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Effects of Forestry Practices on Carabids (Coleoptera: Carabidae) – Implication for Nature Management

T. MAGURA[1, 2], V. KÖDÖBÖCZ[2] and ZS. BOKOR[3]

[1]Hortobágy National Park Directorate, H-4024 Debrecen, Sumen 2, Hungary
[2]Department of Zoology, University of Debrecen, H-4010 Debrecen, P.O. Box 3, Hungary
[3]Ecological Institute, University of Debrecen, H-4010 Debrecen, P.O. Box 71, Hungary

Effects of forestry management were studied in the Szatmár-Bereg Landscape Protection Area (NE-Hungary). Carabid assemblages of forest stands managed by different management techniques (stand put under acorn after clearing the herbaceous and shrub layer, the other prepared for seedlings by grubbing and deep loosening) have been compared with that of a non-managed control stand using pitfall traps. The number of carabid individuals and species has been found to be the highest in the non-managed stand, followed by that of the stand which was put under acorn after clearing the herbaceous and shrub layer. The fewest individuals and species were observed in the stand managed by grubbing and deep loosening. There was no significant difference between the species richness of the control stand and the stand managed by clearing the herbs and shrubs and put under acorn, while both values were found to be significantly higher than that of the stand managed by grubbing and loosening. The composition of the carabid assemblage of the non-managed stand and that of the stand cleared and put under acorn were similar to each other, while the carabid assemblage of the stand managed by grubbing and deep loosening was considerably different from the assemblages of the two above stands. The results suggest that the grubbing and deep loosening management practice completely changes the structure and composition of the carabid assemblage, thus it is not recommended to use in protected areas. Clearing the herbaceous and shrub layer followed by putting under acorn, does not substantially change the structure and composition of the carabid assemblage, so it can be used on protected areas for forestry management.

Keywords: Carabids, forestry practices.

Recently 18.2% of the land surface has been forested in Hungary. However, 75% of these forests is used primarily for economic purposes. In the 20th century the area of forest stands composed of native deciduous trees (e.g. oak, beech, hornbeam etc.) decreased remarkably due to the modern forestry practices, while the area of non-native plantations (conifer, poplar, robinia plantations) expanded exponentially (Mátyás, 1996). In the past 50 years the common forestry plan was that the felled native forest stand was reforested with non-native trees. However, planting of non-native species has drastic effects on the native assemblages through both the direct destruction of their habitats and the alteration of the abiotic and biotic environmental conditions. Therefore, nowadays there has been an increasing demand for the renewing of native forests instead of the establishment of non-native plantations. It is even more important on protected areas (Samways, 1994).

Ground-dwelling beetles are highly sensitive to the changes in the vegetation and the accompanying alteration both in the soil conditions and the microclimate, therefore in the present paper we have studied the reaction of carabid beetles (Coleoptera: Carabidae) to the different forestry practices. Several previous studies (Szyszko, 1986; Magura et al., 1997) revealed that non-native reforestation had significant impacts on carabids. Moreover, it has been reported that the clear cutting also damaged the native carabid assemblages (Mader, 1986; Šustek, 1984; Niemelä et al., 1993, 1994). The Hortobágy National Park Directorate launched a research program in the Szatmár-Bereg Landscape Protection Area in the 1990s to investigate the effects of the different forest management practices on the biota and to prepare an ecologically sound forestry practice.

In the present study we examined the impacts of different forestry practices on carabid beetles. Moreover, we studied whether there was a forest practice that did not substantially change the structure of the native carabid assemblages, therefore which can be used on protected areas for management.

Materials and Methods

Study area and sampling

The sampling area was located in the Szatmár-Bereg Landscape Protection Area, in NE-Hungary. In this area the oak-hornbeam forest *(Querco robori-Carpinetum)* is the most extensive forest type. On the research area forest stands managed by different management techniques were studied: (1) a control stand: a 40–50-year-old oak-hornbeam stand without forestry management, (2) a 40–50-year-old oak-hornbeam stand which was put under acorn after clearing the herbaceous and shrub layer in 1996 and (3) a 16-year-old oak-hornbeam which was clear-cut and prepared for seedlings by grubbing and deep loosening.

All of the studied forest stands were located in the Boc-kerek forest (its forest type was *Querco robori-Carpinetum;* its area was approx. 600 ha). Forest stands were at least 250 meter from the boundaries between the forest and the neighbouring open area (grassland and agricultural area), therefore the carabid assemblages of the forest stands can be considered independent from that of the adjacent open area (Digweed et al., 1995). Moreover, forest stands were at least 150 meter far from each other, thus their carabid assemblages can also be regarded as independent assemblages (Digweed et al., 1995).

Beetles were sampled using unbaited pitfall traps containing ethylene-glycol as a killing-preserving solution (Spence and Niemelä, 1994). In each habitat 12 pitfall traps were used during the sampling procedure. The traps (diameter 100 mm, volume 500 ml) were placed in a grid of 3 x 4 traps (2–3 m far from each other) in the interior of each forest stand. Samples were collected monthly from January to October in 1997. For the numerical analyses pooled samples were used since several authors (Baars, 1979; Loreau, 1992) showed that the total capture of a species over the whole sampling period gave an estimate of the ecological importance of each species in a habitat in case the sampling period was long enough to cover the most of the beetles' activity period.

Data analyses

Observed number of individuals, number of species and expected number of species (ES(m)-diversity) were compared among the studied habitats. ES(m)-diversity eliminates the effect of sample size on species number. ES(m)-diversity (sometimes mentioned as rarefaction) is a statistical method for estimating the number of species expected in a random subsample drawn from a larger sample (Hurlbert, 1971; Smith and Grassle, 1977; Tóthmérész 1995). Thus, ES(m)-diversity gives the number of species present when m individuals are drawn at random from the population:

$$ES(m) = \sum_{i=1}^{S} \{1 - (1 - p_i)^m\}$$

where p_i is the abundance of the i-th species of the assemblage and m is an integer, but real values make mathematical sense.

The resulting value can be interpreted as a "diversity index" because the method takes into account both the species richness and the relative abundance. ES(m)-diversity is an accepted and reliable statistical method studying carabid species richness (Niemelä et al., 1990, 1992b, 1993, 1994; Niemelä and Halme, 1992; Cárcamo et al., 1995). We estimated the number of species in a subsample of 380 individuals from each habitat using ES(m)-diversity. Statistical tests of the difference in the ES(m)-diversity of the compared stands were based on the normal approximations published by Tong (1983). The calculations were performed by the DivOrd package (Tóthmérész, 1993a).

Similarity of the carabid assemblages was calculated by the Bray–Curtis index of similarity, which is a generally used measure of compositional similarity (Ludwig and Reynolds, 1988; Niemelä et al., 1993). The similarity structure was displayed by cluster analysis using the Ward-Orlóci fusion method (Gauch, 1986). The NuCoSA package (Tóthmérész, 1993b) was used during the calculation.

Results

A total of 1697 individuals belonging to 23 species was collected in the pitfall traps *(Table 1).* Number of individuals and species have been found to be the highest in the non-managed stand, followed by that of the stand which was put under acorn after clearing the herbaceous and shrub layer. The fewest individuals and species were observed in the stand managed by grubbing and deep loosening *(Table 2).* There was no significant difference (t-test, df>120, $p>0.05$) between the ES(380)-diversity (expected number of species calculated for 380 individuals) of the control stand and the stand put under acorn after clearing the herbs and shrubs, while both values were found to be significantly higher (t-test, df>120, $p<0.05$) than that of the habitat managed by grubbing and deep loosening *(Fig. 1).* Composition of the carabid assemblage of the non-managed control stand and that of the stand cleared and put under acorn were similar to each other, while the carabid assemblage of the stand managed by grubbing and deep loosening was different from the assemblages of the two above stands *(Fig. 2).*

Table 1

Number of individuals of the carabid species caught in the studied forest stands

	Non-managed stand	Stand managed by clearing the herbs and shrubs	Stand managed by grubbing and deep loosening
Carabus cancellatus	515	356	233
Carabus convexus	11	23	7
Carabus granulatus	37	2	1
Carabus violaceus	33	3	2
Notiophilus palustris	2	2	0
Bembidion lampros	0	0	1
Harpalus rufipes	2	23	2
Acupalpus meridianus	0	0	1
Poecilus cupreus	3	6	3
Pterostichus anthracinus	25	4	0
Pterostichus macer	0	1	0
Pterostichus melanarius	1	0	26
Pterostichus niger	2	0	0
Pterostichus oblongopunctatus	85	28	2
Pterostichus ovoideus	4	6	2
Molops piceus	2	0	0
Abax carinatus	34	2	41
Abax parallelus	42	2	73
Agonum moestum	22	2	0
Agonum obscurum	1	0	0
Platynus krynickii	7	3	0
Chlaenius nitidulus	9	2	0
Brachinus crepitans	0	0	1

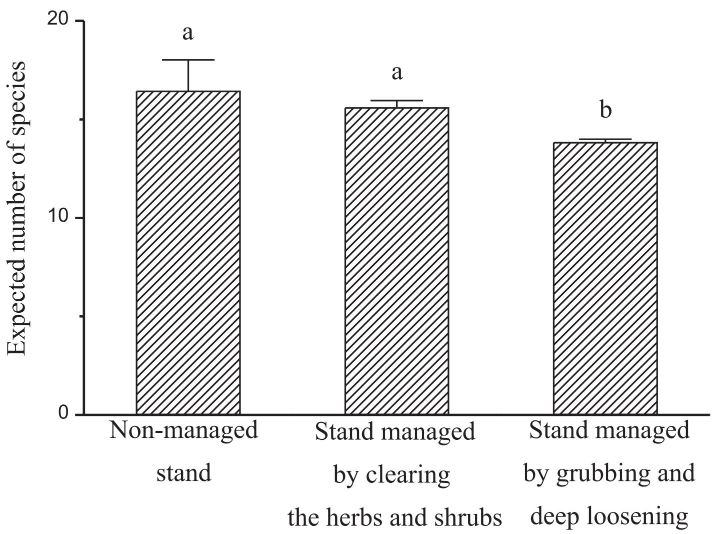

Fig. 1. Expected number of species calculated for 380 individuals (± S.D.) of the studied carabid assemblages. Different letters indicate a significant ($p<0.05$) difference by t-test

Table 2

Characteristics of the studied carabid assemblages

	Non-managed stand	Stand managed by clearing the herbs and shrubs	Stand managed by grubbing and deep loosening
Number of individuals	837	465	395
Number of observed species	19	16	14
ES(380)	16.4466	15.6057	13.8427

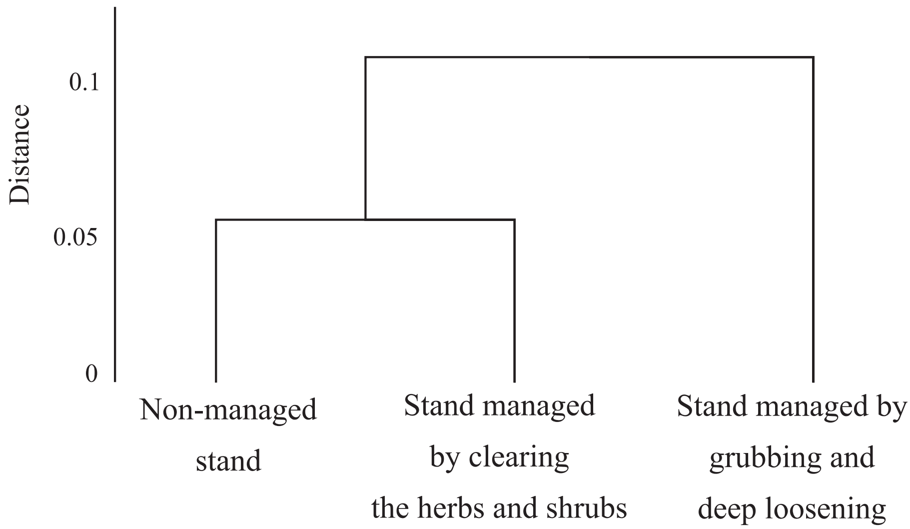

Fig. 2. Similarity of the studied carabid assemblages by cluster analysis. The Bray–Curtis index of similarity and the Ward–Orlóci fusion method was applied

Discussion

Effects of forestry practices on carabids

Our results proved that grubbing and deep loosening management practice completely changed the structure and composition of carabid assemblages. Our research also indicated that even many years (16 years) after the management there were significant differences in the species richness and the composition compared to the non-managed stand *(Figs 1* and *2)*. These changes can be explained with the fact that grubbing and deep loosening on the one hand promotes the extinction of carabid imagoes and larvae, on the other hand it homogenises the forests. Namely, during the grubbing and deep loosening practice the dead and decaying trees, the herbs, shrubs, and leaf litter are removed and structural heterogeneity of the soil (e.g. moisture, porosity etc.) is also disturbed. Previous studies demonstrated that the dead and decaying trees (Niemelä, 1997), the heterogeneity of the vegetation (Niemelä, 1990; Blake et al., 1996; Niemelä et al., 1996; Butterfield, 1997; Ings and Hartley, 1999), the deep leaf litter (Niemelä et al., 1992a, 1996; Eyre and Luff, 1994; Magura et al., 2000) and the structural heterogeneity of the soil (Luff et al., 1989, 1992; Rushton et al., 1991; Niemelä et al., 1992b; Baguette, 1993; Eyre and Luff, 1994; Šustek, 1994) were important factors determining structure and composition of carabid assemblages (Penev, 1996). The above-mentioned factors contribute to the development of microhabitats with suitable microclimate (air moisture, temperature, humidity) for carabids. Previous studies revealed that the greater heterogeneity of habitats (Niemelä et al., 1986, 1988, 1996; Báldi, 1990; Fuisz and Moskát, 1992; Blake et al., 1996; Magura and Tóthmérész, 1997, 1998; Magura et al., 1997) and the accompanying suitable microclimate (Niemelä et al., 1986, 1992b; Niemelä and Spence, 1994; Spence et al., 1996) increased the number of individuals and species richness of carabid assemblages. Moreover, the heterogeneity of habitats and the favourable microclimate may also increase the abundance and species richness of the decomposer and herbivore invertebrates that may serve as potential preys for carabids. The abundant preys may also influence the number of individuals, the species richness and composition of carabid assemblages (Niemelä et al., 1986, 1988, 1992a; Niemelä, 1990, 1993b; Halme and Niemelä, 1993; Lövei and Sunderland, 1996; Butterfield, 1997; Guillemain et al., 1997). Furthermore, the abundant and in time evenly distributed food resources may decrease the intraspecific (Loreau, 1990), interspecific competition among carabids (Lenski, 1982, 1984; Loreau, 1989) and the intraguild predation (Currie et al., 1996), which also play a crucial role in the organisation of carabid assemblages (Niemelä, 1993a).

Our results showed that management by clearing the herbaceous and shrub layer followed by putting under acorn also had effects on the carabid assemblages. The number of trapped individuals and species was fewer in this stand than in the non-managed stand *(Table 2).* Compared to the non-managed stand the number of individuals of *Carabus granulatus* Linnaeus, 1758, *Carabus violaceus* Linnaeus, 1758 and *Pterostichus oblongopunctatus* (Fabricius, 1787) decreased significantly in the stand managed by clearing the herbs and shrubs. Moreover, *Pterostichus niger* (Schaller, 1783) and *Molops piceus* (Panzer, 1793) were absent in the stand that was managed by clearing of the herbs and shrubs *(Table 1).* The expected number of species (ES(380)-diversity) has been also found to be fewer in the stand that was put under acorn after clearing the herbs and shrubs than in the non-managed stand, although the difference in the ES(380)-diversity was not significant *(Fig. 1).* These changes can be also explained with the above discussed direct (habitat heterogeneity, microclimate) and indirect (food resources, intra- and interspecific competition and intraguild predation) effects deriving from the clearing of the herbs and shrubs. However, the result of the cluster analysis proved that the composition of the carabid assemblages of the stand managed by clearing the herbs and shrubs did not change significantly and was similar to that of the non-managed control stand *(Fig. 2).* Several hygrophilous carabid species [*Notiophilus palustris* (Duftschmid, 1812), *Pterostichus anthracinus* (Illiger, 1798), *Agonum moestum* (Duftschmid, 1812), *Platynus krynickii* (Sperk, 1835) and *Chlaenius nitidulus* (Schrank, 1781)] were present only in the non-managed stand and in the stand managed by the clearing of herbs and shrubs which indicates a similar soil moisture condition. These species were absent in the stand managed by grubbing and deep loosening reflecting the changes in the soil conditions caused by the forestry practice.

Implication for nature management

The establishment of non-native plantations destroys the habitats of the native forest carabids, thus directly endangering their existence (Szyszko, 1986; Desender and Turin, 1989; Magura et al., 1997). Moreover, the expansion of plantations and the reduction of native forests have an indirect effect: the native forest assemblages are also damaged as a result of the fragmentation (Den Boer, 1990; Niemelä et al., 1993; Spence et al., 1996; Niemelä, 1997). Because of these facts the management and renewal of the forests which are composed of native deciduous trees came into limelight. In Hungary 90% of the forests were renewed by clear cutting (Mátyás, 1996). However, the clear cutting changed the native forest assemblages drastically (Mader, 1986; Šustek, 1984; Niemelä et al., 1994), therefore a demand arose for the elaboration of an ecologically sound forestry practice (Niemelä, 1997).

Our results showed that forestry practice by grubbing and deep loosening completely changed the structure and composition of carabid assemblages and these changes can be observed even many years after the management *(Figs. 1, 2, Table 2).* Therefore, this forestry practice is not recommended to be used for forest management. Management by putting under acorn after clearing the herbs and shrubs did not substantially change the structure and composition of the native carabid assemblages *(Figs. 1* and *2, Table 2),* so it can be used for forestry management. However, during the application of this forest management practice the felling of the aged trees is unadvisable before the closing of the canopy layer of the recovering seedlings. Selective logging is to be recommended to promote the growing and closing of the renewing seedlings. Because of the felling of the aged trees before the closing of the canopy layer of the recovering seedlings, the light regimes and the microclimatic conditions may change considerably due to the decreasing canopy closure. These changes endanger the survival of the native forest specialists and promote the colonization of the habitat generalists and carabids typical of open habitats (Niemelä, 1993b, 1997; Niemelä et al., 1988, 1993, 1994). In the present study it was also observable that even 16 years after the management habitat generalists and carabids characteristic of open habitats (e.g. *Bembidion lampros* (Herbst, 1784), *Acupalpus meridianus* (Linnaeus, 1767), *Pterostichus melanarius* (Illiger, 1798) and *Brachinus crepitans* (Linnaeus, 1758)) were present in the forest stand managed by grubbing and deep loosening *(Table 1).* These species could colonise in the forest stand when the seedlings were young and the canopy did not close. The selective logging is to be recommended to promote the growing and the closing of the canopy layer of the recovering seedlings, because it may better preserve the original forest conditions and may therefore have moderate effects on the original forest fauna and flora (Atlegrim et al., 1997).

Our results also suggest that the sensitivity of carabids to environmental variation and their rapid responses to habitat changes (Eyre and Rushton, 1989; Eyre et al., 1990; Desender et al., 1994; Blake et al., 1996) make them a suitable indicator group to predict and assess the effects of forest management practices. However, for the elaboration of an universally applicable ecologically sound forestry practice we must possess efficient knowledge of the assemblages of both the different trophic levels and the various geographic locations.

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