

# CHANGES IN VERTICAL DISTRIBUTION OF SOME CARABID BEETLES: CONSEQUENCE OF CLIMATE WARMING OR TEMPORARY SPECIES EXPANSION AND POPULATION FLUCTUATION

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Table 1. Principal characteristics of six study plots in High Tatra

Locality	Vyšné Hágy reference plot	Tatranská Lomnica, Jamy	Tatranská Polianka, Danielov dom	Tatranské Zruby lower plot	Tatranské Zruby upper plot	Nový Smokovec, Vodný les
Locality abbreviations	VH	JA	DD	ZL	ZU	VL
Geographical coordinates	49°07'17.5"N 20°06'15.0"E	49°09'33.7"N 20°15'07.9"E	49°07'15.3"N 20°09'46.0"E	49°07'49.3"N 20°11'49.1"E	49°08'02.7"N 20°11'30.1"E	49°08'07.6"N 20°12'24.8"E
Altitude [m]	1233	1062	1060	1015	1095	1022
Vegetation tier	Spruce	Spruce	Spruce	Spruce	Spruce	Spruce
Trophic series	AB	AB	AB	AB	AB	AB
Group of geobiocoens	Sorbi Piceeta	Sorbi Piceeta	Sorbi Piceeta	Sorbi Piceeta	Sorbi Piceeta	Sorbi Piceeta
Degree of damaging	Intact mature spruce forest	Fallen timber in situ	Timber extracted unburned	Timber extracted, burned	Timber extracted, burned	Timber extracted unburned

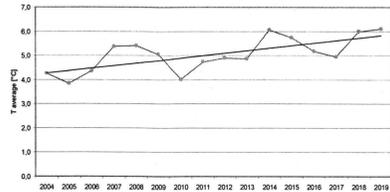


Fig. 1. Trend in average annual temperatures in Tatranská Lomnica in the period 2004-2019

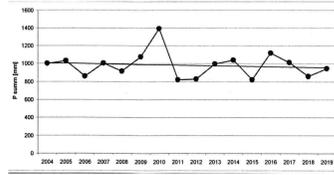


Fig. 2. Trend of annual sums of precipitations in mm in the period 2004-2019

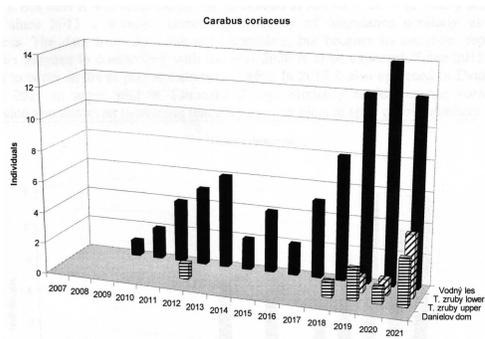


Fig. 3. Spreading of *Carabus coriaceus* in four study plots in High Tatra in 2007-2021

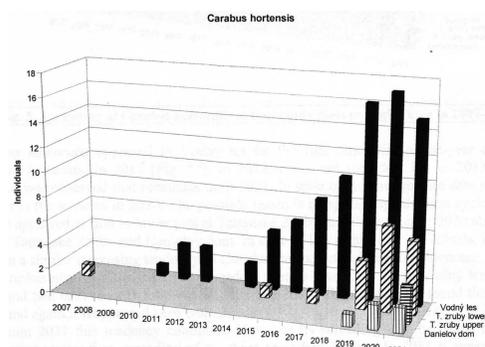


Fig. 4. Spreading of *Carabus hortensis* in four study plots in High Tatra in 2007-2021

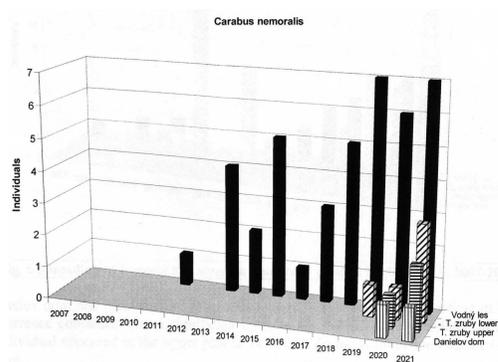


Fig. 5. Spreading of *Carabus nemoralis* in four study plots in High Tatra in 2007-2021

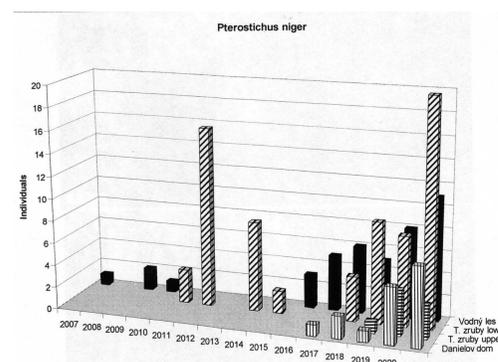


Fig. 6. Spreading of *Pterostichus niger* in four study plots in High Tatra in 2007-2021

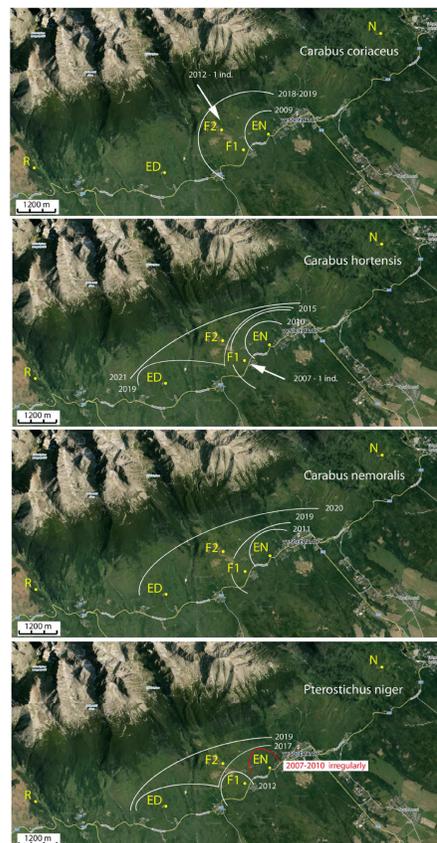


Fig. 7. Isolines of spreading of four Carabid species in the southern slopes of High Tatra in the period 2007-2021 (R-reference plot Vyšné Hágy, N-timber in situ in Jamy near Tatranská Lomnica, ED and EN plots with extracted timber at Danielov Dom and Vodný les, F1 and F2 – burned plots at Tatranské Zruby)

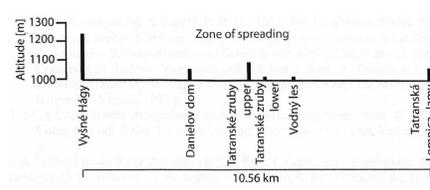


Fig. 8. Altitude and mutual distance of the plots studied in High Tatra

## INTRODUCTION

The succession of Carabid assemblages on the southern slopes of High Tatra damaged in November 2004 by an extensive windstorm represents a complex process managed by several dominant factors. In the growing season next to the windstorm three factors were dominant – destruction of the spruce stands as such, extracting of the fallen timber resulting in a strong disturbance of litter layer and the fire in a large part of the damaged area. It resulted in differentiation of the Carabid assemblages into three groups – the assemblages in the intact sites and in the sites where fallen timber remained in situ, in the sites with extracted timber affected additionally fire (Šustek & Vido 2013). In the next phases, composition of Carabid assemblages on burned sites converged to that in the unburned sites. In the next phase characterized by slow restoration of tree layer proportion of the open landscapes species in all sites with extracted timber decreased in favor of more tolerant forest Carabids. However, the most sensitive mountain forest species have not recolonized these sites and the original composition of the assemblages has not been restored after even 17 years (Šustek et al. 2017, unpublished). In addition, irrespectively of the momentary state of the Carabid assemblages, all of them were subjected to periodic fluctuation of number of species and individuals that were correlated, with certain delay, with fluctuation of humidity indicated by SPEI12 (Šustek & Vido 2013, Šustek et al. 2017).

However, simultaneously with these easily observable changes other two less evident tendencies. In general, it was moderately increasing quantitative representation of species having optimum of their vertical distribution in beech – beech fire vegetation tiers (Zlatník & Raušer 1966), hence by two tiers below the spruce vegetation tier, in which the damaged area is situated. Besides it, in the lowest of the studied sites, in Vodný les, on the western margin of Nový Smokovec, presence of *Carabus coriaceus*, having its optimum in warm lowland forests (oak and beech-oak vegetation tier) was recorded for the first time in 2008 (Šustek & Vido 2013). Since that time, there four other thermophile forest species appeared that are slowly spreading in the major part of the damaged area.

There arises question of correct interpretation of this phenomenon, whether it represents a consequence of the obvious warming of the climate or just an effect of fluctuations of expansiveness of

## CHARACTERISTIC OF THE SPECIES

The characteristics are compiled on the base of monographs by Burmeister (1939), Burakowski et al. (1973), Čurčić et al. (2007), Dahl (1928), Horion (1941), Lindroth (1949, 1985), Kryzhanovskij et al. (1995), Roubal (1930). *Carabus coriaceus* Linnaeus, 1758 distributed in whole Europe, except Iberian and British Islands, reaches to middle Sweden and Norway. It is a typical dominant constituent of the Carabid assemblages in the oak, oak-hornbeam and oak beech forests in the oak at the altitudes up to about 450 m. In higher altitudes its representation strongly declines and in the assemblages in beech-fire vegetation tier it occurs only individually as an accidental species or is absent. It shows a strong preference for the ecosystems on basic substrates (trophic series D), where it finds a rich food bases due to favorable conditions for mollusks. In such habitats it reaches enormous abundance. It also invades the floodplain forests with changed hydrological regime and absenting floods. In such forests, it often takes an autodominant position. In spite of the fact that in free landscape it is strictly bound to forests, it is able to penetrate, in autumn, into the residential parts of large cities with sparse tree vegetation. It is partly due to its autumnal reproducing cycle and culmination of seasonal dynamics in August and September, partly due to more favorable humidity in late summer and early autumn. It is unable to fly, but its large body size (length about 40 mm) favors it in "walking" in comparison with the congeners. *Carabus hortensis* Linnaeus, 1758 is distributed from France to the West Ural in the East, northerly reaches up to the Cancer tropic. It is a typical dominant constituent of Carabid assemblages in mesohydrophilous forests in the oak, oak-beech, beech oak and beech vegetation tier. As an abundant species it reaches up to the altitudes of about 500 m. In higher altitudes, its representation strongly declines and *Carabus hortensis* occurs there only individually as an accidental species or is absent. It has the autumnal reproduction cycle and its seasonal occurrence dynamics culminates in late summer and early autumn. It is expansive and able to increase its dominance on costs of other similarly sized species of the genus *Carabus*. It is unable to fly, but its spreading is easier in comparison with many Carabids by its good ability to pass the vertical obstacles. *Carabus nemoralis* O. F. Müller, 1764 was originally distributed almost in whole Europe, southerly reaching to northern Spain, Italy, Croatia and Serbia, easterly to the European part of Russia. Secondly it was introduced to eastern Canada. It is an obligatory dominant constituent of the spring and early summer aspect of the carabid assemblages in the mesohydrophilous oak, oak-hornbeam and oak beech forests in the oak at the altitudes up to about 400 m. In higher altitudes its representation strongly declines and in the communities in beech-fire vegetation tier occurs only individually as an accidental species or is absent. As the extreme altitude of its occurrence is mentioned 900 m (Roubal 1930). It is less anthropotolerant than *Carabus coriaceus*. Similarly as other Carabids it reaches increased abundances in the ecosystems on basic substrates. Unlike *Carabus coriaceus* it never inhabits the dried floodplain forests. It is unable to fly. In Central Europe does not colonize the large cities, but in eastern part of its distribution area it successfully survives in the large cities like Moscow or Jaroslavl (personal observation of the author). *Pterostichus niger* (Schaller, 1783) is an Euroasiatic species, but absent in northern Fennoscandia. It is primarily a hygrophilous and well flying species, relatively independent on shading by tree vegetation, but preferably occurring in floodplain forests and reed stands (Šustek 1994, 2010). It does not penetrate into mesohydrophilous forests or occurs there only occasionally as a migrant. The highest occurrence is mentioned at 1400 m a.s.l. (Roubal 1930), but it is an exceptional record. It is also known to be able rapidly escape or occupy floodplain habitats according to momentary humidity conditions (Šustek 1997) or to be attracted to fly into city centers by light (Šustek 1999). Due to it, it is able to occupy even small patches of shrubby vegetation in urban ecosystems (Šustek 2019).

## RESULTS

The occurrence of *Carabus coriaceus* in surrounding of the studied sites was observed for the first time in 2008, in late autumn in the interior of Nový Smokovec, in the immediate vicinity of the study plot Vodný les. Next year, 2008 it was also recorded in this plot for the first time (Fig. 3). Then, in 2012, it appeared also once in the upper plot at Tatranské Zruby. Its occurrence in Vodný les continuously increased until 2013. In the next three years its occurrence dropped and varied, but since 2017 it started to increase continuously. The catches from 2021 are still incomplete. In other sites in High Tatra situated at the altitude of about 1,000 – 1,060 m it appeared in a considerably lower number of individuals as late as in 2018. In spite of low abundance, it shows in these plots an increasing tendency in the last years. One individual of *Carabus hortensis* was recorded in the plot Tatranské Zruby already in 2007 (Fig. \*\*). But later it was recorded in one individual as late as in 2010 in Vodný les, where it shows since 2015 a strongly increasing tendency of abundance similarly as *Carabus coriaceus*. The data from 2021 are still incomplete, but because its autumnal reproduction cycle, an increase in comparison with the year 2020 is to be expected. Since 2015 it started (again) to occur in lower plot at Tatranské Zruby. In 2018 it also appeared in Danielov dom and in 2021 in upper plot at Tatranské Zruby. Similarly as in *Carabus coriaceus*, its abundance also shows an increasing tendency in other plots in spite of low numbers. *Carabus nemoralis* appeared in Vodný les for the first time with a one-year delay after *Carabus hortensis*, in 2011 (Fig. \*\*). In 2012 it was not recorded, but in 2013 a sudden increase was observed that continues until 2021. In spite of still incomplete date in 2021, its number is the same as in 2020. The possible reason is its spring reproduction cycle. On other plots it appeared at first in lower plot at Tatranské Zruby in 2019 and since 2020 also in upper plot at Tatranské Zruby and Danielov dom. In spite of low number of individuals, it shows an in them a similar increasing tendency as *Carabus coriaceus* and *Carabus hortensis*. In Danielov dom one individual of *Pterostichus niger* appeared for the first time in 2017 and its occurrence continues with a significant increase since 2020. One year later, in 2018, the first individual appeared in the upper plot at Tatranské Zruby. A moderate tendency is visible also here. The early occurrence of *Pterostichus niger* in Vodný les was in 2007 interpretable as an effect of the rudimentary ripicolous fauna along the narrow creek streaming through this plot. It could function as a migration corridor for this species. However, its later spreading out of the closest creek bank zone suggests that there are other causes. The irregular "outbreaks" of its occurrence as in Vodný les as in lower plot at Tatranské Zruby indicate that they result from short invasions of flying individuals, which were observed in several years after the windstorm in the open landscape species like *Pseudophonus rufipes*, *Poecilus cupreus* and *Poecilus versicolor*. These "outbreaks" are very similar to the sudden changes of abundance in wetland habitats which are the proper environment of *Pterostichus niger*. Similarly as the open landscape species, *Pterostichus niger* is able to fly (it was even found in stomach content of butts, Lauterer personal communication) on large distances (Šustek, 1999) and to occupy small patches of shrubby vegetation in city centers etc. Its abundant appearance in mesohydrophilous forest, which are normally not inhabited by *Pterostichus niger*, was in last years observed in Dubie hill near Krompachy Šustek et al. in press). Thus, it seems that such spreading or even invasions of *Pterostichus niger* represent a general tendency in the last years. However, all four species show a striking increase of numbers individuals in the last years. The spreading of the non-flying species is much slower than that of *Pterostichus niger*, is obviously influenced by the higher mobility of *Carabus coriaceus*, but represents an obvious trend. This trend in all four species strikingly coincides with the increased average *Pterostichus niger*, unlike the three precedent species was recorded in Vodný les still since 2007 and two next records followed in 2008 and 2009. Then it was not found there for four years and again it reappeared here with an increasing tendency in 2016. In spite of incomplete data from 2021 this tendency continues. However its spreading in other plots has a quite different character than spreading of the three precedent species. In 2011 it appeared in two individuals in the lower plot at Tatranské Zruby and in the next year already in 16 individuals, but in 2013 no individual was recorded. In 2014 and 2015 it reappeared, but in 2016 and 2017 disappeared again. A new and in this case continuous increase started in 2018.

annual temperatures in the studied period (Fig. 1). Probably the slightly decreasing trend in annual sums of precipitation has not any effect on the spreading conditions.

The spreading has been still observed only in the sites affected after the windstorm by extraction of timber or also by the fire. The course of spreading of these four species is illustrated in the Fig. 7 by annual isolines. The map shows that the starting point of the spreading of the three *Carabus* species was the plot Vodný les, while the spreading of *Pterostichus niger* started from two places, at the first, in 2007, also in Vodný les, later, in 2012, from the lower plot at Tatranské Zruby.

As to the altitude of individual plots, where the spreading was recorded, all they lay under the altitude of 1,100 m a.s.l. (Fig. 8). The air distance of two most remote plots does not exceed 2.5 km. This is a distance, which could be passed by the walking *Carabus* species within the duration of the investigation. The plot Jamy near Tatranská Lomnica lies in the same altitude, but from other plots at the same altitude is distant almost 5 km. In addition, it is isolated from the lower situated ecosystem by the terrain configuration.

## CONCLUSIONS

The spreading of four Carabid species in the southern slopes of High Tatra was observed since 2007. The centre of spreading was the surrounding of Nový Smokovec and the study plot Vodný les. In the three non flying species it is probably connected only with the increasing temperature in the studied period. In the well flying *Pterostichus niger* it represents a wide tendency to expansion observed also in other places. In general, the spreading is still limited on a relatively small area of about 2.5 km between Nový Smokovec and Danielov dom and the altitudes between 1000 and 1100 m. Obviously the spreading in the upper plot at Tatranské Zruby at the altitude of 1063 m is slower. In the higher situated reference plot at Vyšné Hágy and in the plot Jamy with timber in situ near Tatranská Lomnica this spreading has not still been observed. If this trend is permanent, it indicates the shift of vertical distribution of flora and fauna and potentially indicates danger of limiting area of the highly specialized and endemic cryophilous biota of the alpine vegetation tier. From this aspect it is to be seen negatively from the view of nature protection.