SYLWAN 167 (3): 121-135, March 2023
https://doi.org/10.26202/sylwan.2022079
Journal homepage: https://sylwan-journal.pl

ORIGINAL PAPER

Insect biodiversity and forest pests – the case of ground beetles (Col.: Carabidae) and cockchafers (Col.: Melolonthinae) in south-eastern Poland

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ABSTRACT

Insects can play different roles in forest ecosystems. Ground beetles (Col.: Carabidae) are considered to be a group of insects that are very sensitive to changes in environmental conditions; therefore they are often used as bioindicators of changes in forest ecosystems. Cockchafers (Col: Melolonthinae) are known to be significant forest pests by feeding on the roots of plants (grubs) and tree foliage (adults) resulting in serious damage to tree plantations and forest stands. The aim of study was to assess the effect of disturbances resulting from the long-lasting occurrence of cockchafers on the diversity of ground beetles collected in the affected and non-affected stands. The research was done in two Forest Districts (Lubaczów and Narol) on 141 plots established on a regular grid. Pitfall traps were installed in the centres of the plots and checked during the vegetative period of 2018. The plots with traps were classified (classes 0-4) according to the number of years with a recorded occurrence of cockchafers in the 4-years period covered by the analysis. The number of species, as well as Shannon-Wiener and Margalef indices were used to characterize the diversity of ground beetles. The mean number of species collected increased along with the classes reflecting the number of years with a recorded occurrence of cockchafers. This pattern was not fully reflected by the diversity indices, but their values were higher in the classes with a longer lasting occurrence of cockchafers. We posit that the observed increase in species richness corresponding to the occurrence of cockchafers is related to changes in the food accessibility favourable for several trophic guilds of carabids (predators – hemizoophages – phytophages). The increase in the abundance of dying/dead plants damaged by the feeding grubs may be related to the properties of forest litter that may be more favourable for some carabid species. The demonstrated variability can result from disturbances caused by cockchafers and from changes in species composition of ground beetles in analysed stands based on various characteristics, such as age or composition of tree species.

KEY WORDS

disturbances, ecological indices, forest environment, insect diversity

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Received: 1 December 2022; Revised: 3 February 2023; Accepted: 21 June 2023; Available online: 24 July 2023

Introduction

Insects are a very important component of forest ecosystems. They play different roles, dependant on their biology, behaviour and ecology as well as from a human perspective (humans choose to view insects as pests or beneficial organisms). Therefore, amongst forest insects, herbivores and predators can be found with some considered forest pests and others even used as bioindicators (*e.g.*, Szujecki, 1980, 2001).

All groups of insects (including the aforementioned ones) co-occur in the same ecosystems and remain in complex relationships that shape their environmental conditions and communities. This concerns phytophagous insects whose feeding affects both the physiological status of trees and the forest environment as well as the epigeic fauna, with ground beetles that respond to such changes (*e.g.*, MacLean and Usis, 1992; Płatek *et al.*, 2005; Skalski *et al.*, 2010).

Ground beetles (Col.: Carabidae) are considered a group of insects that are very sensitive to changes in environmental conditions; therefore, carabids are often used as bioindicators of changes in forest ecosystems (*e.g.*, Schwerk and Szyszko, 2007; Koivula, 2011; Skłodowski *et al.*, 2018). Ground beetles occur in various forest environments and are mostly predatory with a well-recognized ecology along with simple, well-known trapping methods (*e.g.*, Szyszko, 1974; Niemelä *et al.*, 2007; Tarwacki, 2012). The occurrence of Carabidae is closely related to their food resources (Riddick, 2008). Several methods are used for the assessment of ground beetle diversity and its variability in time and space including classic ecological indices such as dominance or fidelity (*e.g.*, Huruk, 1993; Konieczna *et al.*, 2012), indices depicting biodiversity (such as the ones proposed by Shannon-Wiener, Simpson, Margalef and others) (*e.g.*, Tarwacki, 2004; Hammond *et al.*, 2018) or indices based on beetle biomass (*e.g.*, Szyszko, 1983; Tarwacki, 2004; Skalski *et al.*, 2010).

The cockchafers (Col: Melolonthinae) are known as important forest pests in Europe (Głowacka and Sierpińska, 2012). In Poland, the damage and control of these insects has remained a serious problem in forestry for the past several decades (Sierota *et al.*, 2019) increasing recently due to the restrictions in the use of insecticides in forests (Skrzecz and Perlińska, 2018). By feeding on the roots of plants (grubs) and tree foliage (adults), they are able to cause serious damage in plantations as well as in forest stands. The main species causing damage in forests are *Melolontha melolontha* L. and *M. hippocastani* F. whose biology is well recognized and very similar (*e.g.*, Ulatowski, 1933; Nunberg, 1948; Szujecki, 1995; Woreta and Sukovata, 2014). The life cycle in both species is 3-5 years, therefore the 'swarming year' with massive flight and feeding of adults usually occurs every 4 years. The damage resulting from the feeding of grubs results in the death of young forest trees (both planted and from natural regeneration), and the adults cause defoliation of deciduous trees which can be very intensive.

An inventory of selected natural and cultural values was done from 2016-2022 in the area of Forest Districts within the Regional Directorate of State Forests (RDSF) in Krosno and in 3 national parks (southeastern Poland). As part of this inventory data related to the ground beetles was collected. This article will analyse the selected data in relation to the processes taking place in the investigated forest ecosystems. It is commonly known that ground beetles respond to the disturbances in forest ecosystems by increasing their species diversity (*e.g.*, MacLean and Usis, 1992; Skalski *et al.*, 2010; Skłodowski, 2017). The aim of this study was to assess the effect of disturbances resulting from the long-lasting occurrence of cockchafers feeding on the roots and aboveground parts of trees on the diversity of ground beetles collected in the affected and non-affected stands. We did not expect direct interaction between cockchafers and ground beetles as the damage caused by the feeding of cockchafers was used as an example of a disturbance in the forest ecosystems. We hypothesize that ground beetles will respond to this disturbance by increasing species diversity as it was found in the other similar cases.

Materials and methods

STUDY AREA. The research area covers forests within the borders of the 2 Forest Districts (FD) of Lubaczów and Narol with a total forest area of 44,526 ha including 35,188 ha of State Forests (BDL, 2022). The stands are dominated by Scots pine *Pinus sylvestris* L. with a 72% share of the total forest area and other tree species of importance being 6% hornbeam *Carpinus betulus* L., 6% oaks *Quercus* sp. and 5% alders *Alnus* sp. The stands in this area have been permanently threatened and damaged by the cockchafers Melolonthinae for a long time which includes grubs feeding on the root systems and to a lesser extent the adults feeding on the assimilative organs of deciduous trees (IBL, 2020). The occurrence and control of cockchafers were intensively studied in this area (Niemczyk, 2015; Niemczyk *et al.*, 2017).

OCCURRENCE OF MELOLONTHINAE. Forest compartments with the presence of cockchafers in any given year that fulfilled at least one of the following criteria (Zarządzenie, 2016) were considered:

– observed increased presence of adults in the stands,
– threat from the grubs assessed yearly by the forest protection service,
– need for replanting of more than 30% of seedlings,
– inability of stand to regenerate or afforestation due to the damage by grubs,
– or treatment with pesticides during 2 subsequent swarming periods.

Data on the occurrence of Melolonthinae in the 4 years analysed, including the year of trapping (2015-2018), were supplied by the Forest Protection Service of the State Forests. The plots with traps were classified according to the number of years with recorded occurrences of cockchafers in the 4-years period covered by the analysis. The number of plots used for the analyses is provided in Table 1.

According to the provided data, 2015 was a year of massive cockchafers (adults) swarming with a subsequent swarming recorded in 2019. In 2015, chemical (920 ha – spraying from the ground using Mospilan 20 SP) and mechanical (990 ha – supervised collection of *Melolontha* adults only) treatments against beetles feeding on the broadleaved trees were applied (Forest Protection Service of the State Forests, unpublished data). No precise information about the location of the treatments is available.

ASSESSMENT OF GROUND BEETLES DIVERSITY. The trapping was done in the inventory plots established in a regular grid of 1×1 km, although every second plot was sampled. In total 190 plots

Table 1.
Number of plots in individual classes representing the number of years with recorded occurrences of cockchafers used for diversity analysis

Class (no of years)	Number of plots
0 (no occurrence)	72
1 (1 year)	39
2 (2 years)	7
3 (3 years)	10
4 (4 years)	13
Total	141

were sampled. Pitfall traps (Barber type, one trap per plot) filled with 100 ml of ethylene glycol were installed in the centres of the plots and checked during the vegetative period of 2018. Insects were collected at 1-month intervals (4 control periods). Carabidae were separated from the collected insects and identified to the species level (except 102 specimens identified to the genus level). The plots on which the number of collected carabids did not exceed 50 individuals were excluded according to the criteria proposed by Schwerk and Szyszko (2007) for the assessment of the mean individual biomass (MIB) of ground beetles. Therefore, the total number of plots used for the analysis was 141 (Table 1). Of this total number there were 69 localities (49%) with an observed presence of cockchafers (Table 1). The spatial distribution of inventory plots included in the analysis in relation to the occurrence of cockchafers is provided in Figure 1.

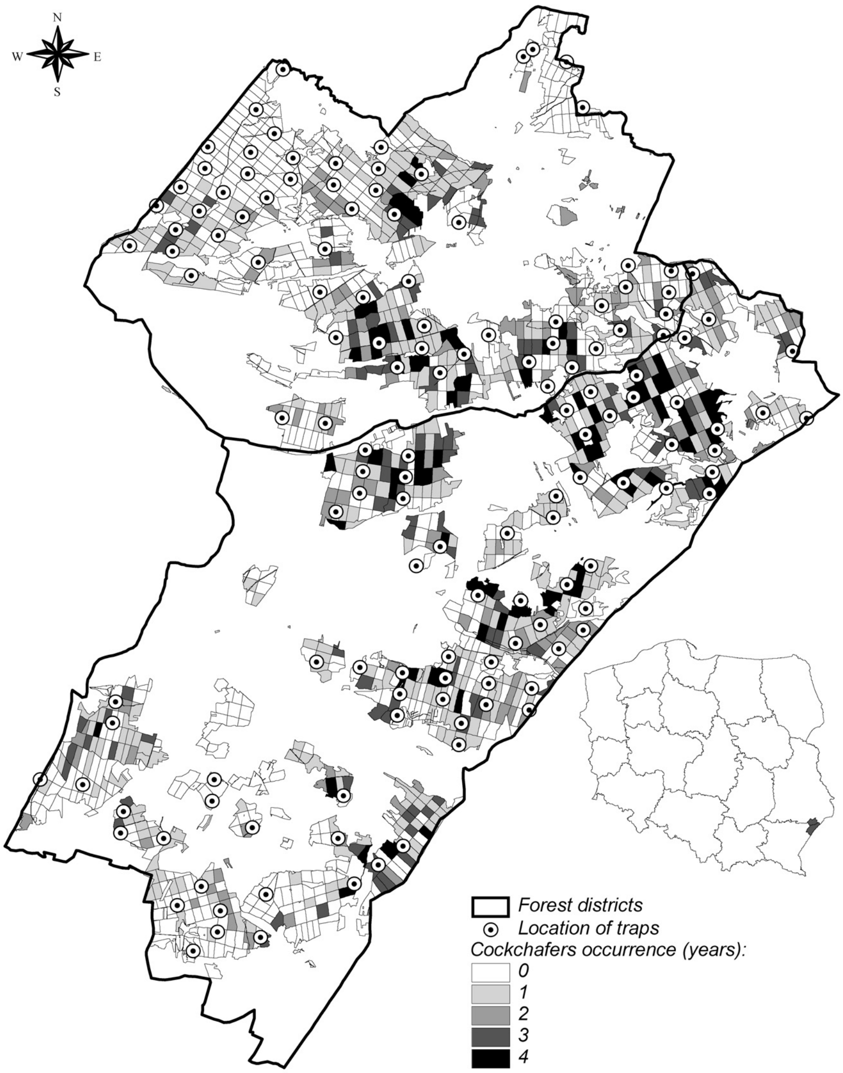

Fig. 1.
Location of inventory plots with traps included in the analysis and the forest compartments in individual classes of cockchafer occurrence (number of years)

In order to characterize the diversity of collected ground beetles, the following indices were calculated for each trapping locality:

number of species (taxa);

Shannon-Wiener index (H) to measure the diversity of species in a community:

$$H = -\sum p_i \cdot \ln p_i$$

where:

p_i – is the proportion of the entire community made up of species *i;*

Margalef index (D_{Mg}) to measure the species richness in a community:

$$D_{Mg} = \frac{S-1}{\ln N}$$

where:

N – the total number of individuals in the sample and

S – the number of species recorded.

Data analysis. The data related to ground beetles (points) have been spatially joined with the data related to the occurrence of cockchafers (polygons) using ArcView 3.2. (ESRI Redlands, California). In order to test the effect of selected stand features, the plots were divided into groups reflecting their species composition as either 'coniferous' with Scots pine or Silver fir as the dominant species or 'deciduous' with deciduous species (mainly oaks *Quercus* sp. and European beech *Fagus sylvatica* L.) as the dominant species in the database based on the forest inventory. In order to test the effect of the stand age, the plots were distributed into two classes of either under ('<60') or over ('>60') 60 years (Lutyk, 2002). The basic statistics and the testing of differences resulting from the presence of cockchafers and the duration (1-4 years) as well as selected stand features,were done using the Levene test, one-way ANOVA and Tukey HSD test using Statistica 13 software (TIBCO, 2017).

Results

Occurrence of cockchafers. During the period covered by the analysis (2015-2018) the number of plots with a recorded occurrence of cockchafers at least in one year was 69. However, it was not even over the years with the highest in 2015 (58), the lowest in 2016 (20), and intermediate in 2017-2018 (27 and 30, respectively). Amongst the 141 stands included in the analysis, there were 98 plots located in 'coniferous' stands including 51 plots with a recorded occurrence of cockchafers, and 43 in 'deciduous' stands including 18 plots with a recorded occurrence of cockchafers. In the sample of 141 plots, 40 were located in the stands under 60 years (18 with cockchafers) and 101 in the stands over 60 years (51 with cockchafers).

Species composition of ground beetles. In total 19,856 beetles were collected (see Appendix) with an average of 140.8 (±SD 95.5; 50-572) beetles per trap. The collected beetles represented 65 species, 102 specimens were identified at the genus level (2 genera: *Amara* sp. – 20 exx. and *Notiophilus* sp. – 82 exx.). In the total sample of collected beetles, five of the most abundant species (68.9% of the total) were *Pterostichus niger* (Schall.) – 3912 (19.7%), *P. oblongopunctatus* (Fabr.) – 3171 (16.0%), *Carabus violaceus* L. – 2761 (13.9%), *C. arvensis* Herbst – 2423 (12.2%), and *C. glabratus* Payk. – 1411 (7.1%). Of the remaining beetles species, 29 were represented by less than 10 specimens and 22 with less than 5 specimens.

Diversity of Carabidae. The mean number of collected species in all 141 plots was 12.5 with variability between 6 to 23 species. The mean value increased with the number of years with a recorded occurrence of cockchafers (classes 0-4) from 12.0 in the plots with no occurrence (class 0) to 14.3 in the plots with 4-years occurrence (class 4). However, the effect was not statistically significant (ANOVA F=1.52, p=0.20). The minimum number increased incrementally from 6 (class 0 and 1), to 9 (class 4), and then to 10 (class 3), while the maximum number (23) was the same in classes 0 and 4 and lower (18-21) in classes 1-3 (Fig. 2).

The mean (±SD) value of the Shannon-Wiener index in all 141 plots was 1.858 ±0.381, varying from 0.630 to 2.506. Its mean value was the lowest in the classes 0 and 1 (1.841 ±0.378 and 1.817 ±0.400, respectively) and higher in the higher classes of cockchafer occurrence. The highest mean value was in the class 3 (2.028 ±0.315) and then slightly decreased in class 4 to 1.928 ±0.369. However, the effect was not statistically significant (ANOVA F=0.76, p=0.55). The minimum value was the lowest in class 1 (0.630) and the highest in class 3 (1.408), while the maximum value was the lowest in class 1 (2.408) and the highest (2.482) in class 4 (Fig. 3).

The mean value of the Margalef's species richness index in all 141 plots was 2.412 ±0.737 varying from 0.927 to 4.302. The mean value was the lowest in class 0 (2.318 ±0.758) and increasing

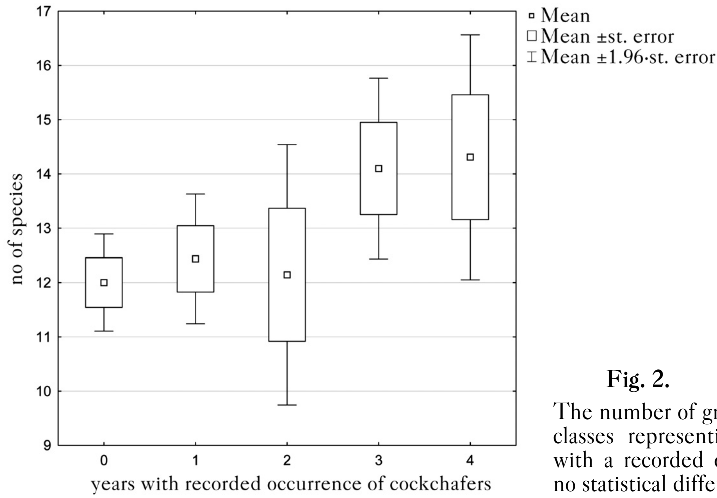

Fig. 2.
The number of ground beetle species in the classes representing the number of years with a recorded occurrence of cockchafers; no statistical differences between classes

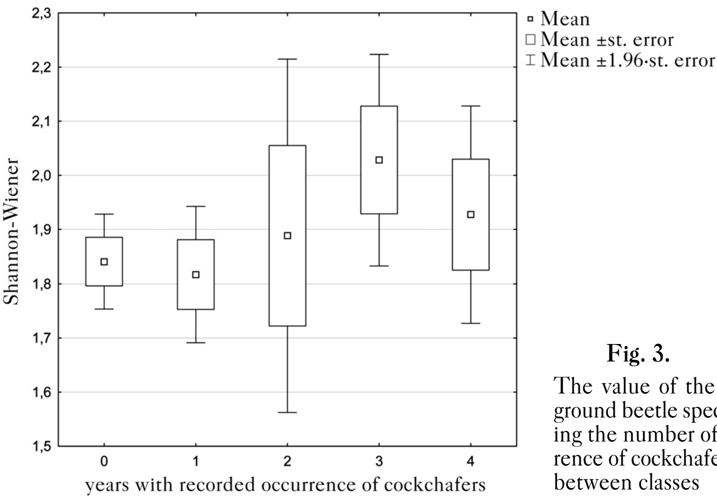

Fig. 3.
The value of the Shannon-Wiener index of ground beetle species in the classes representing the number of years with recorded occurrence of cockchafers; no statistical differences between classes

incrementally in higher classes of cockchafer occurrence up to 2.903 ±0.824 in class 3 and then slightly decreasing in class 4 to 2.720 ±0.676 although the general effect was not statistically significant (ANOVA F=2.090, *p*=0.09) as well as the differences between individual classes. The minimum value was the lowest in class 0 (0.927) and the highest in class 3 (1.860), while the maximum value was the lowest in class 1 (3.517) and the highest (4.302) in class 3 (Fig. 4).

DOMINANT SPECIES. The occurrence pattern of the 5 dominant ground beetle species was not the same within each individual species (Fig. 5). In the case of 2 species (*C. glabratus* and *C. violaceus*) the highest number of collected beetles was recorded in class 4, but in the case of *C. violaceus* the number increased incrementally between classes 2 and 4. *C. arvensis* showed the opposite pattern with the number of beetles decreasing with increasing class of cockchafer occurrence. Lastly, in both species of *Pterostichus* no clear pattern was found.

EFFECT OF STAND FEATURES. The indices describing the diversity of ground beetles were analysed in the whole sample of plots (141). In the stands belonging to the group 'coniferous' (98 plots,

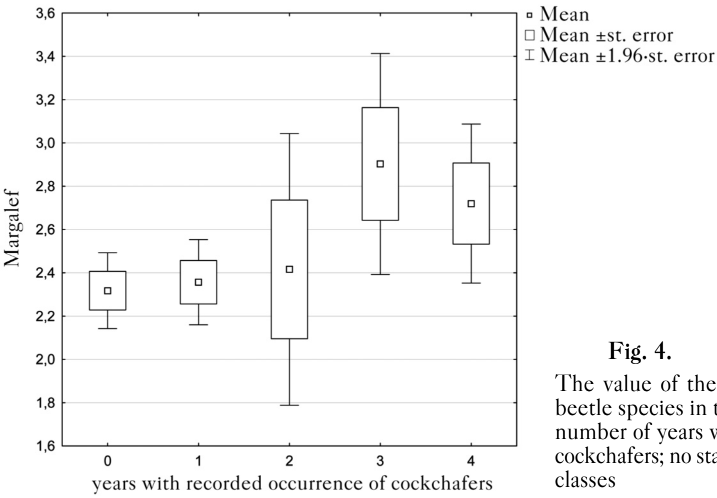

Fig. 4.

The value of the Margalef index of ground beetle species in the classes representing the number of years with recorded occurrence of cockchafers; no statistical differences between classes

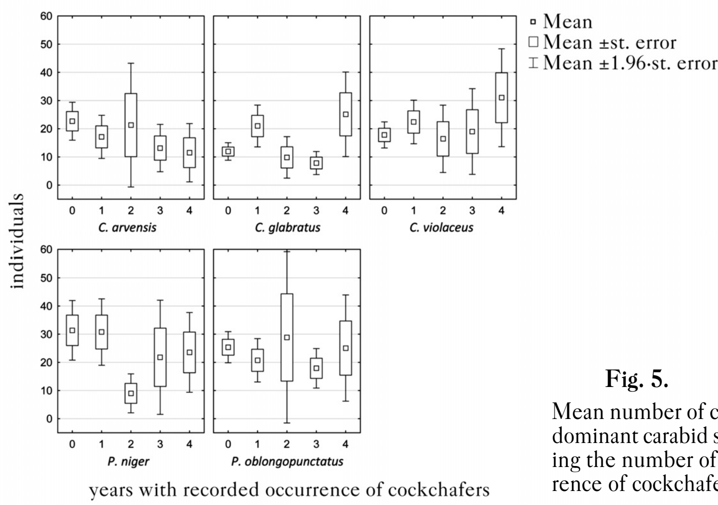

Fig. 5.

Mean number of collected beetles from the 5 dominant carabid species in classes representing the number of years with recorded occurrence of cockchafers including 51 with cockchafers), the mean number of ground beetle species was slightly lower (12.03 ±3.62) than in 43 (including 18 with cockchafers) plots in the stands qualified as 'deciduous' (13.54 ±4.07) with a statistically significant difference (ANOVA F=4.78, p=0.03). Similarly, the Shannon-Wiener and the Margalef indices were lower in 'coniferous' plots (1.83 ±0.38 and 2.31 ±0.69, respectively) than in 'deciduous' plots (1.92 ±0.38 and 2.64 ±0.79, respectively), however the difference was significant only in case of the Margalef index (ANOVA F=6.23, p=0.01).

In regards to the age of stands, no significant effects were observed. In the stands belonging to the group '>60' (101 plots), the mean number of ground beetle species was slightly lower (12.46 ±3.74) than in 40 plots in the stands qualified as '<60' (12.55 ±4.04) with no statistically significant difference found (ANOVA F=0.01, p=0.91). Conversely, the Shannon-Wiener and the Margalef indices were higher in the '>60' plots (1.86 ±0.38 and 2.42 ±0.76, respectively) than in the '<60' plots (1.83 ±0.40 and 2.38 ±0.68, respectively), however the difference was not statistically significant in the case of either indices (ANOVA F=0.32, p=0.57 and F=0.09, p=0.76, respectively).

Discussion

During a one year period of beetle trapping, beetles belonging to 67 species were collected which is almost the same number as in the anthropogenic grasslands of Germany where 66 species were identified (Mayr *et al.*, 2007), but slightly less than in the protected area of Świętokrzyski National Park where 70 species were recorded (Huruk, 1993). Skłodowski and Zdzioch (2006) who studied ground beetles in the Pisz forest which was destroyed by a hurricane found 59 species of ground beetles. Tarwacki (2004) found only 30 species in the Scots pine forest studied, Radawiec and Aleksandrowicz (2013) identified 31 species in an agriculturally managed meadow, and Aleksandrowicz *et al.* (2008) recorded 40 species in a spring wheat field of study. It is obvious that the number of species collected in a study depends on many factors which includes both environmental (site features, species composition, stand age, *etc.*) and technical (number of traps used, frequency of insect collection, trapping period). Therefore, a simple comparison with the results obtained by the cited aforementioned authors should be treated as very general gauge to enabling the comparison of our results to those obtained in other studies. However, taking into account the short trapping period, one can conclude that the range of species captured in the forests of Lubaczów and Narol Forest Districts is relatively rich.

The diversity of ground beetles, expressed by the mean number of species collected, increased with the classes reflecting the number of years with recorded occurrences of cockchafers (Fig. 2). This pattern was not fully reflected by the diversity indices (Fig. 3 and 4), although their values were higher in the classes with longer lasting occurrences of cockchafers. This variability can be explained by features and relationships which will proceed to describe.

As mentioned prior, the occurrence of ground beetles is closely related to food resources. They belong to several trophic guilds with most of the species being predatory (often divided into groups of large and small zoophages), some species which are hemizoophages, and others phytophagous (Riddick, 2008). There are also species with unknown feeding ecologies, therefore one could assume a relationships with decaying organic matter. As ground beetles are widely distributed throughout various environments, the food relationships with their conditions are very complex. Nevertheless, we posit that the observed increase in species richness corresponding with the occurrence of cockchafers is related to the changes in the food accessibility which are favourable for several trophic guilds of carabids. The positive effect of a 'swarming year' (2015) could contribute to the enhancement of food resources resulting in the increase in the number of species (Fig. 2) and diversity indices (Fig. 3 and 4). It was observed that the feeding of foliophagous larvae causes considerable fall of valuable organic matter onto the forest floor which has a positive effect on matter cycling in the ecosystem by fast decomposition processes (Płatek *et al.*, 2005). Therefore, a similar effect of the grubs feeding can contribute to the response of carabid beetles to environmental changes.

The stands in the study area were subjected to protective treatments during the period covered by of the analysis. Two types of treatments were applied: mechanical and chemical. In the mechanical treatment, only the collection of *Melolontha* adults was applied, therefore no effect on epigeic beetles could be ascertained. In the chemical treatment applied for *Melolontha* adults, spraying with Mospilan 20 SP, a neonicotinoid-based product, was used. Laboratory assays demonstrated that Mospilan has no toxic effect on the carabid beetle *Harpalus rufipes* (De Geer) (Lanzi *et al.*, 2022). Further, field investigations showed that the fluctuations in carabid fauna in sprayed and control stands were of more general kind with Mospilan having no effect (Mazur *et al.*, 2015). Therefore, we can assume that control measures applied against *Melolontha* did not substantially disturb the studied relationships with carabid fauna.

The stand features including age and general species composition had a slight or no effect on the analysed results. The 'coniferous' and 'deciduous' plots with and without the presence of cockchafers were almost equally represented (about a half in each group). Therefore, the effect of this stand feature can be regarded as negligible in regard to the disturbances caused by *Melolontha*. Lutyk (2002) reports that in older Scots pine stands (over 60 years) the number of collected ground beetle species was higher (18-20 species) than in the young stands (20-40 years) which was markedly lower (14-15 species). Our findings, in contrast those just cited, are most likely a result of the larger sample size and higher diversity of stands with traps. Nevertheless, the results of our analysis suggest no significant effect of stand features on the studied effects of disturbance on ground beetles.

It has been documented that carabids prey upon the Coleoptera families such as Curculionidae or Nitidulidae (Riddick, 2008) as well as on moths such as , *e.g.*, *Lymantria dispar* (L.) (MacLean and Usis, 1992). The predation of Carabidae on dung beetles has also been documented in the literature (*e.g.*, Young, 2015). A total of 27 species of ground beetle prey upon the larvae of *Phyllophaga* and *Melolontha* (Coleoptera: Scarabaeidae) (Larochelle, 1990). This could explain the effect of the occurrence of cockchafers on carabids, especially in regard to the abundance of large predators. The dominant species in our collected insects were large (*Carabus* spp.) or medium-sized (*Pterostichus* spp.) predatory beetles (Fig. 5) known for feeding on insects (Fawki *et al.*, 2005) and in the case of *P. oblongopunctatus* also in the larval stage (Schelvis and Siepel, 1988). On the other hand, it is hard to ascertain the direct effect on the abundance of grubs as prey as they spend their lives in deep soil layers, being inaccessible for carabids. For this reason, the effect could rather be indirect, through more complex relationships in the microenvironment and inhabiting organisms.

It is probable that non-predatory carabid species (*e.g.*, seed feeding but also saprophagous) are attracted by the decaying organic matter from the roots and plants damaged or killed by the grubs. Beetles from at least some of the species collected in our traps, such as *Amara communis* (Panz.), *A. similata* (Gyll.), *Harpalus rufipes*, and *H. latus* (L.), are known as phytophages (Mayr *et al.*, 2007; Cutler *et al.*, 2012), and representatives of some genera (*Amara*, *Harpalus*, *Poecilus*, *Pterostichus*) are known as seed predators (Honek *et al.*, 2003; Riddick, 2008). The increase in abundance of such species represented by beetles of a relatively small size (and biomass) could contribute to an increase in the number of species (Fig. 2) and value of the Margalef index (Fig. 4) in relation to the number of years with recorded occurrences of cockchafers. The effect related to the increase in the abundance of dying or dead plants damaged by the feeding grubs may also be contigent on the properties of forest litter favourable to some carabid species collected such as *Pterostichus oblongopunctatus* (one of the most numerous in the collected material), *Abax carinatus* (Duft.) (Skłodowski *et al*., 2018) as well as *Abax* species: *A. ovalis* (Duft.) and *A. parallelepipedus* (Pill. *et* Mitt.) and small zoophages which were more abundant in the plots with cockchafers.

The variability between classes, representing the number of years with recorded occurrences of cockchafers (stepwise increase between classes 0 and 4, except class 3), can result from disturbances caused by cockchafers similar to those observed following wind damage (Hilszczański *et al*., 2016; Skłodowski, 2017). However, they might also be attributed to the changes in ground beetle species composition in the studied stands with various characteristics which were only generally analysed in this paper.

Conclusions

- The disturbances in the forest ecosystem related to the feeding of cockchafers (both grubs and adults) positively contributed to the diversity of ground beetles.
- The observed increase in species richness is most likely related to changes in food accessibility favourable for several trophic guilds of carabids (predators – hemizoophages – phytophages).
- The effect related to an increase in the abundance of dying and dead plants damaged by the feeding grubs may change the properties of forest litter which is favourable for some carabid species.
- More detailed analysis of the relationships between the diversity of ground beetles and environmental features could contribute to a better understanding of the presented results obtained in the forest stands with various characteristics of this study.

Authors' contributions

W.G. – concept development, manuscript planning and writing, literature review, data analysis and interpretation, final text editing; M.K. – determination of Carabidae, data collection, literature review, analysis and interpretation, text co-editing, M.R. – determination of Carabidae, data collection, literature review, analysis and interpretation, text co-editing.

Conflicts of interest

The authors declare no conflicts of interest regarding the publication of this paper.

Funding source and acknowledgments

The research was done within the project 'Assessment of the biodiversity status in the selected Forest Districts of the Regional Directorate of State Forests in Krosno, based on selected natural and cultural elements – continuation.' Financed by General Directorate of State Forests in Warsaw.

References

Aleksandrowicz, O., Pakuła, B., Mazur, J., 2008. Biegaczowate (Coleoptera: Carabidae) w uprawie pszenicy w okolicy Lęborka. (Carabid beetles (Coleoptera: Carabidae) in the wheat field near Lębork). *Słupskie Prace Biologiczne*, 5: 15-25.

BDL, 2022. Bank Danych o Lasach. (Forest Data Bank). State Forests. Available from: https://www.bdl.lasy.gov.pl [accessed: 15.09.2022].

Cutler, G.C., Renkema, J.M., Majka, C.G., Sproule, J.M., 2012. Carabidae (Coleoptera) in Nova Scotia, Canada wild blueberry fields: prospects for biological control. *Canadian Entomologist*, 144: 1-13. DOI: https://doi.org/10.1653/024.104.0208.

Fawki, S., Smerup Bak, S., Toft, S., 2005. Food preferences and food value for the carabid beetles *Pterostichus melanarius*, *P. versicolor* and *Carabus nemoralis*. European Carabidology 2003. Proceedings of the 11th European Carabidologist Meeting. *DIAS Report*, 114: 99-109.

Głowacka, B., Sierpińska, A., 2012. Control of adult cockchafers *Melolontha* spp. with Mospilan 20 SP. *Folia Forestalia Polonica, Series A – Forestry*, 54 (2): 109-115.

Hammond, H.E.J., Hoffman, P.G.K., Pinno, B.D., Pinzon, J., Klimaszewski, J., Hartley, D.J., 2018. Response of ground and rove beetles (Coleoptera: Carabidae, Staphylinidae) to operational oil sands mine reclamation in northeastern Alberta, a case study. *Journal of Insect Conservation*, 22: 687-706. DOI: https://doi.org/10.1007/s10841-018-0094-4.

Hilszczański, J., Jaworski, T., Plewa, R., Horák, J., 2016. Tree species and position matter: the role of pests for survival of other insects. *Agricultural and Forest Entomology*, 18: 340-348. DOI: https://doi.org/10.1111/afe.12165.

Honek, A., Martinkova, Z., Jarosik, V., 2003. Ground beetles (Carabidae) as seed predators. *European Journal of Entomology*, 100: 531-544. DOI: https://doi.org/10.14411/eje.2003.081.

Huruk, S., 1993. Studia nad zgrupowaniami biegaczowatych (Carabidae, Coleoptera) uroczysk Chełmowa Góra i Serwis w Świętokrzyskim Parku Narodowym. *Fragmenta Faunistica*, 26 (18): 339-371.

Koivula, M., 2011. Useful model organisms, indicators, or both? Ground beetles (Coleoptera, Carabidae) reflecting environmental conditions. *Zookeys*, 100: 287-317. DOI: https://doi.org/10.3897/zookeys.100.1533.

Konieczna, K., Melke, A., Olbrycht, T., 2012. Bioróżnorodność drapieżnych biegaczowatych (Col., Carabidae) i kusakowatych (Col., Staphylinidae) zasiedlających pole uprawne i zadrzewienie śródpolne. [Biodiversity of predacious ground beetles (Col., Carabidae) and rove beetles (Col., Staphylinidae) assemblages in field and field coppice]. *Progress in Plant Protection* (*Postępy w Ochronie Roślin*), 52 (2): 340-346.

IBL, 2020. Krótkoterminowa prognoza występowania ważniejszych szkodników i chorób infekcyjnych drzew leśnych w Polsce w 2020 roku. Analizy i Raporty, 32. Warszawa: Instytut Badawczy Leśnictwa, 146 pp.

Lanzi, A., Laskowski, R., Bauchinger, U., 2022. Combined effects of insecticides on survival of the carabid beetle *Harpalus rufipes*. Master thesis, Jagiellonian University, Faculty of Biology. Available from: https://ruj.uj.edu.pl/xmlui/handle/item/293390.

Larochelle, A., 1990. The food of carabid beetles (Coleoptera: Carabidae including Cicindellinae). Sillery: Association des entomologistes amateurs du Québec, 132 pp.

Lutyk, P., 2002. Wpływ wieku drzewostanów sosnowych i bonitacji siedliska na epigeiczne chrząszcze (Coleoptera). [Influence of age of scotch pine stands and quality of habitat on epigeic beetles (Coleoptera)]. *Prace Instytutu Badawczego Leśnictwa*, 2 (933): 47-72.

MacLean, D.B., Usis, J.D., 1992. Ground beetles (Coleoptera: Carabidae) of Eastern Ohio forests threatened by the Gypsy moth, *Lymantria dispar* (L.) (Lepidoptera: Lymantriidae). *Ohio Journal of Science*, 92 (3): 46-50.

Mayr, S., Wolters, W., Dauber, J., 2007. Ground beetles (Coleoptera: Carabidae) in anthropogenic grasslands in Germany: effects of management, habitat and landscape on diversity and community composition. *Wiadomości Entomologiczne*, 26 (3): 169-184.

Mazur, S., Tracz, H., Głowacka, B., Byk, A., 2015. Ocena wpływu insektycydów stosowanych w zabiegach agrolotniczych na owady nie będące celem zwalczania. Sprawozdanie końcowe z realizacji tematu badawczego. Warszawa: Szkoła Główna Gospodarstwa Wiejskiego, 90 pp. Available from: https://www.lasy.gov.pl/pl/pro/publikacje/copy_of_gospodarka-lesna/ochrona_lasu/ocena-wplywu-insektycydow.

Niemczyk, M., 2015. Ryzyko masowego występowania pędraków chrabąszczy (*Melolontha* spp.) w strefie ekotonowej drzewostanów dojrzałych na terenie Nadleśnictwa Lubaczów. [Risk of the mass occurrence of cockchafer (*Melolontha* spp.) grubs in the ecotone of mature stands in Lubaczów Forest District]. *Sylwan*, 159 (4): 326-335. DOI: https://doi.org/10.26202/sylwan.2014117.

Niemczyk, M., Karwański, M., Grzybowska, U., 2017. Effect of environmental factors on occurrence of cockchafers (*Melolontha* spp.) in forest stands. *Baltic Forestry*, 23 (2): 334-341.

Niemelä, J., Koivula, M., Kotze, D.J., 2007. The effects of forestry on carabid beetles (Coleoptera: Carabidae) in boreal forests. *Journal of Insect Conservation*, 11 (1): 5-18. DOI: https://doi.org/10.1007/s1084 1-006-9014-0.

Nunberg, M., 1948. Chrabąszcz i jego zwalczanie. *Instytut Badawczy Leśnictwa, Seria C – ulotki i wydawnictwa popularne*, 5, 22 pp.

Płatek, K., Michalski, A., Sałek, P., 2005. Czy żerowanie larw foliofagów sosny może mieć pozytywny wpływ na funkcjonowanie drzewostanów? (Can the feeding of pine foliophage's larvae have positive effect on the functioning of stands?). *Sylwan*, 149 (9): 44-50. DOI: https://doi.org/10.26202/sylwan.2005044.

Radawiec, B., Aleksandrowicz, O., 2013. Biegaczowate (Coleoptera: Carabidae) użytkowanej rolniczo łąki obszaru Natura 2000 w Dolinie Wieprzy. (Carabids (Coleoptera: Carabidae) of the agricultural utilized meadow on Natura 2000 area in the Valley of Wieprza River). *Przegląd Naukowy – Inżynieria i Kształtowanie Środowiska*, 62: 389-401.

Riddick, E.W., 2008. Ground beetle (Coleoptera: Carabidae) feeding ecology. In: J.L. Capinera, ed. *Encyclopedia of Entomology*. Dordrecht: Springer, pp. 1742-1747. DOI: https://doi.org/10.1007/978-1-4020-6359-6_1201.

Schelvis, J., Siepel, H., 1988. Larval food spectra of *Pterostichus oblongopunctatus* and *P. rhaeticus* in the field (Coleoptera: Carabidae). *Entomologia Generalis*, 13 (1/2): 61-66. DOI: http://doi.org/10.1127/entom.gen/13/1988/61.

Schwerk, A., Sałek, P., Duszczyk, M., Abs, M., Szyszko, J., 2006. Variability of Carabidae in time and space in open areas. *Entomologica Fennica*, 17: 258-268. DOI: https://doi.org/10.33338/ef.84341.

Schwerk, A., Szyszko, J., 2007. Increase of Mean Individual Biomass (MIB) of Carabidae (Coleoptera) in relation to succession in forest habitats. *Wiadomości Entomologiczne*, 26 (3): 195-206.

Sierota, Z., Grodzki, W., Szczepkowski, A., 2019. Abiotic and biotic disturbances affecting forest health in Poland over the past 30 years: impacts of climate and forest management. *Forests*, 10: 75. DOI: https://doi.org/10.3390/f10010075.

Skalski, T., Armatys, P., Loch, J., 2010. Wtórna sukcesja zgrupowań biegaczy (Coleoptera, Carabidae) na terenach po gradacji zasnui wysokogórskiej *Cephalcia falleni* w Gorczańskim Parku Narodowym. [Secondary succession of ground beetle assemblages (Coleoptera, Carabidae) on post outbreak areas of sawfly *Cephalcia falleni* in the Gorce National Park]. *Ochrona Beskidów Zachodnich*, 3: 26-33.

Skłodowski, J., 2017. Three phases of changes in carabid assemblages during secondary succession in a pine forest disturbed by windthrow – results from the first 10 years of observations. *Insect Conservation and Diversity*, 10: 449--461. DOI: https://doi.org/10.1111/icad.12237.

Skłodowski, J., Bajor, P., Trynkos, M., 2018. Carabids benefit more from pine stands with added understory or second story of broad-leaved trees favored by climate change than from one-storied pine stands. *European Journal of Forest Research*, 137: 745-757. DOI: https://doi.org/10.1007/s10342-018-1137-9.

Skłodowski, J., Zdzioch, P., 2006. Biegaczowate (Coleoptera: Carabidae) w drugim roku spontanicznej sukcesji regeneracyjnej zniszczonych przez huragan drzewostanów Puszczy Piskiej. [Ground beetles (Coleoptera: Carabidae) in second year of regenerative succession of Pisz forests destroyed by hurricane]. *Wiadomości Entomologiczne*, 25, Supl. 1: 97-110.

Skrzecz, I., Perlińska, A., 2018. Current problems and tasks of forest protection in Poland. *Folia Forestalia Polonica, Series A – Forestry*, 60: 161-172. DOI: https://doi.org/10.2478/ffp-2018-0016.

Szujecki, A., 1980. Ekologia owadów leśnych. Warszawa: PWN, 603 pp.

Szujecki, A., 1995. Entomologia leśna. Tom I. Warszawa: Wydawnictwo SGGW, pp. 201-292.

Szujecki, A., ed. 2001. Próba szacunkowej waloryzacji lasów Puszczy Białowieskiej metodą zooindykacyjną. Warszawa: Wydawnictwo SGGW, 419 pp.

Szyszko, J., 1974. Relationship between the occurrence of epigeic carabids (Coleoptera, Carabidae), certain soil properties and species composition of a forest stand. *Ekologia Polska*, 22: 237-274.

Szyszko, J., 1983. Methods of macrofauna investigations. In: A. Szujecki, J. Szyszko, S. Mazur, S. Perliński, eds. *The process of forest soil macrofauna formation after afforestation of farmland*. Warsaw: Warsaw Agricultural University Press, pp. 10-16.

Tarwacki, G., 2004. Zróżnicowanie gatunkowe zgrupowań biegaczowatych (Carabidae) w monokulturach sosnowych po zastosowaniu ogniskowo-kompleksowej metody ochrony lasu. (Species differentiation of Carabidae communities in Scots pine monocultures after using the complex-centre forest protection method). *Leśne Prace Badawcze*, 1: 103-118.

Tarwacki, G., 2012. Charakterystyka ekologiczno-wskaźnikowa zgrupowań biegaczowatych (Carabidae) w ogniskowo--kompleksowej metodzie ochrony lasu. (Ecological-indicatory characteristics of Carabidae communities in centre--complex method of forest protection) *Sylwan*, 156 (9): 684-694. DOI: https://doi.org/ 10.26202/sylwan.2011124.

TIBCO Software Inc., 2017. Statistica (data analysis software system), version 13. http://statistica.io.

Ulatowski, W., 1933. Pędrak chrabąszcza (*Melolontha vulgaris*) i jego zwalczanie. *Sylwan*, 51 (7/8/9): 251-252.

Woreta, D., Sukovata, L., 2014. Survival and growth of the *Melolontha* spp. grubs on the roots of the forest's main tree species. *Forest Research Papers*, 75 (4): 375-383. DOI: https://doi.org/10.2478/frp-2014-0035.

Young, O.P., 2015. Predation on dung beetles (Coleoptera: Scarabaeidae): A literature review. *Transactions of the American Entomological Society*, 141 (1): 111-155. DOI: https://doi.org/10.3157/061.141.0110.

Zarządzenie, 2016. Zarządzenie nr 7 Dyrektora Generalnego Lasów Państwowych z dnia 11 lutego 2016 r. w sprawie korekty Instrukcji Ochrony Lasu, stanowiącej załącznik do Zarządzenia nr 57 Dyrektora Generalnego z dnia 22 listopada 2011 r. oraz korekty Instrukcji Urządzania Lasu, stanowiącej załącznik do Zarządzenia nr 55 Dyrektora Generalnego z dnia 21 listopada 2011 r. (ZO.0210.1.2016). *Biuletyn Informacyjny Lasów Państwowych*, 3: 33-34.

Appendix

Species of ground beetles collected on the inventory plots of Lubaczów and Narol Forest Districts

Species	Number of individuals collected on plots:	
	without cockchafers	with cockchafers
Abax carinatus (Duft.)	180	303
Abax ovalis (Duft.)	137	238
Abax parallelepipedus (Pill. et Mitt.)	25	116
Abax parallelus (Duft.)	16	6
Acupalpus dubius Schilsky	1	0
Agonum fuliginosum (Panz.)	4	3
Agonum viduum (Panz.)	1	1
Amara aulica (Panz.)	4	0
Amara communis (Panz.)	137	130
Amara similata (Gyll.)	2	0
Amara sp.	5	15
Anisodactylus binotatus (Fabr.)	1	2
Badister lacertosus Sturm	4	1
Bembidion lampros (Herbst)	10	9
Bembidion mannerheimii (Sahlb.)	0	1
Bembidion quadrimaculatum (L.)	2	0
Calathus erratus (Sahlb.)	5	0
Calosoma inquisitor (L.)	1	0
Carabus arvensis Herbst	1496	927
Carabus cancellatus Ill.	80	44
Carabus convexus Fabr.	97	103
Carabus coriaceus L.	257	301
Carabus glabratus Payk.	513	898
Carabus granulatus L.	160	233
Carabus hortensis L.	315	198
Carabus intricatus L.	1	10
Carabus irregularis Fabr.	0	1
Carabus linnei Panz.	147	575
Carabus obsoletus Sturm	2	0
Carabus variolosus Fabr.	0	1
Carabus violaceus L.	1264	1497
Clivina fossor (L.)	2	0
Cychrus caraboides (L.)	361	288
Cymindis humeralis (Geoffr. in Four.)	9	13
Drypta dentata (Rossi)	0	8
Dyschirius globosus (Herbst)	30	1
Elaphrus cupreus Duft.	0	3
Harpalus latus (L.)	40	47
Harpalus rufipes (De Geer)	22	13
Leistus piceus Frölich	12	9
Leistus rufomarginatus (Duft.)	4	15
Molops piceus (Panz.)	7	11
Nebria brevicollis (Fabr.)	4	1
Notiophilus sp.	44	38
Oxypselaphus obscurus (Herbst)	13	17
Panagaeus bipustulatus (Fabr.)	14	3

Appendix continued

Species of ground beetles collected on the inventory plots of Lubaczów and Narol Forest Districts

Species	Number of individuals collected on plots:	
	without cockchafers	with cockchafers
Patrobus atrorufus (Strom)	2	0
Platyderus rufus Duft.	41	47
Platynus assimilis (Payk.)	94	63
Poecilus cupreus (L.)	3	5
Poecilus lepidus (Leske)	2	1
Poecilus versicolor (Sturm)	21	18
Pterostichus aethiops (Panz.)	99	132
Pterostichus anthracinus (Ill.)	57	18
Pterostichus burmeisteri Heer	0	1
Pterostichus foveolatus (Duft.)	2	1
Pterostichus melanarius (Ill.)	255	351
Pterostichus minor (Gyll.)	1	2
Pterostichus niger (Schall.)	2165	1747
Pterostichus oblongopunctatus (Fabr.)	1726	1445
Pterostichus rufitarsis (Dejean)	5	7
Pterostichus strenuus (Panz.)	6	5
Pterostichus vernalis (Panz.)	0	1
Stomis pumicatus (Panz.)	3	5
Syntomus truncatellus (L.)	2	0
Synuchus vivalis (Ill.)	0	1
Trichotichnus laevicollis (Duft.)	11	2
Total	9924	9932

STRESZCZENIE

Różnorodność biologiczna owadów a szkodniki leśne – przypadek biegaczowatych (Col.: Carabidae) i chrabąszczy (Col.: Melolonthinae) w południowo-wschodniej Polsce

Owady stanowią ważny element ekosystemów leśnych, odgrywając różne role w zależności od swojej biologii, ekologii czy behawioru, przez co jedne klasyfikuje się jako szkodniki leśne, a inne jako bioindykatory. Wszystkie grupy współwystępują w tych samych ekosystemach leśnych, a między nimi zachodzą złożone relacje kształtujące ich zbiorowiska oraz warunki środowiskowe. Chrząszcze z rodziny biegaczowatych (Carabidae) są grupą owadów wrażliwych na zmiany warunków środowiskowych, przez co często wykorzystywane są jako bioindykatory zmian w ekosystemach leśnych. Ich występowanie jest silnie związane z zasobami pokarmowymi. Chrabąszczowate (Melolonthinae) znane są w Europie jako szkodniki leśne, które żerując na korzeniach roślin i liściach drzew, wyrządzają szkody w uprawach i w drzewostanach. Największe znaczenie mają chrabąszcze o podobnej biologii: majowy *Melolontha melolontha* L. i kasztanowiec *M. hippocastani* F.

W latach 2016-2022 na terenie Nadleśnictw RDLP w Krośnie oraz w 3 parkach narodowych (południowo-wschodnia Polska) wykonywano inwentaryzację wybranych walorów przyrodniczych i kulturowych, w ramach której pozyskano dane dotyczące biegaczowatych. Celem przedstawio-

nych w artykule badań była ocena wpływu występowania chrabąszczy na różnorodność chrząszczy z rodziny biegaczowatych. Badania prowadzono na terenie nadleśnictw Lubaczów i Narol (RDLP w Krośnie), które od dawna cechuje wzmożone występowanie chrabąszczy powodujących szkody. Dla potrzeb analizy wykorzystano dane dotyczące ich występowania w oddziałach leśnych podczas 4 lat poprzedzających odłowienie biegaczowatych (2015-2018), udostępnione przez Zespół Ochrony Lasu w Krakowie. Za oddziały objęte ich występowaniem w danym roku uznawano te, w których spełnione było przynajmniej jedno z kryteriów kwalifikujących je jako uporczywe pędraczyska. Oddziały sklasyfikowano pod względem liczby lat występowania chrabąszczy (klasy 0-4) w 4-letnim okresie objętym analizą.

Chrząszcze z rodziny biegaczowatych były odławiane do pułapek ziemnych typu Barbera w sezonie wegetacyjnym 2018 r. Ze 190 stanowisk na terenie obu nadleśnictw wybrano do analizy 141, odrzucając te, w których odłowiono mniej niż 50 osobników biegaczowatych (tab. 1, ryc. 1). Spośród tych powierzchni na 69 stwierdzono obecność chrabąszczy przynajmniej w jednym roku. Do scharakteryzowania zróżnicowania pozyskanych biegaczowatych obliczono dla każdego stanowiska liczbę gatunków oraz wskaźniki Shannona-Wienera i Margalefa. Obliczone wskaźniki poddano analizie w relacji do liczby lat w czteroleciu ze stwierdzonym występowaniem chrabąszczy. Liczba powierzchni w oddziałach objętych występowaniem chrabąszczy była największa w 2015 r. (58), najniższa – w 2016 r. (20), a w latach 2017-2018 wynosiła odpowiednio 27 i 30. W 2018 r. na wszystkich powierzchniach odłowiono 19 856 osobników biegaczowatych z 65 gatunków, średnio 140,8 osobnika na 1 powierzchnię. Najliczniej odłowiono biegaczowate z gatunków: *Pterostichus niger* (Schall.) – 3912 (19,7%), *P. oblongopunctatus* (F.) – 3171 (16,0%), *Carabus violaceus* L. – 2761 (13,9%), *C. arvensis* Herbst – 2423 (12,2%) i *C. glabratus* Payk. – 1411 (7,1%). Średnia liczba gatunków odłowionych na jednej powierzchni wynosiła 12,5 (6-23 gatunki), wzrastając w kolejnych klasach odpowiadających liczbie lat z występowaniem chrabąszczy (ryc. 2). Średnia wartość wskaźnika Shannona-Wienera wyniosła 1,858 i była najniższa w klasach 0 i 1, najwyższa w klasie 3 i nieco niższa w klasach 2 i 4 (ryc. 3). Średnia wartość wskaźnika Margalefa wyniosła 2,412 i była najniższa w klasie 0, wzrastając stopniowo w klasach 1-3 (ryc. 4). Spośród dominujących gatunków 2 – *C. glabratus* i *C. violaceus* – wystąpiły najliczniej w klasie 4, podczas gdy u gatunków z rodzaju *Pterostichus* nie stwierdzono w tym zakresie wyraźnego wzorca (ryc. 5).

Występowanie biegaczowatych związane jest z zasobami pokarmowymi, przy czym gatunki z tej rodziny należą do różnych grup troficznych – większość to gatunki drapieżne, część to hemizoofagi, ale niektóre są roślinożercami. Stwierdzony stopniowy wzrost liczby gatunków biegaczowatych w kolejnych klasach występowania chrabąszczy wiąże się ze zmianami w zasobach pokarmowych odpowiadających poszczególnym grupom troficznym. Możliwe, że gatunki niebędące drapieżcami reagują wówczas pozytywnie na wzrost dostępności rozkładającej się materii organicznej, np. z obumarłych sadzonek lub korzeni. Wzrost liczebności tych gatunków, o małych wymiarach ciała, mógł wpłynąć pozytywnie na liczbę gatunków i wartość wskaźnika Margalefa. Wiadomo, że Carabidae pozytywnie reagują na zmiany wynikające z zaburzeń, takich jak żery innych grup owadów, co mogło mieć miejsce także w analizowanym przypadku wzmożonego występowania chrabąszczy.