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Successional patterns of carabid fauna (Coleoptera: Carabidae) in planted and natural regenerated pine forests growing on old arable land

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Pine forests of different age growing on old arable land were studied over the period of two years (2004/2005) with the aim to compare planted stands and stands derived from natural regeneration. Each three stands of the two forest types were subjected to elaboration of the fauna of Carabidae using pitfall traps. In four of the stands three traps were installed and in two of the stands nine traps were installed. Therefore, in total 30 traps were used. The sampling time covered middle of May to middle of September. Data were analysed with respect to number of individuals, number of species, and Mean Individual Biomass (MIB) of Carabidae as indicator of the stage of succession. Principal Components Analysis (PCA) was carried out to display characteristic patterns in the dataset.

In 2004 1615 individuals from 49 species and in 2005 1333 individuals from 51 species were collected. Altogether, 2948 individuals from 60 species were sampled. The most dominant species in both years of study was *Pterostichus niger*. *Pterostichus oblongopunctatus*, *Poecilus versicolor*, and *Carabus hortensis* showed high numbers of individuals in both years, too. In general, the study areas show variability with respect to numbers of species, individuals and MIB values between the respective sampling sites. The natural regenerated forests exhibit a significant decrease in numbers of species and a significant increase of MIB values with increasing age of the stand. The PCA done with the dataset shows a separation of the sampling sites with respect to stage of succession as main factor. However, there is also a separation of the natural stands from the planted forests.

The results provide with some insight into the succession of planted pine forests and natural regenerated pine forests on old arable land. The results of the study indicate that the origin of the stand (i.e. plantation or natural regeneration) indeed seems to be an important aspect concerning the formation of carabid coenoses during the process of succession. Particularly in the beginning, succession runs faster on the planted pine forests. The Carabid coenoses seem to be similar at early stages but differentiate in the run of the succession. However, besides the origin of the stands other factors, as soil factors, should be considered concerning the formation of carabid coenoses, too.

Key words: Carabidae, pine forest, plantation, natural regeneration, succession

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INTRODUCTION

In Poland, pine forest (together with larch) constitutes about 68 % of the total of forests (Fronczak 2003). Since pine forests are of special importance with respect to forestry, knowledge about this forest type is explicitly needed. Particularly the process of succession may be regarded as an important factor. Succession in pine forests has to be taken into account with respect to economical aspects as well as aspects of biological diversity (Szyszko & Schwerk 2006).

However, many aspects of the succession of pine forests are still unknown. With respect to the process of succession, conditions during early stages are often of importance for the future development of the area (e.g. Tilman 1987, Jochimsen 2001). A pine forest succession may start after creation of a young plantation or the forest may originate from natural regeneration. Taking into account the statement made above the successional processes might be different between these two types of pine forests. Besides, a special importance might be attributed to the soil parameters. Soils used for agriculture in history may be transformed to a more or less high degree by human impact, e.g. with respect to soil mechanical aspects or nutrient contents. Therefore, they often constitute special tasks, e.g. with respect to re-establish forest systems.

Among the epigeic animals carabid beetles are known to react sensitive on changes in environmental conditions (Rainio & Niemelä 2003). These reactions include changes in species and abundances, for example after clear cutting of forests (e.g. Szyszko 1990, Halme & Niemelä 1993), as well as changes in activity patterns (e.g. Skłodoswki 1994, Szyszko et al. 2004). Therefore, they are useful as indicators of successional processes in forest habitats. In particular, the Mean Individuals Biomass of Carabidae (MIB) has been described as a good indicator for the stage of succession of a habitat (Szyszko et al. 2000). The more advanced the stage of succession of a habitat the higher the MIB value of the carabid fauna. Furthermore, data collected on representative study areas may be subjected to multivariate statistical analysis. Multivariate statistical methods are powerful tools, because they provide a means to structure the data by separating systematic variation from noise (Gauch 1982) and may provide insights into the impact of natural and human-induced environmental disturbances on biological assemblages (ter Braak & Šmilauer 2002).

The study aims to answer the questions (1) whether characteristic patterns in numbers of species and individuals and MIB values on the planted forests and the natural regenerated forests exist and (2) whether differences in the successional process between the two forest types may be derived from MIB values and multivariate statistical analysis.

MATERIAL AND METHODS

Study areas

Six forest stands were chosen for analysis. Three of these stands constitute planted pine forests of different age, whereas the remaining forests originate from natural regeneration. All stands are growing on old arable land.

Planted forests

Study area 26: A pine/birch plantation, 2 years old in 2004. Three pitfall traps with a distance of 5 m from each other were installed.

Study area 14: A planted pine forest on fallow land, 7 years old in 2004. Three pitfall traps with a distance of about 50 m from each other were installed at this area.

Study area 16: A planted pine forest, 26 years old in 2004. Three pitfall traps with a distance of about 400 m from each other were installed at this area.

Natural regenerated forests

Study area 35: Natural regeneration of pine, estimated age of 5 years in 2004. On this area three study sites (35/1, 35/2, 35/3) were chosen. On each of these study site three pitfall traps, 5 m apart from each other, were installed.

Study area 94: Natural regeneration of pine, estimated age of 5 years in 2004. Three pitfall traps with a distance of 5 m from each other were installed.

Study area 36: Natural regeneration of pine, estimated age of 24 years in 2004. On this area three study sites (36/1, 36/2, 36/3) were chosen. On each of these study site three pitfall traps, 5 m apart from each other, were installed.

More detailed information about the planted forests (study areas 14, 16, 26) is provided by Rylke & Szyszko (2002).

Sampling of data

Collecting of beetles was carried out using pitfall traps following Barber (1931) with modifications (Szyszko 1985). Jar glasses were sunk in the ground and a funnel with an upper diameter of about 10 cm and a lower diameter of about 1.6 cm was placed above them flush with the soil surface. A roof was installed a few centimetres above the funnel. Ethylene glycol was used as trapping fluid.

The sampling time covered middle of May to middle of September.

Determination and nomenclature of the collected individuals was done according to Freude et al. (2004).

Statistical analysis

Mean individual biomass (MIB) of Carabidae was calculated to assess the successional stage of the study sites. MIB is calculated by dividing the biomass of all sampled carabids by the number of specimens caught. Biomass values were obtained using the formula of Szyszko (1983) that describes the relationship between the body length of a single carabid individual (x) and its biomass (y):

$$\ln y = -8.92804283 + 2.5554921 \times \ln x$$

For both types of forests the numbers of species, numbers of individuals and MIB values were tested on correlations with the age of the stands in the years of study using the Spearman rank correlation coefficient (Sachs 1984).

The CANOCO for Windows software package, version 4.5 (ter Braak 1987, ter Braak & Šmilauer 2002) was used to perform gradient analysis.

The dominance values of the carabid species on the sampling sites were used. Detrended Correspondence Analysis (DCA) was carried out in advance to select the appropriate response model. Detrending was done by segments and data were not transformed. Based on the gradient length of first DCA-axis (2.556) Principal Component Analysis (PCA) was chosen (ter Braak & Prentice 1988, ter Braak & Šmilauer 2002).

Principal Component Analysis (PCA) was performed using scaling on inter-species correlations. Species scores were divided by standard deviation. No transformation was done. Only centering by species was done. Species fit range was set from 38 to 100 to display only the ten species with the best fit.

RESULTS

In 2004 1615 individuals from 49 species and in 2005 1333 individuals from 51 species were collected. Altogether, 2948 individuals from 60 species were sampled. The dominant species in 2004 were *Pterostichus niger* (389 individuals), *Poecilus versicolor* (170 individuals), *Pterostichus oblongopunctatus* (159 individuals), and *Carabus hortensis* (126 individuals). In 2005 the same species dominated, but in a different order: *Pterostichus niger* (350), *Carabus hortensis* (217 individuals), *Pterostichus oblongopunctatus* (122 individuals), and *Poecilus versicolor* (89 individuals). Data on numbers of species, numbers of individuals, and MIB values for the sampling sites in the years of study are shown in Table 1.

The species numbers range from 16 to 23 species in the planted forests and from eleven to 23 species in the natural regenerated forests. In the planted forests very high numbers of species were obtained in study area 14 (seven years old in 2004). In the natural regenerated forests the species numbers are highest at the study sites 35/1, 35/2, 35/3 and study area 94, all of them five years old in 2004. There is a highly significant negative correlation of species numbers with age of the stand ($r_s = -0.785$, $p < 0.001$).

The numbers of individuals range from 84 to 301 individuals in the planted forests and from 62 to 211 in natural regenerated forests. Even if not statistically significant, a clear trend towards higher numbers with increasing age can be observed at the planted forests, with the lowest numbers on the youngest study area 26 (2 years old in 2004). In the natural regenerated forests no trend can be observed.

The MIB values range from 72.0 mg to 299.8 mg in the planted forests and from 55.1 to 260.0 in the natural regenerated forests. Both the planted forests as well as the natural regenerated forests show the lowest MIB values at the very young study areas (study areas 26, 35, and 94; two and five years old in 2004 respectively). Concerning the planted forests the highest MIB values were obtained on study area 14 (seven years old in 2004). In the natural regenerated forests MIB val-

Table 1: Data on numbers of species, numbers of individuals, and MIB values for the study areas/sites in 2004 and 2005.

Study area/site	Species		Individuals		MIB (mg)	
	2004	2005	2004	2005	2004	2005
26	19	16	84	91	72.0	140.3
14	22	23	185	263	291.4	299.8
16	18	18	232	202	152.7	291.2
35/1	23	15	106	62	101.3	144.5
35/2	16	16	134	162	129.1	86.1
35/3	20	18	211	134	98.3	55.1
94	18	19	185	102	106.0	79.9
36/1	12	11	185	168	222.0	260.0
36/2	14	11	156	65	139.9	202.1
36/3	15	16	137	84	193.5	133.5

ues are significantly correlated with age of the stands ($r_s = 0.651$, $p < 0.05$), with high MIB values observed on study area 36 (24 years old in 2004). Despite the variation in the data, the study areas may be arranged with respect to increasing MIB in the following order by calculating median values: 94 (median value 93.0 mg), 35 (median value 99.8 mg), 26 (median value 106.2 mg), 36 (median value 197.8 mg), 16 (median value 222.0 mg), 14 (median value 295.6 mg).

The first axis of the PCA explains 44.0 % of the variance of species data, whereas the second axis explains 16.5 %. The study areas are separated along the first axis with the youngest study areas (26, 35, 94) located on the right side. Of these study area 26 is located closest to the center of the diagram. The remaining study areas (14, 16 36) are located at the left side of the diagram with study area 14 closest to the centre. With respect to the stands located on the left side the planted forests are clearly separated from the natural regenerated forests along the second axis. Among the species with the best fit *Carabus cancellatus, Harpalus rubripes, Poecilus lepidus*, and *Poecilus versicolor* are located close

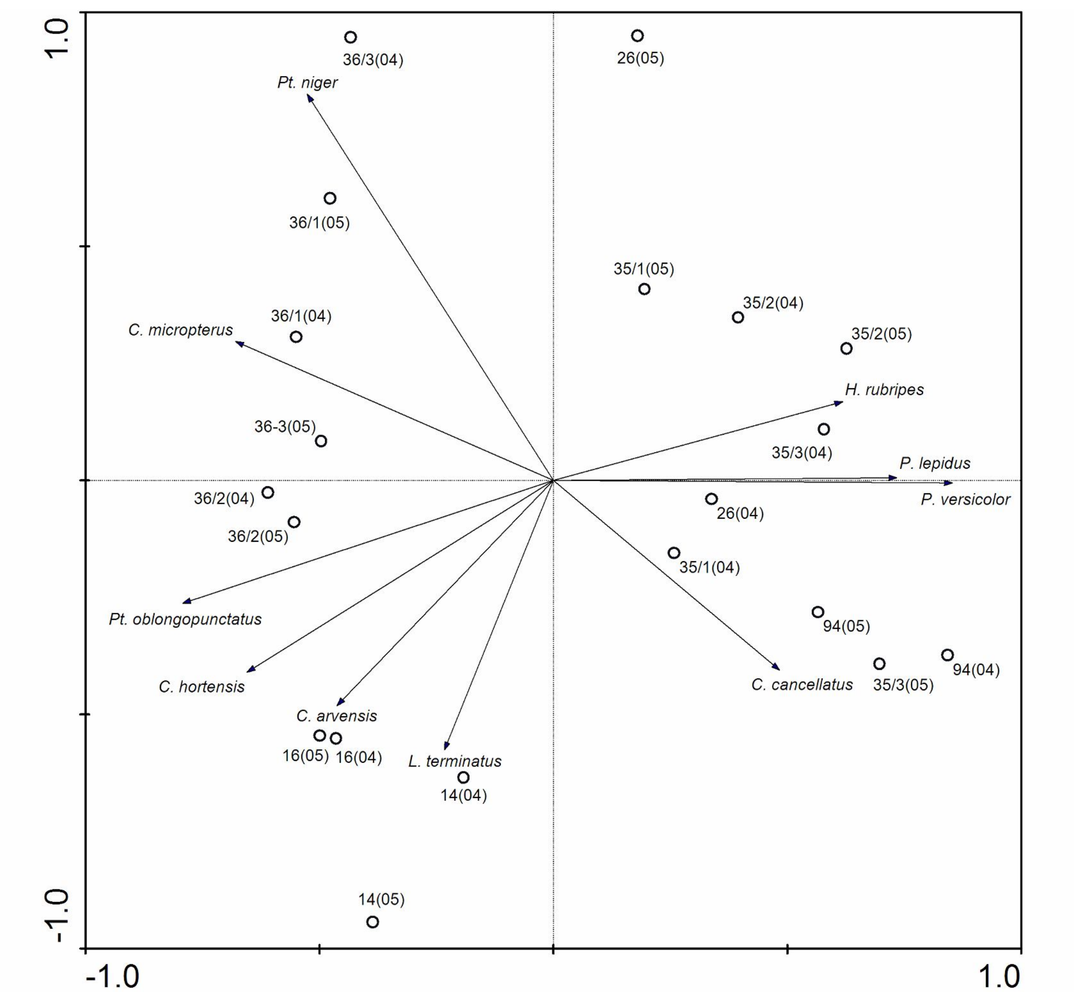

Fig. 1: Principal components analysis (PCA) carried out with the dataset. Years of study are given in brackets behind the study areas/sites.

to the young sites, whereas *Calathus micropterus*, *Carabus arvensis*, *Carabus hortensis*, *Perostichus niger,* and *Pterostichus oblongopunctatus*, are located towards the old sites. *Leistus terminatus* points into the direction of study area 14. As indicated by the length of arrows, *Poecilus versicolor*, *Pterostichus niger* and *Pterostichus oblongopunctatus* are most important indicating site differences, with *Poecilus versicolor* related to young stands, *Pterostichus niger* related to old stands originated from natural regeneration and *Pterostichus oblongopunctatus* more related to old planted forests.

DISCUSSION

Szyszko (1990) demonstrated a decrease of species numbers in pine forests with increasing stage of succession. In the present study, a significant decrease could be recognized only on the natural regenerated pine forests. Analysing the carabid fauna of different-aged clear cut originated spruce stands in Finland Koivula & Niemelä (2002) detected the highest species diversity in five and ten years old stands. This result well agrees with the data of our study. It is must be mentioned here that not only numbers of species but also the species composition changes (e.g. Szyszko 1990, Rainio & Niemelä 2003).

Particularly the fluctuations in numbers of individuals are difficult to relate to processes of succession, because in habitats not being subject to a succession strong fluctuations in numbers of individuals of single species as well as total numbers of individuals exist, too (e.g. Schwerk et al. 2006). It is difficult to separate these fluctuations from changes in numbers of individuals due to succession. Moreover, the degree of fluctuation in abundance of single species depends on its specific relationship to the stage of succession (Szyszko 1990, Szyszko & Schwerk 2005).

According to expectations the youngest study areas (study areas 26, 35, 94) show the lowest MIB values. However, with respect to median value of MIB study area 26 (two years old in 2004) already exceeds study areas 35 and 94 (about five years old in 2004). Exceptionally high MIB values were obtained on study area 14 (seven years old in 2004), being the reason for the failure to detect a statistical increase of the MIB values with time on the planted pine forests. The results clearly indicate a faster process of succession on the young planted forests compared to natural regenerated ones.

The location of the study areas along the first ordination axis may be well explained by stage of succession. This interpretation fits to the results obtained by the MIB values. Accordingly study area 26 and particularly study area 14 are located towards the old study areas. Species placed in the diagram close to the young study areas may be characterized as typical for early stages of succession (e.g. *Poecilus lepidus*, *Poecilus versicolor*), whereas the species close to the old study areas are typical forest species (*Pterostichus niger*, *Pterostichus oblongopunctatus*). The carabid coenoses seem to be similar at early stages but differentiate in the run of the succession, a process, which is also known from post-industrial areas (Schwerk & Szyszko 2006).

The results of the study indicate that the origin of the stand (i.e. plantation or natural regeneration) indeed seems to be an important aspect concerning the formation of carabid coenoses during the process of succession. Particularly in the beginning, succession runs faster on the planted pine forests. However, differences in soil factors should be considered, too. With respect to *Carabus hortensis* Schwerk & Szyszko (2005) detected an influence of the sand fraction as well as the carbon content in the soil. Studying non-native spruce reforestations Magura et al. (2002) showed the importance of several soil characteristics (pH value, compactness, $CaCO_3$ content) for the abundance of carabid species. Besides, attention should be paid to aspects of historical land use. It might be an interesting task to compare the studied stands with those growing on soil, which has not been used for agriculture in history.

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