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ORIGINAL ARTICLE

Small canopy gaps do not affect the predation pressure on large ground beetles (Coleoptera: Carabidae) in a managed forest*

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Abstract. Continuous cover forestry is a silvicultural system designed to mimic natural forest dynamics and maintain the structure of uneven-aged semi-natural forests. One of the key steps in this approach is to create small gaps in the canopy by logging small groups of trees or individual trees. In gap-cutting, the main goal is to determine the optimal shape and size of these gaps in order to ensure spontaneous natural regeneration of the major tree species in the canopy. Yet, it remains relatively unknown how various arthropods respond to such forestry practices. Carabid beetles (Coleoptera: Carabidae) play an important role as predators of various small invertebrates and their predators are mostly vertebrates. The interactions between carabids and their predators might change due to shifts in the distribution of patches of suitable habitat as a result of forest management. Here, the aim was to determine whether gaps in the canopy of two different sizes (small vs. large) and shapes (circular vs. elongated) can affect the predation pressure on large carabids in a Hungarian oak-hornbeam forest. Using 3D-printed decoys of the largest common carabid in the area, *Carabus coriaceus*, placed in each of the four gap treatments and control plots, the seasonal, diurnal, and treatment-specific aspects of predation pressure was estimated. This revealed no significant effects of any of the variables included in this study, which indicates that predation pressure in undisturbed controls located in closed forests and small canopy gaps did not differ significantly. Creating gaps in the canopy by felling few trees seems to be a good strategy for maintaining the forest ecological network with minimal disruption compared clear-felling large areas.

INTRODUCTION

There is an increasing demand for silvicultural practices that mimic natural forest dynamics. The so-called "closer-to-nature" forestry or continuous cover forestry (hereafter CCF) involves the maintenance of a permanent canopy (Pommerening & Murphy, 2004). By avoiding felling large areas, this approach maintains the characteristics of an uneven-aged natural forest and therefore is more likely to maintain the ecosystem services and biodiversity than rotational silvicultural systems (Peura et al., 2018; Mason et al., 2022). One option for maintaining CCF is to create small gaps in the canopy by felling small groups of trees or individual trees. This avoids the dramatic changes in the environment in terms of light, temperature and soil moisture that result from clear-felling of large areas (Pommerening & Murphy, 2004). For foresters, the main aim is to determine the optimal shape and size of the gaps in the canopy for maximizing the spontaneous regeneration of trees in the main canopy layer (Horváth et al., 2023; Zhu et al., 2003).

The ground-dwelling arthropods, including ground beetles (Coleoptera: Carabidae), are important and favourite groups for studying the various effects of forest management, especially assemblage composition and changes in rotation forestry or their comparison with CCF (e.g., Moore et al., 2004; Negro et al., 2014; Šebek et al., 2015; Elek et al., 2018). However, the effect of different types of gaps on forest ground-dwellers is still relatively unknown (Samu et al., 2023). For instance, carabids have an important role as predators in forest food webs, feeding mostly

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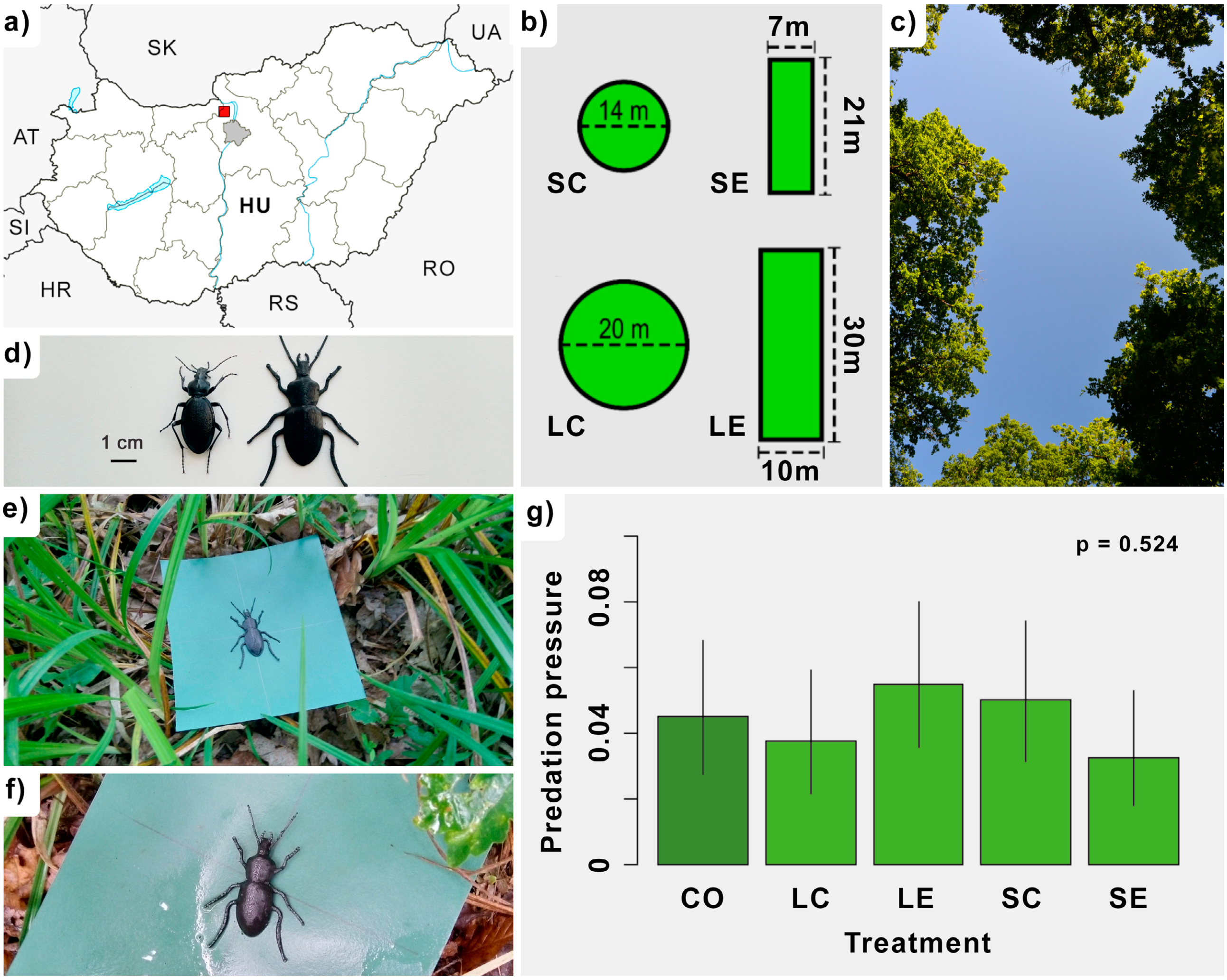

Fig. 1. The area study is located in the Pilis Mountains in northern Hungary (a) where the four different gap treatments (b) and undisturbed control was established. The treatment abbreviations: SC – small circular gap, SE – small elongated (also pictured in c), LC – large circular, LE – large elongated. The decoys (on the right) mimicking the largest ground beetle in the area, *Carabus coriaceus* on the left (d), were placed on green sheets of cardboard e) and checked for whether they were upended (f), had broken parts or relocated. The results indicate no significant differences between different type of gaps and undisturbed control plots on the average predation pressure on this large carabid (g). The whiskers indicate 95% confidence intervals.

on small invertebrates, but they are also eaten by vertebrates (Graclik & Wasielewski, 2012; Fukuda & Konuma, 2019). The interactions between carabids and their predators might change due to management-induced changes in the distribution of suitable habitats possibly leading to so-called ecological traps (Růžičková & Elek, 2021). Nevertheless, these interactions, where carabids are the prey, are not well studied and as for the effects of gaps in the canopy there is no information.

For studying predation pressure there are several non-lethal methods for various target groups (Lövei & Ferrante, 2024), often referred to as sentinel methods. Despite the difficulties in mimicking living prey, decoys do not move and have no odour, nevertheless their use provide estimates of predator activity, which are suitable for comparative purposes (Ferrante et al., 2024). Plasticine has been used to produce artificial prey, such as, caterpillars and other small invertebrates with simple body shapes, in large numbers (Low et al., 2014; Lövei & Ferrante, 2017). This method is, however, not suitable for mimicking beetles due to their body complexity. Instead of plasticine, 3D-printed decoys have been used as artificial prey for recording the predation pressure on large insects, such as carabids (Růžičková & Elek, 2021). In temperate managed oak-hornbeam forests, the predation pressure is greater in clear-felled areas than in undisturbed forests. In this study, the focus was on CCF, in particular the effects of gaps in the canopy of different shapes (circular vs. elongated) and sizes (small vs. large) on the predation pressure on large carabids and in control forests without management. As these gap treatments mimic environmental characteristics and the natural gap dynamics in closed-canopy forests (Horváth et al., 2023), it is presumed that the interactions between carabids and their predators will remain mostly unchanged with minimal or slight effect on predation pressure. Moreover, it is also hypothesized that the predation pressure will be lower than in previously evaluated in large-scale rotational forests (Růžičková & Elek, 2021).

MATERIAL AND METHODS

The experiment was implemented within the framework of the Pilis Gap Experiment (https://piliskiserlet.ecolres.hu/en), located close to Pilisszántó village in the mountains of northern Hungary (Fig. 1a). The forest is an approximately 90-year-old oak-hornbeam forest with a relatively homogeneous tree species composition and a closed canopy. The upper canopy was dominated by sessile oak (*Quercus petraea* (Matt.) Liebl., 1784) with a few turkey oak (*Q. cerris* L., 1758) and the lower canopy by hornbeam (*Carpinus betulus* L., 1758) and manna ash (*Fraxinus ornus* L., 1758). *Carex pilosa* Scop., 1772 and *Melica uniflora* Retz. dominated the herbaceous plant layer, while the shrub layer was sparse. Four treatments were established by Pilisi Parkerdő Ltd. in the winter of 2018/2019, which consisted of creating gaps in the canopy of different sizes and shapes by felling and removing the trees, which favoured spontaneous tree regeneration (Fig. 1b). These treatments were: Large Circular (LC) gap with a 10 m radius and 300 m^2 area; Small Circular (SC) gap with a 7 m radius and area of 150 m^2; Large Elongated (LE) gap with a north-south orientation, length of 30 m, width of 10 m and same area as LC and Small Elongated (SE, Fig. 1c) with a north-south orientation and same area as SC, length of 21 m and width of 7 m. Finally, Control plot (CO) was established nearby in un-managed closed-canopy forest. These treatments and control were replicated in six blocks, i.e., each block contained one LC, SC, LE, SE and CO with a distance of 600–1000 m between blocks.

In order to assess predation pressure, 3D-printed models of the largest carabid in the study area, *Carabus coriaceus* L., 1758, were used. As it is relatively large (33–40 mm, Hůrka, 1996), it is suitable for 3D printing (Fig. 1d). This species is also one of the most common in the area (Elek et al., 2022), so it is familiar to predators. The life-sized decoys (the length was 40 mm, measured from the top of the head to the end of the abdomen) were 3D-printed using black polylactic acid (PLA, see Růžičková & Elek, 2021 for the technical details of the printing). The field experiment was carried out in spring and autumn (May and October 2023), which is when this carabid is most active. In the approximate centre of each plot, 10 decoys were each placed on A5 sized pieces of green cardboard at least 2.5 m apart (Fig. 1e). The pieces of cardboard were fixed to the ground by stones or branches in order to prevent them moving. The exact position of the decoy on the cardboard was secured by placing it on the intersection of two perpendicular lines. The ground cover was estimated in terms of bare soil, litter, herbaceous plants and shrub layers in a 1 m radius circle around each decoy. Each treatment was replicated twice (i.e. only two blocks of the Pilis Gap Experiment were used), thus 100 decoys were used in each season (spring or autumn). The decoys were checked twice a day, in the morning and evening for five consecutive days (10 observation events), leading to a total of 2000 observations for the whole experiment. If the decoy was upended (Fig. 1f), moved or missing, or damaged in terms of scratches and missing parts, this was considered to be a result of a predation event/attack. After measurements, decoys were placed in their original position or replaced if damaged.

The same type of analysis was used as in our previous study on predation pressure (Růžičková & Elek, 2021). The main reason for this was to be able to compare the results of the different gap treatments in CCF but also the previously assessed effects of rotation forestry (preparation felling and clear-felling in particular) on the predation pressure on large carabids. The predation pressure was recorded as the ratio between attack and no-attack events on 10 decoys in a plot per observation session, coded as a two-column matrix [1 – attack; 0 – no attack] using the *cbind* function. Then three derivatives of generalized linear models (the *glm* function) with binomial distribution and logit link function, were developed for different spatial and temporal scales. In the first model, treatment was the only factorial explanatory variable with five levels (LC, SC, LE, SE and CO). The second model included treatment, time of day (two levels: day and night) and season (spring and autumn). Then, the third model included treatment and only the environmental variables: cover of bare soil and leaf litter, and the presence of trees was included as an explanatory variable. Cover of herbaceous plants and shrubs were not included in subsequent analysis because they are significantly negatively correlated with leaf litter (Pearson $r = -0.52$; $p < 0.001$ for herbaceous plant layer and $r = -0.69$; $p < 0.001$ for shrubs). Then, using the *model.sel* function in the 'MuMIn' package (Bartoń, 2019), these models were tested and the best selected using the information criterion corrected for small sample sizes (Akaike Information Criterion – AICc, Burnham & Anderson, 2002). The best model was the most parsimonious explanation of the data when the Δ AICc was greater than two (Δ AICc > 2). The performance of the best model was checked by diagnostics graphs for goodness of fit, variance homogeneity and influential points. All analyses were done in R 4.3.2 (R Core Team, 2023).

RESULTS

A total of 91 attacks were recorded based on a total of 2000 observations (62 upended, 18 scratched or with broken parts and 11 displaced), indicating a total percentage predation of 4.55%. The majority of the upended decoys were displaced by between 5 and 10°, and the maximum was 45°. Broken parts consisted of missing or bent legs or antennas. While upended decoys are likely to indicate a consequence of a predator's explorative behaviour and interest in the decoy, missing parts or removal is a clear sign of attempted predation. The model selection revealed that model #1 that only included treatment (i.e., type of gap and control) as a response was the most parsimonious (Table 1). This indicated there was no significant difference in predation pressure recorded in the gaps of different sizes and shapes compared to the controls (Fig. 1f, Table 1). In addition, neither temporal aspects nor micro-environmental variables (Table 1) significantly affected predation pressure.

Table 1. Summary of model selection (top) based on estimates of their AICc values, which provide a measure of the weight of evidence in favour of the different models, and the model outputs (bottom) of the effects of gap treatment, time of day, season and environmental variables on predation pressure.

Model comparison	df	logLik	AICs	delta	weight
Habitat scale	5	–179.890	370.1	0.00	0.833
Temporal scale	3	–183.925	374.0	3.86	0.121
Micro-habitat scale	6	–181.705	375.9	5.77	0.046

Model outputs	Variables	χ^2	df	p
1. Habitat scale	treatment	3.207	4	0.524
2. Temporal scale	treatment	3.211	4	0.523
	time of day	1.720	1	0.190
	season	0.197	1	0.662
3. Micro-habitat scale	treatment	3.274	4	0.513
	bare soil	0.091	1	0.763
	leaf litter	0.163	1	0.686
	tree	0.075	1	0.784

DISCUSSION

This study indicates that small gaps in the canopy can buffer changes in managed forests and their effect on predator-prey interactions. The predation pressure on large carabids was the same for the gaps in the canopy of various shapes and sizes, and their controls. Comparing these findings with a previous study done in two rotation forestry treatments of 0.5 ha, where the average predation pressure reached 7.8% in clear-felled areas and 6.5% in those prepared for felling (Růžičková & Elek, 2021), the average predator pressure recorded in this study is lower in gaps and varies from 3.3% in SE to 5.5% in LE. Some management practices in rotation forestry can act as ecological traps for large carabids because they temporally utilize these treatments in high numbers (Elek et al., 2021; Růžičková et al., 2021), but experience a higher predation pressure than in undisturbed closed-canopy forests (Růžičková & Elek, 2021). It is assumed that, unlike the above-mentioned results for large areas clear felled, cutting gaps in the canopy did not significantly alter the interactions between large carabids and their (potential) vertebrate predators, such as Wild boars (*Sus scrofa* L., 1758), European badgers (*Meles meles* L., 1758), Northern white-breasted hedgehogs (*Erinaceus roumanicus* Barrett-Hamilton, 1900), Greater mouse-eared bats (*Myotis myotis* Borkhausen, 1797) and Eurasian nuthatches (*Sitta europaea* L., 1758). These predators commonly occur in oak-hornbeam forests in the area studied and are reported feeding on large carabids (e.g., Marassi & Biancardi, 2002; Schley & Roper, 2003; Graclik & Wasielewski, 2012). Hence, creating gaps in the canopy as part of CCF, can be used to maintain ecological networks in forests with minimal disturbance compared to clear-felling large areas. From the perspective of vertebrate predators with a high dispersal capacity, habitats associated with gaps in the canopy may not be recognized as distinct habitats, resulting in uniform foraging behaviour and predation pressure on large carabids in the different gap treatments.

These findings also underline the legacy of not being able to publish non-significant results, whereas significant findings are more frequently and rapidly published than non-significant ones (Csada et al., 1996), leading to a biased interpretation of ecological processes (Murtaugh, 2002). However, the publication of statistically non-significant results in forest ecology (with a certain level of caution) is crucial for preventing the reinforcement of potentially ineffective management strategies, optimizing resource allocation and ensures a more comprehensive and balanced understanding of forest ecosystems (Di Stephano, 2001). In addition, the lack of statistical significance is not indicative of a lack of biological importance (Nakagawa, 2004). These findings provide valuable evidence that can inform and enhance conservation efforts (Wood, 2020).

CONCLUSIONS

The results of this study indicate that gaps in the canopy can create conditions that buffer changes in managed forests, particularly in predator-prey interactions. As CCF seeks to mimic natural forest dynamics while promoting biodiversity (Pommerening & Murphy, 2004; Mason et al., 2022), the neutral findings recorded indicate that certain aspects of the ecological network may remain unaffected by forest management in the system studied. They also highlight the importance of the interpretation of statistical analyses in ecology in mitigating publication bias and p-hacking (i.e., Csada et al., 1996; Nakagawa, 2004; Fanelli, 2011). They help prevent the duplication of unsuccessful experiments, saving resources and time for researchers to provide a more accurate perspective of ecological research and enhance scientific knowledge.

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