

ECOLOGY, DISTRIBUTION AND CONSERVATION OF *VERTIGO* SPECIES OF EUROPEAN IMPORTANCE IN SLOVAKIA

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Abstract The purpose of this paper is to summarise up-to-date information on the ecology and distribution of *Vertigo angustior*, *V. geyeri*, and *V. moulinsiana* in Slovakia. *V. moulinsiana* is an inhabitant of both treeless calcareous-fens and calcium-rich sedge marshes situated in warm lowland regions. *V. angustior* occurs in various types of habitats (i.e. different types of calcium-rich wetlands, mainly treeless calcareous-fens). *V. geyeri* is an exclusive inhabitant of treeless fens and has a relatively broad ecological range along the gradient of calcium. It frequently lives in *Sphagnum*-fens at higher altitudes. *V. angustior* is the most common of these three species and more data on its occurrence are expected in the near future. The occurrence of *V. geyeri* and *V. moulinsiana* reflects their relict distribution in Slovakia, in particular in the northern part (*V. geyeri*) and southern and eastern part (*V. moulinsiana*). The recent conservation status of the species in Slovakia based on the categories and criteria of the IUCN (version 3.1, 2001) is as follows: *V. angustior* – Vulnerable, *V. geyeri* and *V. moulinsiana* – Endangered.

Key words *Vertigo* spp., Annex IV, Slovakia, ecology, distribution, conservation.

INTRODUCTION

By joining the European Union in May 2004, Slovakia has made a commitment to implement the EU directives related to nature conservation. Some of the most important as well as the most publicly discussed directives are the *Council Directive 79/409/EEC of 2 April 1979 on the conservation of wild birds* (hereafter 'Birds Directive') and the *Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora* (hereafter 'Habitats Directive'). According to the Directives the member states are obliged to create a network of protected areas (known as 'Natura 2000') to protect habitats and species of European Importance. In Slovakia it was proposed to include 38 important bird areas and 382 special protected areas in the Natura 2000 network.

For the conservation and management of endangered mollusc species, the Habitats Directive and its annexes, particularly Annex II (Animal and plant species of Community Interest whose conservation requires the designation of special areas of conservation) and Annex IV (Animal and plant species of Community Interest in need

Species	Habitats Directive	
	Annex II	Annex IV
<i>Anisus vorticulus</i> (Troschel 1834)	x	x
<i>Bythinella pannonica</i> (Frauenfeld 1865)	x	x
<i>Theodoxus transversalis</i> (C. Pfeiffer 1829)	x	x
<i>Unio crassus</i> Philipsson 1788	x	x
<i>Vertigo angustior</i> Jeffreys 1830	x	–
<i>Vertigo geyeri</i> Lindholm 1925	x	–
<i>Vertigo moulinsiana</i> (Dupuy 1849)	x	–

Table 1 A list of mollusc species in Slovakia listed in Annex II and Annex IV of the Habitats Directive.

of strict protection) play an important role. So far, seven mollusc species found in Slovakia have been included in Annex II and four of them are also listed in Annex IV.

In this paper we focus on the *Vertigo* species of European Importance (namely *Vertigo angustior* Jeffreys, *V. geyeri* Lindholm, and *V. moulinsiana* (Dupuy)). The main purpose is to summarise

their distribution based on both published and unpublished records, to analyse their ecology using quantitative samples collected from 127 treeless spring fens, and to consider their actual conservation status.

PAST RESEARCH, OLD RECORDS AND CURRENT DISTRIBUTION

The main goal of this chapter is to give a brief overview of the history of research on the target species in Slovakia. Therefore we will only mention the most important publications containing relevant information.

Historically, there has been relatively intensive research on the occurrence and distribution of molluscs in Slovakia, especially of forest species and species preferring rocky habitats. Only a small number of published papers have focused on wetlands and their mollusc fauna up to 2000. For example Ložek & Šteffek (1983) compiled available data on the distribution of *V. moulinsiana* in Czechoslovakia, and Ložek (1992a) and Lučivjanská (1992) published records of *V. angustior* and *V. geyeri* in the Rakšianske rašelinisko National Nature Reserve. In general, data on wetland molluscs are rare, very often as incidental results of field studies related to specific regions and areas (e.g. mountains, protected areas, etc.). All these older data were published by Lisický (1991) in his comprehensive study on the distribution of molluscs in Slovakia up to and including 1981. Due to habitat loss and destruction, *V. geyeri* and *V. moulinsiana* were listed as threatened species (Šteffek, 1987) and were also included in the national Red List of molluscs of Slovakia by Šteffek (1994). Revision of the Red List took place in 2006 and *V. angustior* was included in the list of threatened species as well (Šteffek & Vavrová, 2006).

Since 2000, there has been more intensive research focused on species listed in annexes of the Habitats Directive. Several studies have focused on fen and other wetland habitats and they have yielded important records of the species (Čejka, 2003; Horsák, 2005; Horsák & Hájek, 2005; Juříčková *et al.*, 2006), including the first records for eastern Slovakia (Šteffek & Vavrová, 2004). All available published and unpublished records of *V. angustior*, *V. geyeri* and *V. moulinsiana* in Slovakia were projected onto a mapping

grid system of Central Europe (Ehrendorfer & Hamann, 1965; see Anonymous, 1983; square size of ca 11×12 km) to show both the historical and present distribution of the species (Figs 1–3).

More intensive malacological research in wetlands during the last 10 years has resulted in more data on the distribution of the species in Slovakia. Concerning *V. angustior*, the number of known sites of occurrence more than 10 years ago was 147 (covering 68 DFS squares). During the last 10 years the species has been found at 154 sites (77 DFS squares) in Slovakia. As for distribution of *V. geyeri*, the number of known sites has increased from 13 (7 DFS squares) to 32 (18 DFS squares). A different situation exists regarding records of *V. moulinsiana*. While more than 10 years ago the number of known sites was 18 (14 DFS squares), during the last 10 years the species has been recorded only at 10 sites (8 DFS squares). This is due to the fact that from 1997 to 2007 the main focus was on 'blank' squares and already known data were only occasionally checked. This resulted in rather a high number of 'new' DFS squares recording the presence of the species, specifically 53 DFS squares for *V. angustior*, 14 DFS squares for *V. geyeri*, and 6 DFS squares for *V. moulinsiana*.

The map of *V. angustior* distribution in Slovakia shows that this is a relatively common species, and more records are expected in the near future. *V. geyeri* is a species with relict distribution in Slovakia, especially in the northern part (Tatra Mts.). One site in the Turiec region has also been recorded, and due to the character of the habitats it is possible that more data on distribution in this region will be gathered in the future. Southern and eastern parts of Slovakia are the areas that the relict species *V. moulinsiana* prefers. Regarding distribution of this species, the main focus during the last decade was on the Biele Karpaty and Východné Karpaty region. For instance numerous populations of *V. moulinsiana* were recorded on a small wetland near Vyšná Jablonka.

ECOLOGY OF THE STUDIED SPECIES

Field sampling, explanatory variables, and statistical analyses Data for assessment of the target species' ecology were collected at 127 treeless fen sites situated across Slovakia. The sites were chosen in

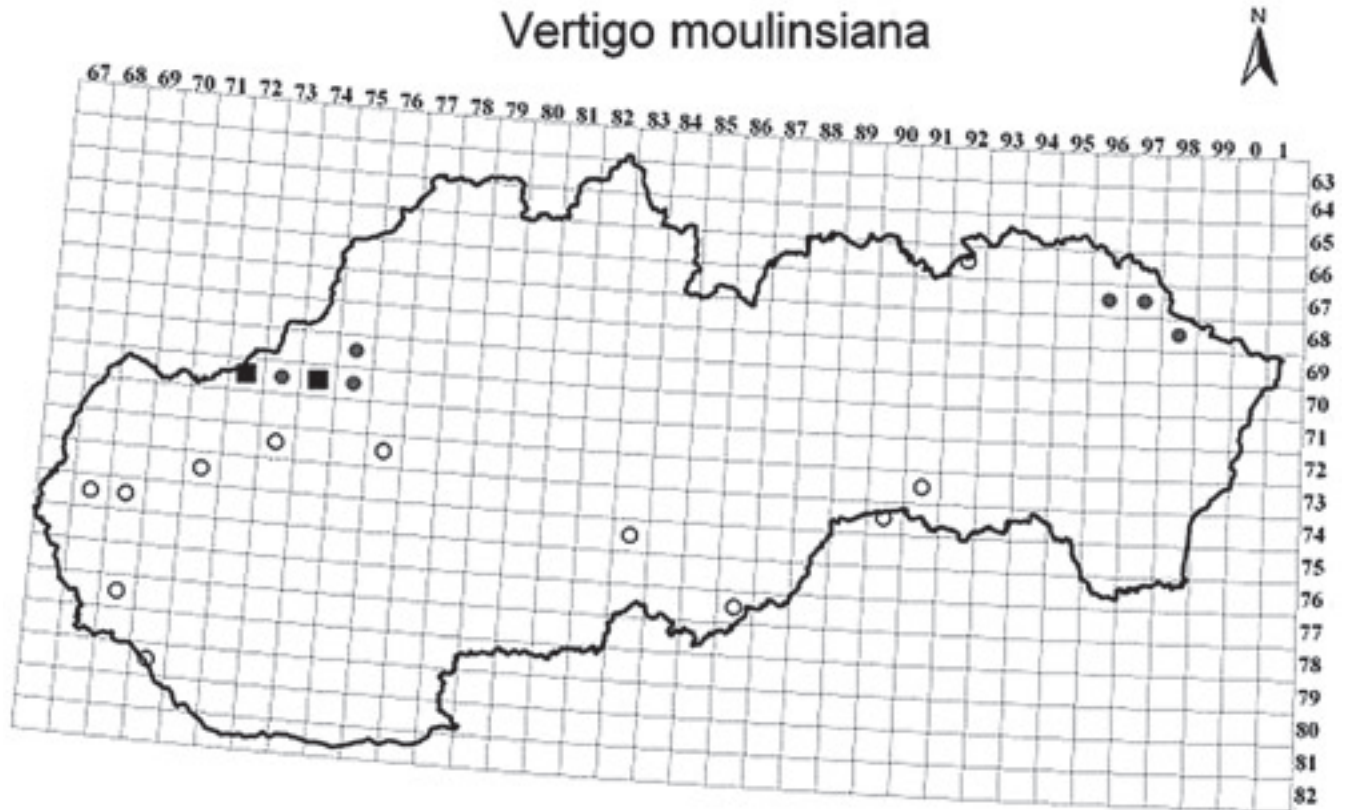


Figure 1 Known distribution of *Vertigo moulinsiana* in Slovakia (solid dots – data not older than ten years, empty dots – data older than ten years, squares – both recent and historical data).

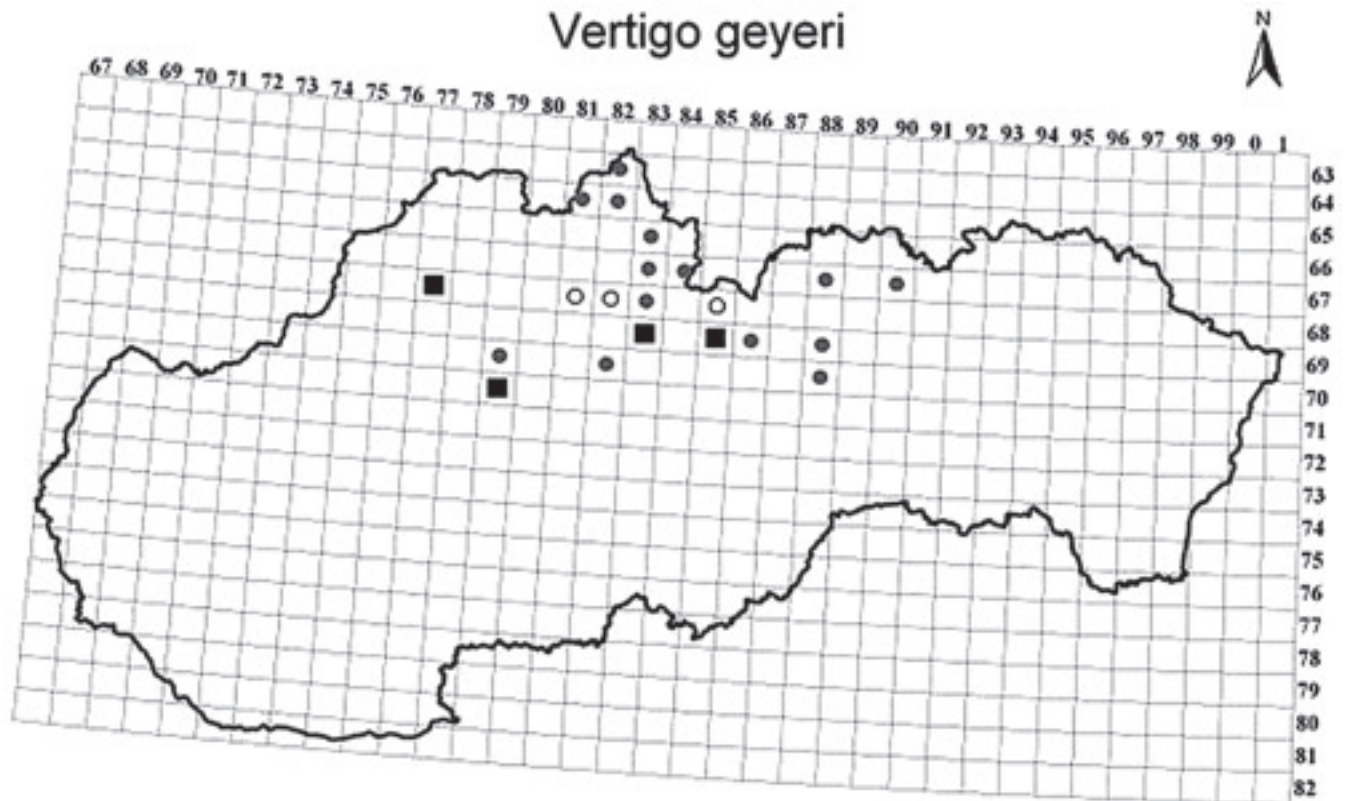


Figure 2 Known distribution of *Vertigo geyeri* in Slovakia (solid dots – data not older than ten years, empty dots – data older than ten years, squares – both recent and historical data).

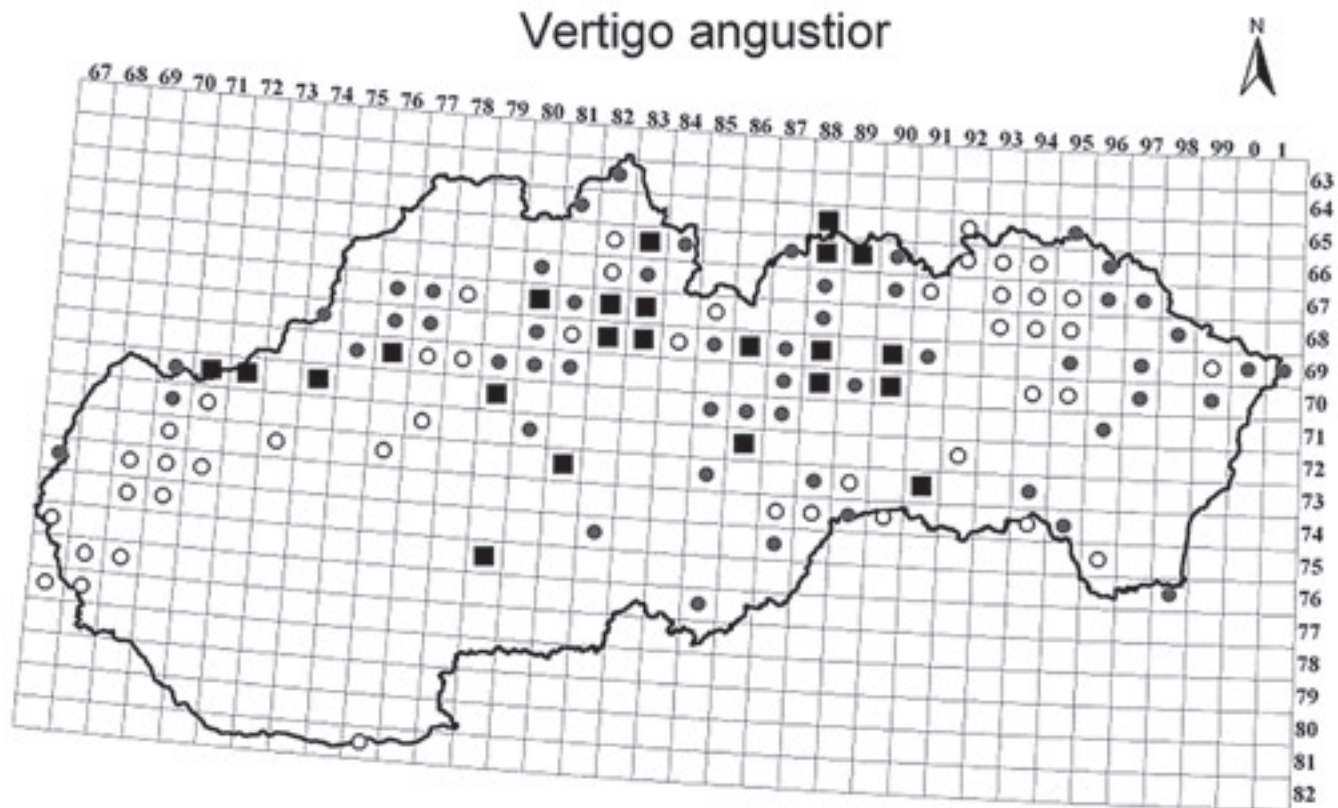


Figure 3 Known distribution of *Vertigo angustior* in Slovakia (solid dots – data not older than ten years, empty dots – data older than ten years, squares – both recent and historical data).

order to cover a broad a range of calcium content, altitude, climate, and habitat size as possible. During 2000–7, one 12 litre volume sample was collected from a homogeneous area of 16 m² in the central part of each site and processed using the wet washing technique (Horsák, 2003, 2006). All such quantitative samples were taken by M. Horsák and the sites with positive finds of the target *Vertigo* species are given in the Appendix and are plotted on the maps (Figs 1–3).

The following environmental parameters, known to be important predictors of fen snail

species distribution (Horsák & Cernohorsky, 2008) were compiled for each sampling plot (Table 2). (1) Water conductivity and pH were measured at the micro-sites best supplied by water in small shallow holes dug in the sampling plots, using portable instruments with automatic temperature compensation (CM 101 and PH 119, Snail Instruments, Beroun, Czech Republic). The readings were standardised to 20 °C. In acid water the conductivity caused by H⁺ ions was subtracted (Sjörs, 1952). As water conductivity correlates well with the concentration of calcium

Explanatory variables	Median	Mean	Standard deviation	Minimum	Lower quartile	Upper quartile	Maximum
Water conductivity (µS/cm)	372	378	202	27	273	471	1050
Water pH	7.1	6.9	0.7	4.2	6.8	7.3	8.2
January temperature (°C)	-5.5	-5.1	0.8	-6.5	-5.5	-4.5	-2.5
July temperature (°C)	15.0	14.5	1.4	13.0	13.0	15.0	17.0
Annual temperature (°C)	5.0	4.7	1.4	1.0	3.0	5.0	7.5
Annual rainfall (mm)	950	938	208	575	850	1100	1400
Altitude (m a.s.l.)	665	645	165	310	480	780	975
Total area (m ²)	425	5682	18328	23	72	1150	10 ⁵

Table 2 Descriptive statistics for variables used in the analyses of ecological requirements.

ions in fens ($r = 0.9\text{--}0.95$; Sjörs and Gunnarsson, 2002; Hájek *et al.*, 2005), it can be used as a reliable proxy of calcium concentration (Horsák, 2006). (2) Geographical co-ordinates, altitude and total habitat area were measured in the field using GPS; altitude was then checked against 1:50,000 topographic maps. (3) Basic climatic variables (mean annual rainfall, mean annual temperature, mean July temperature, and mean January temperature) were obtained by using overlays of plot locations with a digital elevation model and climatic maps, based on Miklós (2002) and Tolasz (2007), in the ArcGIS 8.3 programme (ESRI, 2003).

All 127 fen sites were ordinated based on explanatory variables (except geographical coordinates); the Principal Components Analysis (PCA) of a correlation matrix (i.e. variables were centred and standardised) was used. Geographical coordinates and log-transformed species abundances were only passively projected onto the ordination diagram in order to show whether there were any correlations between the species abundance and environmental gradients. The CANOCO 4.5 package (ter Braak & Šmilauer, 2002) was used for the ordination technique and the STATISTICA 7.1 programme (Hill & Lewicki, 2007) was used for the other (uni-dimensional) analyses and for constructing the box plots. Significance values in multiple tests were corrected using the Bonferroni method (Holm, 1979).

RESULTS

Ecological requirements The first PCA axis

accounted for 47.3% of the variance of the correlation matrix. High loadings on this axis, reflecting correlations with the sample scores, were obtained for all explanatory variables except habitat area (Table 3). The first axis expressed a complex ecological gradient combining the main mineral poor-mineral rich gradient and climatic gradients. The second axis accounted for 16.2% of the variance of the correlation matrix. The highest loadings were obtained for habitat area ($r = 0.68$, $P < 0.001$). Significant correlations with the third axis, which explained 12.7% of the variance, were found for water pH and habitat area (Table 3). The abundance of *Vertigo moulinsiana* and *V. angustior* was positively correlated with the first axis ($r = 0.29$, $P < 0.003$ and $r = 0.32$, $P < 0.001$, respectively) unlike *V. geyeri*, which was positively correlated with the second axis ($r = 0.32$, $P < 0.001$).

Sites at which *V. moulinsiana* was found were plotted towards the calcium-rich and climatically-warm part of the ordination space (Fig. 4). This species was found to have a relatively narrow ecological range along both calcium and climatic gradients (Figs 5 and 6). It is an exclusive inhabitant of calcareous fens with a strong tufa precipitation but only in those situated in the warmest lowland regions (Fig. 5). Different preferences were found for the other two species. *V. angustior* was the most frequent species, and possessed a broad ecological range especially along the altitudinal (i.e. climatic) gradient (Fig. 5). It inhabited different types of calcium-rich fens including the most mineral-rich salt travertine fens (conductivity $> 1000 \mu\text{S}/\text{cm}$). However, this species avoided calcium-poorer sites at which *Sphagnum* species were found.

Explanatory variables	1st axis		2nd axis		3rd axis	
	r	p	r	p	r	p
Water conductivity ($\mu\text{S}/\text{cm}$)	0.700	< 0.001	0.499	< 0.001	-0.110	n.s.
Water pH	0.503	< 0.001	0.348	< 0.001	-0.697	< 0.001
January temperature ($^{\circ}\text{C}$)	0.733	< 0.001	-0.378	< 0.001	0.050	n.s.
July temperature ($^{\circ}\text{C}$)	0.816	< 0.001	-0.175	n.s.	0.239	n.s.
Annual temperature ($^{\circ}\text{C}$)	0.860	< 0.001	-0.227	n.s.	0.178	n.s.
Annual rainfall (mm)	-0.670	< 0.001	-0.408	< 0.001	0.061	n.s.
Altitude (m a.s.l.)	-0.796	< 0.001	0.269	n.s.	-0.073	n.s.
Total area (m^2)	0.054	n.s.	0.677	< 0.001	0.648	< 0.001

Table 3 PCA of eight explanatory variables in the 127 fen sites. Pearson correlations of explanatory variables with the first three PCA axes (r) and their significance (p) are shown.

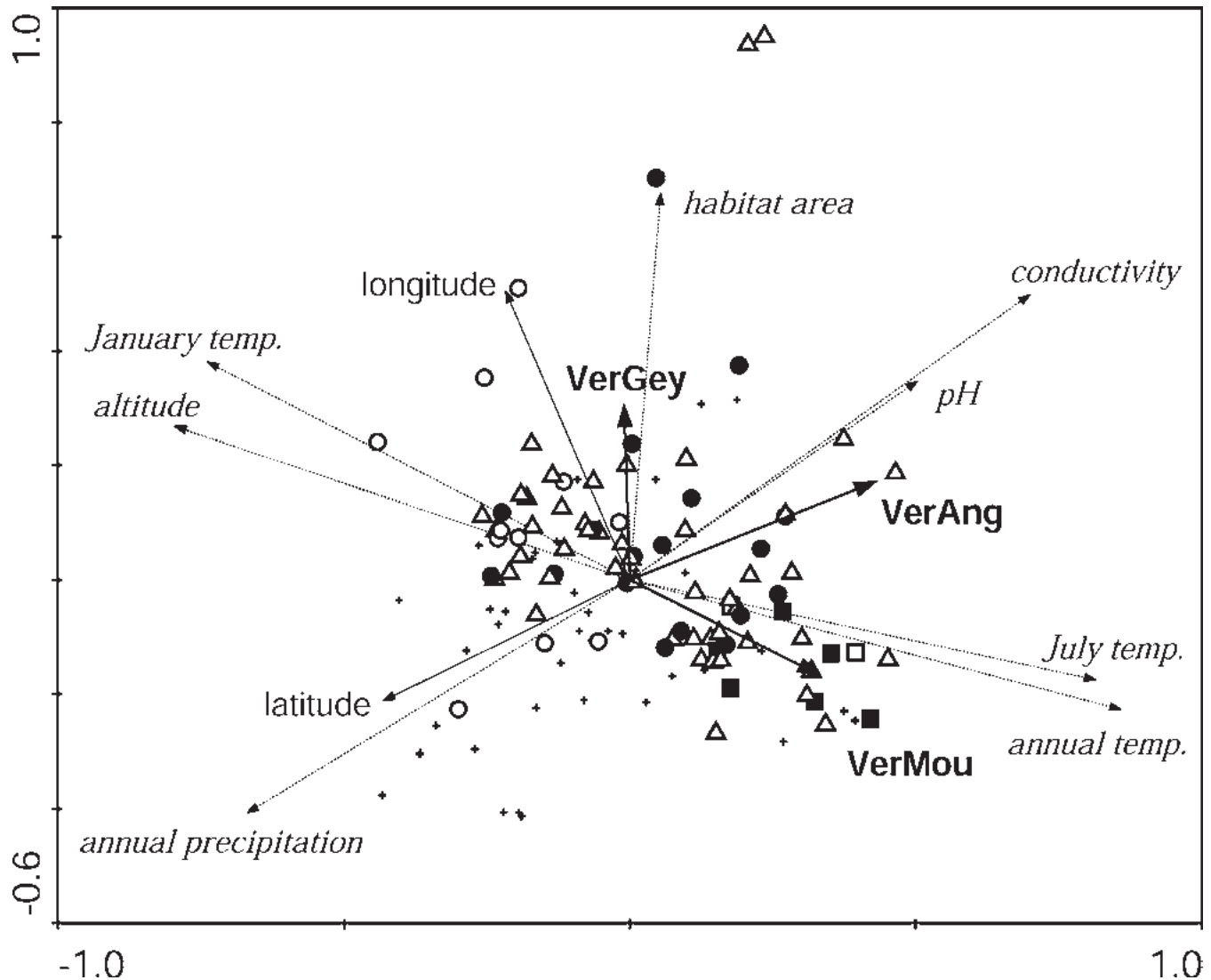


Figure 4 Principal component analysis (PCA): ordination plot of explanatory variables (except geographical coordinates) on the first two PCA axes. Geographical coordinates and log-transformed species abundances were only passively projected onto the ordination diagram. Classification of investigated sites based on occurrence of studied species: empty squares – *Vertigo moulinsiana* (n=2), filled squares – *V. moulinsiana* and *V. angustior* (n=6), empty circles – *V. geyeri* (n=11), filled circles – *V. geyeri* and *V. angustior* (n=19), empty triangles – *V. angustior* (n=48), crosses – negative records. VerGey – *V. geyeri*, VerAng – *V. angustior*, VerMou – *V. moulinsiana*.

It was documented only at the few sites with calcitolerant *Sphagna* but at those it was always limited to the most calcium-rich patches with or without a low cover of *Sphagna*. An approximately similar ecological range along the mineral gradient was observed for *V. geyeri*, although compared with the previous species it was shifted towards the mineral poorer part of the gradient (Fig. 6). It is true that this species avoids the most calcium-poor *Sphagnum*-fens and bogs, but was frequently found in rich and moderately-rich *Sphagnum*-fens in which the calcitolerant *Sphagna* also occurred. In calcium-poorer sites it also preferred calcium-rich patches with a low cover of

Sphagna. In contrast to *V. angustior* this species avoided extremely mineral-rich travertine fens. When looking at altitudinal range it is clear that this snail preferred colder sites at higher altitude (Fig. 5). We only observed a significant positive relationship with total habitat area for this species (Fig. 6), which demonstrated that this species favoured large preserved and usually relict fen sites.

DISCUSSION

Comparison with published data on habitat require-

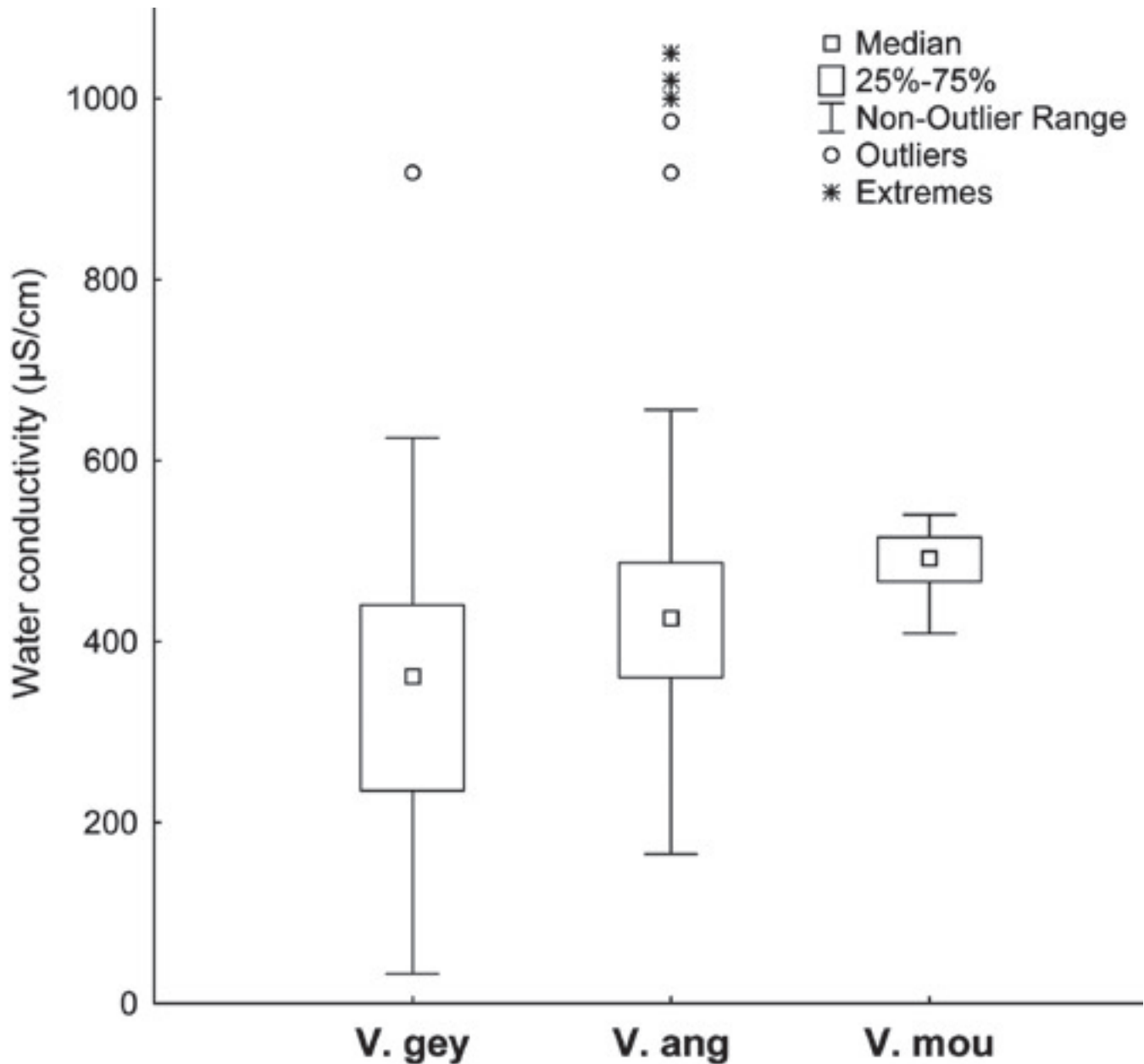


Figure 5 Variation of water conductivity of sites with occurrence of studied species. *V. gey* – *Vertigo geyeri* (n=30), *V. ang* – *V. angustior* (n=73), *V. mou* – *V. moulinsiana* (n=8).

ments Habitat and ecological requirements of the target species have been relatively well studied in several other countries. Published data are available from Finland and Russian Karelia, Norway, Sweden, Denmark, Scotland, Ireland, England, Poland, Germany, Czech Republic, Slovakia, Austria, and Hungary (Pokryzsko, 1990, 1993, 2003; von Proschwitz 1993, 2003; Jueg & Menzel-Harloff, 1996; Mildner, 2000; Cameron *et al.*, 2003; Falkner, 2003; Holyoak, 2003, 2005; Hornung *et al.*, 2003; Killeen, 2003; Moorkens & Gaynor, 2003; Tattersfield & McInnes, 2003;

Valovirta, 2003; Willing, 2003; Horsák & Hájek, 2005; Beran, 2006). Most of these works are available in Speight *et al.* (2003). These data enable to make a comparison of the observed species' ecological demands and frequencies in Slovakia with those known from elsewhere in Europe.

Vertigo angustior was found to be a quite common and widespread species in Slovakia contrary to the other two species involved in this study. A similar situation is particularly known from the adjacent countries (Czech Republic, Hungary, Austria, and Poland) but towards western and

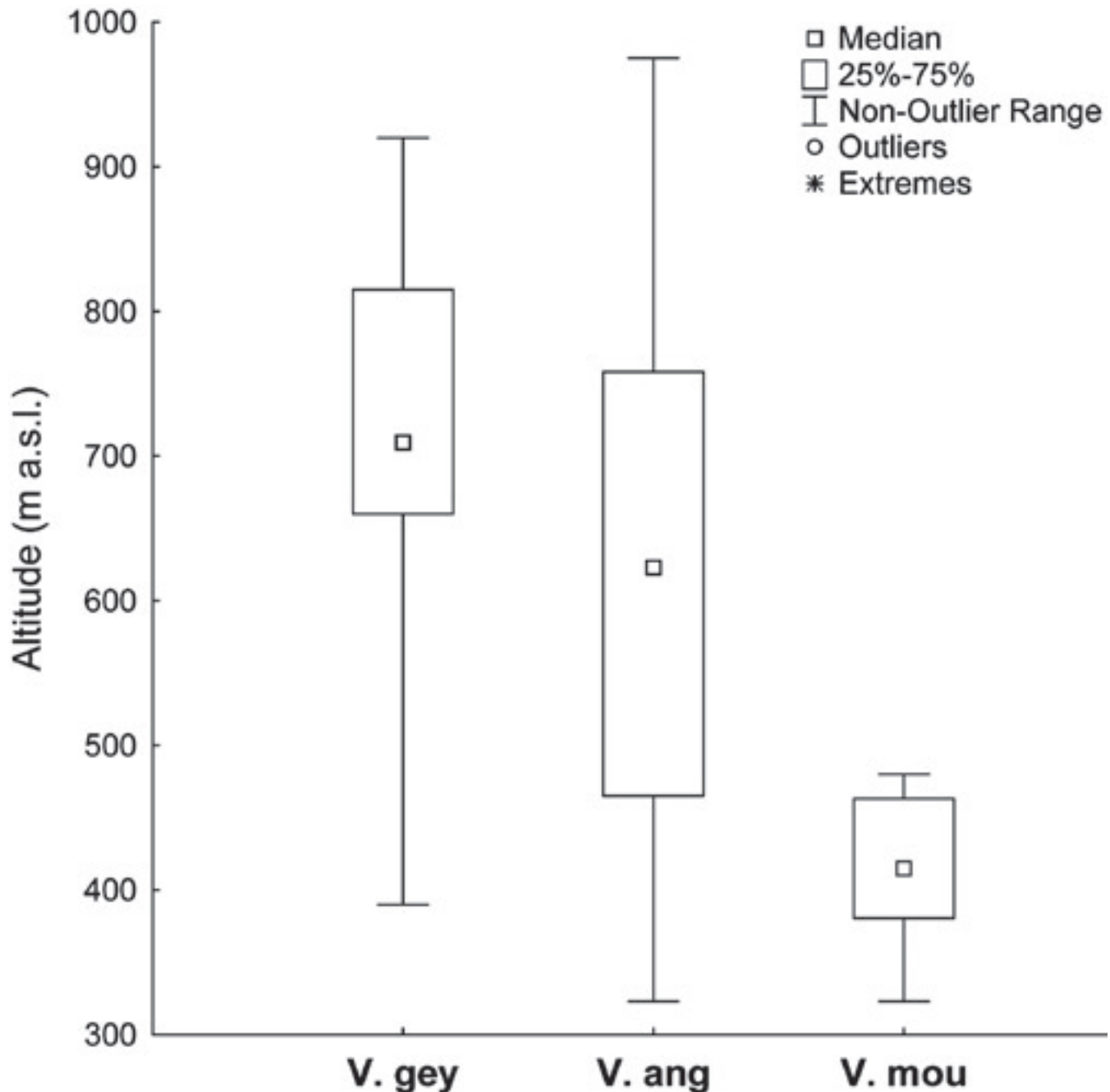


Figure 6 Altitude range of sites with occurrence of studied species. *V. gey* – *Vertigo geyeri* (n=30), *V. ang* – *V. angustior* (n=73), *V. mou* – *V. moulinsiana* (n=8).

northern Europe this snail starts to be less frequent or even very rare (see Speight *et al.*, 2003). This species is considered an inhabitant of a very wide range of habitat categories from coastal dunes to alder swamp forests or woody talus slopes (Cameron *et al.*, 2003). A different situation was observed in Slovakia where *V. angustior* was encountered mainly in calcium-rich treeless fens and wet meadows, and less frequently also in wet riparian margins of ponds and streams.

There are only few records from alluvial wet forests and just one population is known from an andesine boulder slope with deciduous trees (Čejka, 1999). These regional differences in habitat occupancy are, however, in good accordance with the previously published finding that habitat preferences of this *Vertigo* species are subject to much regional variation (Pokryzsko, 2003).

In contrast, the habitat ranges of the other two studied species are considerably narrower than

that of *V. angustior*. *V. moulinsiana* is a calciphilous and thermophilous species which is quite rare in all countries (see Speight *et al.*, 2003). The observed ecology in Slovakia perfectly matches with the overall ecology of this species. Its habitats are lowland calcium-rich wetlands such as calcareous fens, riparian large sedge communities, and alluvial swamp stands. However, most of the Slovak records came from treeless calcareous fens of warm lowland regions.

Vertigo geyeri is probably one of the most specialized snail species. In Slovak it lives only in alkaline treeless fens and moreover only in those located in the regions where fens have a historical continuity throughout the Holocene (Horsák *et al.*, 2007). This is linked with the fact that this species represents in central Europe a rare relict from the late Glacial and the early Holocene (Ložek, 1964, 1992b). In the Slovak part of the Western Carpathians it is probably the most frequent when compared with the other central European countries. This species is significantly more common only in Scandinavia. Its habitat requirements are surprisingly stable throughout the whole distributional range. It inhabits exclusively treeless fen sites of circumneutral conditions; ranging from calcareous fens to transition mires (Cameron *et al.*, 2003; for more details see Horsák & Hájek, 2005). The only exception from the above mentioned habitat requirements was reported from Finland and Russian Karelia where this species has also been found in wet, open deciduous forests (Valovirta, 2003).

SPECIES CONSERVATION IN SLOVAKIA AND EUROPE

The species on which this paper is focused are protected in Slovakia according to Act. No. 543/2002 on Nature and Landscape Conservation, and are listed as protected species. To carry out any research, including taking away samples of the species, permission has to be issued by the relevant state institutions at the national or regional levels.

By joining the EU the need to update the existing national Red List of molluscs in Slovakia published in 1994 (Šteffek, 1994) in accordance with the IUCN categories and criteria version 3.1 (2001) became apparent. This took place in 2006 and a new Red List was presented at an interna-

tional conference in Ukraine (Šteffek & Vavrová, 2006). According to the Red List, *V. angustior* is vulnerable in Slovakia and the other two species (*V. geyeri* and *V. moulinsiana*) are considered as endangered, mainly due to the fragmentation and destruction of suitable habitats. Recent field research has provided more new data on the distribution of the species in Slovakia. In particular, *V. angustior* seems to be more common than expected. On the other hand recent human activities such as intensive agriculture, drainage, etc. have caused a dramatic decline in the extent of the species habitats. Since the species are very sensitive in terms of habitat changes, regular updating of the Red List is necessary.

To ensure conservation and appropriate management of species of European Importance, the EU countries made a commitment to adopt and implement the Birds and Habitats Directives and its Annexes (see "Introduction"). The countries are obliged to identify sites that are important for species conservation and to apply an appropriate management strategy. For each of the species, categories and criteria of favourable conservation status were developed (Vavrová & Šteffek, 2007) and have been monitored on a regular basis. Another important tool for nature and biodiversity conservation is the Bern Convention, also implemented in the non-EU signatory countries. Most of the European states have developed and regularly updated national Red Lists and species conservation has been secured through implementation of national legislation as well.

THE MAJOR THREATS AND PROPOSED MANAGEMENT ACTIVITIES TO ACHIEVE FAVOURABLE CONSERVATION STATUS OF THE SPECIES

Although in Slovakia the number of sites at which the species are found is increasing, from the pan-European point of view the species distribution area is decreasing and their habitats are endangered. For instance *V. angustior* is a rather common species in Slovakia, occurring in different types of wetland. More intensive research on the species in Europe has provided data on both occurrence and population density in different countries. New localities and numerous populations as well as local extinctions of the species have been recorded in Europe, e.g. in Bavaria

(Falkner, 2003) and England (Killeen, 2003). The development of the European Community agricultural programme, which began in the 1960s, is considered to be one of the main reasons for the species population decline in the lower Bavarian plains of the Danube (Falkner, 2003). According to Pokryszko (2003), the main threats to the European *Vertigo* species are as follows. (1) Destruction of habitats due to changes in the water regime and their conversion to cultivated or urban areas. The activities have a negative impact on all studied species. (2) Disturbance of habitats, particularly intensive grazing, trampling and mowing also has a significantly negative impact especially on the *V. moulinsiana* populations. (3) Eutrophication, until recently restricted mainly to freshwater habitats, has become one of the main threats in Europe in the case of *V. angustior*. (4) Successional changes are threatening particularly isolated populations of *V. geyeri*. Habitats in temporary stages of succession that are preferred by the species need regular management to maintain suitable ecological conditions for the long-term occurrence of the species.

In order to achieve and maintain a favourable conservation status of the species in Slovakia the following management measures have been proposed (Vavrová & Šteffek, 2007). (1) To eliminate activities causing changes in the water regime and hydrological conditions that have a significant negative impact on the populations. (2) To avoid excessively intensive grazing, trampling, and mowing that reduces the plant species preferred by the *Vertigos*. (3) To regularly remove both invasive and allochthonous vegetation to avoid overgrowing and shading of the habitat. (4) To prevent use of any pesticides, herbicides, and other chemicals in the vicinity of the habitat.

By carrying out regular monitoring of species abundance and habitat conditions (water regime, hydrology, vegetation succession, chemical conditions, etc.) it is possible to recognise the negative impact of activities as they begin and therefore to implement appropriate management measures or to increase their effectiveness in time. A detailed methodology for monitoring of the species was discussed by Vavrová & Šteffek in 2005 and is available at the Directorate of the State Nature Conservancy of Slovakia in Banská Bystrica, or from the authors upon request.

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