Graphical presentation of sample plot no. 31 with cross-section and crown projection

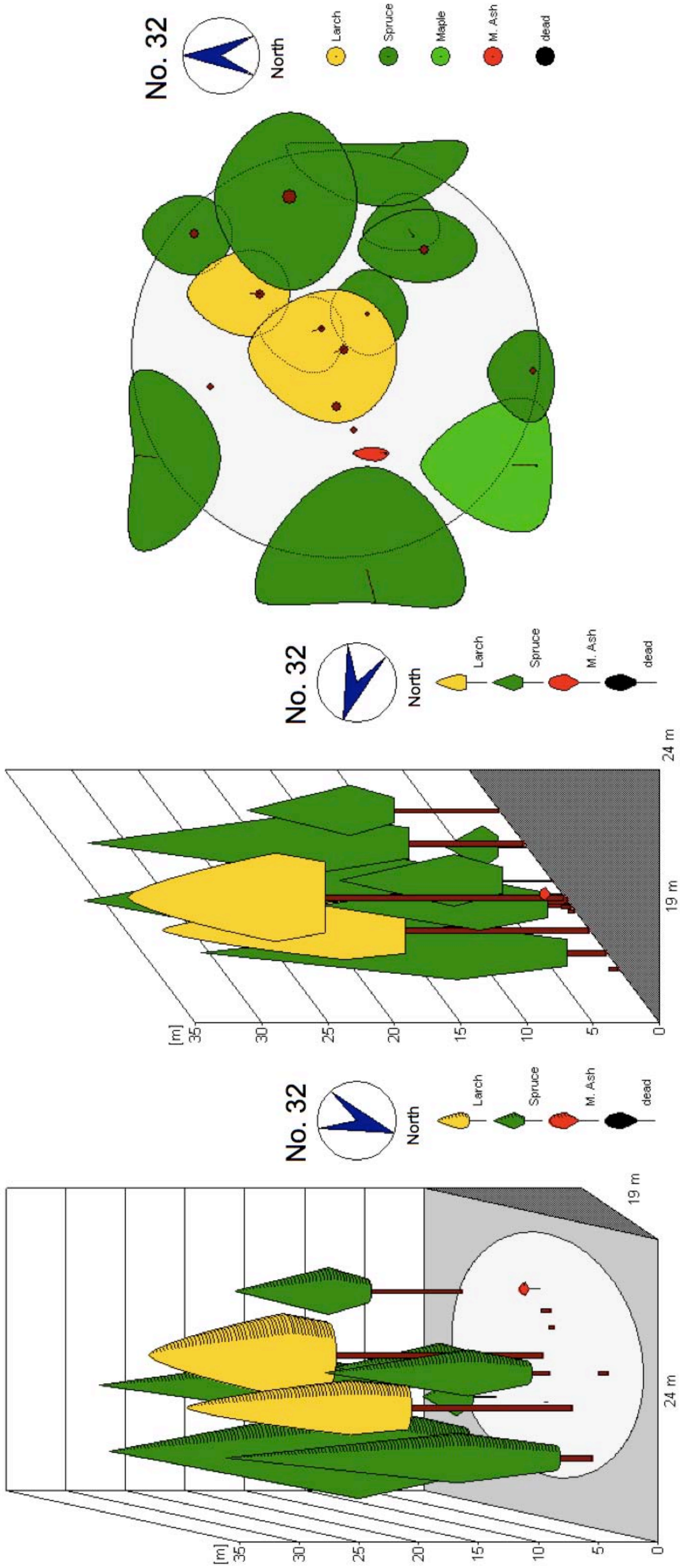


Fig. 52 Graphical presentation of sample plot no. 32 with cross-section and crown projection

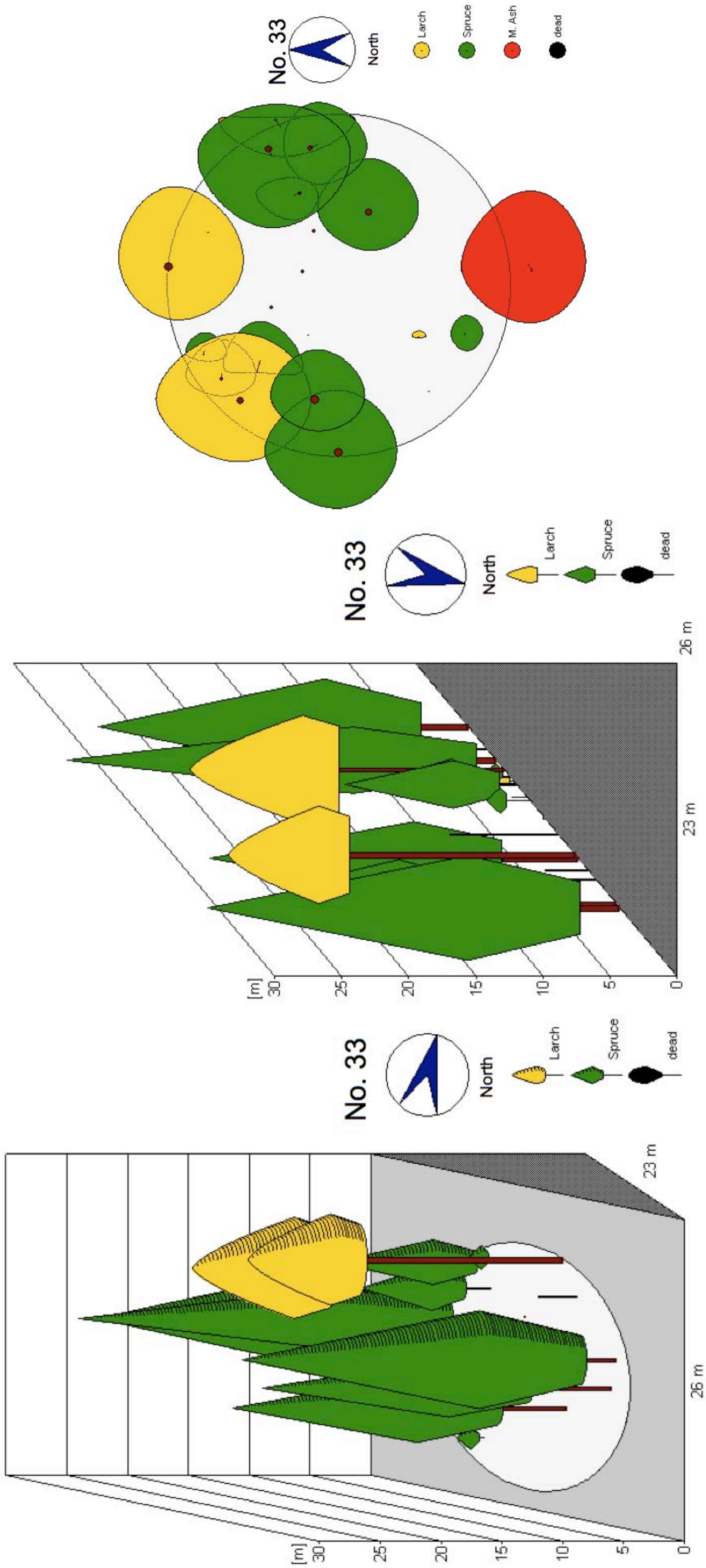


Fig. 53 Graphical presentation of sample plot no. 33 with cross-section and crown projection

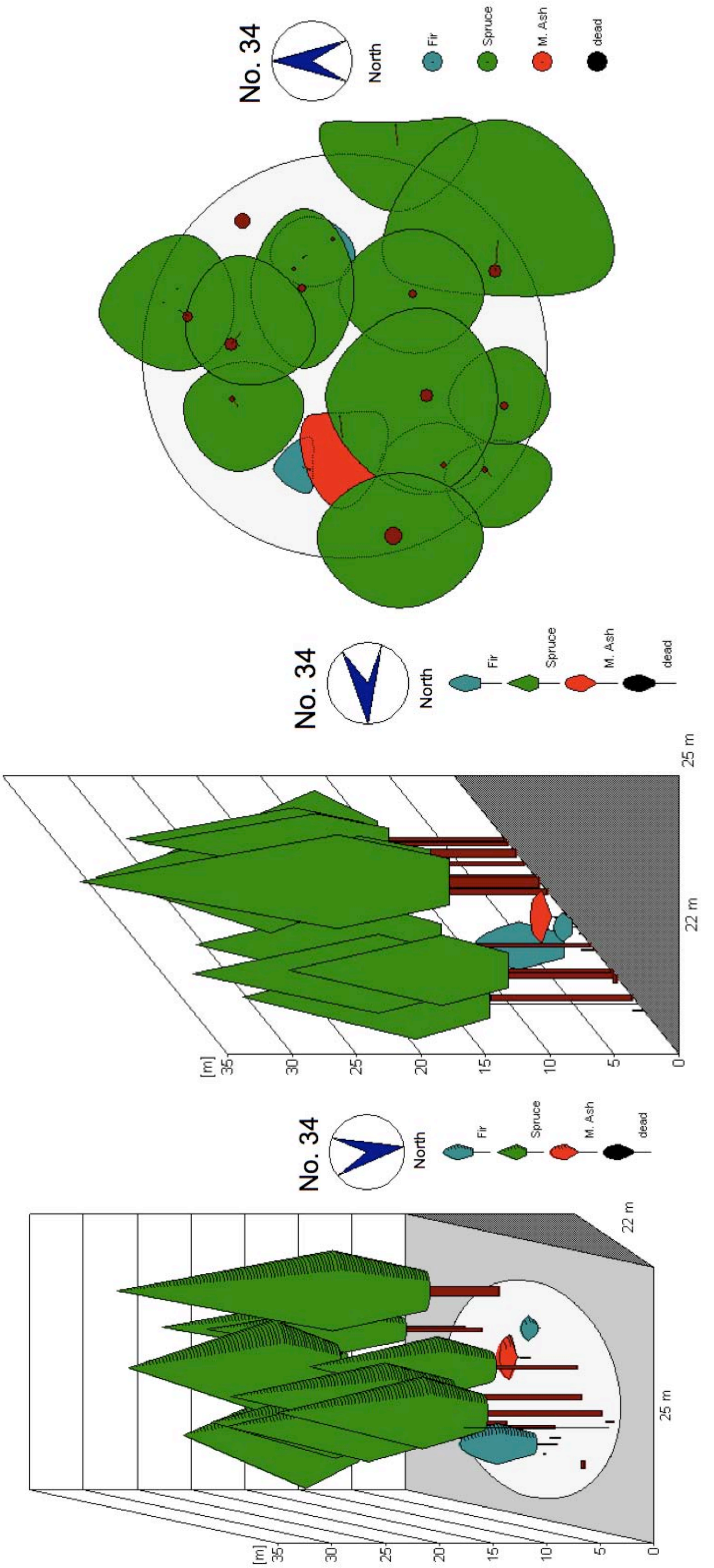


Fig. 54 Graphical presentation of sample plot no. 34 with cross-section and crown projection

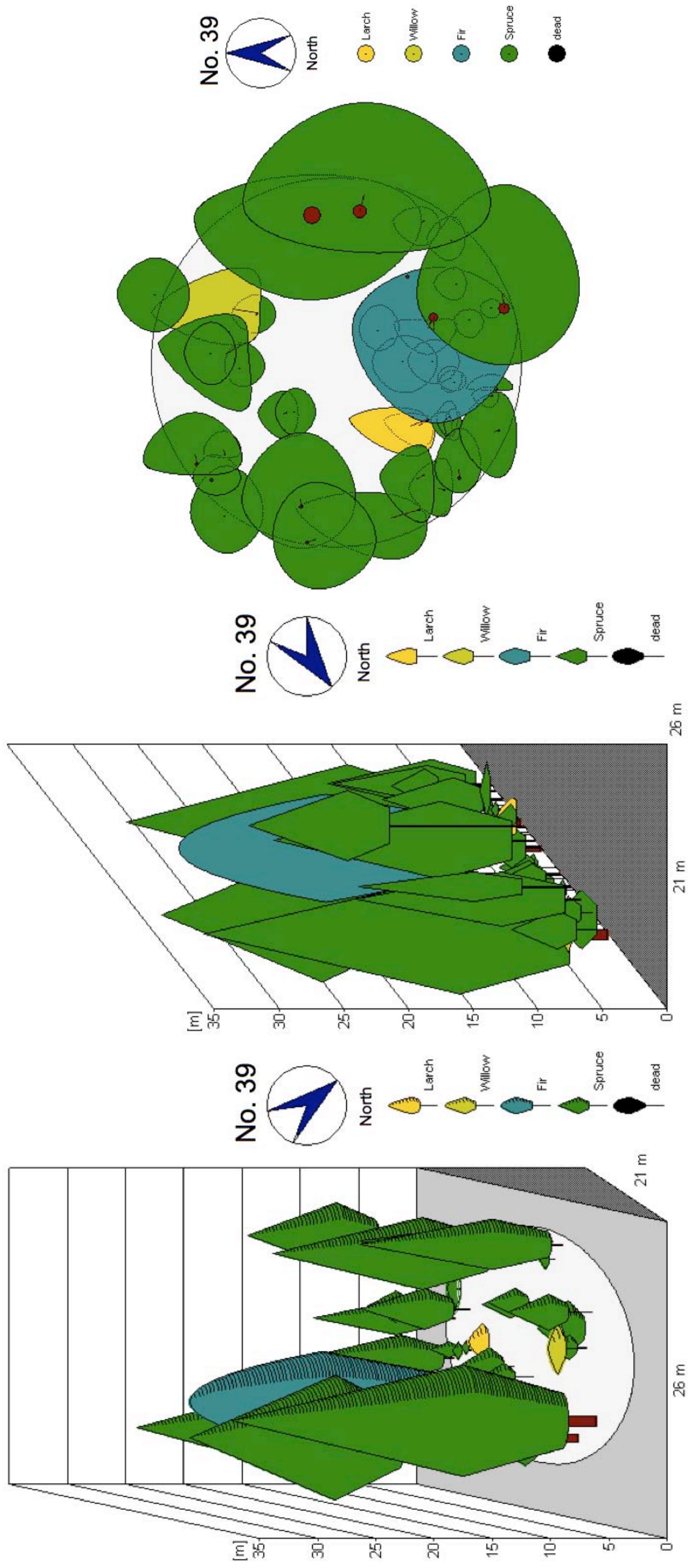


Fig. 55 Graphical presentation of sample plot no. 39 with cross-section and crown projection

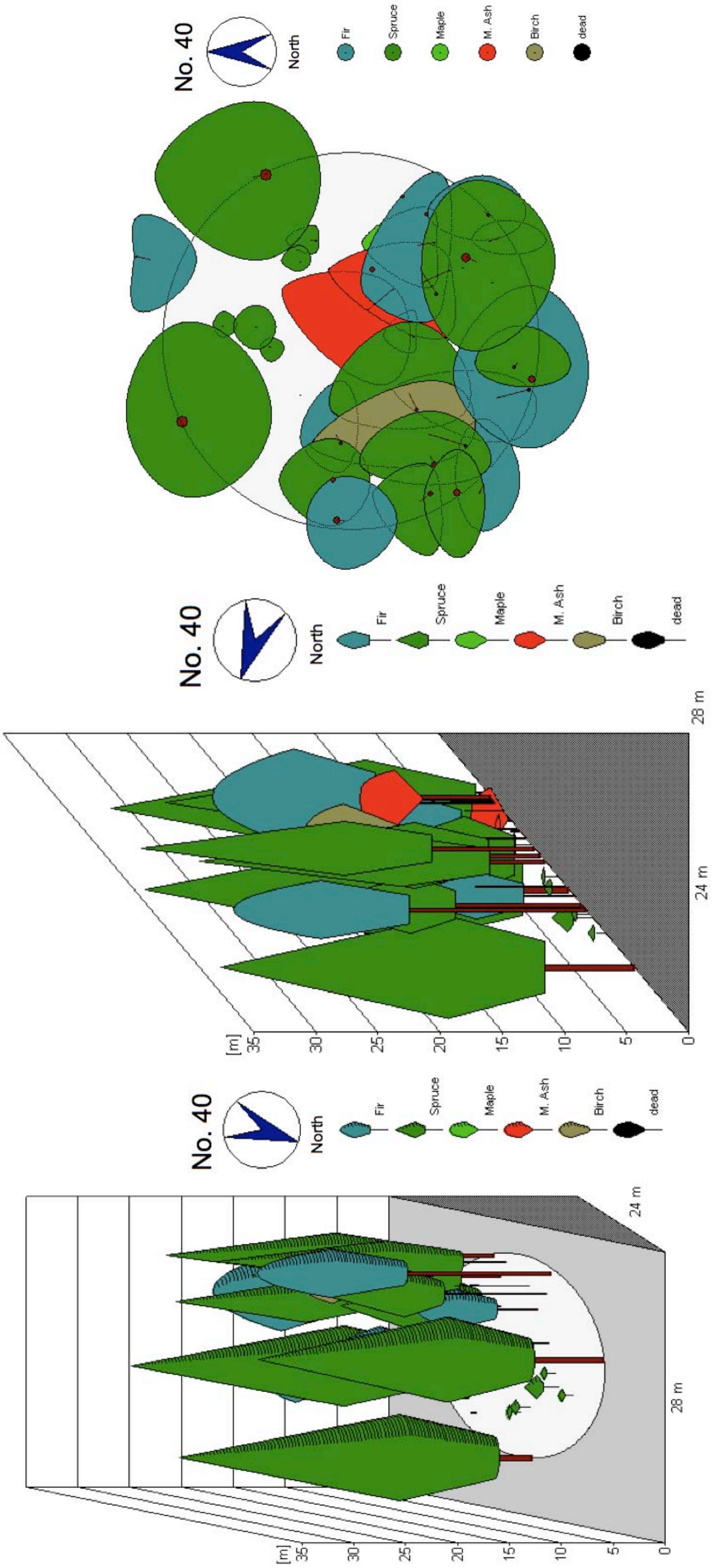


Fig. 56 Graphical presentation of sample plot no. 40 with cross-section and crown projection

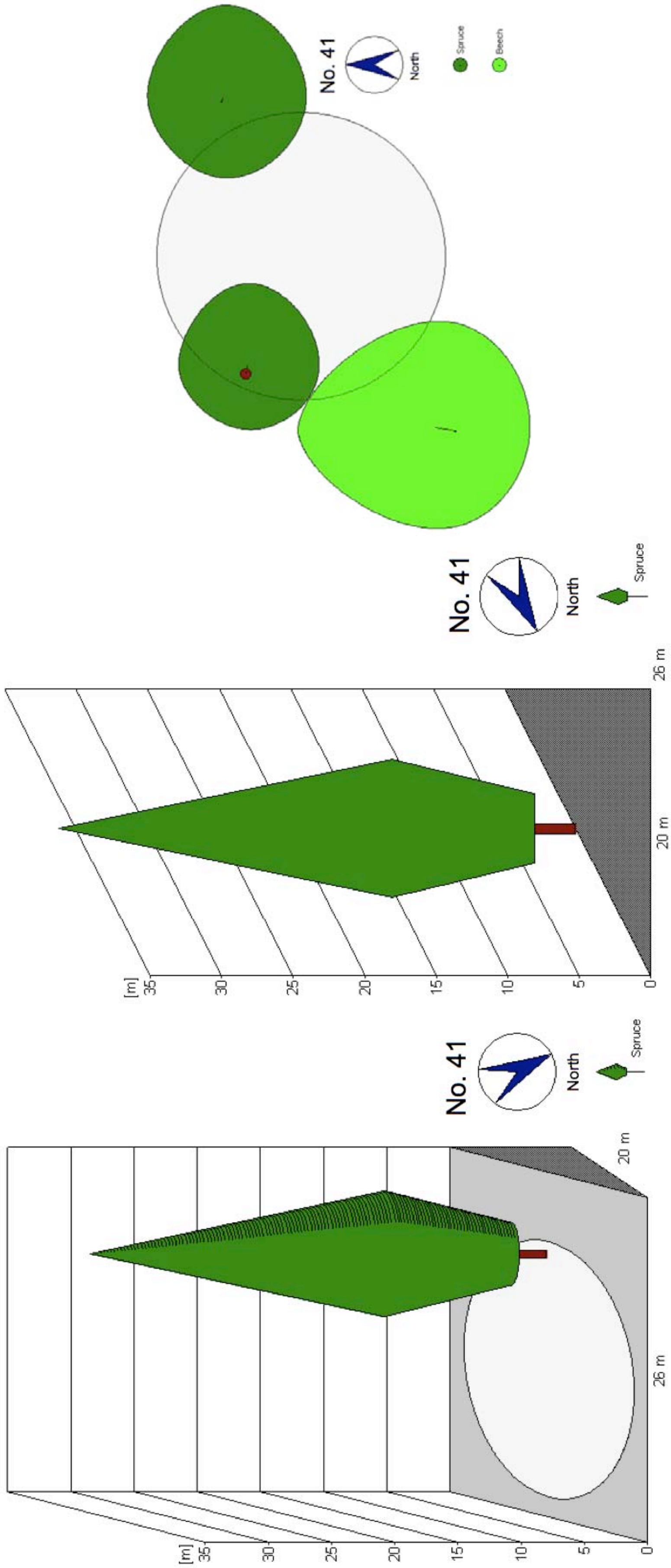


Fig. 57 Graphical presentation of sample plot no. 41 with cross-section and crown projection

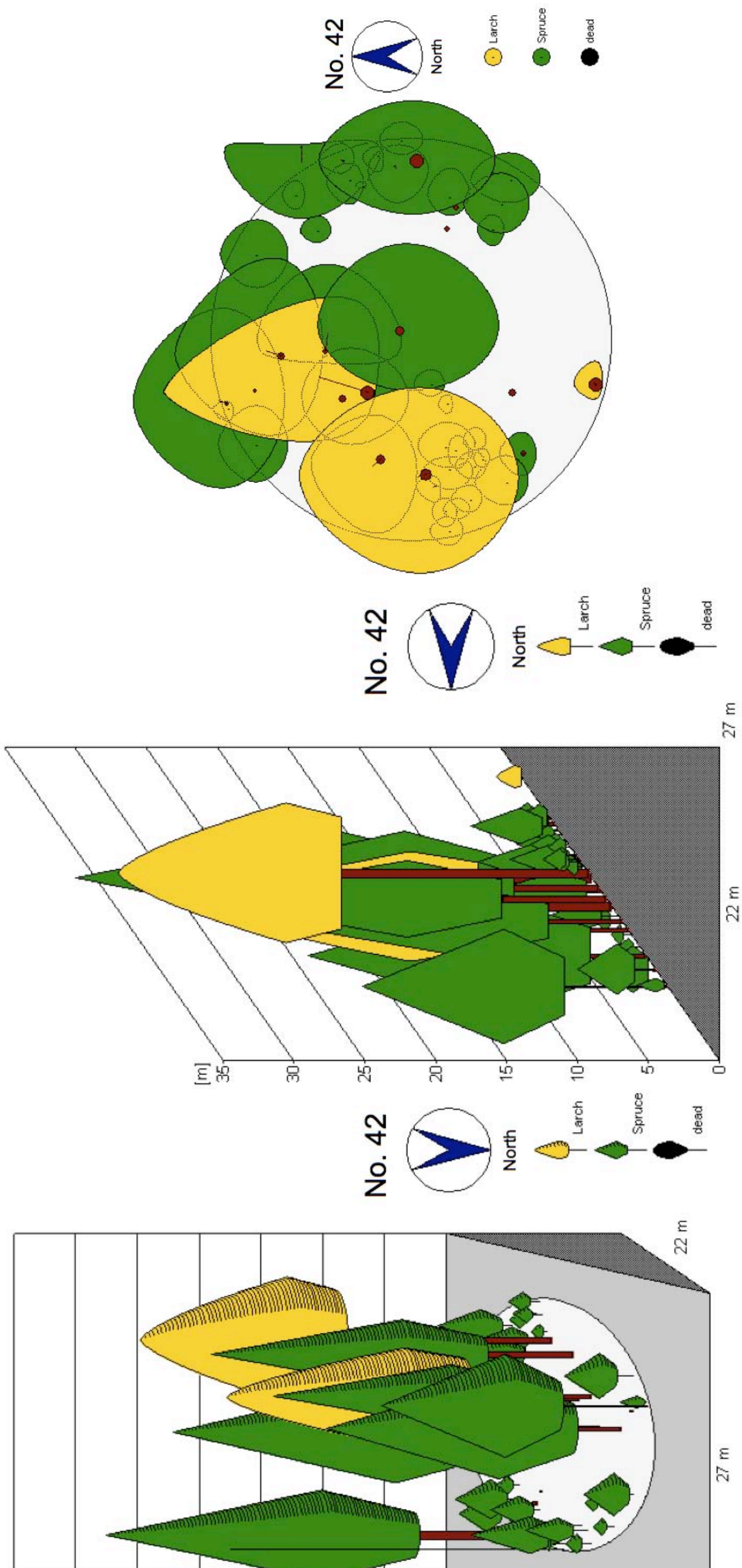


Fig. 58 Graphical presentation of sample plot no. 42 with cross-section and crown projection

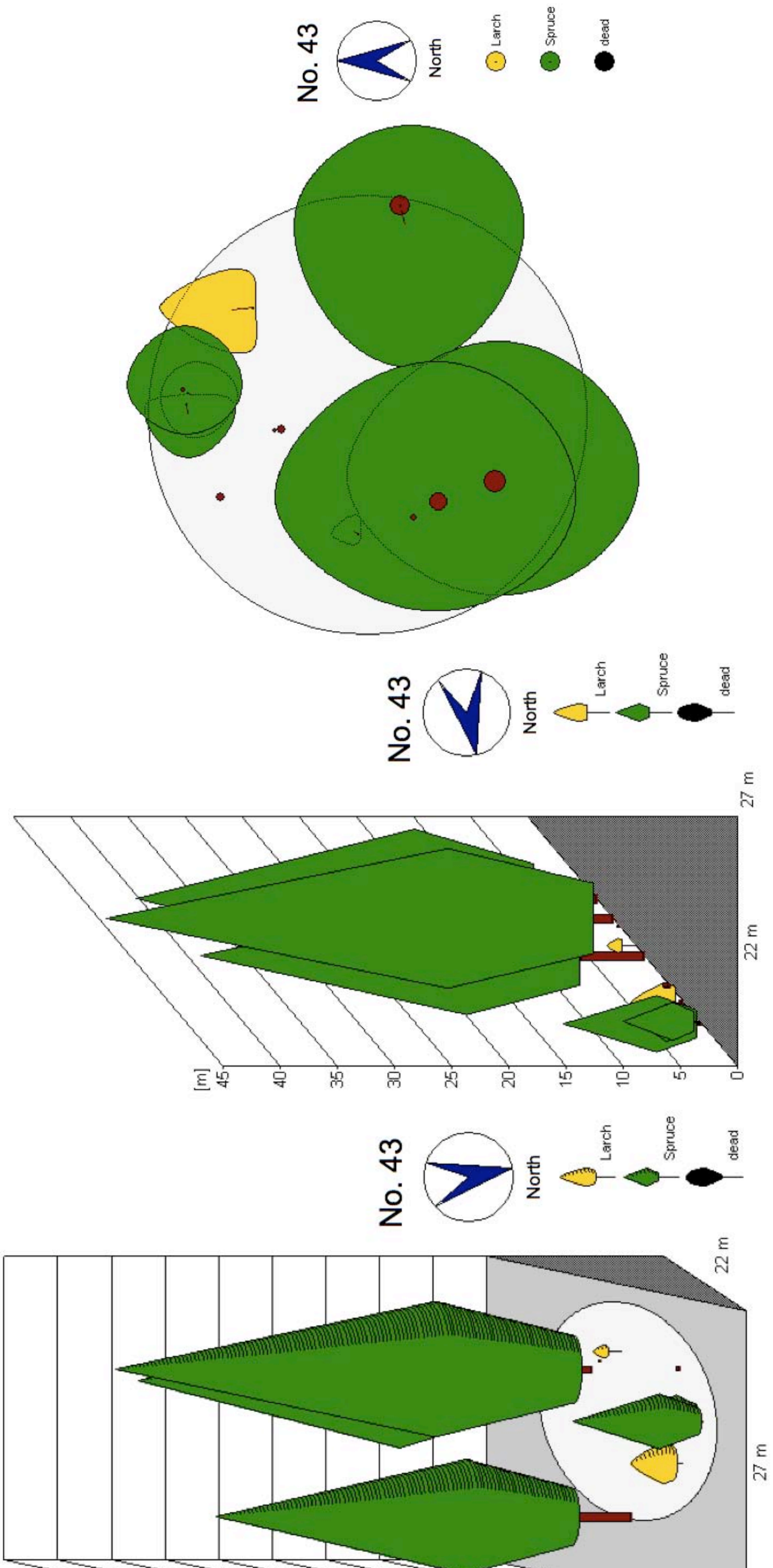


Fig. 59 Graphical presentation of sample plot no. 43 with cross-section and crown projection

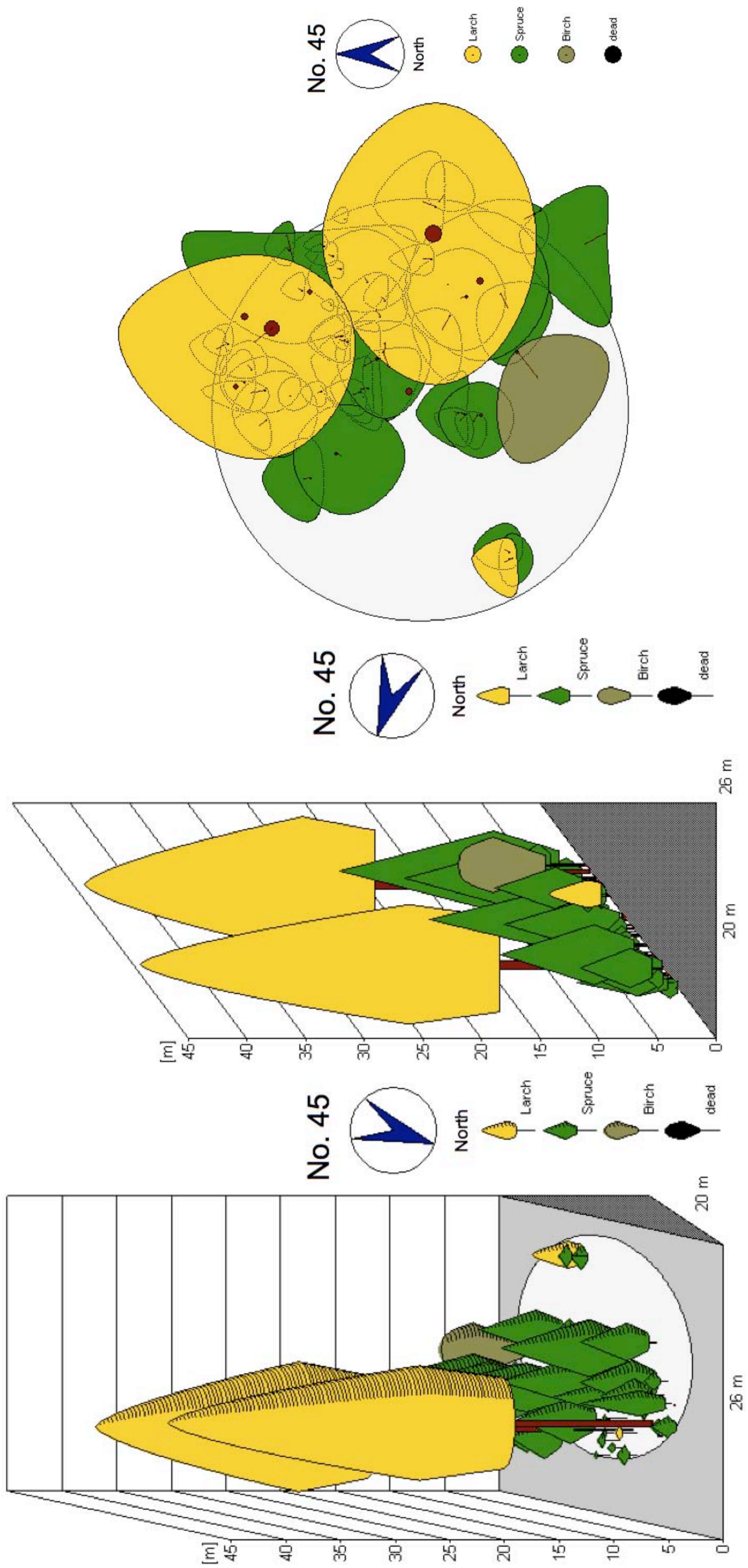


Fig. 60 Graphical presentation of sample plot no. 45 with cross-section and crown projection

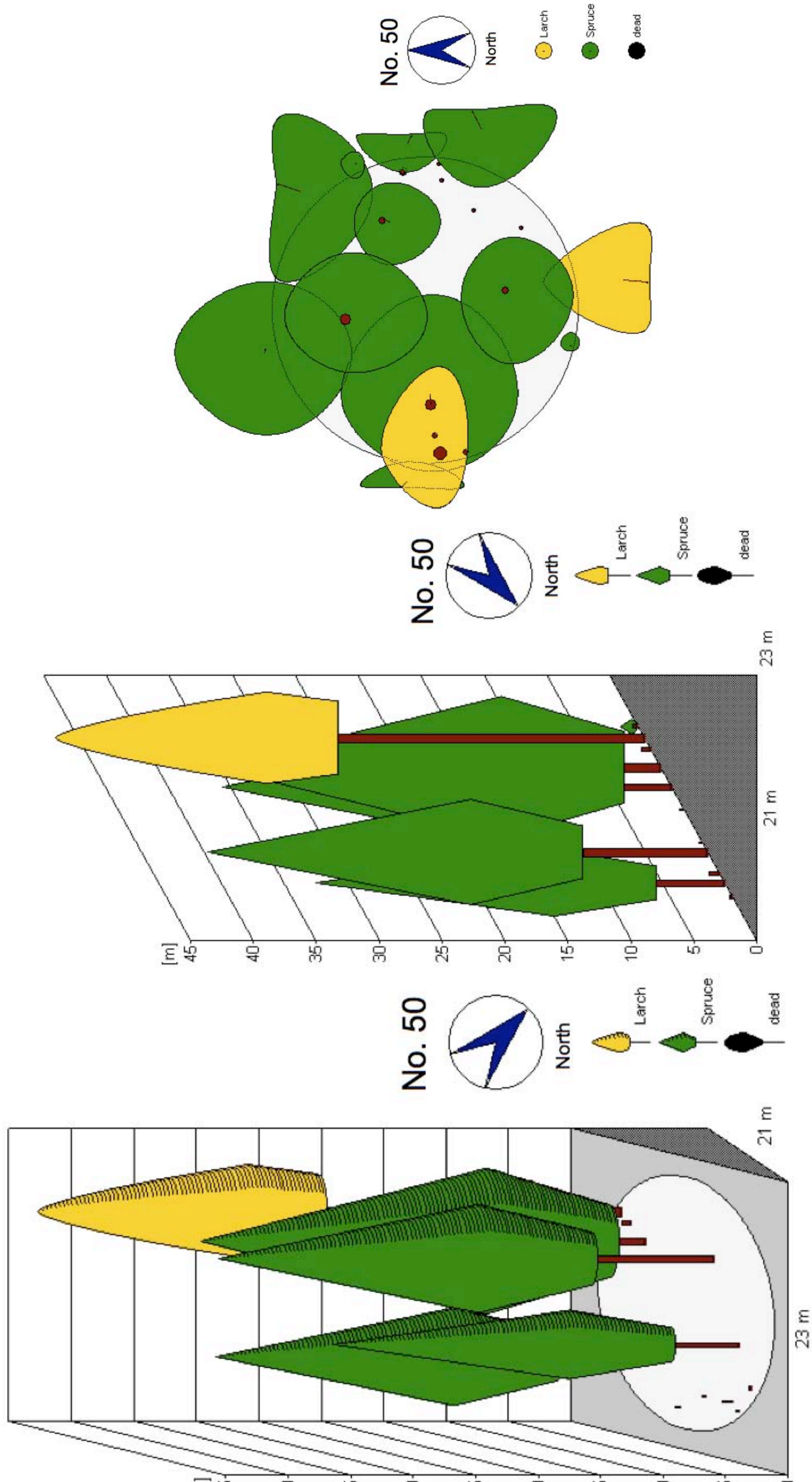


Fig. 61 Graphical presentation of sample plot no. 50 with cross-section and crown projection

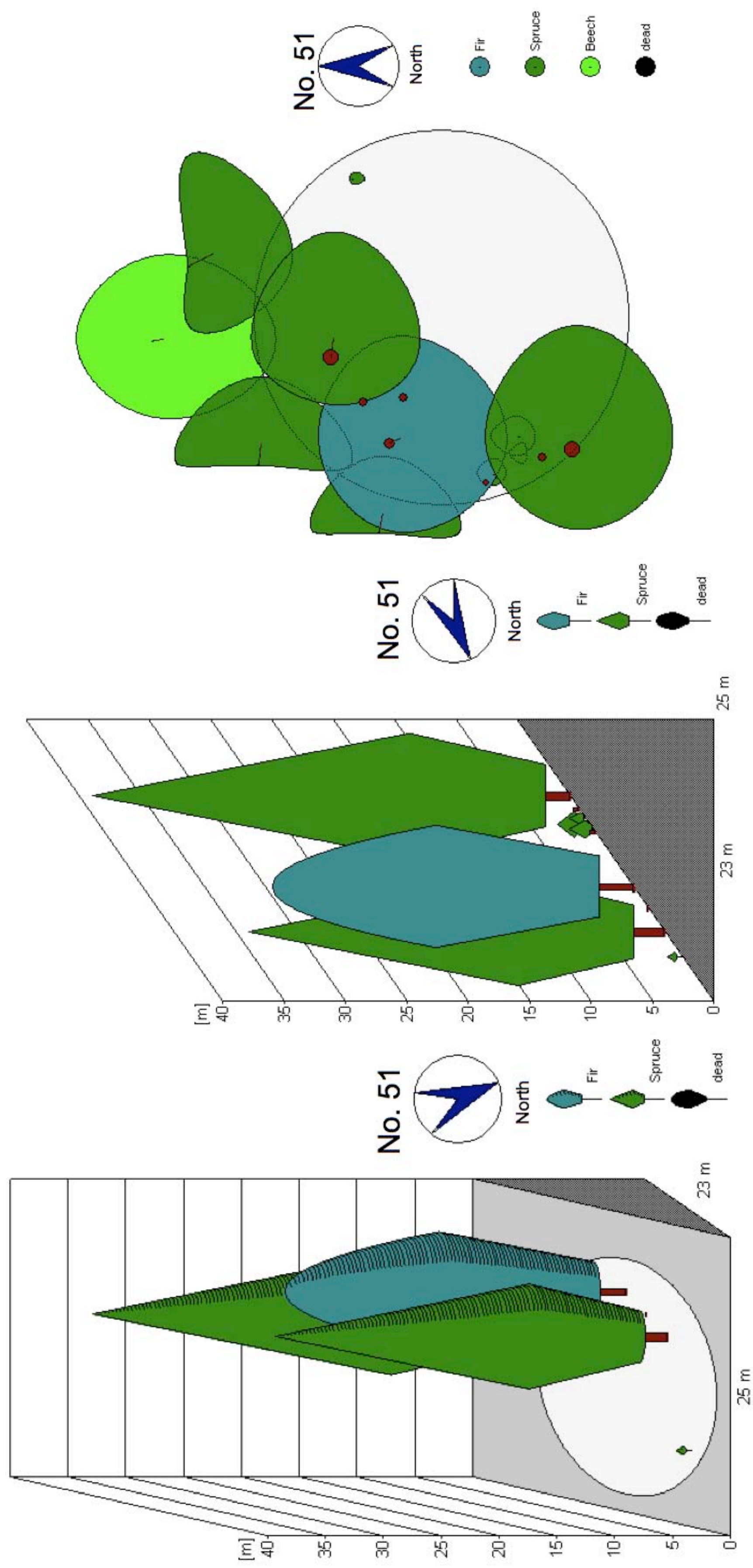


Fig. 62 Graphical presentation of sample plot no. 51 with cross-section and crown projection

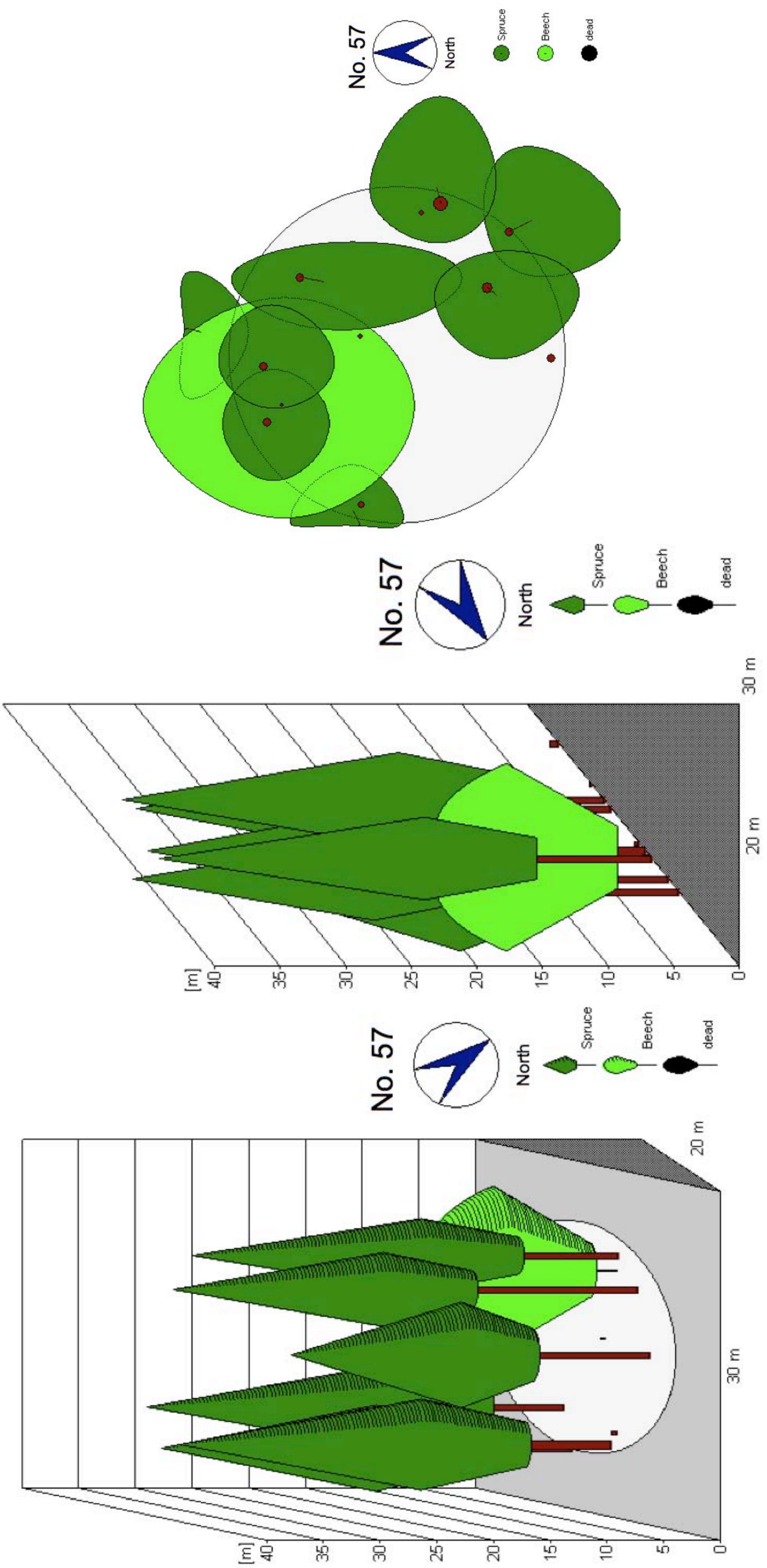


Fig. 63 Graphical presentation of sample plot no. 57 with cross-section and crown projection