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Loss of floristic diversity in the Karkonosze Mts (SW Poland)

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ABSTRACT: The paper presents the transformations of species composition in the main plant communities of the Karkonosze Mts subalpine and alpine belts during the last 35 years. Floristic changes in the associations *Carici (rigidae)-Nardetum, Carici-Festucetum supinae, Crepidi-Calamagrostietum villose* and *Empetro-Vaccinietum* were investigated, and some vegetation transformations in the remaining belts were also indicated. The progressive floristic degradation of plant communities in the subalpine and alpine belts consists in *(a)* expansion of grasses, *(b)* decline of rare vascular plants and *(c)* elimination of terricolous bryophytes and lichens. In spruce forest belts, species connected with old-growth spruce forests such as *Listera cordata* and *Moneses uniflora* are declining. The changes in plant communities of low mountain swards (*Nardetalia*) caused by cessation of pasture and mowing is the cause of retreat of many rare plants such as *Arnica montana.* The main cause of the community transformations still occurring in the Karkonosze Mts is change in the soil environment connected with anthropogenic nitrogen fertilization. The large inflow of mineral nitrogen from the atmosphere (1138 mg/m^2 total for the vegetative season) accelerates decomposition of organic matter and intensifies nitrification. The high content of nitrates in soil (5 times higher than in Tatra Mts swards) is the reason for expansion of graminoids, mainly *Deschampsia flexuosa*, *Calamagrostis villosa* and *Carex bigelowii* subsp. *rigida*. Overfertilization of habitats makes rare high mountain vascular plants retreat and terricolous bryophytes and lichens decline.

KEY WORDS: Karkonosze Mts, flora, biodiversity, nitrogen mineralization, nitrification

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INTRODUCTION

The Karkonosze Mountains has gained a bad reputation because of forest dieback occurring there since the 1960s. The dieback of spruce forests, progressing mainly in the upper forest belt, is only one of the sharply appearing symptoms of drastic changes in the mountain vegetation during the last four decades. The elimination or thinning of the tree layer leads to noticeable changes in ecological conditions, the consequence of which is transformation in the species composition of floor vegetation (Fabiszewski *et al.* 1993; Fabiszewski & Wojtuń 1994). Recent investigations (Wojtuń *et al.* 1995, 1997) revealed that the ongoing acidification and eutrophication of habitats in the Karkonosze Mts is harming not only the forests but also communities of subalpine and alpine vegetation. The transformations of plant communities above the Karkonosze Mts timberline are, however, more subtle than the impressive dieback of high mountain spruce forests, and are not very noticeable in the initial phase. They consist in the expansion of one species (usually grass) with a parallel decline of rare species, frequently inconspicuous mountain plants. The latter are the most valuable as their presence or absence determines the floristic and geobotanical position of our mountains.

The Karkonosze Mts plant communities were described in detail decades ago (Matuszkiewicz & Matuszkiewicz 1974 and unpubl.). The information from these papers enables comparative studies of the former and present floristic composition of almost all the Karkonosze plant communities.

This study characterizes modifications of the species composition of the main plant communities of the Karkonosze Mts subalpine and alpine belts during the last 35 years, and briefly indicates some of the changes in the vegetation of the remaining belts. The paper also presents the most important causes and effects of the ongoing changes leading to the loss of floristic diversity in this important European mountain range.

Objectives and methods of investigation

The object of the our investigations in 1993–1995 were *Carici-Nardetum* matgrass swards, *Carici-Festucetum supinae alpinum*, subalpine and alpine swards, *Crepidi-Calamagrostietum villose* subalpine grasslands, and *Empetro-Vaccinietum* dwarf shrub heaths. The plots and their locations were selected according to the descriptions of W. and M. Matuszkiewicz (1969, 1974), and their phytosociological methods were followed closely as well. Our areas conform strictly to the places they investigated in 1960. They were selected so as to overlap the previously investigated areas. The precise locations of the studied plots are described in Wojtuń *et al.* (1995, 1997).

On the basis of earlier investigations (Wojtuń *et al.* 1997) it was accepted that changes in soil environment are an important cause of the decline of biodiversity in the Karkonosze Mts. Our soil investigations included measurements of mineral nitrogen content and the rates of mineralization and nitrification. Net mineralization and nitrification was studied directly in the field on the basis of intact cores incubated in situ inside polyethylene bags (Piccolo *et al.* 1994). The mineral forms of nitrogen were extracted with water (nitrates) and a 6% solution of KCl (ammonium ions). Ammonium and nitrate concentrations were determined colorimetrically using an automated flow injection system (Braun+Luebe AutoAnalyzer). Ammonium-nitrogen was measured by the indophenol blue method and nitrate-nitrogen was measured as NO_2 following reduction with a cadmium column. Mineralization was calculated as the change in NH_4 plus NO_3 during incubation.

For analyses of nitrogen conversion in Karkonosze Mts soils, swards of *Hieracio-Nardetum* in the subalpine belt at Hala Gąsienicowa in the Tatra Mts (Mirek & Piękoś-Mirkowa 1995) were chosen as control plots for the association *Carici-Nardetum*. They have a similar origin and floristic composition resembling the Karkonosze swards, particularly the mutual domination of the grasses *Nardus stricta* and *Deschampsia flexuosa*. In both the Tatras and the Karkonosze Mts, this community covers acidic podzol soils built up of various kinds of granite.

Nomenclature follows Mirek *et al.* (1995).

RESULTS

Floristic transformations in lower mountain belts

In the Karkonosze Mts, an example of the disappearance of rare plants as a result of the degradation of the mountain spruce forest ecosystem is the deterioration of two species, *Listera cordata* and *Moneses uniflora* (Fig. 1), connected with old spruce forests. They are dying out irrevocably together as the oldest and best-preserved mountain spruce forests disappear (Fabiszewski & Jenik 1994).

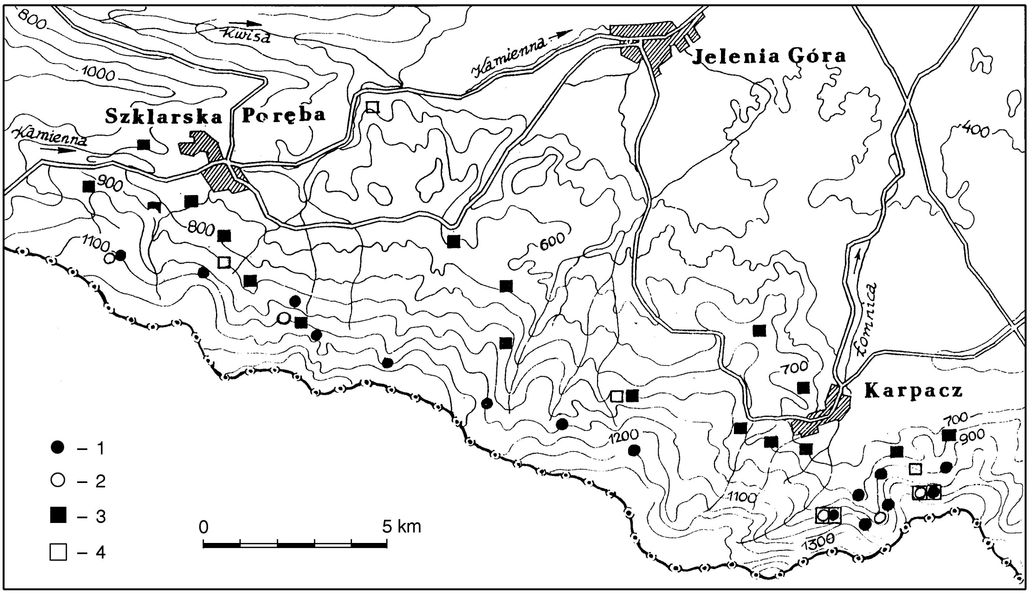

Fig. 1. Plant retreats from mountain spruce forest as examples of old-growth forest decline. 1 – *Listera cordata* (L.) R. Br., historical data (literature and herbaria); 2 – the same species, localities in 1994; 3 – *Moneses uniflora* (L.) A. Gray, historical data (literature and herbaria); 4 – the same species, localities in 1994.

Other vanishing species in the Karkonosze Mts are *Arnica montana* and *Hieracium aurantiacum* (Fig. 2). Their stands have shrunk drastically on the whole massif to about 10% of the area given in old German data (Schube 1903). The range of that species (data from other parts of Europe; e.g., Schwabe 1990; Pegtel 1994; Brej & Fabiszewski 1997)

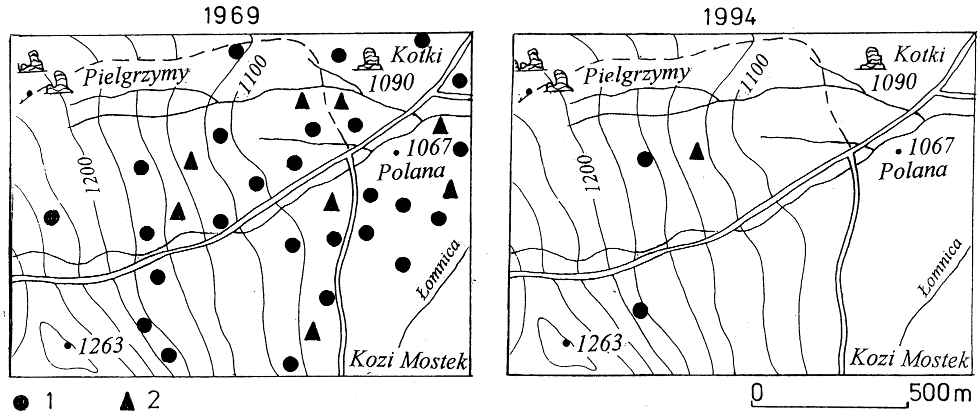

Fig. 2. Decline of matgrass swards species in the last 25 years in a part of the Karkonosze Mts. 1 – *Arnica montana* L.; 2 – *Hieracium aurantiacum* L.

may be shrinking because of chemical changes in the soils covered by *Nardetalia* swards, noticed also in the Karkonosze Mts.

Comparison of the losses of these and other valuable plants with data from European and Scandinavian mountains does not always unequivocally indicate the reasons for their decline. Transformations leading to forest thinning may be a factor. Many of the declining species were linked to natural old forests whose ecological status is difficult to preserve. These species include the increasingly rare pteridophytes and the genus *Dentaria*, both from the lower mountain belts connected with forests of the order *Fagetalia*.

Floristic changes in alpine and subalpine mountain belts

An effect of the transformation of the Karkonosze Mts high mountain phytocenoses is clearly seen in changes in the number of species (Table 1). In 35 years the number of

Table 1. Plot number, species number and Shannon index *H'* in 1960 and 1995 for five plant associations from subalpine and alpine belts in the Karkonosze Mts. Figures are means ± 1SD. *** $p < 0.001$, N.S. not significant.

Plant communities	Plot number		Species number		Shannon index *H'*	
	1960	1995	1960	1995	1960	1995
Carici-Nardetum	22	94	15.9±3.0	7.2±2.8***	2.41±0.25	1.53±0.30***
Crepidi-Calamagrostietum villosae	16	36	21.8±6.4	13.7±3.6***	2.75±0.34	2.27±0.33***
Carici-Festucetum supinae subalpine type	13	58	14.0±3.0	12.4±1.5 N.S.	2.41±0.21	2.06±0.14***
Carici-Festucetum supinae alpine type	8	19	16.8±1.3	11.71±0.8***	2.61±0.08	2.17±0.13***
Empetro-Vaccinietum	20	30	17.5±2.8	13.1±2.8***	1.11±0.07	0.88±0.64***

Table 2. Vascular plant species noted (frequency at least 10%) in 1960, but not confirmed (+) or noted only sporadicaly (*) in 1995.

Community	Species	
Carici-Nardetum	*Diphasiastrum alpinum*	*
	Huperzia selago	*
	Luzula sudetica	*
	Melampyrum sylvaticum	+
	Pulsatilla alba	+
Crepidi-Calamagrostietum villosae	*Aconitum firmum*	+
	Adenostyles alliariae	*
	Cicerbita alpina	+
	Geum montanum	+
	Hieracium alpinum	+
	Huperzia selago	*
	Hypericum maculatum	+
	Leontodon hispidus	+
	Potentilla aurea	+
	Pulsatilla alba	*
	Ranunculus platanifolius	*
	Viola biflora	*
Carici-Festucetum supinae – subalpine form	*Diphasiastrum alpinum*	+
	Primula minima	*
	Pulsatilla alba	*
	Solidago virgaurea	*
Carici-Festucetum supinae – alpine form	*Pulsatilla alba*	*
	Solidago virgaurea	*
	Vaccinium vitis-idaea	*
Empetro-Vaccinietum	*Empetrum hermaphroditum*	*
	Huperzia selago	*
	Pulsatilla alba	*
	Solidago virgaurea	*

species decreased on average by 30% in all the examined plant communities. The highest decrease was recorded in *Carici-Nardetum* matgrass swards, with a mean of 15.9 species in 1960 and only about 7 species in 1995. The least decline in number was observed in *Carici-Festucetum supinae* subalpine swards, from 14.0 species in 1960 to 12.4 in 1995. During the same period the Shannon index *H*' value decreased by about 20% on average, from 2.5 to 2.00.

The localities of many plants have completely disappeared or been seriously reduced in the Karkonosze Mts subalpine and alpine communities, and this is reflected in species numbers. As can be seen in Table 2, among 20 species recorded with at least 10% frequency in 1960, as many as 10 taxa were not found in 1995 and a further 10 were met only sporadically. Among the ones not found were not only rare mountain species typical high mountain swards such as *Luzula sudetica*, *Pulsatilla alba*, *Diphasium alpinum* and

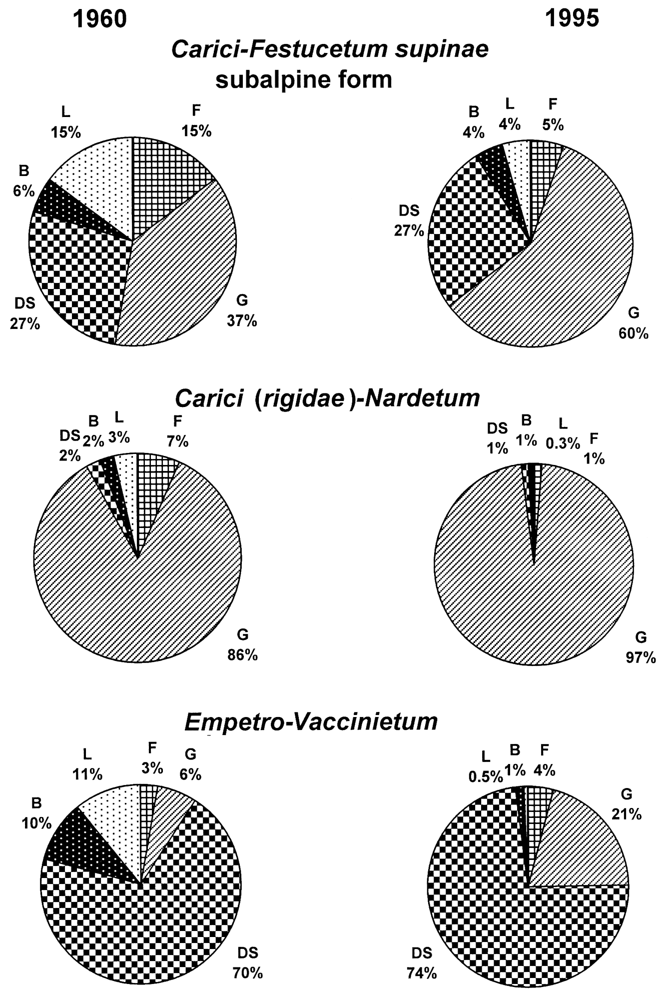

Fig. 3. Plant functional growth forms in three subalpine plant communities in 1960 and 1995. B – bryophytes; DS – dwarf shrubs; F – forbs; G – graminoids; L – lichens.

Huperzia selago but also plants frequently found until recently in the Karkonosze Mts such as *Ranunculus platanifolius, Aconitum firmum, Geum montanum* and *Hypericum maculatum.* The decline of some species common in swards such as *Vaccinium vitis-idaea* and *Solidago alpestris* is astounding.

Growth forms naturally differ among swards and dwarf shrub communities (Fig. 3). For example, in *Carici-Nardetum* matgrass swards, plants of graminoid form dominate, while dwarf shrubs dominate in *Empetro-Vaccinietum* dwarf shrub heaths. In *Carici-Fesucetum supinae* swards there is a distinct share of other forms: forbs, dwarf shrubs and lichens. During the last 35 years in these communities the shares of growth forms have changed considerably (Fig. 3). At present, no other growth forms accompany the considerable share of graminoids in the investigated *Carici-Nardetum* swards. In *Carici-Fesucetum supinae* subalpine swards the share of graminoids has increased considerably, and at the same time the share of dicot forbs and lichens has decreased by a factor of 3. In *Empetro-Vaccinietum* phytocenoses there has been a moderate increase of cover by graminoid species and a drastic decrease of bryophytes and lichens.

Conversion of soil nitrogen in Tatra Mts and Karkonosze Mts swards

Despite the similarities in nitrogen dynamics in high mountain swards, we recorded significant differences between the Tatra Mts and Karkonosze Mts areas, regarding anthropogenic factors:

– in the Karkonosze Mts the inflow of nitrogen in ammonium and nitrate forms is almost three times higher than in the Tatra Mts (1138 and 369 mg/m^2, respectively). The proportions between ammonium and nitrate in the two mountain ranges are identical.

– the mean content of mineral nitrogen in the soils of both areas in the vegetative season was 1.30 mg/100 g dry weight (Table 3). Ammonium nitrogen predominated in both areas. The share of nitrates in the total content of mineral nitrogen was small, but was five time higher in Karkonosze Mts *Carici-Nardetum* swards than in *Hieracio-Nardetum* in the Tatra Mts.

Table 3. Nitrogen deposition (monthly average and sum for vegetation season) in the Tatra Mts and the Karkonosze Mts ecosystems in 1992–1993 and amounts of nitrogen in soil of *Hieracio-Nardetum* and *Carici-Nardetum* (values are means for vegetation season of 1995). d.w. = dry weight.

	$N\text{-}NH_4$	$N\text{-}NO_3$	$N (NH_4 + NO_3)$
Monthly average for vegetation season (mg/m^2)			
Hala Gąsienicowa[1]	50	49	92
Karkonosze[2]	152	133	285
Sum for vegetation season (mg/m^2)			
Hala Gąsienicowa[1]	201	195	369
Karkonosze[2]	607	531	1138
Amounts in soil (mg N/100 g d.w.)			
Hieracio-Nardetum	1.31	0.019	1.33
Carici-Nardetum	1.19	0.097	1.29

[1] according to Wathne *et al*. 1993
[2] according to Zwoździak *et al*. 1995 and Kmieć *et al*. 1994

– field mineralization of nitrogen calculated as the accumulation of ions NH_4 and NO_3 in soil differed between the two studied communities in the Tatras and Karkonosze Mts. The increment of mineral nitrogen in soils of Karkonosze Mts swards was three times that in Tatra Mts swards (Fig. 4). Nitrates were the dominant form of nitrogen accumulated in field tests in *Carici-Nardetum* (Karkonosze Mts), whereas in *Hieracio-Nardetum* soils (Tatra Mts) ammonium ions predominated.

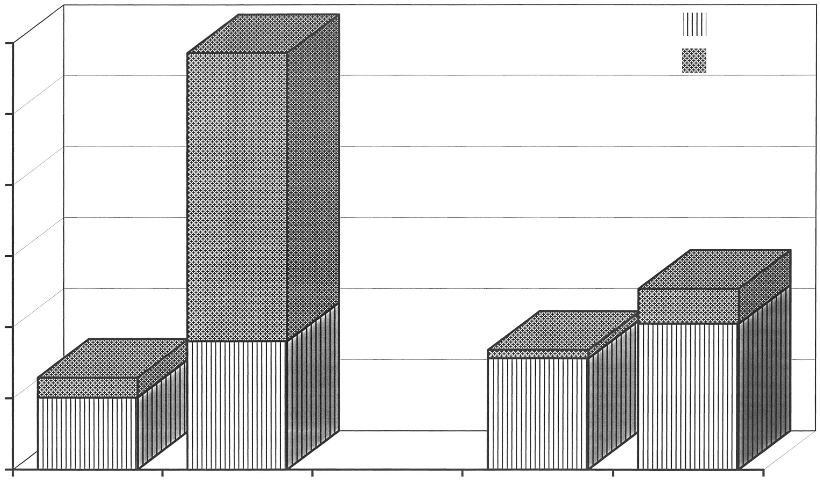

Fig. 4. Soil concentration of ammonium and nitrate in different swards associations in the Karkonosze Mts and the Tatra Mts (measures of 62 days of mineralization). CN – *Carici-Nardetum*; HN – *Hieracio-Nardetum*; 1 – start of mineralization (August 5, 1995); 2 – end of mineralization (October 5, 1995).

Discussion

For decades the Karkonosze Mts plant communities have been under strong pressure from various stress factors connected with air pollution containing hydrogen ions, nitrogen and sulphur compounds, and heavy metals. The transported pollutants produce a chain of effects beginning with the abiotic environment and resulting in floristic changes. Unfortunately we do not know much about the changes taking place in whole ecosystems. The most dangerous of the continuing processes of ecosystemic effects are eutrophication and acidification of natural habitats (Fabiszewski & Wojtuń 1994; Żołnierz *et al.* 1994; Wojtuń *et al.* 1997).

Degradation of vegetation

Quantitative and qualitative investigations of the floristic composition of plant communities and changes in the shares of growth forms in various associations in 1960–1995, and measurements of nitrogen conversion in soil, revealed a number of phenomena which add up to progressing floristic degradation in plant communities, particularly in the subalpine and alpine belts. Among the most significant ones are the expansion of grasses, the decline of rare vascular plants and the elimination of terricolous bryophytes and lichens.

The expansion of grasses and grass-like species is proceeding at various intensities in all the studied phytocenoses. The species expanding most is *Deschampsia flexuosa*, whose cover has tripled or quadrupled in almost all the communities since 1960. The sedge *Carex bigelowii* subsp. *rigida* also shows high expansion, expanding most in *Carici-Nardetum* matgrass swards.

Together with the expansion of grasses and the decline of the ground layer of cryptogamic plants in phytocenoses, particularly alarming for botanists and conservators is the decline of many vascular species (Table 2). Many plants which occurred (some of them rarely) in 1960 in as many as 79 phytosociological relevés were not found now in 237 new relevés. These species include *Rhinanthus alpinus, Arnica montana, Leucorchis albida, Lycopodium clavatum, Hypochoeris uniflora, Crepis conyzifolia,* and *Carex atrata*. Most of them represent typical high mountain flora characteristic of the upper belt of the Karkonosze Mts. Their decline deprives the area of its significant individuality among European mountains. These declining plants are known from only a few localities in the Karkonosze Mts, and all of them are threatened species.

Another distinct feature of the non-forested belts is the decline of terricolous bryophytes and lichens. Characteristic and once-common mosses such as *Dicranum scoparium, Pleurozium schreberii, Hylocomium splendens* and *Politrychum* spp., and epigeic lichens like *Cetraria* spp. div., *Cladonia* and *Cladina* spp. div., *Thamnolia vermicularis* and *Alectoria ochroleuca* are retreating from phytocoenoses or are drastically reducing their cover. This has meant an almost total decline of the ground layer of cryptogamic plants and lichens in almost all the communities studied, particularly strongly marked in *Carici-Nardetum* and *Empetro-Vaccinietum*, where the bryophyte cover and lichen layer are less than a tenth what they were 35 years ago. The elimination of the “d” layer leads to the decline of specific microhabitats that retain moisture and preventing erosion during wet periods, and during drought this leads to disintegration of turf and vegetation. A simplified picture of the floristic changes in various vegetation belts in the Karkonosze Mts is presented in Figure 5.

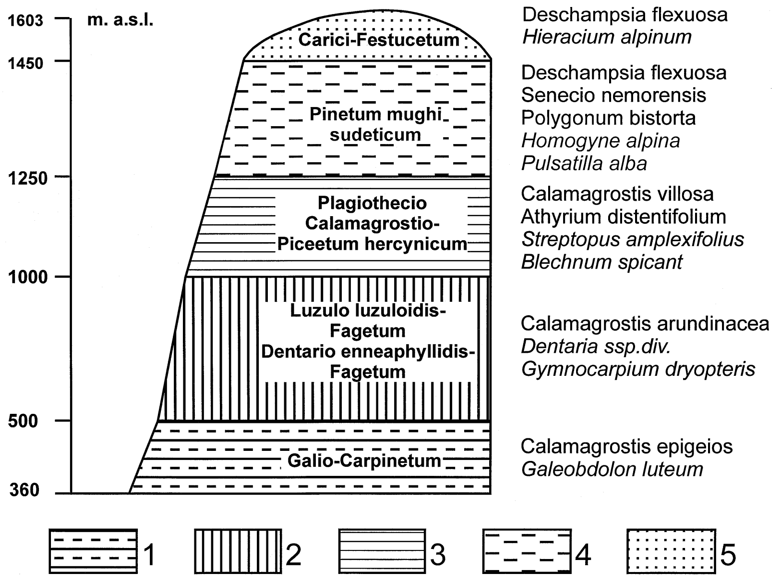

Fig. 5. Examples of invasive and retreating (italics) plants in the vegetation belts in the Karkonosze Mts. 1 – submontane belt; 2 – low mountain belt; 3 – high mountain belt; 4 – subalpine belt; 5 – alpine belt.

Changes like those presented above for the Karkonosze Mts phytocoenoses have also been described in many forested and non-forest communities of Eastern, Central and Northern Europe, for example in high mountain phytocoenoses of the Czech part of the Karkonosze Mts (Štursová 1985; Štursová & Kociánová 1995), in Alps swards (Hegg 1984; Dähler 1992a–b) in Czech spruce forests (Kubíková 1989), in Germany (Heinsdorf 1993) and in Scandinavia (Rosén *et al.* 1992).

Ecological consequences of excessive nitrogen supply

The inflow of mineral nitrogen to the Karkonosze Mts ecosystems we recorded burdens the high mountain soils with that element. This is revealed in the mineralization of nitrogen and in the predominance of nitrification and in consequence the higher nitrate content in the association *Carici-Nardetum.*

The high mineralization rate in *Carici-Nardetum* swards is probably the result of the persistent inflow of mineral nitrogen from the atmosphere. Many authors point to the stimulating influence of constant nitrogen inflow upon the mineralization of organic matter, particularly in habitats with a shortage of this element (Hanson *et al.* 1994; Aber *et al.* 1998). Higher nitrogen content in organic matter (over 1.4%) makes it more susceptible to decomposition (Haynes 1986). Bieńkowski (1995) reported 1.85% to 2.07% concentrations of total N in the aboveground parts in the three grasses *Deschampsia flexuosa, Calamagrostis villosa* and *Nardus stricta* in the Karkonosze Mts. The organic matter produced is probably susceptible to rapid decomposition and release of soil nitrogen, particularly NH_4 ions (Haynes 1986; Chapin *et al.* 1995). It can be suggested that the large amounts of nitrogen brought with rain to the Karkonosze Mts swards has increased not only the accessible pool of nitrogen saturation but also changed the quality of organic matter. It simply has become more susceptible to decomposition and release of nitrogen. In the vegetative season the evidence supporting this view is that the decomposition of fresh organic matter and the mineralization rate in the Karkonosze Mts subalpine belt correlates with the amount of nitrogen from the atmosphere, particularly in ammonium form (Pietr *et al.* 1995). The importance of NH_4 availability during nitrification has been noted in other areas by Haynes (1986), Tamm (1991) and Nadelhoffer *et al.* (1997).

Hence the reasons for the high nitrification role in soils of *Carici-Nardetum* swards are the large amount produced during mineralization of organic nitrogen and the inflow of ammonium ions from the atmosphere.

High nitrate content in soil can stimulates the expansion of plants capable of rapidly using the increasing amounts of nitrogen. Such plants are most certainly the grasses, which are of the highest negative significance in the transformation of the floristic composition in Karkonosze Mts communities (Fig. 3). Rosén *et al.* (1992) observed a close relation between the growth of *Deschampsia flexuosa* floor vegetation in Swedish spruce forests and an excess of soil critical loads of nitrogen (mainly nitrates) in soils. The increase of the cover of fast- growing grass species as a response to the inflow of mineral components, particularly nitrates, is noted mainly in habitats naturally short in mineral elements (Jonasson 1992; Press *et al.* 1995; Shevtsova & Neuvonen 1997).

In dwarf shrub tundra, Press *et al.* (1998) observed a large decrease in the share of bryophytes, a phenomenon confirmed in our phytocoenoses. The reason for the elimination of terricolous bryophytes and lichens could be overfertilization of habitats and/or grass competition. Terricolous lichens are usually typical nitrophobic and/or oligotrophic species. The elimination of bryophytes probably depends on reduction of light by grasses (Chapin & Korner 1994). The density of the "d" layer decreased most in those Karkonosze Mts communities in which grass cover considerably increased, that is, in *Carici-Nardetum* and *Carici-Festucetum supinae* swards, and to a lesser extent in *Empetro-Vaccinietum*, dwarf shrub heaths.

Reasons for reduced floristic diversity

The expansion of one or more species usually causes the retreat of other taxa from the community and as a result a fall in the species abundance of the phytocoenosis (Whittaker 1977; Rosén *et al.* 1992). Very similar phenomena were observed in the Karkonosze Mts communities. The species diversity of communities (expressed by the *H'* index) decreased by 30–40%, whereas the number of species was even halved. Species significant to the Karkonosze Mts flora and met frequently in the 1960s have died out or occur there only sporadically. This applies particularly to high mountain plants like *Diphasiastrum alpinum, Potentilla aurea* and *Huperzia selago.* Long-term observations of permanent plots of the association *Sieversio-Nardetum* from the Alps (Hegg 1984; Dähler 1992a–b) have shown that N, P and K fertilization was the reason for the decline of many species typical for these swards, such as *Arnica montana, Solidago virgaurea, Potentilla aurea* and *Geum montanum.*

The decline of rare elements of flora and the general impoverishment of Karkonosze Mts plant communities have various causes and effects. The data presented here indicate the significant role of anthropogenic cycling of nitrogen in ecosystems. The persistence of high species diversity in phytocoenoses depends among other things on the spatial heterogeneity of habitats (Tilman 1985). Usually a higher number of species persists in ecosystems abundant in microhabitats than in homogenous habitats. Because of their simple geological structure, rather uniform soil cover and poorly diversified microrelief, the Karkonosze Mts have never been classed among the mountains with high biodiversity, but the flora and vegetation cover of the massif are distinct, individual and peculiar in character. Anthropogenic changes are leading to reduced biodiversity in the Karkonosze Mts and the domination of its vegetation by several species of monocots, particularly in the subalpine and alpine belts.

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