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Studies on carabid assemblages and life-history characteristics of two *Carabus* (Coleoptera, Carabidae) species

THESIS OF PHD DISSERTATION

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1. INTRODUCTION

One of the cornerstones of conservation planning is the identification of priority areas for biodiversity conservation (Margules & Pressey 2000). Many studies have focused on various species indicator groups in identifying area networks for the conservation of biodiversity. Besides, some studies have successfully tested the usage of species attributes of different indicator groups (Cleary et al. 2009). Ground beetles are among these good ecological indicators, because their taxonomy and ecology are well documented (Lövei & Sunderland 1996) and many studies proved their sensitiveness to habitat alterations/disturbance. They are appropriate organisms for ecological quality assessments (Luff 1996). Ground beetles show clear associations with environmental parameters such as soil type and vegetation cover; thus they are good indicators of environmental change (e.g., Thiele 1977). The abundance, species richness and attractive coloration of many species have made carabids popular objects of studies for entomologists (Lövei & Sunderland 1996). Furthermore, carabids are relatively long-lived animals allowing sampling to be carried out by easy-to-use pitfall traps (Lindroth 1974). All of these issues make carabids suitable organisms for assessing microhabitat selection or seasonality on small spatio-temporal scales. The seasonality could provide a snapshot about the viability of the population; some quantitative description methods are now available (Fazekas et al. 1992; Bérces & Elek 2013). Moreover environmental change-related concerns make it relevant to have a more precise understanding of the spatial and temporal variation in the seasonal dynamics of ground beetles. Most of the recent papers concentrate on processes at community level using mechanistic modelling of habitat alterations (Niemelä 2001; Niemelä et al. 2007), and only few papers are concerned with the life-history traits and reproduction of carabids (Barbaro & van Halden 2009). However, sometimes the classical elements of species attributes such as life-history characteristics provide clues for conservation of biodiversity. Given that several species are protected, such information would be useful to harmonise conservation efforts during habitat management operations, like the use of chemicals in agricultural lands, forest management, etc., to minimise risk to non-target ground beetles. Throughout their worldwide distribution and abundance they also prove a reliable snapshot about the conservation status of the studied habitat types.

2. MAIN OBJECTIVES

This thesis is divided into the two following sections.

2.1. Section I. - Spatio-temporal fluctuations of carabid assemblages in forested habitats

Based on long term investigations within the framework of the Man and the Biosphere Programme (MAB) the first section of this thesis contains relevant information on habitat fragmentation and forest management throughout the fluctuations of carabid assemblages. One of the purposes of this study was to describe and assess the possible role of small-scale spatial heterogeneity occurring in forest ecosystems on the composition of ground beetle assemblages in the Pilis Biosphere Reserve (PBR), in Hungary, in the course of a long-term investigation, covering the period of twenty years (1986-2006). Long-term studies describing year-to-year variability in the catch of carabid species are rare, and some of the longer studies do not show the number of individuals caught per year and location separately (Günther & Assmann 2004). In the present long-term investigation, we also examined the temporal variation of the abundance and species richness of carabid assemblages inhabiting this MAB reference site, recovering from a forest-management period. The main aim of our research was to study the distribution of carabid assemblages between two small forest fragments (circa 0.5 ha) and the adjacent transition zone within these in the Simon Valley of Pilis Mountains, Northern Hungary. We tried to provide appropriate answers for the following questions:

1. Are carabids able to reflect changes in traits of habitat at small spatial scale (within 100 meter) among habitats?
2. Is there any difference between the studied habitat types (beech, oak and transition zone) based on the abundance and species richness of ground beetles?
3. How do the composition and abundance of the carabid assemblages change in time in the studied habitat?

2.2. Section II. -Life-history characteristics of two *Carabus* species

The population biology and the seasonality have been found as important components of ecological assessments for insect communities. Therefore, the second part of this thesis includes information on the life-history characteristics of two *Carabus* species containing data

on their seasonal activities, age composition and reproductive characteristics and also reviews current knowledge of life-history characteristics of ground beetles and the effects of habitat fragmentation on carabids. The aim of this study was to examine the usefulness of two different age-estimating methods (based on the mandible wear and the development stages of the ovaries), and to investigate the habitat preference and the components of the reproductive strategies of two *Carabus* species. Our objective was to describe the patterns of seasonal activity, age structure, and reproductive characteristics, such as different ovarian stages, number of ripe eggs of a *Carabus scheidleri* population living in an abandoned agricultural field in Hungary. We also intended to present the classification of this species into one of the breeding categories already discussed in the literature. The second study species was *Carabus ullrichi* captured in woodland habitats in Hungary, already mentioned above (Pilis Biosphere Reserve). Besides the examination of seasonality, age-composition and reproductive characteristics of this large carabid species, we also assessed its habitat selection considering the effects of environment conditions that might influence the distribution of *C. ullrichi*. We examined whether there were any differences in the abundance and seasonal activity patterns among three different habitat types (beech, oak and transition zone).

In summary, our main questions were the followings:

1. How does the seasonal activity pattern of the two *Carabus* species' populations change during and between years?
2. How does the age-structure of the two *Carabus* species' populations change during and between years?
3. What are the differences between the reproductive characteristics and the life-cycles of the two *Carabus* species?
4. In which cases can the two different age-estimating methods be applied together or independently?

3. MATERIALS AND METHODS

3.1. Section I. - Spatio-temporal fluctuations of carabid assemblages in forested habitats

The study area was located in the PBR. Prior to 1982 forest management practices were regulary applied, such as thinning (F. Kádár *pers. comm.*). These forest ecosystems have been

unmanaged since 1982, which means that no regular forestry service has been used in these habitats. The forest stands were similar in their size, circa 0.5 ha of each was used for sampling. Three forested habitats were sampled during the study: a) beech forest, b) oak forest and c) transition zone intersecting the beech forest from the adjacent oak forest. Carabids were collected by pitfall traps which were emptied weekly from the end of April to the beginning of September always in two consecutive years, in 1985-1986, in 1993-1994 and in 2005-2006, covering a twenty-year period. Five pitfall traps were installed in each habitat. For comparison of the average activity density and the mean number of species per traps between the different habitat types Kruskal-Wallis tests were used. Species diversities of the pooled samples of each habitat type were compared by the Rényi one-parametric diversity index family. In order to evaluate the differences in the species composition between the years, we applied Mantel test. The characteristic species of the habitats were explored by the IndVal (Indicator Value) procedure. Finally, for numerical analyses, beetles were classified according to their body size and habitat preference.

3.2. Section II. - Life-history characteristics of two *Carabus* species

Two carabid species (*Carabus scheidleri* and *Carabus ullrichi*) with sound differences in reproductive characteristics observed in the fields were studied, in order to determine whether the ageing based on mandible wear only gave a reliable estimate of the age of the beetles. *C. scheidleri* was studied in an abandoned, uncultivated field at Nagykovácsi (Julianna-major). Ten pitfall traps were installed in two rows. Samples were collected weekly between mid-May and the end of August in 2000 and 2001, and from the end of April until mid-September in 2002. Collections were sieved and transferred to 4% formaldehyde in the field, sorted under microscope in the laboratory and stored in the same fluid for dissection. In case of *C. ullrichi* the examinations were carried out in the same area (PBR) as already described in the first section of this thesis. Beetles were collected in 2005 and in 2006 from the end of April until the end of September. To explain the possible effects of environmental differences among the three studied habitats at PBR, we measured the most relevant environmental variables, which could have an influence on the distribution of the carabids (Butterfield et al. 1995): relative humidity, light intensity, ground and air temperature. Beetles from each sample were sexed, aged and dissected. Ageing was firstly based on the extent of bristle and on mandible wear, elytral hardness and coloration (Wallin 1989). Three groups were classified: young, old and middle-aged beetles. Females were dissected in order to determine the developmental stage of their ovaries and the number of eggs found in their ovaries following the method of van Dijk

(1972, 1979), Wallin (1989) and Diefenbach et al. (1991). Three categories were distinguished: immature, gravid and spent females. To test for differences based on the total number of individuals, the total number of females and males per trap between the years, and also to test for differences between the mean abundances of females and males per trap according to their age and ovarium categories repeated measures ANOVAs was used. Significant difference among the sampling periods was revealed by Fisher's *post hoc* LSD test.

4. RESULTS

4.1. Section I. - Spatio-temporal fluctuations of carabid assemblages in forested habitats

1. Our results suggest that the ground beetle assemblages may reflect the small scale spatial heterogeneity among the different habitat types through the specific responses of the species, but most of the species use these habitats regardless the spatial variations.
2. Most of the species were characteristic of all habitat types; only few species was specific to any one habitat.
3. The overall abundance and species richness were highest in the transition zone. This zone was occupied by species characteristic of both adjacent habitats, thus, it explained the high species richness of that site. The ground beetles probably used these habitats during dispersal, between the hibernating and reproducing sites. Small-scale movements of carabids between the habitats might affect ground beetle assemblages in the adjacent habitat patches.
4. Our study proved that there was a remarkable change in the species composition and activity density of ground beetles in this investigated area from 1985 until 2006. The thinning as a forest management which was implemented before our study, was likely to highly influence the composition of the carabid assemblages inhabiting the area. The diversity increased during the twenty years in each habitat. After ten years we found significant differences neither in the abundance, nor in the species composition in the carabid assemblages. However, twenty years after the forest management (in 2005 and 2006), we found significant increases in the number of the majority of the

large forest carabids, which might be the indicator of the increasing naturalness of these habitats. All these indicate the remarkable resilience of the carabid populations.

5. Our results emphasize that carabids are also appropriate organisms for ecological studies on macroscale and landscape level as well. We also propose that the long-term monitoring (even) of only one assemblage is an efficient tool to improve our knowledge on insect population dynamics.

4.2. Section II. - Life-history characteristics of two *Carabus* species

1. We summarize that *C. scheidleri* has two activity peaks in one season, develops during one year, overwinters both as larva and as adult, adult females live more than one year, they reproduce more than once, and the different generations overlap during one season, assuring the persistence of the population. Old beetles participate also in the reproduction.
2. Based on our results, we suggest that *C. scheidleri* has evolved to persist in unstable environments and it is well adapted to the human disturbances.
3. *C. ullrichi* is a typical spring breeder species with summer larvae. This species has two activity peaks in one season, and one reproductive period in the season exclusively. This species has summer larvae and hibernates as adults.
4. However *C. ullrichi* preferring the stable, deciduous forests where no such high habitat alterations occur, ensures the population's survival with the already mentioned spring breeder strategy.
5. Based on our experiences the determination of the mandible wear for age-estimation is an objective estimation, which is sex- and size-independent. In the case of *C. scheidleri*, we could estimate the age of the adults and also the type of overwintering, which were supported by the results of the dissection. Accordingly, age estimation based on mandible wear is a good age estimator when different generations of the species do not overlap, like in case of *C. ullrichi*. When generations overlap, the two age-estimations - the one based on mandible wear and the other on the developmental stage of the ovaries - together give good results.

5. CONCLUSION

In many European countries the habitat fragmentation has become relevant problem in the last twenty years. Changes in land use are considered to be the most important driver of global biodiversity loss (Sala et al. 2000; Buckley & Roughgarden 2004) and are also considered to be the most important threats for European forests. The forest practices had considerable effects on the ratio of the natural and semi-natural forests. Therefore, the monitoring and comparing of this kind of habitats is unavoidable and a very important skill (Eyre et al. 1996; Magura et al. 2000). The examinations of the ground-dwelling arthropod assemblages in the natural and semi-natural habitats are also essential, because these habitats have an important role in the recolonization of the regenerating habitats. The focus of most of studies is at supra-individual level with their inevitable time constraints: effects on populations and assemblages need one or more generations to unfold. Organisms may also react to conditions in their habitats at lower organisational levels. Using life-history traits for ecological assessments might be beneficial due to the fact that these reflect better to the local environmental parameters than species richness and abundance. These adaptations can be morphological or behavioural which makes these traits more suitable to track any changes in their environment (Nylin & Gotthard 1998). Therefore knowledge on life histories of the study organisms in ecology is essential. While most of the recent papers concentrate on processes at community level, only few papers are concerned with the life-history traits and reproduction of carabids. Thus, we have tried to study the ground beetles at individual and also at supra-individual level. At individual/population level, our results are consistent with the suggestion that physiological state indicators could be a powerful early warning method of population decline during habitat change (Janin et al. 2011). Further, the complex interaction between tolerance limits, feeding conditions and stress levels during advancing habitat alteration underline the importance of using multiple criteria for assessing the impact of habitat fragmentation on biodiversity. Our results emphasize that carabids are also appropriate organisms for ecological studies on macroscale and landscape level as well. Based on the above mentioned facts we suggest careful consideration of the forest management practices in order to avoid further losses. We also propose that the long-term monitoring of assemblages is an efficient tool to improve our knowledge on insect population dynamics. These efforts correspond to the national conservation responsibilities, and Hungary is in the upper responsibility class due to the high ratio of unique habitat types and endemic species, especially of invertebrates (Schmeller et al. 2008). Moreover, our results prove Schmeller et al.'s (2008) initiative, that

the identification and monitoring of biodiversity should require prioritization of conservation actions, such as (long-term) monitoring.

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