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Ecological conditions and the distribution of alpine juniper (*Juniperus communis* subsp. *alpina*) in the Hrubý Jeseník Mts

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Abstract: In the Hrubý Jeseník Mts of the Czech Republic, research was carried out from 2001–2005 aimed at completing an up-to-date census of alpine juniper [*Juniperus communis* subsp. *alpine* (Smith) Čelakovský] and an evaluation of the overall health status of the populations, and at investigating the impacts of the main environmental factors on the viability of this species. 13 sites were identified with 283 individuals in total, but the sites differed dramatically in the number of recorded individuals. Comparisons with historical literature sources show that the species has been in decline. The main reasons for this decline include: a lack of suitable sites for colonization connected with a lack of adequate disturbance factors, competition from shading trees, and the presumed high age of the juniper populations combined with zero generative reproduction. More than two thirds of the individuals showed slight damage to their assimilation system. A health status of bad or very bad was determined for 5 % of the alpine juniper individuals. These trees in the Hrubý Jeseník Mts are also exposed to pressure from some herbivore insects and mammals. The populations are not yet in a literally critical state, but considering the range of impacts affecting them, it will be necessary to pay significant attention to their conservation strategies. Some recommendations for future management are suggested.
Key words: *Juniperus communis* subsp. *alpina*; alpine juniper; ecology; distribution; Hrubý Jeseník Mts

Introduction

Alpine juniper (*Juniperus communis* subsp. *alpina*) is mentioned in the literature under different synonyms (Christensen 1985): *J. sibirica* Burgsdorff (1787), *J. nana* Wildenow (1796), *J. alpina* (Smith) S.F. Gray (1821), *J. communis* subsp. *nana* (Willd.) Syme in Sowerby (1866). This species is an amphiboreal arctic-alpine taxon that is vicarious for common juniper above the alpine timberline and in the Artic. Alpine juniper is distributed in mountain ranges of the northern hemisphere, in the supramontane, subalpine and alpine zones of the temperate zone, and in lower tundras (Hejný & Slavík 1988).

Juniper is considered to be one of the early colonizers of the post-glacial landscape (van der Merwe et al. 2000), and its present populations in Central Europe are only fragments of its distribution at that time (McGowan et al. 2001). The Hrubý Jeseník Mts, in the oreophytic zone of High Sudeten Mts (Hejný & Slavík 1988), is considered to be an area with the most numerous occurrence of alpine juniper in the Czech Republic (Fiek 1881). The continual presence of *Juniperus* sp. since the subboreal period has been detected in pollen diagrams from the uppermost part (Velký Děd) of the central Hrubý Jeseník Mts (Rybníček & Rybníčková 2004). Data on the occurrence of pollen grains and wood of *Juniperus* sp are also provided by Opravil (1959) who revealed several localities very close to the recent alpine timberline in the western parts of the mountain range. The oldest records related to the existence of dwarf juniper in the Hrubý Jeseník Mts dates to the early 19th century, and then later during the 19th and 20th centuries (Tab 1).

Despite numerous records on the presence of alpine juniper, there was no associated information on population sizes. Hence, data about the extent of historical populations are deduced from incomplete descriptions. Data concerning the health status of populations in the Hrubý Jeseník Mts are not available either. Without basic knowledge of the condition of the species where this Czech critically endangered species occurs, it is impossible to create a management proposal for these localities.

This work is aimed at presenting more detailed information on the current distribution of alpine juniper in the Hrubý Jeseník Mts. It also focuses on evaluating the impacts of the main environmental factors on the presence of this species at particular sites, and on the overall health status of alpine juniper populations in these mountains.

Material and methods

Study area

The Hrubý Jeseník Mts are the second highest mountain range within the Hercynian middle-mountains of Central Europe (*sensu* Jeník & Štursa 2003) and are considered

Table 1. A list of localities with alpine juniper (*Juniperus communis* subsp. *alpina*) and related information sources in chronological order.

Locality (synonyms)	Information source
Mravenečník (Mravenčí vrch) *	Rohrer & Mayer (1835), Formánek (1887–1897), Otruba (1925, 1926), Nožička (1957), Bureš et al. (1989)
Vysoká hole (Janovická hole) *	Rohrer et Mayer (1835), Grabowski (1843), Fiek (1881), Formánek (1887–1897), Hans (1868), Bureš et al. (1989)
Praděd	Rohrer et Mayer (1835), Grabowski (1843), Fiek (1881), Formánek (1887–1897), Kolenati (1860), Otruba (1925, 1926), Pospíšil (1958)
Šerák	Grabowski (1843), Fiek (1881)
Břidličná *	Fiek (1881), Formánek (1887–1897), Bureš et al. (1989)
Červená hora	Fiek (1881) Thomasdorfer Strasse
Vozka (Trojmezí, Fuhrmannštýn)	Formánek (1887–1897), Opravil 1959
Keprník *	Formánek (1887–1897), Otruba (1925, 1926), Bureš et al. (1989)
Hole u tří studánek*	Formánek (1887–1897) "Dreibrünnenheide"
Pecný *	Formánek (1887), Bureš et al. (1989)
Kamzičník (Heiligenhübel) *	Formánek (1887)
Velký Máj *	Formánek (1887), Bureš et al. (1989)
Malá kotlina *	Podpěra (1906)
Velká kotlina *	Laus (1910, 1931), Kavina (1918)
Petrovy kameny	Laus (1927)
Mezikotlí *	Bureš et al. (1989)
Pec	Bureš et al. (1989)
Ztracené kameny	Bureš et al. (1989)
Vřesník *	Bureš et al. (1989)

* currently confirmed

to be part of the High Sudeten (Jeník 1961). Alpine juniper occurs here above the approximate alpine timberline (Treml & Banaš 2000; Treml & Banaš 2005), i.e. in the subalpine and alpine zones of the mountain range (Jeník 1972). In general, the region is characterized by highly variable weather, underscored by the mountain relief. The highest altitudes of the Hrubý Jeseník Mts have an extreme climate which corresponds to high alpine and subarctic areas (Quitt 1971). The average annual temperature in the highest elevations is 1.1 °C. Long-term average rainfall is 1213 mm and snow cover lasts for up to 180 days a year, usually from November to May (Lednický 1977, 1985). In geological terms, the study area is formed of crystalline rocks; while there is mostly gneiss in the core of the mountain range, the outer parts of the range are formed of metamorphosed Devonian rocks (Demek 1987). The territory covered by this research is a residue of a leveled surface, reshaped by subnival and periglacial processes (Treml et al. 2005). In pedological terms, rankers, alpine humus, podzolic and peaty soils prevail (Kubiena 1953).

Data collection

Monitoring was focused on alpine forest-free areas, i.e. islands of alpine tundra, in the Hrubý Jeseník Mts (*sensu* Jeník & Hampel 1991; Treml & Banaš 2005) – Fig. 1. In all of these localities, detailed field mapping was carried out during the vegetation seasons from 2001–2005 in order to record the presence of all alpine juniper individuals. For every individual found, a basic description was made as well as a description of the main environmental properties of each site where the species occurs.

The length, width and height of each individual alpine juniper found were recorded (McGowan et al. 2001). To make subsequent statistic data processing easier, all of these three dimensions were multiplied together to produce just one number characterizing the size of a particular individual. In order to preserve information on the growth forms, the individual shrubs were divided into three categories: 1 upright – where height is the largest dimension; 2 prostrated

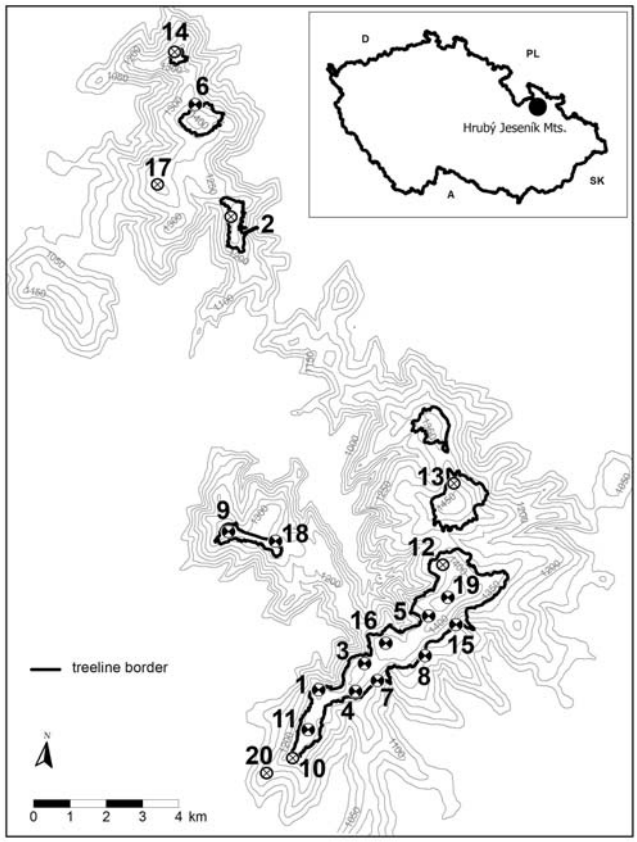

Fig. 1. Location of the study area in the Czech Republic and positions of sites where alpine juniper was either recently confirmed (semi-filled marks) or unconfirmed (solid marks) in the Hrubý Jeseník Mts. 1 – Břidličná, 2 – Červená hora, 3 – Jelení hřbet (Hole u tří studánek), 4 – Jelení studánka, 5 – Kamzičník, 6 – Keprník, 7 – Malá Kotlina, 8 – Mezikotlí, 9 – Mravenečník, 10 – Pec, 11 – Pecný, 12 – Petrovy kameny, 13 – Praděd, 14 – Šerák, 15 – Velká kotlina, 16 – Velký Máj, 17 – Vozka, 18 – Vřesník, 19 – Vysoká hole, 20 – Ztracené kameny.

Table 2. The number of individuals of *Juniperus communis* subsp. *alpina* at particular localities in Hrubý Jeseník Mts and average altitude above sea level.

No.	Locality	Number of individuals	Average height [m a.s.l.]
1	Břidličná	149	1332.9
2	Jelení hřbet	18	1337.7
3	Jelení studánka*	3	1303.3
4	Kamzičník	8	1379.3
5	Keprník	1	1375.0
6	Malá Kotlina	8	1320.8
7	Mezikotlí	27	1343.5
8	Mravenečník	2	1322.5
9	Pecný	2	1316.5
10	Velká kotlina	5	1410.4
11	Velký Máj	33	1371.2
12	Vřesník	4	1324.3
13	Vysoká hole	23	1449.3

* newly described

– a cushion-like form with length and/or width as the prevailing dimension; 3 transient – individuals which did not fit in category 1 or 2.

Health status, defined on the basis of the extent of the crown's dryness (percentage of withered leaves), was determined for each individual shrub found. Five categories were distinguished: 1. 20% or less withered leaves; 2. 20–40% withered leaves; 3. 40–60% withered leaves; 4. 60–80% withered leaves; and 5. 80% or more withered leaves.

We also focused on selected biotic factors which may affect the populations and influence the growth of juniper. The presence of the insect pests *Oligotrophus juniperinus* and *Otiorrhynchus niger* on shrubs was recorded, as well as damage caused by game, i.e. bark and foliage browsing. These biotic factors were recorded as just presence or absence for particular juniper individuals, without further qualitative assessment.

Data analysis

Multivariate methods computing by Canoco for Windows 4.5 (ter Braak & Šmilauer 2002) were used to analyze our data sets. The size and health status of the shrubs were used as response variables, and environmental factors were used as predictors (explanatory variables). The analysis was adjusted for localities as covariable data (concomitant or nuisance variables). A detrended correspondence analysis (DCA) resulted in a short response-variable gradient; hence redundancy analysis (RDA) was chosen. Response variables were standardized and centered, and a Monte-Carlo permutation method was used to determining the significance of each test (499 permutations).

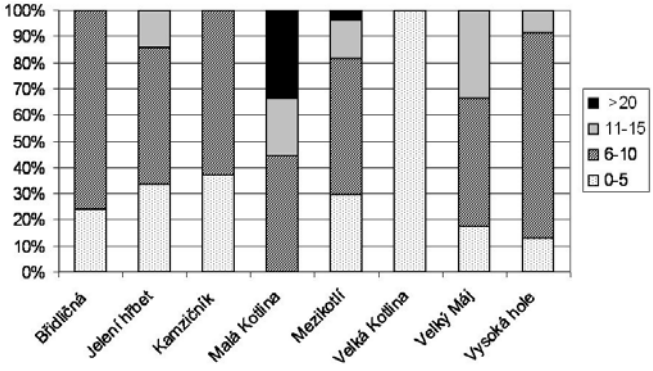

Fig. 2. The distribution of slope declination at selected sites with the presence of five or more juniper individuals, in degrees.

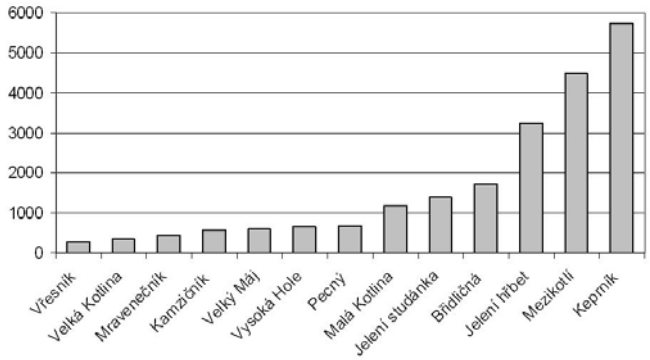

Fig. 3. Average size of shrubs at particular sites (dm^3). The length, width and height were multiplied to produce one number characterizing the growth form of each individual.

Results

In the alpine belt of the Hrubý Jeseník Mts, we recorded 283 individuals of alpine juniper at 13 localities (Table 2). The "Jelení studánka" site is considered to be newly described for this species. The "Jelení hřbet" site is very close to the historically described locality "Hole u tří studánek". Therefore we do not describe "Jelení hřbet" as being newly discovered and do not designate "Hole u tří studánek" as unconfirmed. All juniper individuals found were sterile, so there are any information about sex ratio in the Hrubý Jeseník Mts.

Juniper populations were only found on slightly declined slopes (Fig. 2) at similar altitudes, with an average of 1345 m a. s. l. The maximum was recorded at the site "Vysoká hole" (1464 m), the minimum at the site "Velký Máj" (1294 m).

Most localities differ in the average size of shrubs (Fig. 3). Also, each site has a different composition of size categories, which is a consequence of the low number of individuals. Nearly the whole range of shrub diameters is present at the most abundant site Břidličná.

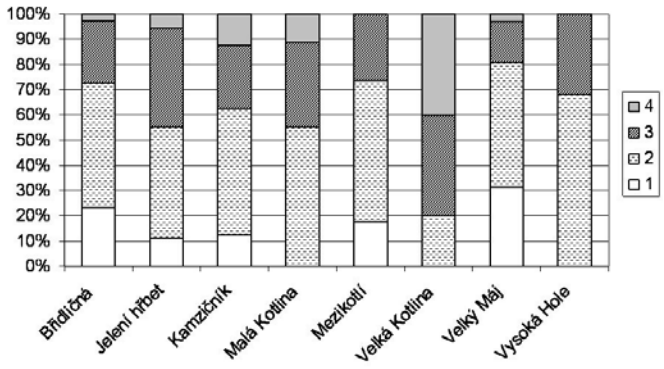

Fig. 4a. The proportion of health-status categories at selected sites with the presence of five or more juniper individuals. Health status, as the extent of crown dryness (percentage of withered leaves), was determined for each individual shrub found: 1. 20% or less withered leaves; 2. 20–40% withered leaves; 3. 40–60% withered leaves; 4. 60–80% withered leaves.

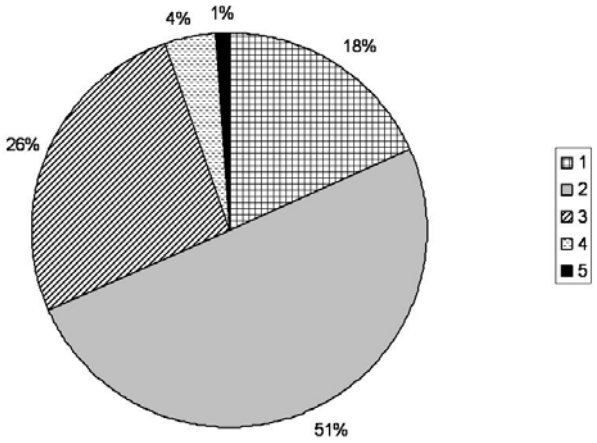

Fig. 4b. Relative proportion of health status categories for all alpine juniper individual shrubs found. Percentage of withered leaves: 1. 20% or less; 2. 20–40%; 3. 40–60%; 4. 60–80%; 5. 80% or more.

Out of the total number of individual shrubs found, the transient form was most common: 74 were prostate, 84 upright, and 126 transient (an approximate ratio of 2:2:3).

The relative proportion of health status categories determined on the basis of crown dryness is shown in Fig. 4a/b. The healthiest sites, i.e. with a higher number of individuals with health status 1, are Velký Máj, Břidličná and Mezikotlí. At only one site – Vřesník – were there shrubs with the worst health status (5), while the remaining sites Velká kotlina, Kamzičník and Vysoká hole mostly had individuals with health status 4 and 3.

It was also discovered that alpine juniper in the alpine belt of the southern part of the Hrubý Jeseník Mts are exposed to several biotic factors which could be linked to juniper size and health status. There are two important insect pests, *Otiorrhynchus niger* (Coleoptera, Curculionidae) and *Oligotrophus juniperinus* (Diptera, Cecidomyiidae), but these have no apparent impacts on the juniper in the Hrubý Jeseník Mts

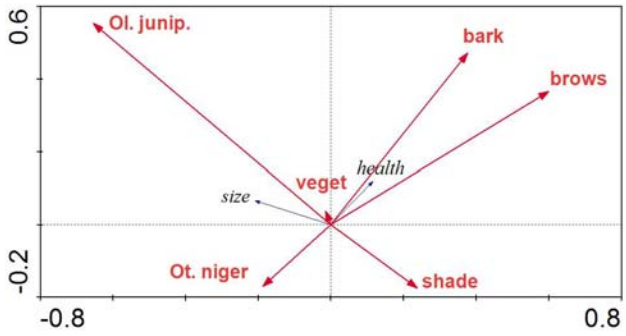

Fig. 5: RDA ordination diagram showing the distribution of selected biotic factors: Ol. junip – *Oligotrophus juniperinus*, Ot. niger – *Otiorrhynchus niger*, bark – browsing of bark, brows – browsing of foliage, veget – vegetation overgrowing, shade – proximity to spruce and/or dwarf pine, shrub size and health status as response variables.

(Fig. 5). The presence of *Oligotrophus juniperinus* is not correlated with the health status of juniper at all, while the presence of *Otiorrhynchus niger* is negatively correlated with percentage of withered leaves. In addition, there is only a slight positive correlation ($r = 0.245$) between *Oligotrophus juniperinus* and shrub size, and no correlation between *Otiorrhynchus niger* and shrub size ($r = 0.075$). Nevertheless, both pests are only found in the south-east part of study area, in particular the sites Břidličná, Mezikotlí, Malá kotlina, Jelení hřbet, Velká kotlina. The pest *Monoctenus juniperi* (Hymenoptera, Diprionidae) was found as well, but just at the site Vřesník, where it had serious impact on the health of shrubs.

During our observations, it became clear that game browsing of bark and foliage are important biotic impacts on the alpine juniper populations in the territory examined. Traces of these impacts were observed in almost one third (28.5 %) of all juniper shrubs. From Fig. 5 it is clear that game animals prefer healthy shrubs, regardless of size.

Surprisingly, the health status and size of juniper shrubs are independent of each other. This means that larger individuals do not necessarily have a lower percentage of withered leaves (Fig. 5), nor are smaller shrubs inevitably less healthy.

There are some sites where juniper shrubs are apparently overgrown by surrounding vegetation from wind-swept or closed alpine grasslands. Nevertheless, no correlations were found between this phenomenon and the tested shrub parameters. The health and dimensions of some juniper individuals are also apparently affected by proximity to dwarf pine and low-rise spruce, though, this influence was not significant ($\alpha = 0.05$).

Discussion

The census of populations and individuals

This work is the first summary of data concerning the occurrence and status of *Juniperus communis* subsp. *alpina* in the Hrubý Jeseník Mts. It is possible that there are some additional individuals struggling to survive among dwarf pine stands; nevertheless, the total

number of junipers in the area of interest definitely does not exceed 300 individuals. Our research focused on the growth forms and size of juniper individuals, because determinations of age or ontogenetic phase on the basis of height, girth, size of above-ground biomass, and annual increment are uncertain (Ward 1973; Ward 1982; Diotte & Bergeron 1989). Unfortunately, we were not able to confirm fertility for any individuals in the Hrubý Jeseník Mts, and no other studies in this area have quantified the amount of fruits or fruit-giving individuals of alpine juniper in more detail.

Changes in time

In comparison with the historical data, alpine juniper in the Hrubý Jeseník Mts has been in decline, both in the number of localities where it occurs, and in abundance at most sites. Out of 20 sites that had been described in the past, we managed to identify only 12. One example of a site with substantial decline is "Mravenečník", where alpine juniper occurred in ample numbers according to Nožička (1957), but where at present there are only two individual shrubs remaining. A similar example is "Vysoká Hole" where alpine juniper was plentiful (Fiek 1881), and reached down to the forest edge. Other sites that were mentioned in the past, but where shrubs are not currently found, are: "Červená hora", "Pec", "Petrovy kameny", "Praděd", "Vozka", "Ztracené kameny". Only "Jelení studánka" was a newly identified site for alpine juniper.

Management changes

It is clear that the decrease in the numbers of alpine juniper in the Hrubý Jeseník Mts and changes in the health status within populations are caused by several factors. The presence of juniper at a particular site, and the spread and regeneration of its populations are influenced by the type of land management, both in the past and at present (Ward 1973). Our research shows that current individual alpine juniper shrubs often grow as a part of closed grass communities with no indication of disturbances. One of the most important preconditions for the occurrence of juniper, slight disturbances of the environment (Ward 1973; Ward 1977; Diotte & Bergeron 1989; McGowan et al. 2001), is not therefore fulfilled in the Hrubý Jeseník Mts. Juniper colonizes new sites in periods of increased land damage, usually as a result of intensive pasturing followed by erosion, land movement and subsequent decreases in disturbance intensity (Dearnley & Duckett 1999). Such pasturing was documented in the Hrubý Jeseník Mts until the middle of 20th century (Jeník & Hampel 1991) and likely led to the contemporary distribution of juniper shrubs. These populations of alpine juniper have probably persisted in the form of long-lived individuals that occasionally reproduce vegetatively. Therefore, *Juniperus communis* subsp. *alpina* in the Hrubý Jeseník Mts can be characterized, as in Great Britain (McGowan et al. 2001), as an isolated relict with aged individuals prevailing. In addition, for some verified historical sites of alpine juniper (e.g. Praděd, (Grabowski 1843); Keprník, (Otruba 1925, 1926)) there is a clear connection between the extinction of juniper and the planting of dwarf pine (*Pinus mugo*). Large portions of these localities are covered with thick dwarf pine stands at present and little to no alpine juniper. At Keprník, which is covered to a wide extent with dwarf pine, only a single individual juniper shrub has been recently identified. A comparison of the present state of alpine juniper with the situation described by Micklitz (1857a,b) also shows this connection between declines in alpine juniper and the planting of wood species, especially dwarf pine.

Health status

More that that three-quarters of the studied individuals have 20–60% withered leaves. This poor health status might be a consequence of the above-mentioned population aging. It might also be hypothesized that the health status of heliophilic alpine juniper shrubs is affected by the proximity shading of taller woody species in the alpine environment. We were unable to confirm this to low number of juniper individuals found in these conditions. However, the low number of juniper close to other woody species might indicate such a negative relationship. Juniper distribution could therefore be limited mainly to sites in the alpine belt without large stands of taller tree species (Jeník 1973; Jeník & Hampel 1991; van der Merwe et al. 2000; Tinner & Kaltenrieder 2005).

Abiotic environment

Any relationships between the presence of juniper to altitude, slope or exposition were not evident, since the available space for the growth alpine juniper in the Hrubý Jeseník Mts is limited to forest-free areas above the alpine timberline, a relatively narrow belt of about a 200 m rise in altitude. Similar results were obtained by Ward (1973) in Southern England. García et al. (2000) and Yanagisawa & Fujita (1999) stated that alpine juniper is a species of poor soils and harsh environments. Most often, it grows at flat sites with low slope on stony substrates, with a mosaic of stones, bare land and vegetation, and where vegetation higher than 10 cm does not exceed one third of the site's area (McGowan et al. 2001). Populations in the Hrubý Jeseník Mts fit this description.

Ward (1982) and McGowan et al. (2001) demonstrated that the conditions of a particular site are reflected in the appearance of individual shrubs. Three growth forms of juniper were identified in our study area, but were not related to environmental conditions. The relative proportion of these three forms, with the transient form prevailing, was relatively stabile, especially for more numerous populations. From this point of view, we were unable to confirm that multi-stemmed junipers are an adaptation to a severe environment, characterised by hard topographical, edaphic and climatic conditions (Bertaudière et al. 2001). The relationships between environment, genetics and growth forms could benefit from more detailed research in the Hrubý Jeseník Mts. Our analysis also indicates that the size of alpine juniper individuals and their health status are

not related. The larger alpine juniper individuals may merely be faster-growing individuals (Ward 1973) or might be growing in a more suitable microhabitat.

Biotic factors

Our findings on the number of insect pests do not allow extensive deductions about their influence on long time scales. In the Hrubý Jeseník Mts, bigger juniper individuals are more often attacked by insects, namely *Oligotrophus juniperinus*. This is a northern species, where predators and plant parasites are less completely studied. This herbivorous insect was already observed on junipers by Polívka (1902), who mentioned small "tumours" on the branches. The second parasite found on alpine juniper shrubs in the study area (*Otiorrhynchus niger*) is a rhizophagous species, which is why its occurrence did not correlate with the quality or quantity of above-ground biomass. Diptera (including *Oligotrophus juniperinus)* occur on juniper especially at the beginning and end of the vegetation season, while Curculionidae, namely *Otiorrhynchus niger*, occur on juniper throughout the season. Our study confirmed the presence of both these species in the Hrubý Jeseník Mts. The number of insect species that have been recorded on juniper (*Juniperus communis*) differs according to climatic conditions, and includes up to 40 species (Ward 1973, 1977). There are also pest species that affect species of both the *Pinus* and the *Juniperus* genera. Entomological research of juniper and dwarf pine (*Pinus mugo*) in the study area might elucidate mutual interactions between them.

Our findings also show that when browsing bark and foliage, game animals prefer healthy alpine juniper individuals, regardless of their size. Juniper tissues are a suitable supplemental food source for game out of the growing season. During this time period, browsing has the biggest negative effect (Fitter & Jennings 1975). Nevertheless, the influence of game does not dramatically worsen the state of juniper populations in the Hrubý Jeseník Mts.

The most critical factors impacting the viability of alpine juniper populations in the Hrubý Jeseník Mts concern the lack of suitable habitats for colonization. Closed grasslands without disturbances are difficult for juniper individuals to colonize (Ward 1973; Fitter & Jennings 1975). This means there is a need for habitats with adequate disturbance factors and the exclusion of competitive woody species. The absolute exclusion of pasturing and considerable reductions in other disturbance factors have enabled the growth of more competitive and stronger types of vegetation and led to the closure of herb communities, preventing the recruitment of new juniper individuals.

Management proposal

Management methods for the replenishment of juniper populations in alpine zone of central Europe have not yet been adequately identified. There are difficulties in promoting the regeneration of populations comprised of older bushes which are dying off and becoming less successful in producing seeds (Ward 1982). A successful strategy for the restoration of alpine juniper populations in the Hrubý Jeseník Mts should comprise several points. First, a detailed genetic examination of the population structure is needed to analyze heterogeneity, relationships and the evolutionary background (Ward 1982; Loreen et al. 2007). Second, the existing populations in the Hrubý Jeseník Mts should be strengthened. To accomplish this, research should be focused on breeding and dispersal problems. A species gene bank from stem cuttings (Dearnley & Duckett 1999) should be established for possible reintroductions in the future. Third, intentional disturbance of the vegetation and land cover in proximity to adult individuals is important, in spite of contemporary fertility problems. In the Hrubý Jeseník Mts, land use of the alpine zone was abruptly changed after the Second World War, which resulted in the degradation of the unique plant communities there. Sheep grazing and pasture management should be considered a suitable alternative for European middle-mountains (Krahulec et al. 2001; Matějková et al. 2003). Finally, it is necessary to reduce the shading by woody species, namely dwarf pine plantations, from the close surroundings of alpine juniper individuals.

Acknowledgements

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