Relationship between rodent density, environmental factors and tree damage caused by rodent species

J. Suchomel, L. Čepelka, L. Purchart

ABSTRACT: The impact of rodent bark gnawing on common beech plantations was studied in the area of the Jeseníky Mts. in the course of four years. The extent of damage fluctuated significantly on 18 monitored plantations and was affected by a set of environmental factors, particularly by the altitude and herb layer character, which had a significant impact on the abundance and distribution of rodents. The ratio of grasses increased with decreasing altitude and conditioned the increasing abundance and occurrence of the field vole (*Microtus agrestis*), which proved to be the major pest in the area. Its impact was substantially more intensive ($P < 0.05$) than that of the more abundant bank vole (*Myodes glareolus*), whose abundance increased with increasing altitude, conditioned by higher numbers of its preferred dicotyledonous plants. However, the relation between an increase in abundance and the degree of damage was not significant in this species, unlike in the former. Although the damage of tree seedlings, caused by small rodents, can locally be serious, generally they do not generate an important impact on forest regeneration in mountainous regions.

Keywords: small rodents; field vole; bank vole; common beech; artificial plantations

The rodents, mainly voles of the genera *Microtus* and *Myodes*, are considered to be major mammalian pests in deciduous and coniferous tree plantations in North America and Eurasia (Gill 1992; Baxter, Hansson 2001). Voles usually cause damage during the earliest phases of forest regeneration by gnawing bark and severing young seedlings. This increases the risk of seedling mortality (Hansson, Zejda 1977; Gill 1992; Sullivan, Sullivan 2008). The tree seedling damage has also been demonstrated in Europe, especially in its central and northern parts (e.g. Borowski 2007; Huitu et al. 2009; Heroldová et al. 2012).

The mountainous regions of the Czech Republic frequently suffer from damage to forest trees caused by small rodents. This is due to a transition of non-indigenous spruce monocultures into close-to-nature forests, which encompasses an increase in the ratio of deciduous tree species, particularly of the common beech (*Fagus sylvatica*) (e.g. Bryja et. al. 2001; Heroldová et al. 2007, 2008). Its bark provides an attractive food supply in times of food shortages and rodents damage it mainly in winter (Gill 1992; Baxter, Hansson 2001) because it is more attractive than the bark of other tree species (Heroldová et al. 2009). The intensity of bark gnawing by rodents and the impacts which affect it have been studied in selected mountainous regions of the Czech Republic (Beskydy, Krušné Hory Mts.) for many years. However, comparative studies from other mountainous regions are missing. At present, the Beskydy Mts. have been subject to probably the most intensive research in this field (Heroldová 1995; Heroldová, Zejda 1995; Bryja et. al. 2001; Heroldová et al. 2007, 2008, 2009, 2012), with several studies focusing also on the Krušné Hory Mts. (Heroldová 1992; Bejček et al. 1999). Other mountain ranges are subject to sporadic monitoring of damage (e.g. Kamler et al. 2010), yet assessments of the impact of various factors are not available. The Jeseníky Mts. are among such mountain ranges. Apart from two one-off studies (Kamler et al. 2011; Suchomel et al. 2011), virtually no other information on the given issue is available. The

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present paper contains the results of a four-year study of damage caused to common beech plantations in the given area.

MATERIAL AND METHODS

A total of 18 plots within beech plantations were selected in the area of the Jeseníky Mts. (Czech Republic), each of them situated at a different altitude and different exposure (Table 1). The age of saplings in the first year of monitoring ranged from 5–7 years (2007). 50 saplings were monitored at each site annually. The monitoring took place in spring in four consecutive years (2008–2011) after the snow has melted. The height, stem diameter and possible occurrence and extent of gnawing were determined for each specimen. Gnawing on the stem was described in detail, including its vertical length (cm), horizontal extent (%) and the gnawing degree on branches. The obtained data were then related to the given stem diameter and converted into area in cm^2 (Table 2). A total of 900 saplings were monitored annually, which represents 3,600 specimens over the four-year monitoring period. Close attention was paid to the gnawing height above the surrounding terrain, which allows us to distinguish damage caused by particular vole species. Voles of the genus *Microtus* (L.) browse up to 20 cm above the ground, the bank vole (*Myodes glareolus* [Sch.]) over 20 cm above the ground (Heroldová et al. 2007). Important environmental factors included plot characteristics, which were monitored as well, including their altitude, age of plantations, total herb layer cover from which data were collected and divided into total cover of grasses, cover of *Calamagrostis* sp., cover of *Avenella* sp., cover of dicotyledonous plants, cover of *Rubus* sp., combined cover of dicotyledonous plants and *Rubus* sp. and cover of weeds (Table 3).

Small mammals were captured at the plots as well. This took place once a year in autumn (September), always prior to the spring monitoring of gnawing (2007–2010). Sampling was conducted with the help of snap traps arranged in lines (one line of 34 traps per plot, distance between traps was 3 m). Wicks fried in flour and vegetable oil were used as bait and repeatedly smeared with peanut butter in the course of each monitoring session. Traps were exposed for three nights. The aim of the trapping was to verify the occurrence of rodent species at the plot, to determine their species composition and abundance.

The impact of environmental variables on the structure and distribution of voles was tested with the help of redundancy analysis (RDA), using the Monte Carlo Permutation Test (999 permutations) and processed by CANOCO for Windows (ter Braak, Šmilauer 2002; Lepš, Šmilauer 2003). Particular variables were tested separately. The resulting model thus included only variables with a significant impact (Table 3, Fig. 2).

Linear regression analysis (StatSoft, Inc. 1999) was implemented to verify whether the environmental variables change in relation to changing altitude. The relation between the environmental factors, monitored variables (sapling damage) and voles was tested by the Spearman's rank correlation in STATISTICA CZ.

RESULTS AND DISCUSSION

From the small rodents damaging trees by bark gnawing (Baxter, Hansson 2001), a total of 314 specimens of voles (Arvicolinae) were collected at the experimental plots. The most abundant were the bank vole (*Myodes glareolus*) (n = 153; 27.0%) and the field vole (*Microtus agrestis*) (n = 138; 24.4%), whose abundances were comparable. The common vole (*M. arvalis*) was significantly less abundant (n = 21; 3.7%) and the European pine vole (*M. subterraneus*) occurred only rarely (n = 2; 0.4%).

Out of the total number of monitored saplings (n = 3,600), 13.6 % (n = 489) were damaged by rodents in the course of the four-year monitoring period, the extent of damage oscillating between 1.5 and 33% at particular plots. The stem diameter of the monitored saplings ranged from 0.3 to 5 cm (mean diameter 1.1 cm) and their height from 10.5 cm to 230 cm (mean height 61.0 cm). The extent of damage at the monitored plots oscillated substantially in particular years (Table 2), which can be accounted for by changes in the vole population dynamics and the varying degree of the impact of environmental factors (climate, snow cover, site character, etc.) (Table 1). The combined effect of these factors in a forest environment is so variable that changes in the impact monitored in particular years are difficult to explain, should the research be conducted in a short time frame (Hansson, Zejda 1977; Gill 1992). The issue thus requires a long-term study and a longer time series of data.

The fluctuation of damage caused in particular years in the monitored area reflected the fluctuation of the vole population dynamics, both reaching their peaks in the last year of monitoring, i.e. rodent abundance peaked in autumn 2010 and the extent of damage peaked in spring 2011 (Fig. 1).

Table 1. Basic and vegetation cover characteristics of the experimental plots in the Jeseníky Mts. in 2007–2011. Figures accompanying the particular components of the herb layer represent cover in %

Site	Altitude (m)	Exposure	Size (ha)	Age (years)	E1 cover	E1 height (cm)	Grass	Weeds	Dicotyl.	*Calamagrostis* sp.	*Avenella* sp.	*Rubus* sp.
					mean ± SD							
bk06	1035	NE	0.2	1	96 ± 3	52.5 ± 15	85 ± 0	7 ± 1	5 ± 4	65 ± 10	20 ± 10	1 ± 0
bk07	910	W	0.3	4	100 ± 0	62.5 ± 15	94 ± 1	4 ± 2	2 ± 1	83 ± 5	12 ± 5	1 ± 0
bk08	1010	0	0.4	3	68 ± 15	37.5 ± 5	41 ± 23	4 ± 4	22 ± 12	28 ± 16	3 ± 0	0 ± 0
bk11	785	SE	0.5	2	100 ± 0	70.0 ± 20	83 ± 4	8 ± 4	9 ± 8	33 ± 5	51 ± 9	7 ± 1
bk12	820	SE	0.5	2	100 ± 0	70.0 ± 20	87 ± 4	8 ± 4	5 ± 0	15 ± 10	72 ± 6	14 ± 11
bk13	770	NW	0.4	4	99 ± 3	80.0 ± 0	79 ± 13	9 ± 2	11 ± 13	34 ± 3	45 ± 10	7 ± 0
bk14	790	NW	0.3	4	100 ± 0	70.0 ± 20	86 ± 3	10 ± 0	4 ± 2	44 ± 8	43 ± 5	12 ± 9
bk16	730	0	0.4	2	96 ± 3	70.0 ± 20	76 ± 13	0 ± 0	20 ± 10	61 ± 13	23 ± 5	1 ± 1
bk18	705	E-SE	0.4	1	96 ± 3	60.0 ± 20	72 ± 1	3 ± 1	24 ± 8	33 ± 5	41 ± 8	2 ± 0
bk19	755	0	0.3	2	96 ± 3	52.5 ± 15	89 ± 3	0 ± 1	8 ± 5	55 ± 0	35 ± 1	0 ± 0
bk20	745	0	0.2	1	96 ± 3	55.0 ± 10	63 ± 15	0 ± 0	38 ± 15	49 ± 18	14 ± 3	0 ± 0
bk21	710	SW	0.25	5	100 ± 0	47.5 ± 5	48 ± 5	48 ± 5	5 ± 0	43 ± 5	5 ± 0	44 ± 3
bk23	690	SW	0.35	6	100 ± 0	60.0 ± 0	62 ± 14	28 ± 14	10 ± 0	49 ± 8	15 ± 0	24 ± 13
bk24	720	NE	0.35	1	70 ± 20	57.5 ± 5	35 ± 12	25 ± 8	10 ± 0	28 ± 9	5 ± 0	18 ± 9
bk25	1085	E	0.5	2	91 ± 3	30.0 ± 0	9 ± 3	0 ± 0	82 ± 4	3 ± 2	4 ± 2	0 ± 0
bk26	1070	NW	0.2	3	100 ± 0	40.0 ± 0	70 ± 0	13 ± 5	16 ± 3	5 ± 1	1 ± 1	5 ± 0
bk27	1040	SW	0.4	1	95 ± 0	37.5 ± 5	61 ± 12	35 ± 10	1 ± 3	10 ± 0	0 ± 1	1 ± 1
bk28	1065	0	0.3	2	95 ± 0	32.5 ± 5	54 ± 2	16 ± 8	25 ± 10	8 ± 5	8 ± 4	5 ± 0

size – size of plots, age – age of plots in 2007, E1 cover – total cover of herb layer, E1 height – herb layer height, grass – total cover of grasses, weed – total cover of weeds, Dicotyl. – total cover of dicotyledonous plants, *Calamagrostis* sp. – total cover of *Calamagrostis* sp., *Avenella* sp. – total cover of *Avenella* sp., *Rubus* sp. – total cover of *Rubus* sp., SD – standard deviation

Table 2. Extent of damage caused to saplings at experimental plots in the Jeseníky Mts. in 2008–2011

Site	Surface (cm^2)				Gnaw			
	2008	2009	2010	2011	2008	2009	2010	2011
bk06	0	31.29	0	0	0	9	0	0
bk07	2.4	0	0	0.47	5	0	0	1
bk08	1.33	0.42	0	0	2	1	0	0
bk11	7.7	0	12.76	591.04	5	0	2	17
bk12	0.4	1.76	0	58.36	1	1	0	6
bk13	22.64	411.45	16.87	1126.31	4	14	5	31
bk14	4.1	480.8	551.17	745.2	3	7	14	22
bk16	26.53	6.29	392.44	795.3	13	5	10	38
bk18	10.69	36.25	0.69	669.14	7	6	1	31
bk19	20.24	2.26	41.26	191.59	10	1	3	15
bk20	8.54	0.86	0	83.21	4	1	0	11
bk21	71.34	225.34	784.41	17.9	6	17	29	2
bk23	1.18	48.11	181.71	13.17	1	11	16	4
bk24	0	0	11.78	218.95	0	0	5	15
bk25	318.84	42.86	6.53	0	29	4	1	0
bk26	26.31	61.09	0	0	8	3	0	0
bk27	199.67	132.62	0	21.35	10	12	0	1
bk28	3.81	50.92	11.78	0	5	3	1	0

every year 50 saplings were monitored at each plot: surface – total surface damage caused by small mammals to saplings, gnaw – total number of damaged saplings

This gives evidence of a relation between the size of rodent population and the intensity of damage. Especially, when the population dynamics oscillations are regular, then these fluctuations may contribute to extensive damage to forest stands (Huitu et al. 2009). The extent of damage caused to plantations correlated positively with the vole abundance. Their growing abundance conditioned an increase in the extent of damage as well as an increase in the number of damaged saplings. The obtained values were significant both in Arvicolinae (r = 0.37 and 0.28, resp.; $P < 0.05$) and in voles of the

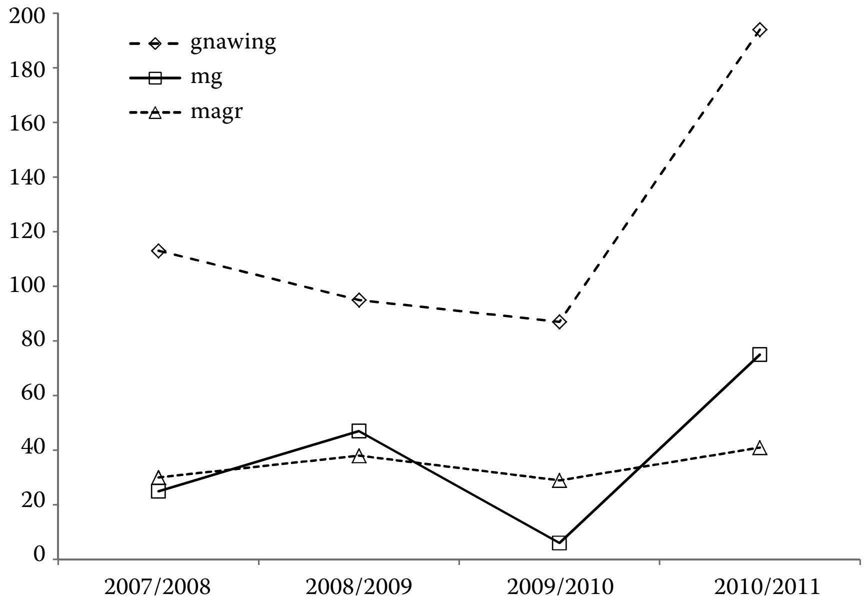

Fig. 1. Dynamics of gnawing on common beech saplings and of vole populations (mg – *Myodes glareolus*; magr – *Microtus agrestis*) in the monitored area. Values on the y-axis represent numbers of specimens and numbers of damaged saplings

genus *Microtus* (r = 0.37 and 0.33, resp.; P < 0.05) in summary values, and also separately in the most abundant vole, *M. agrestis* (r = 0.42 and 0.34, resp.; P < 0.05). The values obtained for the bank vole were insignificant.

The most damaged saplings were browsed only up to the height of 20 cm (89.0%) and with increasing altitude this type of damage decreased significantly (Table 3). This suggests voles of the genus *Microtus*, particularly the most common of them, the field vole (*Microtus agrestis*) (Gill 1992; Heroldová et al. 2007), whose abundance decreased with increasing altitude as well. The decrease in abundance was not significant, yet the trend was obvious. However, at some plots where this species occurred, the saplings were gnawed not only at the base but also at heights exceeding 20 cm, which is generally typical only of the climbing bank vole under normal circumstances (Heroldová et al. 2007). Moreover, a relation between the field vole abundance and gnawing intensity higher up the stems was statistically highly significant (Table 4). This can be explained by the high snow cover under which even voles of the genus *Microtus* are capable of gnawing bark up to the height of 1 m (Hansson, Zejda 1977; Baxter, Hansson 2001). This merely confirms the key significance of voles of the genus *Microtus* as primary bark gnawing pests in the area. Saplings with 100 % gnawed bark around the entire stem girth are most susceptible to dying off (Gill 1992; Heroldová et al. 2007; 2008). Out of the total number of damaged saplings, such specimens amounted to 6.3%.

Spearman's rank correlation did not confirm the impact of plantation age on the extent and intensity of gnawing damage. The only exception was gnawing height exceeding 20 cm, which positively correlated with the increasing age of plantations (Table 3). This can be explained by increased preferences to the bark of older saplings higher above the ground, as it is tenderer and has a higher nutritional value (Bergeron 1996). Another explanation may be a potentially higher impact of the bank vole which has an easy access to this type of bark thanks to its ability to climb (Heroldová et al. 2007).

The gnawing intensity was also affected by the herb layer composition. A conducted regression analysis revealed that its individual components

Table 3. Results of statistical analyses: regression analysis – tested the dependence of changes in environmental variables on altitude; RDA – tested the impact of environmental variables on the structure and distribution of voles; Spearman's rank correlation – analysed the relation between environmental variables and voles and damage to saplings

Environmental factor	Regression analysis	RDA		Spearman's rank correlation										
							Microtus				gnaw			
		F	*P*	arvicol	*Microtus* s.l.	*Myodes*	*agrestis*	*arvalis*	*subter.*	surface	sum	(%)	< 20	> 20
Altitude	nent	ns		ns	ns	ns	ns	ns	ns	–*	–**	–**	–**	ns
Age of plantations	nent	ns		ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	+*
Total E1	ns	3.848	0.022	+*	+**	ns	+**	ns	ns	+*	ns	ns	ns	+*
Grass total	–*	3.826	0.027	ns	ns	–**	ns	ns	ns	ns	ns	ns	ns	ns
Calamagrostis sp.	–***	9.68	0.001	–***	–**	–**	–**	ns	ns	ns	ns	ns	ns	ns
Avenella sp.	–***	6.772	0.001	ns	+**	–**	ns	+***	ns	ns	ns	ns	ns	ns
Dicotyledonous plants	+*	ns		ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Rubus sp.	–***	5.856	0.006	+***	+***	ns	+***	ns	ns	ns	ns	ns	ns	ns
Dicotyledonous + *Rubus* sp.	ns	5.358	0.009	+*	ns	+**	ns	ns	ns	ns	ns	ns	ns	+*
Weeds	ns	4.658	0.016	+**	+*	ns	+**	ns	ns	ns	ns	ns	ns	ns

nent – not entered, ns – not significant, surface – total surface of gnawing on a surface (cm^2), gnaw sum – total sum of gnawed saplings, gnaw (%) – percentage of gnawed saplings out of the total sum of checked specimens, < 20 – the sum of gnawing below 20 cm of sapling height, > 20 – the sum of gnawing over 20 cm of sapling height, – indicates negative relationship between variables, + indicates positive relationship between variables, *P < 0.05, **P < 0.01, ***P < 0.001

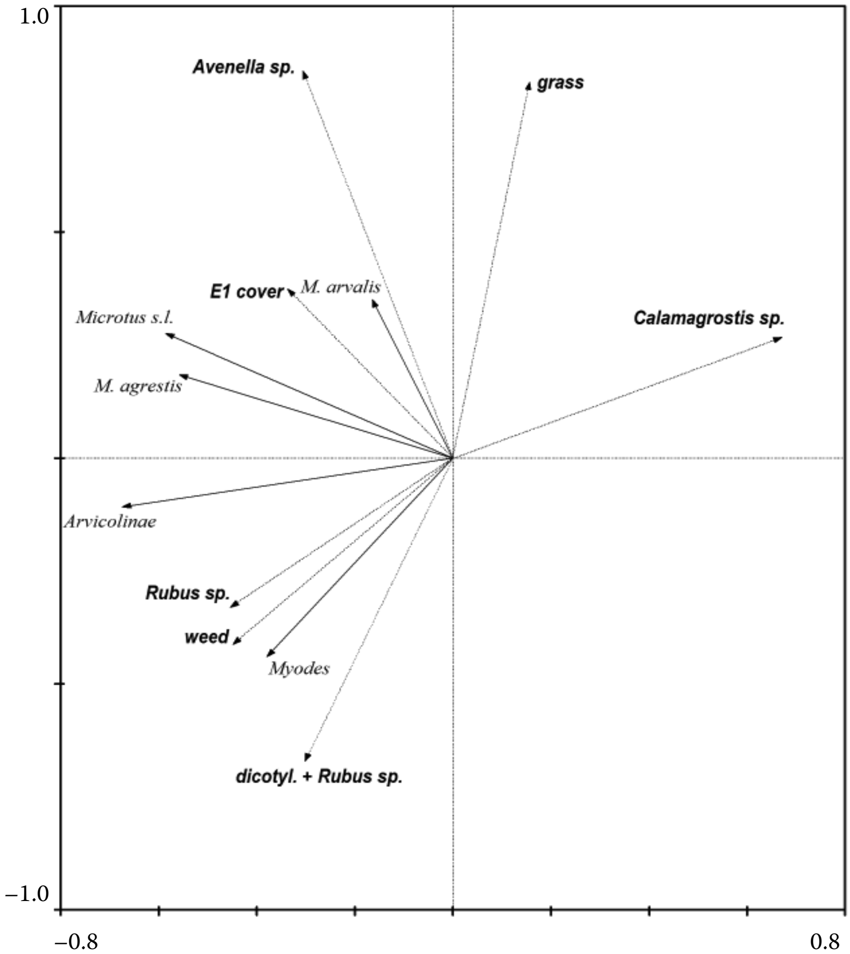

Fig. 2. Results of RDA analysis: a diagram depicting the relation between voles and environmental variables. Only variables with significant impacts are depicted (P < 0.05). The extremely rarely occurring *M. subterraneus* is not represented. Differences between particular years were statistically significant (F = 6.193; P = 0.039) and as such were included in the analysis as covariables. The resulting model was highly significant (F = 6.499; P = 0.001) and explained 33.5% (axis 1) and 42.1% (axis 2) of species data variability

(grasses and dicotyledonous plants) are more or less dependent on the altitude (see the commentary below). RDA analysis then significantly confirmed an impact of selected components of the herb layer on the species composition of voles and on the distribution of particular species. The specific significant evidence of both analyses is shown in Table 3 and Fig. 2.

The increasing ratio of dicotyledonous plants (along with *Rubus* sp.) at particular plots was related to an increasing number of gnawing injuries at stem heights exceeding 20 cm. Both these variables were correlated positively (P < 0.05, Table 3). This bears evidence of damage caused by the bank vole (Heroldová et al. 2007), which is associated with habitats of herb layers with prevailing dicotyledonous plants that provide a major part of its diet during the vegetation period (Holišová 1971; Hansson 1985). This habitat preference was also verified by a positive correlation between the bank vole abundance and the ratio of dicotyledonous plants (along with *Rubus* sp.) at the given site (P < 0.05). On the contrary, the bank vole abundance correlated negatively with grass cover (P < 0.05), which is an unsuitable habitat for this species (Suchomel et al. 2009).

Altitude also displayed a significant relation to gnawing intensity, which decreased with increasing altitudes. Both the extent of damage and the number of damaged saplings decreased significantly (Table 3). More extensive damage at lower altitudes may be related to higher abundances of voles of the genus *Microtus* at these altitudes. The decrease may be explained by a significant decline in grass cover conditioned by increasing altitudes (P < 0.05, see Table 3). Grass cover represents a key prerequisite for the occurrence of the said voles, with respect to their habitat and food preferences (Heroldová 1992; Heroldová et al. 2007; Suchomel et al. 2009, etc.). Increasing altitudes, on the other hand, were associated with increasing abundances of the bank vole. This trend, however, was not significant either. It may be explained by changes in the herb layer character, particularly by an increased ratio of dicotyledonous plants, which condition the occurrence of this species (Heroldová et al. 2007; Suchomel et al. 2009) at plots situated at higher altitudes, since dicotyledonous plant cover increased significantly with increasing altitudes (P < 0.05).

Upon comparison of our results with overall situation in the Czech Republic, a regional character

Table 4. Results of Spearman's rank correlation showing the relation between the type and number of damaged common beech saplings and voles

Damage type	Spearman's rank correlation					
	arvicol	*Microtus* s.l.	*Myodes*	*M. agrestis*	*M. arvalis*	*M. subteraneus*
Surface	+**	+**	ns	+***	ns	ns
Gnaw sum	+*	+**	ns	+**	ns	ns
Gnaw (%)	+*	+**	ns	+**	ns	ns
< 20	+*	+*	ns	+**	ns	ns
> 20	+**	+***	ns	+***	ns	ns

ns – not significant, surface – total surface of gnawing on a surface (cm^2), gnaw sum – total sum of gnawed saplings, gnaw (%) – percentage of gnawed saplings out of the total sum of checked specimens, < 20 – the sum of gnawing below 20 cm of sapling height, > 20 – the sum of gnawing over 20 cm of sapling height, – indicates negative relationship between variables, + indicates positive relationship between variables, $^{*}P < 0.05$, $^{**}P < 0.01$, $^{***}P < 0.001$

of forest stand damage is apparent (Kamler et al. 2010). An analogous situation may also be found in other European countries, where generally only a small percentage of forest sites is affected, yet with significant economic damage in the given areas (Borowski 2007; Huitu et al. 2009 etc.). This has been recorded throughout Central and Northern Europe. For instance in Poland, economically significant damage was determined at 4% of monitored forest stands (Borowski 2007), while in Finland the damage caused was assessed at EUR 2.2 to 4.0 mil per single winter (e.g. Huitu et al. 2009). Differences in the species spectrum of damaged trees and the extent of damage in various areas of Europe give evidence of a number of different complex factors at play and as such require an assessment of the issue at a regional level and deem any generalization of results unsuitable. While mainly coniferous species are damaged in the boreal zone (Sullivan, Sullivan 2008; Huitu et al. 2009), which is related mainly to the given environmental conditions, the area of Central Europe encompasses regionally differing spectrums of tree species with various ratios of broadleaved and coniferous species, which is affected both by the specific natural conditions and silviculture as well (Borowski 2007; Kamler et al. 2010, 2011). While for example mainly rowan and beech are damaged in the Czech Republic (Kamler et al. 2010), larch and ash are damaged in Poland (Borowski 2007).

CONCLUSIONS

The main result of the study is that small rodents do not generate an important impact on forest regeneration in mountainous regions. Only 13.6 % (489 out of 3,600) controlled common beach saplings were damaged by voles. Compared with similar mountainous regions in the Czech Republic, the extent of damaged saplings in the Jeseníky Mts. is higher than in the Krušné Hory Mts. (Kamler et al. 2008) and roughly comparable with the situation in the Beskydy Mts. (Heroldová et al. 2008). The results obtained reveal that the most significant pest in the area is the field vole (*Microtus agrestis*), which was responsible for most of the damage caused, both by its trademark bark gnawing at stem bases but due to favourable conditions (high snow cover) also higher up above the ground, which is usually attributed to the bank vole (*Myodes glareolus*). The latter species, however, caused significantly less damage despite its higher frequency of occurrence. Most of the gnawing damage was monitored at lower altitudes, which is related to the character of the herb layer (grasses) and thus to a higher abundance of the field vole. With respect to the management of silvicultural plantations in the area it is therefore advisable to focus on the elimination of conditions which are favourable for this vole species. This includes removal of the herb layer with dominant grasses and protection of plantations particularly at lower altitudes (Table 1).

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Corresponding author:
Doc. Ing. Josef Suchomel, Ph.D., Mendel University of Agriculture and Forestry in Brno,
Faculty of Forestry and Wood Technology, Department of Forest Ecology, Zemědělská 3, 613 00 Brno, Czech Republic
e-mail:suchomel@mendelu.cz