Phyton (Horn, Austria) Special issue: "Achenkirch II"	Vol. 36	Fasc. 4	[33]-[54]	1. 7. 1996

Woodland Communities and Sites at Two Altitude Profiles Near Achenkirch (The Tyrol)

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Key words: Site survey, altitude zones, woodland communities.

Summary

ENGLISCH M. & STARLINGER F. 1996. Woodland communities and sites at two altitude profiles near Achenkirch (the Tyrol). - Phyton (Austria) 36 (4): 33 - 54.

The survey area is situated along two altitude profiles, each covering an altitude difference of about 800 m, west of Achental at the northern fringe of the Alps. From dolomite and limestone Rendzic Leptosol and Chromic Cambisol developed as predominant soil types. These are mainly resilient against (anthropogenic) depositions. Nine woodland communities (plant associations) were found. Montane spruce-fir-beech woodlands and subalpine spruce woodlands are predominant. Aposerido-Fagetum and Adenostylo-Piceetum are further divided into subassociations and variants. 18 site types were classified and mapped. The forest line, formed by Norway spruce (*Picea abies*), is situated at an altitude of about 1700 m, but is widely depressed due to anthropogenic impact and edaphic factors. Forest use started in the Middle Ages and was initialized by the needs of neighbouring salterns and mining. This caused changes of the tree species composition (decrease of Silver fir, *Abies alba*) and humus dynamics. More recent impacts are caused by tourism, especially skiing, and cattle grazing in the forest.

Introduction

The concept of the Integrated Monitoring Project of Achenkirch as stated by HERMAN & SMIDT 1994, is to increase the so far insufficient knowledge about the sensible ecosystems of the Northern Tyrolean Limestone Alps by taking measurements of potential single stressors and by testing bioindicators at intensively sampled plots along the altitude profiles. In order to assist in these objectives the sub-project on forest ecology has concentrated on site and soil studies (MUTSCH 1995 a,b) of the intensive plots on the one hand and on a site

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classification along the altitude profiles "Schulterberg" and "Christlum" (ENGLISCH 1992a, ENGLISCH & STARLINGER 1995) on the other hand.

Area of investigation

General remarks

The study area is situated on the eastern-most slopes of the Karwendel mountains in Achental. It ranges from the bottom of the valley (900 m a.s.l.) to the tree line (about 1700 m). Forest history is characterized by large-area clearcuttings, which started as early as in the 15^{th} century in order to satisfy the growing demands of mines and salterns in the valley of the river Inn (silver mines of Schwaz, salterns of Hall; RUF 1865). The influence of traditional land use such as woodland and alpine pasturing, litter raking and pruning is significant, the latter two only ending in the middle of this century. Recent impacts are mainly caused by multiple demands of tourism, by forest and alpine pasturing, and browsing of game. Direct and indirect demands are reflected in the regional Forest Development Plan (LANDESFORSTDIREKTION TIROL 1987) as well as in the Landuse Potential Analysis for the Area of Achenkirch (OTTITSCH 1995).

Climate

According to the climate classification of FLIRI 1975 the study area with the exception of the bottom of valley "Achental" is located in climatic region '4 sk'. This region is characterized by an annual mean precipitation of more than 1500 mm, precipitation maximum in summer and variability of precipitation of less than 18 %, which FLIRI 1975 states as typical of the northern fringe of the Alps in the Tyrol. According to FLIRI 1975 the 13.5 °C-isotherm of mean maximum temperature in July, which fits well with the forest line, is situated between 1700 m and 1800 m above sea level in the study area. Another value that is characteristic of the location of the forest line is 10 °C isotherm of July. Extrapolating the values of BUNDESMINISTERIUM FÜR BAUTEN UND TECHNIK 1984 (Planfeld No. 100) the climatic forest line has to be located at about 1800 m a.s.l. Mean annual temperatures in Achenkirch region range between 5.6 °C (bottom of the valley, 900 m a.s.l.) and 3.1 °C (1600 m a.s.l.) (MARGL 1994). Temperature measurements done for this project (SMIDT & al. 1993, 1994, 1995) between 1992 and 1994 demonstrate the possible extreme values in very warm summers like 1992 and 1994. While mean July temperature at 900 m a.s.l. (Achenkirch climate measurement station) is 14.7 °C, it was 17.5 °C in 1994. In 1994, even at Christlumkopf (1740 m) mean July temperatures of 14.6 °C were measured. As stated above, this corresponds to the long-year July mean temperature of 900 m a.s.l.

MARGL 1994 estimated the atmospheric water balance of the region as having a surplus every month of the year (the monthly surplus ranging between

62 mm in April and 109 mm in July) at 1000 m a.s.l. Annual surplus was calculated as being as high as 1013 mm.

Geology

According to the geologic map of AMPFERER & OHNESORGE 1950 dolomite ("Hauptdolomit") is the predominant substrate on the mountains Christlum and Schulterberg, while Mühleggerköpfl is entirely formed of dolomite. The cirque east of the summit of Christlum is filled with the remains of the moraine of Inntal-glacier. The summit and upper part of the northern slope of Schulterberg are formed by limestone ("Plattenkalk"). At small areas, block moraines and the remains of ground moraines were mapped at the northern and north-eastern slopes of Schulterberg. The field-works for this study resulted in the following amendments in respect to the map of AMPFERER & OHNESORGE 1950:

a. In the lower parts of Christlum a cover of gravel from a landslide was found (between plots 001/10 and B5).

b. Neokom layers were found in a small area around plot 020/03 at 1000 m above sea-level at Schulterberg.

Construction and maintenance of ski-runs at Christlum have been done using sewage sludge as well as silicate gravel and moraine materials from Zillertal. Large area cover by sewage sludge was assessed in the cirque east of Christlum-summit, which is situated between 1400 and 1700 m. The effects of the application of sewage sludge on forest soils and forest ecosystems in the Achenkirch region are described in KILIAN & al. 1986 and GLATTES & TOMICZEK 1984.

Methods

Vegetation samples were done using the approach and scale of BRAUN-BLANQUET 1959. Species names of vascular plants follow EHRENDORFER 1973, species names of mosses FRAHM & FREY 1983. Areas and form of samples were chosen primarily depending on the demands of homogeneity.

For the assessment of the naturalness the method of ABTEILUNG FÜR VEGETATIONSÖKOLOGIE UND NATURSCHUTZFORSCHUNG, UNIVERSITÄT WIEN 1994 was used. This was done by comparing the actual tree species composition of the stands of each site type with phytosociological models for the expected tree species composition. This is based on the concept of the "potential natural vegetation" of TÜXEN 1956. From that comparison, according to a given scheme of valuation, the stands are rated by means of a numerical scale ranging from 1 (lowest degree of naturalness) to 9 (highest degree of naturalness).

The final vegetation table (ENGLISCH & STARLINGER 1995) was prepared by rearranging samples and species. As a base a vegetation table originally created by the programme TWINSPAN (HILL 1979) was used.

Site description was carried out according to KILIAN & MAJER 1990, soil description was originally done using the Austrian Soil Classification (FINK 1969). For this paper the FAO system (FAO-UNESCO 1989) has been used. Humus classification was done according to the system of KLINKA & al. 1981, site classification according to JELEM 1960.

Soil sampling was done by ground auger (d = 6.3 cm) at plots 3, 5, 7 and 8 (soil intensive plots, container stations) only. On the other plots disturbed bag samples were taken. In either case, samples were taken from the geometric mineral horizons 0-5, 5-10, 10-20, 20-30, 30-50 and, if possible, 50-80 cm. On each sample plot at least 3 cores were taken or soil pits were dug and combined to one sample per plot and geometric horizon. Ectohumus was sampled by sampling frame (s = 25 cm, > 2 repetitions).

Chemical analysis included: pH ($CaCl_2$), pH (H_2O), carbonate, organic carbon (dry combustion), total nitrogen (Kjeldahl method), nutrients and anorganic pollutants P, K, Ca, Mg, Fe, Mn, Cu, Zn, Co, Cr, Ni, Pb, and Cd as well as Al in the ectorganic horizons (digestion by aqua regia) and the exchangeable cations K, Ca, Mg, Fe, Mn, Al, and H (extractant $BaCl_2$). The applied methods of chemical analysis are described as by ENGLISCH & al. 1992.

Data administration and part of the calculations were done by means of the relational ORACLE-data base systems GEA and FOREC. Ecological indicator values were calculated by means of the programme OEKSYN (SPATZ & al. 1979) using the indicator values list of ELLENBERG 1979 and the amendments of KARRER & KILIAN 1990, ENGLISCH & al. 1991 and KARRER 1992.

Results and Discussion

Soils and humus

Rendzic Leptosols and Chromic Cambisols take up large portions of the study area and are closely interlocked. Soils show high small-area variability as concerns depth of soils and depth of horizons: Organic mineral horizons (A_h, A_hC) vary between 10 and 56 cm (Rendzic Leptosols), mineral horizons (B) of Chromic Cambisols between 11 and 48 cm.

Only steep (inclination 50-70 %) and very steep relief forms (> 70 %) are solely occupied by Rendzic Leptosols. Due to the mosaic-like interlocking of soil types and high relief energy various transition forms between the two soil types were found. Those forms are mainly Rendzic Leptosol-like developments from the remains of Chromic Cambisols or colluvial material. At small, very steep areas near the summit of Schulterberg and at special sites (landslide area, site type H) Lithic Leptosols were found.

From moraine material profound Eutric Gleysols (up to 90 cm depth) developed. Those sites are almost totally deforested as a consequence of alpine pasturing and construction of ski-runs. In the course of the construction of ski-runs the original soils were changed largely; further impacts were caused by the grading and maintenance of the ski-runs. As a result of covering with soil materials brought up from other regions Anthrosols (mainly on ski-runs, which were excluded from this site survey) of varying depth and properties were formed. The topsoils are changed by repeated application of sewage sludge in order to prevent erosion on the ski-runs.

Overall, the chemical characteristics of the main soil types, Rendzic Leptosol and Chromic Cambisol (Fig. 1), are to be rated as favourable: Means of pH ($CaCl_2$) in Rendzic Leptosols vary between 6.03 (0-5 cm) and 7.23 (30-50 cm) respectively 4.73 to 6.19 (Chromic Cambisols).

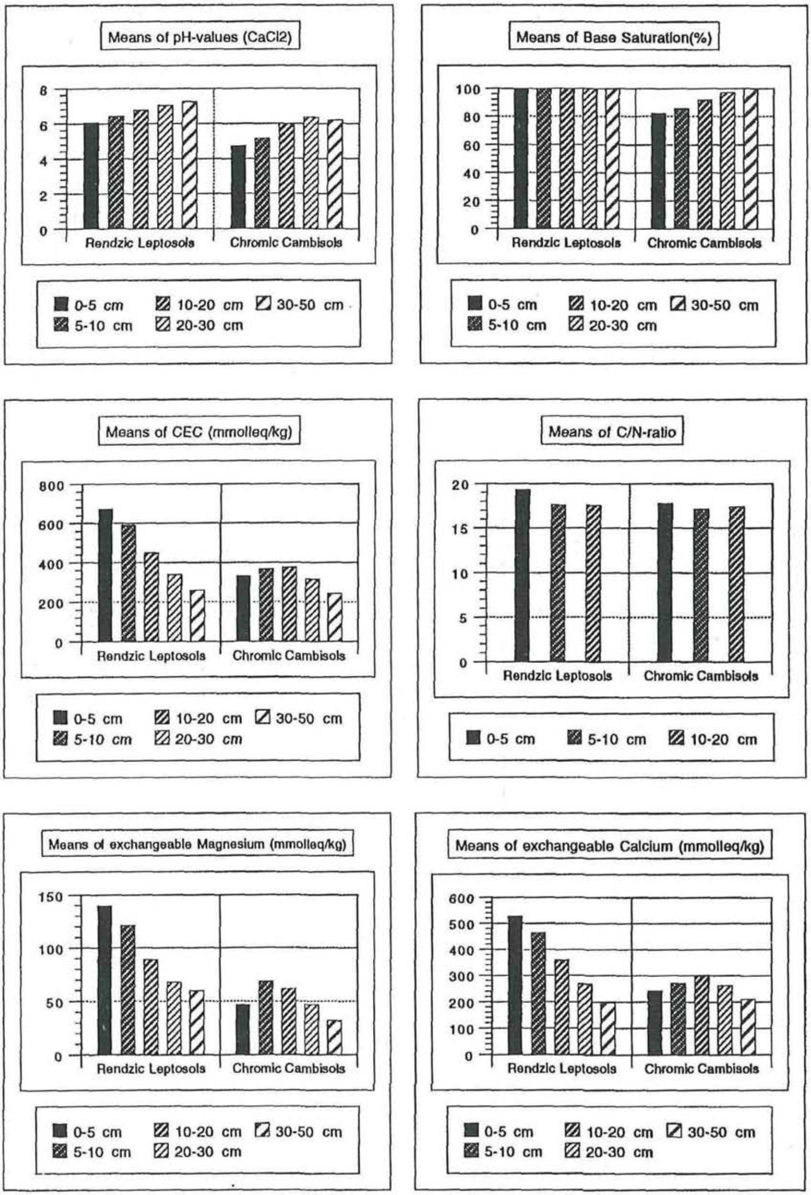

Fig. 1. Means of important chemical parameters for soil types Rendzina (n=11) and Chromic Cambisol (n=7); geometric horizons; sample plots of altitude profiles Achenkirch.

Both main soil types have a very high base saturation (Fig. 1). Profiles of Rendzic Leptosols are fully saturated while the topsoil (0-20 cm) of Chromic Cambisols shows de-saturation, which is not at all to be rated as critical. From 18 soil profiles analyzed only one shows 'high elasticity' against acidification according to MEIWES & al. 1984 (ratio of exchangeable calcium and magnesium to CEC between 0.15 and 0.50). Each of the other profiles is to be rated as having a 'very high elasticity' (> 0.50). Means of cation exchange capacity of Rendzic Leptosols are very high in the topsoil, but rapidly decreasing corresponding to the content of organic substance in the lower soil strata. Means of CEC of Chromic Cambisols are lower and do not vary much throughout the profiles due to the lower content of organic substance. The values of exchangeable magnesium and calcium show similar characteristics as CEC throughout the profiles.

As a consequence of favourable conditions for decomposition (high base saturation, north-eastern to southern aspect, frequent low stand density or high proportion of deciduous trees) humus forms Mull and Mullmoder prevail at Christlum and Schulterberg profiles. Mean C/N-ratios are narrow corresponding to humus forms and range from 17.5 to 19 (Rendzic Leptosols) and from 16.5 to 17.5 (Chromic Cambisols). Mors and Mormoders were mainly encountered at edaphically caused permanent associations of Norway spruce on Lithic Leptosols (Asplenio-Piceetum, site type H) and at dwarf pine stands.

Table 1 gives mean nutrient stores for the topsoils of intensive plots B3, B5, B7 and B8. At each of plots B7 and B8 four subplots (B7/1 to B7/4; B8/1 to B8/4) were assessed. For plot 7, which is homogenous in respect of soil type and relief, it was possible to calcalute an overall mean of nutrient stores, while at plot 8 two separate means had to be calculated for the subplots on different soil types.

Each of the plots shows high mean carbon stores. Rendzic Leptosols have higher stores due to their pedogenesis. The by far lowest stores were found on plot 5, where litter raking took place. The carbon stores in the Achenkirch region are partly much higher than the mean stores given for Rendzic Leptosols and Chromic Cambisols within the Austrian Forest Soil Monitoring System (ENGLISCH 1992b); but they are within the variance.

Extractable phosphorus and nitrogen stores in the topsoil are to be rated as medium ranging from 3500 to 6000 $kg.ha^{-1}$ and from 325 to 792 $kg.ha^{-1}$, respectively. The lowest stores were assessed at plots B5 and B8, where biomass removal (litter raking) took place for a long time.

Extractable magnesium and calcium stores of the plots differ in a wide range. Stores on Rendzic Leptosol plots are about ten times higher than those of the plots on Chromic Cambisol.

A comparison of the order of magnitude of stores using data from the Forest Soil Inventory in Bavaria (stores in soil stratum 0-30 cm, GULDER & KÖLBEL 1993) for the Upper Bavarian Limestone Alps gives the following results:

Phosphorus stores of the Achenkirch plots range between the 5-percentile and the median, magnesium and calcium stores between the 5- and the 75-percentiles.

Stores of lead and cadmium at high-altitude plots are significantly higher than those at lower altitudes. Zinc and copper stores at plot B8 are by far lower than those of all other plots. Overall, lead and cadmium stores at the study plots are higher than "frequent stores of non-polluted soils" (Pb: 60 $kg.ha^{-1}$, Cd: 0.7 $kg.ha^{-1}$) given by BLUM & WENZEL 1989. Copper stores are by far lower than the "frequent stores" (45 $kg.ha^{-1}$).

Site evaluations, regarding the hazards of acidification are subject to uncertainties and need to be done carefully because the output from the ecosystems could not be quantified within the current project. Annual input (Plots B1a, B5; data from BERGER 1995) equals 0.9 keq H+. To neutralize that, stores of exchangeable

Table 1. Nutrient and heavy metal stores of intensive plots in the Achenkirch region, soil stratum 0-20 cm, [$t.ha^{-1}$ and $kg.ha^{-1}$] (exch = exchangeable).

Plot	C	N	P	Ca	Mg	Pb	Zn	Cu	Cd
No.	$t.ha^{-1}$	$kg.ha^{-1}$							
B3	**117.8**	**5978**	**558**	**72845**	**46422**	**92.0**	**126.4**	**11.3**	**1.8**
B5	**57.4**	**3511**	**430**	**11699**	**14398**	**68.4**	**164.2**	**15.4**	**1.5**
B7	**76.8**	**6049**	**650**	**4022**	**5238**	**83.5**	**113.6**	**14.0**	**2.9**
B7/1	93.3	6930	785	5263	6108	88.5	142.8	18.0	1.7
B7/2	74.3	6066	792	4751	5495	83.0	117.7	14.5	8.5
B7/3	76.4	5747	590	2550	5317	79.1	124.1	13.0	0.6
B7/4	63.1	5451	431	3525	4032	83.3	69.9	10.6	0.8
B8/1	**80.0**	**4240**	**325**	**2326**	**6105**	**57.8**	**77.9**	**5.4**	**0.5**
B8/2-4	**98.5**	**4721**	**452**	**87356**	**63993**	**50.0**	**45.7**	**7.3**	**0.8**
B8/2	104.8	6110	475	131379	73335	55.4	23.1	6.2	0.9
B8/3	103.1	3784	484	119238	61722	46.1	49.2	6.9	0.7
B8/4	87.6	4268	397	11450	56921	48.5	64.9	8.8	0.9

Plot	K exch	Ca exch	Mg exch	Soil type
No.	$kg.ha^{-1}$			
B3	**51**	**6713**	**1440**	**Rendzic Leptosol**
B5	**48**	**3300**	**801**	**Rendzic Leptosol**
B7	**100**	**2890**	**184**	**Chromic Cambisol**
B7/1	171	4496	210	Chromic Cambisol
B7/2	147	3299	231	Chromic Cambisol
B7/3	92	1165	123	Chromic Cambisol
B7/4	88	2601	171	Chromic Cambisol
B8/1	**67**	**1291**	**355**	**Chromic Cambisol**
B8/2-4	**33**	**4556**	**940**	**Rendzic Leptosol**
B8/2	26	5027	978	Rendzic Leptosol
B8/3	23	4577	911	Rendzic Leptosol
B8/4	49	4065	930	Rendzic Leptosol

calcium alone, which amount to between 58 and 336 keq, is available. At Wank (Loisachtal, Upper Bavaria) ecosystem study plots (LIU & al. 1993) calcium output of 19 $keq.ha^{-1}.y^{-1}$ was measured at comparable ecosystems on Chromic Cambisols. Annual input on these plots amounted to 1.6 keq H+. In analogy to this it may be presumed that washout of carbonates due to atmospheric input is very low compared to washout caused by internal processes.

Woodland communities

The study area includes nine woodland associations, some of them further divided. A floristic table of the vegetation samples and more detailed comments have been presented in our previous paper (ENGLISCH & STARLINGER 1995). A synopsis of the woodland vegetation found in the study area and its classification according to MUCINA & al. 1993 is given in Table 2.

Table 2. Synopsis of the woodland vegetation at the Achenkirch altitude profiles.

Class: Querco-Fagetea Br.-Bl. & Vlieger 1937
Order: Fagetalia sylvaticae Pawlowski 1928
  Alliance: Fagion sylvaticae Luquet 1926
  Suballiance: Daphno-Fagenion T. Müller 1966
    Ass.: Aposerido-Fagetum Oberd. ex Passarge 1963
      Subass.: caricetosum albae prov.
        saniculetosum prov.
        caricetosum sempervirentis prov.
        caricetosum ferruginei prov.
    Ass.: Adenostylo glabrae-Fagetum Moor 1971
      Subass.: aruncetosum Moor 1971
  Suballiance: Eu-Fagenion Oberd. 1957
    Ass.: Asperulo odoratae-Fagetum Sougnez & Thill 1959
Class: Vaccinio-Piceetea Br.-Bl. 1939
Order: Athyrio-Piceetalia Hadac 1962
  Alliance: Abieti-Piceion (Br.-Bl. 1939) Soó 1964
    Ass.: Asplenio-Piceetum Kuoch 1954
    Ass.: Carici albae-Piceetum H. Mayer & al. 1967
  Alliance: Chrysanthemo-Piceion (Krajina 1933) Brezina & Hadac 1962
    Ass.: Adenostylo glabrae-Piceetum Zukrigl 1973
      Subass.: seslerietosum Zukrigl 1973
        luzuletosum sylvaticae Zukrigl 1973
Class: Erico-Pinetea Horvat 1959
Order: Erico-Pinetalia Horvat 1959
  Alliance: Erico-Pinion mugo Leibundgut 1948
    Ass.: Laricetum deciduae Bojko 1931
    Ass.: Erico carneae-Pinetum prostratae Zöttl 1951
    Ass.: Vaccinio myrtilli-Pinetum montanae Morton 1927

In the first place, the great diversity is a consequence of the existence of several altitudinal zones. Each of these can be seen as a specific climatic region characterized by an own climax vegetation and, on extreme sites, appropriate permanent communities. Besides, different temporary forms of state of the vegetation (substitute communities), caused by anthropogenic impact, can be identified.

Spruce-fir-beech woodlands

Central montane and altomontane altitudinal zones, reaching from the bottom of the valleys (820/930 m) to an altitude of about 1450/1500 m, are under natural conditions occupied mainly by spruce-fir-beech woodlands, which are dominated by common beech (*Fagus sylvatica*).

Aposerido-Fagetum, the most common type, is characterized by high abundance of *Aposeris foetida*.

In the central montane sub-communities *Carex alba* has higher frequency; *Pinus sylvestris* sometimes is occurring in the canopy. The field layer of Aposerido-Fagetum caricetosum albae is dominated by *Carex alba* and *Sesleria varia*. That sub-association adapted to comparatively dry and shallow soils is found on the eastern slope of Christlum up to 1200-1300 m a.s.l. In our study area that sub-community is particularly frequently represented through degraded forms caused by human activity. On less dry sites Aposerido-Fagetum saniculetosum is found. *Abies alba*, *Sanicula europaea* and *Carex montana* are distinctive here, *Carex alba* is less abundant.

The altomontane sub-communities are characterized by *Carex ferruginea*. Some species with comparatively high demand for moisture (e.g. *Aster bellidiastrum*, *Viola biflora*) are concentrated here. High precipitation in connection with lower temperatures cause their occurrence. Grassy stands with *Sesleria varia*, *Carex sempervirens* and *C. ferruginea* on sunny south-eastern and eastern slopes of Christlum are classified as Aposerido-Fagetum caricetosum sempervirentis. On the steep northern slopes of Schulterberg Aposerido-Fagetum caricetosum ferruginei develops. In this sub-community *Adenostyles alliaria*, *Primula elatior* and *Chaerophyllum hirsutum* indicate good supply with water and nutrients.

Very steep northern slopes on rubble at the Schulterberg profile are occupied by Adenostylo glabrae-Fagetum, a permanent community described by MOOR 1971 from comparable special sites of the Swiss Jura. The field layer is composed of species belonging to different ecological groups. Species with comparatively high demands for moisture and nutrients (e.g. *Athyrium filix-femina*, *Mercurialis perennis*) exist as well as *Aruncus dioicus*, usually growing in gorge woodlands, *Adenostyles alliaria*, a subalpine tall herb, and the crevice fern *Asplenium viride*.

Central montane spruce-fir-beech woodlands on more gentle northern slopes of the Schulterberg profile are classified as Asperulo odoratae-Fagetum. The community prefers loamy soils, which are not as strongly influenced by carbonate parent rock.

Montane spruce woodlands

In the montane altitudinal zones of the northern fringe of the Alps conifer stands under natural circumstances appear only if dominance of beech is prevented by unfavourable site conditions. On such special sites permanent associations built up by Norway spruce or, under more extreme conditions, Scots pine, occur. They constitute a very heterogenous group as the site conditions, which lead to the exclusion of beech, can be very different.

Asplenio-Piceetum occurs on blocky carbonatic rubble (landslip material). The site represents a complex mosaic composed of carbonatic rocks, crevices and soil pockets, where acidophilous plants occur together with more demanding plants from deciduous woodlands. Humus form Mor prevailing in this soil pockets means a germinating bed more favourable for spruce than for beech.

Completely different is Carici albae-Piceetum, which was found on a steep and sunny slope with very shallow soils. Field layer is dominated by drought resistent grasses (*Sesleria varia*, *Carex humilis*).

Subalpine spruce woodlands

Beginning from the climatic upper limit of beech and fir, which is situated at 1450/1500 m a.s.l. in the study area, spruce is dominant. As a result of the extreme climate and enhanced by cattle grazing, open and gappy stands, regularly interspersed with alpine grassland, are found.

Adenostylo glabrae-Piceetum is the only association encountered. On the south-eastern slopes of the Christlum profile the sub-association seslerietosum occurs on shallow soils. *Sesleria varia*, *Adenostyles glabra* and *Aposeris foetida* are the dominant species of the field layer. On an average deeper soils at the Schulterberg profile are occupied by Adenostylo glabrae-Piceetum luzuletosum sylvaticae. More demanding species, such as *Adenostyles alliariae*, are found there.

Larch woodlands

Natural larch woodlands of the subalpine spruce zone occur on special sites, mostly on steep northern slopes rich in snow. Under mechanical stress caused by snow larch is superior to spruce. On the northern slope of Christlum, at 1600 m a.s.l., a larch stand fits with that. The field layer, dominated by *Carex ferruginea* and *Aposeris foetida*, has a similarity to Adenostylo glabra-Piceetum luzuletosum sylvaticae. The classification within Laricetum deciduae is only provisional.

Krummholz of dwarf mountain pine

In the upper subalpine zone, that is from approximately 1700 m a.s.l. upward, dwarf mountain pine (*Pinus mugo*) forms the climax vegetation. The uppermost points of the study area are just bordering at that zone. Underneath, krummholz is found on sites where spruce and larch are missing because of long-lasting snow cover or direct effects of avalanches. Besides, it occurs as a substitute community for spruce woodlands.

Erico carneae-Pinetum prostratae of the Christlum profile is characterized by basidophilous dwarf shrubs (*Rhododendron hirsutum*, *Erica herbacea*). That association prefers sunny and comparatively warm sites.

On a north-eastern slope of the Schulterberg summit area Vaccinio myrtilli-Pinetum montanae is found. Acidophilous plants (e.g. *Vaccinium myrtillus*) and tall herbs (e.g. *Chaerophyllum hirsutum*) are dominant.

Site types

Site classification in the study area (Table 3) is based on natural woodland communities and the climatic classification implied. The geologic conditions being largely homogenous in contrary to the sequence of horizons of the main soil types (Chromic Cambisol, Rendzic Leptosol), which are closely interlocked within small areas, one site type corresponds to one natural woodland community (site types D to O). Natural woodland communities of site types B and C could be subdivided using the site parameters of soil depth, aspect, inclination and water regime. Forms of state (e.g. degradation) were taken into account as classification criterion.

The situation of the study plots and site types is to be taken from the maps in ENGLISCH & STARLINGER 1995 as well as from the documentation of the soil profiles.

Table 3. Synopsis of the site types and characterizing parameters in the study area

Location: C - Christlum, S - Schulterberg, M - Mühleggerköpfl; altitudinal zone: l.mont. - lower montane, c.mont. - central montane, a.mont. - altomontane, subalp. - lower subalpine; slope position: UpS - upper slope, MdS - middle slope, LwS - lower slope; slope gradient: m.incl. - moderately inclined (15-50 %), st. - steep (50-70 %), v.st. - very steep (> 70 %); soil type: m.dp. - moderately deep, sh. - shallow, v.sh. - very shallow, LPk - Rendzic Leptosol, LtLp - Lithic Leptosol, CMx - Chromic Cambisol, GLe - Eutric Gleysol; soil moisture regime: m.dry - moderately dry, sl.dry - slightly dry; actual vegetation: deg. - degraded form.

Site type	Loc.	Altitudinal zone	Slope position	Slope gradient	Soil type	Potential rooting depth	Soil moisture regime	Aspect	Potential natural woodland community	Actual vegetation
A	M	c.mont.	UpS-MdS	m.incl.	sh.-m.dp. LPk-CMx	15-55	m.dry-sl.dry	-	Aposerido-Fagetum saniculetosum (?)	Aposerido-Fagetum caricetosum albae (deg.)
B	C	c.mont. (l.mont)	MdS	m.incl.-st.	sh. LPk	<30	sl.dry	S-SE	Aposerido-Fagetum caricetosum albae	Aposerido-Fagetum caricetosum albae
B'	C	c.mont.	MdS	st.	v.sh. LPk	<15	sl.dry	E	Aposerido-Fagetum caricetosum albae	Erico-Pinetum sylvestris s.lat./ Picea forests/ Aposerido-Fagetum caricetosum albae (deg.)
C	C	c.mont.	MdS	m.incl.-st.	LPk-CMx	20-60	fresh	E	Aposerido-Fagetum saniculetosum	Aposerido-Fagetum saniculetosum
C'	C	c.mont.	MdS	st.	LPk-CMx	30-35	fresh	E-SE	Aposerido-Fagetum saniculetosum	Picea forests/ Aposerido-Fagetum caricetosum albae (deg.)
C"	C	c.mont. (a.mont.)	LwS	v.st.	sh. LPk	20	sl.dry-fresh	E-SE	Aposerido-Fagetum saniculetosum	Aposerido-Fagetum saniculetosum
D	C	a.mont.	MdS-LwS	v.st.	(v.)sh. LPk	<20	sl.dry-fresh	E-SE	Aposerido-Fagetum caricetosum sempervirentis	Aposerido-Fagetum caricetosum sempervirentis (deg.)/(forest) pasture
E	S	a.mont.	MdS	v.st.	(v.)sh. LPk	±20	fresh	N-NE	Aposerido-Fagetum caricetosum ferruginei	Aposerido-Fagetum caricetosum ferruginei (deg.)/(forest) pasture
F	S	a.mont. (c.mont)	MdS	v.st. (m.incl.)	sh.-(m.dp.) LPk-CMx	±30	fresh	N	Adenostylo glabrae-Fagetum aruncetosum	Adenostylo glabrae-Fagetum aruncetosum
G	S	c.mont.	-	m.incl.	m.dp. CMx	±40	fresh	-	Asperulo odoratae-Fagetum	Picea forests/Asperulo odoratae-Fagetum
H	S	c.mont.	MdS	m.incl.	LtLp-LPk	<30	fresh	N	Asplenio-Piceetum	Asplenio-Piceetum

Site type	Loc.	Altitudinal zone	Slope position	Slope gradient	Soil type	Potential rooting depth	Soil moisture regime	Aspect	Potential natural woodland community	Actual vegetation
I	C	c.mont.	UpS-MdS	v.st.	v.sh. LPk	<10	m.dry	S-SE	Carici albae-Piceetum	Erico-Pinetum s.lat./ Carici albae-Piceetum (deg.)
J	C	subalp.	UpS-MdS	st.	sh. LPk (-CMx)	±20	sl.dry	E-SE	Adenostylo glabrae-Piceetum seslerietosum	Alpine pasture/ Erico carneae-Pinetum prostratae/ Adenostylo glabrae-Piceetum seslerietosum (deg.)
K	S	subalp.	UpS-MdS	var.	m.dp.-v.sh. CMx-LPk	20-70	fresh	-	Adenostylo glabrae-Piceetum luzuletosum sylvaticae	Alpine pasture/Adenostylo glabrae-Piceetum luz. sylv. (deg.)
L	C	subalp.	UpS	st.	v.sh. LPk	±15	sl.dry-fresh	N-NE	Laricetum deciduae (Adenostylo glabrae-Piceetum luz. sylv.?)	Laricetum deciduae (deg.)
M	C	subalp.	UpS-MdS	v.st.	(v.)sh. LPk (-CMx)	±25	sl.dry-fresh	SE-E	Erico carneae-Pinetum prostratae	Alpine pasture/Erico carneae-Pinetum prostratae
N	S	subalp.	MdS	v.st.	sh. LPk	±30	fresh	N	Vaccinio myrtilli-Pinetum montanae	Vaccinio myrtilli-Pinetum montanae
O	C	subalp.	MdS-LwS	v.st.	CMx, GLe	45-90	moist	E	Adenostylo alliariae-Piceetum (?)	Alpine pasture/ skiing grounds

Central montane Sites

The montane site types (A-C", G-I, see Table 3) of the study area are to be differentiated mainly by water regime. The moister sites go along with less shallow soils and Chromic Cambisols, the drier sites are usually more inclined; Rendzic Leptosols are predominating. The differences in the water regime are also reflected in different subassociations of the woodland communities. The aspect of all those sites at Christlum is east to south-east.

At site type A (Mühleggerköpfl) vegetation indicates this site to be located at the transition between lower montane and central montane altitudinal zones (light and warmth indicators *Sorbus aria*, *Acer platanoides*, *Galium sylvaticum*). This is backed up by the woodland community, which is a transitional form between the montane Aposerido-Fagetum caricetosum albae and the submontane Carici albae-Fagetum.

The central montane sites of Christlum are situated near the village of Achenkirch. They were therefore subject to impacts of traditional land use (clearcuttings, cattle grazing in the wood). At the most degraded sites types, B' and C', anthropogenic impacts led to changes from natural woodland communities to substitute communities (cf. Table 3). Additionally at site type B' humus form has changed to Mormoder or Leptomoder (rarely Mor). Various indicator plants for acidity or lack of nutrients appear. Even at the more natural site types B, C and C" human impacts result in a decreased proportion of Silver fir (*Abies alba*).

Slopes of very high inclination and south-eastern to southern aspect are occupied at present by spruce-pine forests. That site type (I) is characterized by very shallow Rendzic Leptosols.

At Schulterberg two site types were classified in this altitudinal zone. On plain and slightly inclined sites on marl and dolomite Chromic Cambisol of 40 to 50 cm depth was found (site type G). Here, the water regime is balanced due to texture, inclination and higher soil depth. Favourable conditions for transformation of organic substance result in the humus forms of Mull and Mullmoder.

On landslip material a permanent association of spruce was found. That site type (H) covers a body of rubble which shows a mosaic-like site character. Soil type ranges from Lithic Leptosol to Rendzic Leptosol, soil depth is highly variable. Low pH-values of the Endohumus (humus form: Mor), low potential rooting space and cold micro-climate favour spruce before beech in spite of the altitudinal zone.

Altomontane Sites

The altomontane altitudinal zone ranges between approximately 1300 m and 1450/1500 m. The varying altitude of the upper limit of the altitudinal zone is mainly due to differences in relief and aspect.

Site type D at Christlum is characterized by shallow Rendzic Leptosols and high inclination between 40 and 75 % on middle and lower slopes with south-eastern to eastern aspect. Cattle grazing of the nearby Alpine pasture resulted in an opening up of the stands. In spite of the high altitude dominating humus forms are Mull and Mullmoder due to increased light and warmth supply. This correlates with the occurance of species of high demand on light.

At Schulterberg this altitudinal zone is partly occupied by middle slopes of high inclination with north-eastern to northern aspect (site type E). More profound soils, mostly influenced by colluvial input, having organic mineral soil horizons (15 to 25 cm) of considerable depth characterize site type F. The tree species mixture here is very close to the natural woodland community.

Subalpine sites

The subalpine altitudinal zone ranges from 1450/1500 m to the highest elevations of the study area. The natural vegetation, which was originally dominated by spruce woodlands, has widely been replaced by grassland or dwarf pine communities.

At Christlum, corresponding to climatic extremes and the nearby Alpine pastures, cover of the canopies is low. Influence of altitude results in the absence of species of decidous forests in the herb layer, while species indicating grazing are of high abundance. Shallow Rendzic Leptosols are predominant at that site type (J).

Upper slopes of northern to north-eastern aspect are occupied by larch stands with small amounts of spruce. Anthropogenic impact fom the nearly Alpine pasture Moosenalm could have prevented the development from larch pioneer-stands to subalpine spruce woodlands. Very shallow Rendzic Leptosols are the main soil type. Due to low temperatures and slow decomposition of larch-needles Leptomoder dominates at that site type (L).

Site type K occupies the plateau of Schulterberg-summit as well as upper and middle slopes near the summit. At the plateau soil types vary small-scale between Rendzic Leptosols and Chromic Cambisols (rarely with stagnic properties), while at the slopes Rendzic Leptosols dominate. Stands are opened up as a consequence of intensive alpine pasturing. The water regime of that site type is even in areas of southern aspect more balanced than at sites of type J, which is due to a higher portion of fine soil and higher potential rooting depth.

Extreme sites of the subalpine zone are occupied by permanent associations of dwarf pine. At the slopes of eastern to south-eastern aspect of Christlum the natural woodland community indicates relatively warm, more basidophilous site conditions (site type M). At Schulterberg (slopes of northern aspect) long-term snow-cover and thus short vegetation periods inhibit litter decomposition. The prevailing humus form of that site type (N) is therefore Mor, indicating acidification of the topsoil. The water regime is balanced. Windslabs prevent the development of spruce stands, resulting in the natural plant community of Vaccinio myrtilli-Pinetum montanae.

The cirque east of the Christlum summit is presently almost totally deforested due to the construction of ski-runs and alpine pasturing. Here the most profound soils of the study area have developed from the moraines of Inn-glacier and colluvial material. The depth of the A_h-horizons is very regular (6-8 cm) due to the repeated application of sewage sludge as a step of maintenance of the ski-runs.

Ecological indicator values

Ecological indicator values (ELLENBERG 1979, ELLENBERG & al. 1991) make it possible by means of vegetation samples to characterize sites approximately. Even ecological parameters, that are difficult to measure (e.g. climate) can be commented on. The procedure is based on a list which contains empirical values on the ecological behaviour of vascular plants. The values follow an ordinal scale consisting of nine grades mostly. The unweighted arithmetic means of the species values of a particular sample are used for the characterization of its site quality. Although that practice is not unobjectionable from the mathematical point of view, it is applied frequently and, cautiously interpreted, can give valuable indications (ELLENBERG & al. 1991).

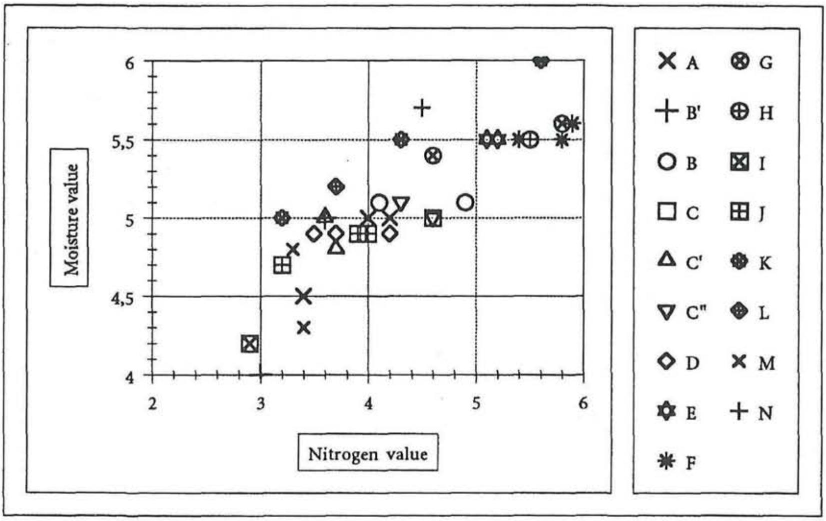

Fig. 2. Ecogram of nitrogen and moisture values from the vegetation samples at the Achenkirch altitudinal profile.

"Nitrogen values" and "moisture values" (Fig. 2) are positively correlated. Moisture values of the Schulterberg profile (site types E, F, G, H, K, N), lying between (5)5.4 and 6, are clearly higher than the values of the Christlum profile and the Mühleggerköpfl, which are between 4 and 5.2. The reason could be found in the chiefly northern aspect and the mostly greater profoundness of the soils. The nitrogen values of both profiles show a rather strong overlap, with the highest values at the Schulterberg profile. Within the Christlum profile the site types that are not that heavily affected by human influence (B, C, C'') show higher nitrogen values than the degraded types (B', C'). Compared to nitrogen values from the Austrian Forest Soil Monitoring System (KARRER 1992), site types E, F, G, H and partly K from the Schulterberg profile roughly are to be rated as averagely supplied. Site types from Christlum and Mühleggerköpfl as well as the samples from the summit area of Schulterberg can be rated as slightly to clearly below average.

"Temperature value" and "light value" (Fig. 3) allow an approximate characterization of the stand climate. The temperature values correspond to the altitudinal zones. The subalpine site types (J-N) show values between 2.9 and 3.5, the altomontane (D-F) between 3.5 and 4.3 and the central montane site types (A-C, G-I) between 4 and 4.6. Light values are correlated to the degree of anthropogenic thinning of the stands. All subalpine site types, the altomontane types, which until present times are affected by cattle grazing (D, E), as well as the more seriously degraded types (B, C', I) from near the settlement of Achenkirch generally show values of more than 5.6. As opposed to this, the least affected site types (F-H), showing high naturalness, have light values between 4.4 and 5.2.

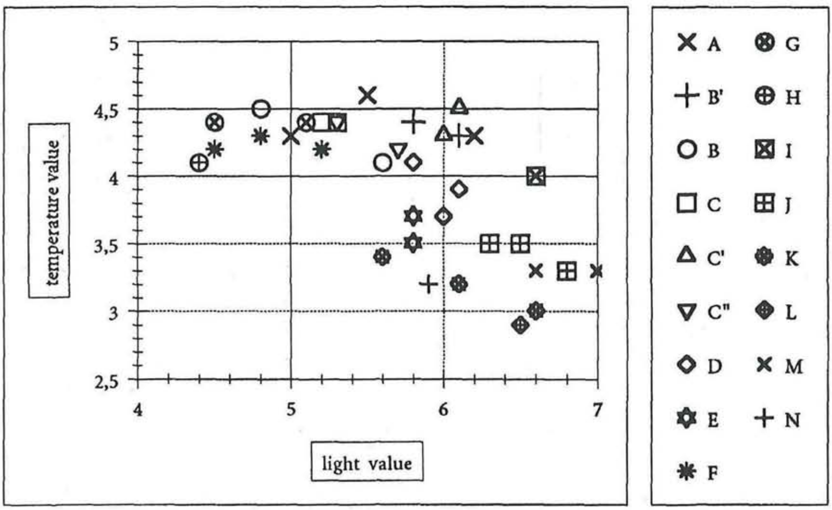

Fig. 3. Ecogram of light and temperature values from the vegetation samples at the Achenkirch altitudinal profile.

Evaluation

Owing to more or less intense human impact on the site types, stands of differing naturalness exist in the study area. In Table 4 an attempt is made to estimate the degree of naturalness of the tree species composition.

The highest values of naturalness are found in site types F and H from the Schulterberg profile, which are situated far from the greatest density of settlement. In both the pathless very steep northern slopes (F) and the permanent community on blocky carbonatic rubble (H) forest use is of minor economic interest.

The lowest degree of naturalness was determined on site types B' and C', which are situated within the lower part of the Christlum profile. In consequence of the immediate neighbourhood of the settlement of Achenkirch those stands have been most seriously affected by historic forms of land use (litter raking, pasture). So the stands originally dominated by beech have mainly been converted to pine-spruce stands.

Site types B and C'' of the Christlum profile show comparatively high naturalness. They are both situated far from settlements and below the area which is still influenced by alpine pasturing.

Site type D, which borders on upwards, presents a clearly lower value of naturalness. Browsing of beech and fir in consequence of the forest pasture results in a modified tree species composition. Moreover, the stands are opened up as a result of cattle grazing. That is even more true for the adjacent subalpine spruce woodland (site type J), where opening up only in a minor degree is reflected in tree species composition. The altomontane and subalpine site types, which are subject to that, are marked with "*" in Table 4. The values of naturalness of the altomontane and subalpine sites both of Schulterberg and Christlum profile are changed in a similar way by forest pasture.

The value of naturalness of site type G is the result of a compromise between very natural stands of Asperulo odoratae-Fagetum and less natural spruce plantations and clearcuttings, both present on the site type.

Generally speaking, spruce and to some extent also pine and larch have increased in the whole area, whereas beech and much stronger fir have been reduced in consequence of human activities. That change of tree species is confirmed by the differences in tree species composition between production forests and protection forests as stated by SCHADAUER 1995, Table 1 based on data from the Northern Tyrolean Limestone Alps. Human impact shows the strongest effects in stands which are in contact with areas in agricultural use. These effects are caused on the one hand by historic land use (e.g. litter raking, forest pasture) in the surroundings of the settlements down in the valley, on the other hand by present alpine pastures in the subalpine zone.

In Table 4 reference is given to site types, where indication of litter raking or forest pastures has been found. Acidophilous plants, such as *Calluna vulgaris* and *Vaccinium vitis-idaea* were used as indicators of former litter raking. Indicators of

Table 4. Potential and actual tree species composition, evaluation of naturalness, influence of pasturing, litter raking and drought stress in the site types of the Achenkirch altitude profiles.

Site type	Loc.	Altitudinal zone	Tree species of potential natural woodland community	Actual tree species composition	Degree of naturalness	Pasture	Litter raking	Drought stress
A	M	c.mont.	**Bu** Fi Ta *BAh (RFö)*	Bu **Fi** *(TaBAh)*	4,5	x	x?	(x)
B	C	c.mont.	**Bu** Fi *Ta (BAh RFö)*	**Bu** Fi *(BAh RFö)*	8	x?		x
B'	C	c.mont.	**Bu** Fi *Ta(BAh)RFö(Lä)*	*(Bu)***Fi***(BAh)*RFö*(Lä)*	3	x	x	x
C	C	c.mont.	**Bu** Fi Ta *BAh (RFö)*	Bu **Fi** *Ta (BAh)*	5,5	x?		
C'	C	c.mont.	**Bu** Fi Ta *BAh (RFö)*	Bu **Fi***(BAh) RFö*	3	x	x	
C"	C	c.mont. (a.mont.)	**Bu** Fi Ta *BAh (RFö)*	**Bu** Fi *Ta (BAh RFö)*	7,5	x?		x?
D	C	a.mont.	**Bu** Fi *Ta BAh (Lä)*	Bu **Fi** *(Ta BAh) Lä*	5,5*	x		x?
E	S	a.mont.	**Bu** Fi Ta *BAh (Lä)*	Bu **Fi** *(Ta BAh Lä)*	4,5*	x		
F	S	a.mont.	**Bu** Fi Ta *BAh*	Bu Fi Ta *BAh*	9			
G	S	c.mont.	**Bu** Fi Ta *BAh*	Bu **Fi** *(TaBAh)*	4,5			
H	S	c.mont.	*(Bu)* **Fi** *(Ta BAh)*	*(Bu)***Fi***(BAh)*	9			
I	C	c.mont.	**Fi** *RFö*	Fi **RFö**	6	x	x	x
J	C	subalp.	*(Bu)* **Fi** *(Ta BAh) Lä*	*(Bu)* **Fi***(TaBAh)* Lä	8*	x		x?
K	S	subalp.	**Fi** *(BAh Lä)*	**Fi** *(BAh)*	9*	x		
L	C	subalp.	Fi **Lä**	*(Fi)* **Lä**	7	x		
M	C	subalp.	*(Fi BAh Lä)* -	*(Fi BAh Lä)*-	-	x		x?
N	S	subalp.	*(Fi BAh Lä)* -	*(Fi BAh Lä)*-	-	x		
O	C	subalp.	**Fi** *(BAh Lä)*	-	-	x		

Legend:

Tree species: Bu = Common beech, Fi = Norway spruce, Ta = Silver fir, BAh = Sycamore, RFö = Scots pine, Lä = European larch; portions of the tree species are expressed by means of type letters, e.g. **Bu** - dominant, Bu - subdominant, *Bu* - admixed tree species (actual)/obligatory admixed (potential), *(Bu)* - sprinkled occurence (actual)/possible occurence (potential); locations and altitudinal zones see Table 3.

pasturing are e.g. *Brachypodium pinnatum*, *Carlina acaulis* or *Prunella grandi-flora*.

Clearcuttings for the requirements of neighbouring salterns (Hall) and silver mines (Schwaz), forest fires (RUF 1865) as well as recent plantations of spruce also contribute to a decrease of naturalness.

In addition, site types where episodic drought stress might be expected are marked in Table 4.

Because of the magnitude of the nitrogen stores, the narrow C/N- ratios and the climate (see also ENGLISCH 1992b) sufficient supply of plant available nitrogen by mineralisation can be expected, except from very shallow soils. Especially the comparatively high nitrogen indicator values of the Schulterberg profile point to sufficient supply.

Low concentration of nitrogen in soil water on the study plots B1a and B5 (BERGER 1995) and low nitrogen content in spruce needles (HERMAN 1994), which according to GUSSONE 1964 are to be rated as deficient, suggest the conclusion that at least on sites with very shallow or degraded soils periodical nitrogen deficiency is to be expected. In particular site types B' and I with especially low nitrogen indicator values should be mentioned in that context.

The existing data do not indicate any eutrophication or soil acidification by nitrate leaching.

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