SZENT ISTVÁN UNIVERSITY

Environmental Doctoral School

THE ROLE OF BIRDS IN THE NATURAL CONTROL OF CATERPILLAR PESTS IN TEMPERATE OAK FORESTS

THESIS OF PH.D. DISSERTATION

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1. BACKGROUND AND OBJECTIVES

Based on the Global Forest Resources Assessment published in 2010, the total annual area of abiotic and biotic forest damages is about 35 million ha. Moreover, the long-term data on forest damages indicates a clear increasing trend in relation to the extent of the damaged area as well as to the severity of damages. This increasing trend is particularly clear in the case of insect damages. Insects are responsible for half of the total biotic damages, thus they are in key importance especially in the perspective of forest protection. The highest proportion of insect damages is caused by leaf consuming insects, especially by caterpillars. Their leaf consumption may decrease the growth of trees, negatively influencing their health condition, fecundity and inhibiting regeneration. The economic value of the wood losses in consequence of the decreased growth increases exponentially with the extent of defoliation and may reach the 310 $/ha/year. On top of these losses, the regular insect outbreak may trigger decline chains, resulting in mass tree mortality. Predicting climate change scenarios foresee more frequent and severe insect outbreaks. A possible and sustainable way to prevent these large-scale damages is the facilitation of the self-protection ability of forests against insect damages. One of the most important components of the “immune system” of forest ecosystems is the natural enemies, the predator and parasitism organisms.

The main predators of caterpillars in forests are passerine birds. Through their caterpillar consumption, they may decrease the size of caterpillar population and thereby positively influence the health condition of trees and may contribute to the mitigation of economic losses. Thus, the natural pest control provided by birds is one of those ecosystem services, which has a clear economic value beyond their importance of maintaining the health of ecosystems. The role of birds in forest protection can be illustrated by the study

of Gyurkó. According to this, a Great tit pair prey approximately 15–20 thousands caterpillar to rear their nestlings. This amount of caterpillars may cause moderate or severe defoliation in the territory of tits. Moreover, the most frequent prey of insectivorous birds is the geometrid and noctuid species, which often cause severe defoliation. Thus, the presence and activity of insectivorous birds is in key importance to maintain the health of forest ecosystems. The density and diversity of birds, however, strongly depends on the local habitat features and on the characteristics of the broader landscape. Consequently, both local structural variables and landscape effects may influence the efficiency of the natural pest control provided by birds and thereby the forest damages caused by caterpillars. The local and landscape variables moreover may influence the caterpillar populations and thereby they have an effect on the intensity of trophic connections between birds and caterpillars. The structural and landscape variables of forests as well as the bird and caterpillar populations create a complex system, which are linked to the processes of predation and herbivory. The environmental (climate change) and social (forest management) changes however strongly influence the elements of this complex trophic system, which eventually affect the entire system resulted in the increasing of the vulnerability against insect damages. To create and maintain a sustainable forest management, there is an urgent need to study and understand how the whole system of forests – birds – caterpillars – forest damage functions and how the service birds provide can be maintained and improved.

Altough the relationship between forest structure and bird abundance as well as the predation of caterpillars by birds has been widely examined; we are lack of the complex, experimental studies. One of the reasons of that is the difficulty of the experimental measurement of bird predation under open field conditions. In consequence of the appearance of dummy caterpillars made by plasticine, the number of experimental studies has been increased rapidly; however, most of these studies concentrated on tropical and tundra ecosystems.

Consequently, we lack knowledge on the efficiency and mechanism of caterpillar conrol service in temperate oak forests. Thereby, the aim of this PH.D dissertation is the complex, experimental examination of the natural caterpillar control provided by passerine birds in temperate oak forests. We simultaneously studied the bird and caterpillar assemblages, the trophic links among them, the extent of caterpillar damage as well as the effects of forest structure and landscape variables on these processes. The dissertation consists of two closely related studies. The aim of the first study was to reveal the effect of forest heterogeneity and forest structural variables on the relationships among birds, caterpillars and leaves. Examining heterogeneous and homognenous forest stands in pairs, we assumed that the heterogeneous forest stands maintain higher abundance and species richness of insectivorous birds, than do homogeneous forests, which results in higher predation rate, lower caterpillar abundance and leaf damage. Analysing the examined stands in general, we tested the following hypothesis:

1) The structural variables characteristics of natural ecosystems (tree species diversity, presence of old trees, diverse shrub vegetation, high density of dead wood, etc.) positively influence both abundance and species number of insectivorous birds, while have a negative effect on caterpillar assemblages
2) Increasing bird abundance in heterogeneous sites increases the predation pressure on caterpillars.
3) The higher predation pressure results in lower caterpillar abundance and in lower leaf damage.
4) The species composition of birds and caterpillars is strongly influenced by the forest structural variables.

In the second part of the PH.D thesis, we examined the effect of forest edges – as landscape variables – on the species richness and abundance of bird assamblages as well as on the intensity of bird predation. To reveal the fine-

scale changes of bird abundance and predation rate with the growing distance from edges to interior, we examined four different distances from the immediate edge to the interior. We tested the following hypothesis:

1) The abundance of insectivorous birds is higher in immediate forest edges compared to forest interior.
2) Predation rate is positively related to bird abundance, thus the pattern of predation rate across edges follow the pattern of bird abundance.
3) Bird abundance is positively affected by forest edges.
4) The distribution of birds across edges can be explained by the changes in forest vegetation structure.
5) We further presumed, that both predation rate and bird abundance change linearly (on a transformed or untransformed scale) with the growing distance from forest edge.

2. MATERIALS AND METHODS

2.1. I. Study

2.1.1. Study site and experimental design

The experiment was carried out in the southern part of the Mátra Mountains. The experimental plots were pointed out using stratified sampling design. At first, we selected the sessile and turkey oak dominated forest stands of the study area, avoiding the northern and steep (> 25°) slopes as well as water influenced areas. The selected forest stands were then categorized as homogeneous and heterogeneous. The distinction between the heterogeneous and homogeneous structural states was a qualitative decision based on the characteristics of the stand structure and on the density of shrub and understorey layer. In each systematically selected forest stands, one sessile oak tree was randomly selected. The selected focal trees were paired, in a way that one of the pairs situated in

homogeneous forest stand, while the other in a heterogeneous stand. Altogether 40 sessile oaks, i.e. 20 tree pairs were selected. The maximum distance between the two members of the pairs was 500 m, while the distance between the different pairs was 500-2000 m.

2.1.2. Data collection

The data collection was carried out in the vegetation period of 2011. The data collection included the quantitative assessment of forest structure, the experimental measurement of the predation rate, the estimation of bird and caterpillar abundance and species number, as weel as the estimation of leaf damage.

Around the selected focal trees, a vegetation assessment was carried out, during which the tree composition, the characteristics of stand structure and the shrub layer were measured. From field data, the following structural variables were calculated:

- *tree species composition*: number of tree species (db/ha)
- *stand structure*: number of stems (number/ha), density of large trees (DBH > 40 cm) (number/ha), basal area (m^2/ha), mean DBH (cm), tree size heterogeneity, amount of dead wood (m^3/ha), number of cavities (number/ha), canopy closure (%), health condition s
- *shrub and understorey layer*: density of shrubs (number/ha), species number of shrubs (number/ha), shrub cover (%), cover of understorey layer (%)

To measure predation rate of caterpillars, we used artificial prey made of green plasticine resembling to the fifth instar larvae of winter moth (*Operophtera brumata*). Fifteen artificial caterpillars were attached to the branches of each focal tree. After six days, the caterpillars were removed and carried to the laboratory, where the signs of predation were identified under

microscope. The level of predation was expressed as the percentage of damaged caterpillars during the explosure period.

To estimate the abundance of insectivorous birds, we used a 10 min point count method around each focal tree using a 100 m radius. All observed or heard individuals were recorded. During the analysis we excluded bird species that do not prey upon caterpillars.

The abundance of real caterpillars was measured by collecting foliage samples from randomly selected sessile oak trees around the focal trees. On each of the selected trees, one branch of approximately 30 cm of length was cut with a pole branch cutter. The foliage samples were put into bags and were carried to laboratory, where caterpillars were identified to species level. The abundance of caterplillars was expressed as the number of individuals per 100 leaves.

Leaf damage was estimated in the same leaf samples than caterpillar abundance. All leaves per sample was evaluated as damaged or not and the stand level leaf damage was expressed as the proportion of damaged leaves in the samples.

2.1.3. Data analysis

The statistical analysis was carried out in three steps. At first, we examined the effect of markedly different stand structure on the animals (birds and caterpillars) and on the ecological processes (predation and herbivory). During this part of the analysis, the homogenous and heterogeneous trees were considered as different groups. To give a quantitative substantiation of our qualitative assignment of heterogeneous and homogeneous forest stands, a linear discriminant analysis (LDA) was carried out. To investigate the differences of biological variables between the two members of the pairs, Student's t-tests were used. In the second part of the analysis, we aimed to examine the relationships between the biological variables and ecological processes using general linear mixed regression models (GLMM). In this part of the analysis the

heterogeneous and homogeneous stands were pooled and the effect of each structural variables on the birds and caterpillars were analysed. In the last part of the statistical analysis, we examined the effect of forest heterogeneity and structural variables on the composition of bird and caterpillar species. We applied an indicator-species analysis to reveal the differences in the species compositions between the heterogeneous and homogeneous forest stands, then we applied a redundancy analysis (RDA) to test the effect of each forest structural varieble on the composition of bird and caterpillar assemblages. All tests were carried out in R 2.13.0 environment using the packeges of „MASS", „nlme", „gplots" and „vegan".

2.2. II. Study

2.2.1. Study sites and experimental design

The study was conducted in the northern part of the Zselic Hills region in southwest Hungary.

Based on the forestry database four middle aged forest stands dominated by sessile and turkey oaks were selected situated next to open areas. The selected stands were characterized by pronounced edge and avoided steep slpoes and water influenced areas. In the selected forest stands, four transects were laied out parallel to the edge with a total lengh of 100 m. The distances of transects from the edge were the following: 0 m, 10 m, 25 m and 50 m.

2.2.2. Data Collection

The data collection was carried out in the vegetation period of 2013, during which we measured forest structural variables, estimated bird abundance and experimentally measured the predation rate on artificial caterpillars.

To quantify predation rate of caterpillars, we used artificial preys made of light green plasticine. For the experiment, four sessile oak trees were selected laong each transect with a distance of 25 m among them. On each of the selected

trees, ten artificial caterpillars were attached to the branches near to the leaves. After thet the same method was used as in the first study. The level of predation was expressed as the percentage of damaged caterpillars during the exposure period.

To estimate bird abundance, a line transect method were carried out, using the four parallel transects with a length of 100 m. All observed or heard individuals were recorded within 5 m width on each side of the transect taking care to avoid double counting of individuals. During the analysis we excluded bird species that do not prey upon caterpillars.

Forest structure assessment was conducted in one randomly selected quadrat along each transect. From field data, the following structural variables were calculated:

- *tree species composition*: number of tree species (db/ha)
- *stand structure*: number of stems (number/ha), basal area (m^2/ha), mean DBH (cm), tree size heterogeneity
- *shrub and understorey layer*: density of shrubs (number/ha), shrub cover (%)

2.2.3. Data analysis

During the analysis, we tested the effect of forest edges on bird abundance and predation rate. Besides edge effect, we investigated the relationhips among birds, predation rate and forest stand characteristics across edges to interior. To reveal the relationships between the biological variables (forest structure, bird abundance, predation rate), general linear mixed models (GLMM) were built. The effect of edges was also examined using linear models. In addition to linear models, multiple comparisons with Tukey post hoc tests were used to reveal all differences among the four distance categories. All tests were carried out in R 2.13.0. environment using the package “nlme”.

3. RESULTS

3.1. I. Study

3.1.1. The measured values of the biological variables

The recorded mean predation rate of artificial caterpillars was 27.5%, of which 80.9% was bird predation. Mandible marks of arthropods were found on 43.2% of the preys, while 1.2% of the signs remained unidentified. 25.3% of the artificial caterpillars contained more than one sign of predation. From all study sites, we detected 31 species of birds, of which 26 were insectivorous, i.e. potential predator of caterpillars. The mean abundance of insectivorous birds was 7.58 individuals per plot, while the mean species richness was 5.28 bird species per plot. We identified larvae of 19 lepidopteran and 1 hymenopteran species. The mean standardized abundance of caterpillars was 1.28 individuals per 100 leaves and the mean standardized species richness was 0.71 caterpillar species per 100 leaves. The mean proportion of damaged leaves was 0.49.

3.1.2. Differences between heterogeneous and homogeneous forest stands

The separation of heterogeneous and homogeneous stands based on LDA was appropriate. The apriori and aposteriori classification was the same in the 85% of the objects.

Between the two stand types, significant structural differences were found based on the Student's t-tests. In heterogeneous stands the density of large trees, tree size heterogeneity, shrub density, shrub diversity and the density of cavities were significantly higher than in homogeneous stands. Mean tree size, tree density, the volume of dead wood, the degree of canopy closure and health condition were similar between the two stand types.

Heterogenepus stands also supported higher abundance of insectivorous birds and suffer from less leaf damage compared to homogeneous stands. The

predation rate and the caterpillar abundance, however, did not differ significantly between heterogeneous and homogeneous stands.

3.1.3. Relationships between the biological variables

The hypothesized and experienced relationships between the examined biological variables are shown in the Figure 1. According to our hypothesis, the forest structure significantly influenced the abundance of insectivorous birds, however, contrary to our expectations, the structural variables did not affect caterpillar abundance (*1*,*2*). Among the examined structural variables, the tree size heterogeneity and tree species richness had the most significant effect on bird abundance. Thus, the increase in tree size heterogeneity and tree species richness resulted in increased bird abundance. The higher bird abundance, in turn leads to higher predation rate (*3*). The high predation rate, however, did not resulted in decreased caterpillar populations. Contrary to our hypothesis, that predation has negative effect on caterpillar abundance, we found a positive correlation between predation rate and caterpillar abundance. I.e. caterpillar abundance had a significant positive effect on predation rate (*4'*). Thus predation pressure – and along with that the bird abundance – was higher in areas, were caterpillar abundance was high. Contrary to our hypothesis, caterpillar abundance had no effect on leaf damage (*5*).

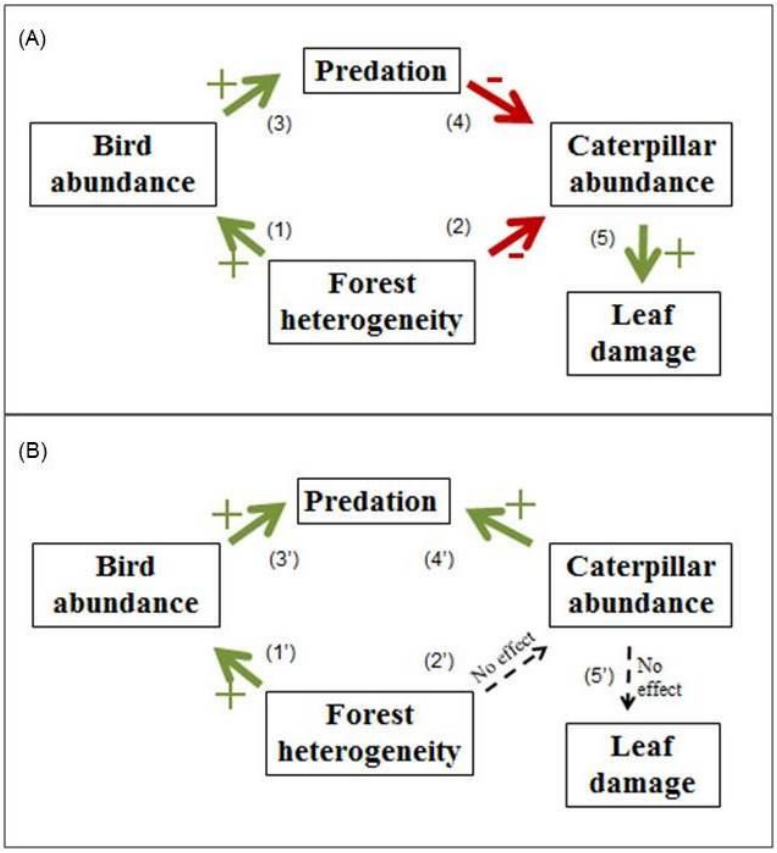

Fig.1. The hypothesized effect of the studied system (A), and the effects between the elements according to our results (B). The arrows show the direction of the hypothesized and detected effects between the elements of the studied system. + indicatess positive effect, – indicates negative effect, while no effect means no significant effect was found by linear mixed models.

3.1.4. Effects of forest structure on species composition

We revealed slight differences in species compositions between heterogeneous and homogeneous forest stands. In relation to both birds and caterpillars, only one species was connected to a given stand type. Considering birds, the Collared flycatcher (*Ficedula albicollis*) was more frequent in heterogeneous stands. In contrast, the March moth (*Alsohila aescularia*) was related to hemeogeneous stands.

In the RDA ordination related to insectivorous birds, the sum of all unconstrained eigenvalues was 75.32% and the eigenvalues associated with the two first axis were 0.06 and 0.05. These axes explained 84.04% cumulative variance of the species dataset and 40.63% cumulative variance of the species-environment relationships. Few species were strongly associated with particular forest structural variables. Among them, the strongest association was detected in the case of the Great spotted woodpecker (*Dendrocopus major*), which species was detected more frequently in habitats characterized by higher basal area. Conserning caterpillar assamblages, the sum of all unconstrained eigenvalues was 65.70% and the eigenvalues associated with the two first axes were 0.03 and 0.02. These axes explained 99.92% cumulative variance of the species dataset and 99.43% cumulative variance of the species-environment relationships. Contrary to bird communities, the frequency of some caterpillar species decreased with the presence of structural elements characteristics of heterogeneous forests. For example, the *Mesoneura opaca* was related the forest stand with low richness of tree species, while the Alsophila aescularia was more frequent in those stands, where the tree size heterogeneity was the lowest.

3.2. II. Study

3.2.1. Predation rate

The recorded mean predation rate of artificial caterpillars was 19.06%, of which 66.42% was bird predation. Mandible marks of chewing arthropods were found on 27.82% of artificial preys, 0.32% of them were attacked by small mammals, while 3.28% of the marks remained unidentified.

Bird predation rate was correlated with bird abundance: we found a significant positive effect of bird abundance on bird predation. According to linear models, the bird predation did not affected by the distance from forest edges. Multiple comparisions among the four different distances, however, showed significant differences in predation rate: at the distances of 10 and 25 m

from the edge the predation rate was significantly lower compared to forest edge and forest interior. Thus, the changes in predation rate from edges to interior showed a negative humped-shaped pattern.

3.2.2. Bird abundance

We recorded a total of 15 bird species from the four forest stands, of which 14 was insectivorous, i.e. potential predators of caterpillars. The mean abundance was 3.38 individuals per transect and the mean species richness was 2.75 bird species per transect. Abundance of insectivorous birds changed significantly with the distance from forest edges, but this change was not linear. Multiple comparisions among the four examined distances showed that bird abundance was the highest in the forest interior and the lowest at the distances of 10 and 25m. Forest edges maintain higher abundance than the transitional distances, but lower than forest interior. In addition to the distance from forest edges, forest structure also affected insectivorous birds. The tree species richness and the basal area had a significant negative effect on bird abundance according to linear mixed models. The number of tree species as well as basal area changed significantly from edges to interior. In addition to these variables, the distance from edges had significant effect on the number of tree individuals as well as on the mean diameter at breast height. These two structural variables however did not influence bird abundance.

3.3. New scientific results

1. In Hungary, I was the first, who applied artificial prey to experimentally measure predation pressure on caterpillar pests. I clarified the method through preliminary experiments and I successfully applied artificial caterpillars in temperate oak forests.
2. Using this method, I was able to experimentally examine the relationships between birds, caterpillars and the leaf damage caused by them as well as

the effect of forest structure and forest edges on these relationships. This complex approach is considered novel in the international science.

3. I showed that the predation rate is positively related to bird abundance as well as to caterpillar abundance.
4. I found that forest structure has a significant effect on bird abundance as well as on leaf damage caused by caterpillars. Heterogeneous stands maintain higher bird abundance than do homogeneous forests and suffer lower leaf damage.
5. Among the examined forest structural variables, tree size heterogeneity and tree species richness had the highest effect on bird abundance and thereby on predation rate. From this point of view, forest management can significantly contribute to the improvement of the efficieniency of natural pest control provided by insectivorous birds through the spatially heterogeneous, finer scale implementation and the maintenance of the retention tree groups.
6. Forest structure also affected the species comporition of insectivorous birds. Some bird species (Great spotted woodpecker, Blue tit, Great tit, Common chaffinch) were associated with structural variables characteristics of heterogeneous stands. Especially woodpeckers were closely related to forest structure, which presence is neccesery to the settlement of cavity nesting birds. Contrary to bird assamblages, some caterpillar species were more frequent in stands with lower heterogeneity.
7. In addition to local structural varibales, I examined the effect of forest edges – as landscape parameter – on the abundance of insectivorous birds as well as on bird predation. From edges to interior, I found an unexpected pattern both for birds and predation rate. According to this pattern, edges and interiors maintain higher bird abundance and predation rate compared to the distance of 10 and 25 m from the edge. This negative humped-shaped pattern implies that examining one edge and one interior plot is not always

enough to show the effect of immediate edge on species distributions and species interactions.

4. CONCLUSIONS AND RECOMMENDATIONS

The insectivorous birds proved to be efficient natural enemies of leaf consuming caterpillars. In the predation experiments, birds were responsible for 60–80% of the total predation pressure measured on artificial caterpillars. The predation rate was primarily depended on the abundance of insectivorous birds, while the bird species richness had no significant effect on the intensity of bird predation. Thus, the maintenance of the high density of bird assamblages leads to high predation pressure on caterpillars. In our study, however, the high predation rate was not translated into the decrease of caterpillar abundance. The lack of the hypothesized negative impact of bird predation on caterpillar abundance may be explained by the synoptic population model of Sothwood and Comins. According to this model, the restriction effects of generalist predators – like insectivorous birds – cannot be manifested at high prey densities. At high prey densities other factors, such as starvation or disases cause the population to collapse. Thus the role of insectivorous birds is not to depress high caterpillar densities, but to maintain caterpillar populations at low densities and thereby to extend the period between two outbreaks. Thus, the high predation rate experienced at low caterpillar densities did not decrease caterpillar abundance, but may hinder the further growth of populations. In line with this, predation pressure by birds was highest in areas, where caterpillar abundance was higher. In other words, we can conclude that birds exhibit numerical response to caterpillar densities. The presence and activity of birds did not mean the decrease of caterpillar abundance, however, the areas characterized by higher bird abundance suffered from less leaf damage. From this result, we can conclude that the high foraging activity of birds reduce the foraging activity of

caterpillars. I.e, birds may have an indirect positive effect on the health condition of the trees, thus they can play an important role in the maintenance of forests in good health condition.

Based on the above mentioned results, the efficient caterpillar control is primarily relies on the abundance of insectivorous birds. Bird abundance, however, strongly depends on the local structural varibales as well as on landscape factors. In the present dissertation, we examined the effect of forest heterogeneity and forest edges on bird assamblages and thereby on the efficiency of caterpillar control. We showed that heterogeneous forest stands maintained a significantly higher abundance of birds, than do homogeneous forests and along whith this, suffer lower leaf damage. Among the examined forest structural parameters, tree size heterogeneity and tree species richness had the highest positive effect on bird abundance. Thus, the maintenance of the heterogeneity of these structural variables may result in more efficient caterpillar control. European oak dominated forests are mainly managed by shelterwood silvicultural system, which results in basically even-aged, homogeneous forest stands. According to our results, this stand type maintains low bird abundance and suffers from high damage. Within this silvicultural system, the stand level heterogeneity may be increased by spatially heterogeneous, fine-scale implementation and by the maintenance of the retention tree groups and by the extension of regeneration period. In Hungary, high effort has been made in direction to the continouos forest cover forestry. This management type includes among all the tree selection system in which all age and size classes are simultaneously present. In this dissertation, the tree size heterogeneity is proved to be the most important explanatory variables of bird abundance. Thus any management practice, which increases these types of heterogeneity, can have a positive effect on the self-protecting ability of forests against insect damages and thereby on the forests health conditions.

In addition to the local structural variables, the effect of forest edges on caterpillar control service was also examined. We showed that both bird abundance and predation rate change with the growing distance from forest edges to interiors, but these changes can not be measured in linear scale. We got an unexpected pattern both for bird abundance and bird predation as the measured values were high in the edges as well as in the interiors but was low at transition distances. From this result, we can conclude, that both edges and interiors are preferred habitats by insectivorous birds. Thus, birds are able to control caterpillar pests in the edges of fragmented landscapes through the maintenance of the high predation pressure.

5. PUBLICATIONS IN CONNECTION WITH THE PHD DISSERTATION

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IF: 2,667

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IF: 0,263

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Conference proceedings, native language, abstract:

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Bereczki, K., Molnár, D., Csóka, Gy., Báldi, A. (2014): The effects of local habitat features on the predation of Gypsy moth (*Lymantria dispar* L.) egg masses. – IX. Hungarian Conference of Conservation Biology (MTBK), 20–23. November 2014, Szeged. Book of abstracts, p. 38–39.