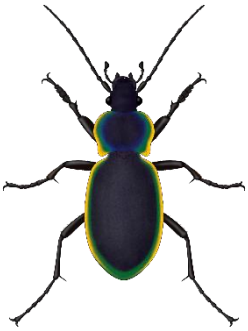
UNIVERSITY OF WARMIA AND MAZURY IN OLSZTYN

FACULTY OF BIOLOGY AND BIOTECHNOLOGY

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Energy willow plantations as a refuge for ground beetle assemblages (Coleoptera, Carabidae) in agricultural lands



Doctorate dissertation carried out in the Department of

Ecology and Environmental Protection

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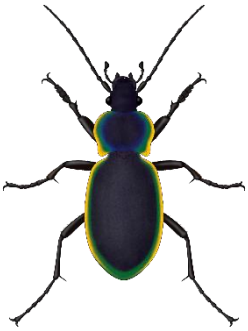
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UNIWERSYTET WARMIŃSKO-MAZURSKI W OLSZTYNIE

WYDZIAŁ BIOLOGII I BIOTECHNOLOGII

NATALIA STEFANIA PIOTROWSKA

Plantacje wierzby energetycznej jako refugium dla zgrupowań biegaczowatych (Coleoptera, Carabidae) na terenach użytkowanych rolniczo



Rozprawa doktorska wykonana w Katedrze Ekologii i Ochrony Środowiska pod kierunkiem dr hab. Stanisława Zbigniewa Czachorowskiego, prof. UWM i prof. dr hab. inż. Mariusza Jerzego Stolarskiego

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Granting information

1. INTRODUCTION

Over the past few decades, European agricultural landscape has changed significantly. Traditional, extensive farming systems have been largely replaced by intensive farming, which is characterized by greater use of fertilizers, plant protection products and a large number of agrotechnical treatments performed. It is believed that the trend of agricultural intensification, especially in less developed Central Europe, accelerated as a result of European Union policy (Henle et al., 2008; Pe'er et al., 2020; Scown et al., 2020). The ongoing transformation increased anthropopressure and contributed to the breakdown of the ecological networks. It resulted in the deterioration of the natural environment, including a decline in biodiversity.

A group that very well reflects changes in the environment are insects (Montgomery et al., 2021). Recent studies show a significant decrease in their biomass, as well as in species diversity, especially in Europe and North America (Leather, 2018; Sánchez-Bayo and Wyckhuys, 2021; Shortall et al., 2009). In some areas, even a 75% decrease in insect biomass was observed (Hallmann et al., 2017). The main reasons are considered anthropogenic factors such as the aforementioned land use changes (Sánchez-Bayo and Wyckhuys, 2019; van Klink et al., 2020), land fragmentation by roads (Keller et al., 2005, 2004), environmental pollution and pesticides, as well as climate change (Sánchez-Bayo and Wyckhuys, 2019; van Klink et al., 2020).

A well-known group with a long tradition of use in environmental monitoring are beetles from the Carabidae family (Coleoptera, Carabidae) (Allegro and Sciaky, 2003; Cameron and Leather, 2012; Ghannem et al., 2018; Koivula, 2011; Ludwiczak et al., 2020; Magura et al., 2017; Rainio and Niemelä, 2003). They meet all the requirements of a good bioindicator - they are numerous in the environment, dynamically react to habitat changes, and their ecology is relatively well known. More than 500 species of Carabidae have been found in Poland, and the characteristics of their communities inhabiting various environments have also been described. The role of ground beetles in agricultural areas is not to be underestimated. Carabidae, being mostly predators, provide valuable ecosystem services by contributing to the control of pest populations (Holland, 2002; Honek et al., 2003; Kromp, 1999; Menalled et al., 2007). Therefore, they are a desirable element of entomofauna in arable plantations. This is especially true of large, predatory species of the genus Carabus, which also are indicators of good habitat conditions (Rainio and Niemelä, 2003).

The unification of the landscape structure related to the intensification of agricultural management contributes to the decline in biodiversity (Concepción et al., 2012). This process can be reversed by introducing crop-mosaic patterning at the local and regional landscape scale.

According to the assessment of the European Commission, ecological focus areas (ECFs), including short rotation coppice (SRC) can increase the heterogeneity of the landscape mosaic, and by creating new habitats improve biodiversity on arable farms in the EU. Establishing crops of this type is also consistent with the current energy policy of the European Union, in which the search for new solutions to reduce greenhouse gas emissions plays an important role (European Commission, 2017; *Global Energy Review 2021*, 2021; Haberl et al., 2011; López-Bellido et al., 2014; Popp et al., 2011, 2021; Ruppert et al., 2013; WBA, 2021). With an appropriate management system, short rotation coppice (SRC) crops do not compete with existing food crop production and do not lead to the destruction of natural lands, especially those with high nature conservation value (Cossel et al., 2019; Dauber and Miyake, 2016; Stolarski et al., 2019, 2011; Valentine et al., 2012; von Cossel, 2020). The most popular plant grown in this system in Poland is willow (*Salix* spp.), especially basket willow (*S. viminalis*), a low-growing, deciduous tree or shrub native to Europe. The influence of willow plantations on abiotic factors is broadly described and considered, generally, positive (Dickinson and Pulford, 2005; Greger and Landberg, 1999; Kacálková et al., 2015; Mleczek et al., 2018; Pandey et al., 2016). In addition, it was found that willow crops can provide a habitat suitable for herbaceous plants and serve as a shelter for many animal species, including beneficial epigeic beetles from the Carabidae family.

The knowledge about Carabidae assemblages, occurring in energy plantations, including willow, remains still incomplete. Due to the gap in this knowledge, research on ground beetles inhabiting willow plantations has been undertaken, including species composition and ecology. The cultivations of other perennial bioenergy crops: the cup plant (*Silphium perfoliatum*), the virginia mallow (*Sida hermaphrodita*) and the giant miscanthus (*Miscanthus* × *giganteus*) as well as the row crop and fallow land served as comparative plots for the study conducted. The research problem was formulated in the form of a question: "Can willow plantations be a refuge for ground beetles from the Carabidae family in the agricultural landscape, and thus contribute to increasing biodiversity in the model of sustainable agriculture?". In order to answer this question, the ground beetles assemblages inhabiting different plots were investigated, taking into account their ecology and role in determining the state of the natural environment. Based on the literature, the following research hypotheses were formulated:

H1: Carabidae assemblages inhabiting the willow plantations differ significantly from assemblages inhabiting other perennial bioenergy crops, as well as row crops and fallow land.

H2: Energy willow, as a woody plant, is a valuable habitat for Carabidae preferring a forest environment, creating corridors that allow brachypterous species to disperse in an agricultural landscape dominated by large monocultures.

H3: Plantations maintained in the Eco-Salix system are inhabited by the largest number of ground beetles from the Carabidae family preferring the forest environment.

Therefore, the aim of this doctoral dissertation was to clarify the impact of willow (*Salix* spp.) plantations on the Carabidae assemblages in areas intensively used for agricultural purposes. The aforementioned aim was achieved through the implementation of the following detailed objectives:

1. To identify the Carabidae species inhabiting particular research plots,
2. To assess the functional traits of Carabidae assemblages inhabiting particular research plots,
3. To compare the differences noticed between Carabidae assemblages occurring in
4. particular research plots,
5. To assess the impact of willow plantations on species preferring the forest environment and on brachypterous species,
6. To compare Eco-Salix and short rotation coppice (SRC) willow plantations in terms of the Carabidae assemblages inhabiting them,
7. To conclude, which of the studied plots was inhabited by the beetle communities with the highest ecological value.

The added value of this doctoral dissertation is providing a more complete understanding of the importance of energy willow plantations as a refuge for the ground beetles from the Carabidae family. Due to the valuable ecosystem services provided by ground beetles, this is of great importance, especially in intensively farmed areas, where a more environmentally safe sustainable agriculture model should be implemented. Moreover, understanding the species composition and assemblages functional traits of carabid beetle fauna in energy plantations will not only broaden the knowledge about this group but also contribute to facilitating the monitoring of biodiversity in agrocenoses. In addition, understanding the role that willow plantations can play as a habitat for ground beetles in agricultural areas can have

strategic importance in spatial planning in a sustainable farming model. It enables creating a system of mutual benefits: plantations serving as a precious habitat - refugium for ground beetles inhabiting disturbed agrocenoses, and Carabidae - as providers of valuable ecosystem services (pest population control) for plantations and adjacent crops.

2. LITERATURE REVIEW

2.1. Concepts of shaping the agricultural landscape in the context of sustainable agriculture

With the growing world population, the demand for agricultural production rises (FAO, 2009; Spiertz and Ewert, 2009). In response, arable land expansion and higher cropping intensities have been observed. Agriculture places a serious burden on the environment, degrading natural resources. Monocultures, widely used in intensive farming systems do not create stable ecosystems and can have a detrimental influence on the landscape (Dudley and Alexander, 2017; Wright et al., 2021). High intensively cropped plantations can cause over-extraction of groundwater, water pollution, as well as soil contamination. Additionally, they contribute to landscape fragmentation, causing habitat loss, and food-webs degradation (Eeraerts et al., 2019; Karp et al., 2012; Science Communication Unit, 2017; Steckel et al., 2014; Tsiafouli et al., 2015). It results in the isolation of populations and disruption of biological communities, especially species with low dispersion capacity (Birkhofer et al., 2015; Flynn et al., 2009; Pardini et al., 2018). The decrease in landscape heterogeneity often leads to local extinction, observed at all levels of the trophic chain (Chase et al., 2020; Habel et al., 2019; Hallmann et al., 2017; Krauss et al., 2010; Pilling et al., 2020).

The observed negative ecosystem changes caused a lively debate on sustainable agriculture, the main assumption of which is the implementation of solutions that are beneficial both from the economic and environmental points of view. Sustainable agriculture provides a solution to enabling rural areas development, achieving a sustainable environment, and protecting resources. One of the solutions, proposed in the debate, was increasing the landscape mosaic, providing a more diversified habitat. The result of the SLOSS debate, taking place since the 1970s, has been redefined by proving that increasing habitat patchiness contributes to the growth of biodiversity (Bennett and Isaacs, 2014; Bennett et al., 2006). It was emphasized that under migration-promoting factors a larger number of small environmental patches may be more beneficial than single, extensive environmental patches (Báldi, 2008; Fahrig et al., 2022). Moreover, the diversification of landscape composition is assumed to increase the number of ecosystem services (Bennett and Isaacs, 2014; Steckel et al., 2014). On the other hand, it is also proposed to introduce environmental corridors connecting separated environmental patches. They will increase the continuity of the landscape, improving the stability of the habitat (Damschen, 2013; Rogan and Lacher, 2018). Creating environmental corridors in monoculture areas also will enable the movement of animals between land patches with different

characteristics, and will provide better plant dispersion (Çoban et al., 2019; Damschen et al., 2006; Tewksbury et al., 2002; Vergnes et al., 2012; Wehling and Diekmann, 2009).

Increasing the mosaic pattern of the landscape can be achieved by either fallowing (leaving the part of an arable area without sowing for one or more years in a crop rotation system) or introducing crops grown in extensive farming (Corbet, 1995; Staley et al., 2012; Wehling and Diekmann, 2009; Weissteiner et al., 2016). These include perennial energy crops, for example, willow cultivated in the short rotation coppice system. Importantly, with appropriate spatial planning, perennial energy crops do not compete with food security goals and can be successfully planted on land unsuitable for intensive agricultural production (Dauber et al., 2012; Dauber and Miyake, 2016; Fischer et al., 2014; Valentine et al., al., 2012).

2.2. Dynamics of lignocellulosic biomass production in Poland in comparison to other European Union countries

The climate crisis, as well as related social changes, requires managing the transition from fossil fuels to more environmentally friendly renewables. Due to its high availability, biomass plays an important role in the conversion to a sustainable, low-carbon economy. It can be obtained from many different sources, such as agriculture, forestry or industrial residues and waste.

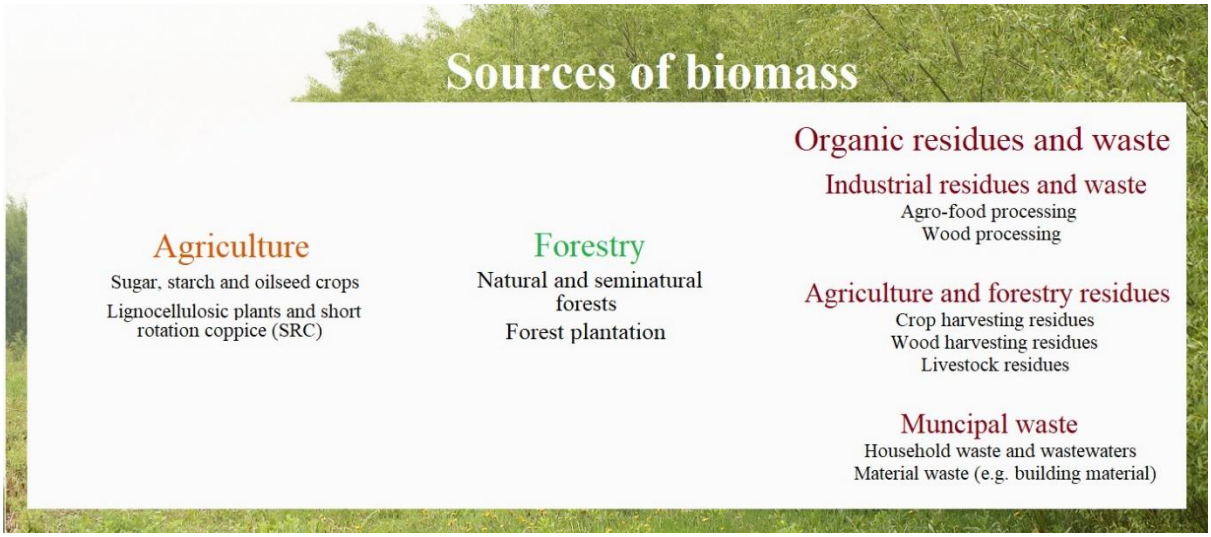


Figure 1. The different biomass sources (the chart was made on the basis of IEA ETP 2017; https://www.ieabioenergy.com/bioenergy-a-sustainable-solution/)

According to the definition contained in the amended Act on Renewable Energy Sources of February 20, 2015 ('RES Act', Dz.U. 2015 poz. 478, 2015; 'Act', Dz.U. 2015 poz. 2376, 2021), biomass is: "biodegradable part of products, waste or residues of biological origin

from agriculture (including plant and animal remains), forestry and related industries (including fisheries and aquaculture), processed biomass (in particular in the form of briquettes, pellets, torrefied biomass and biochar), as well as the biodegradable fraction of industrial or municipal waste of plant or animal origin, including waste from the waste treatment installations and waste from water treatment plants and wastewater treatment plants (in particular sewage sludge) ('RES Act', Dz.U. 2015 poz. 478, 2015; 'Act', Dz.U. 2015 poz. 2376, 2021). Biomass of agricultural origin has also been defined, that is: "biomass from energy crops, as well as waste or residues from agricultural production and industry processing its products" ('RES Act', Dz.U. 2015 poz. 478, 2015; 'Act', Dz.U. 2015 poz. 2376, 2021). It is predicted that the demand for biomass may increase by about two to four times in 2050, from 3.4 t per year to 6.7 t per year or even 13.4 t per year (Haberzettl et al., 2021). A large part of the demand is currently covered by the biomass acquired from energy crops. Especially perennial plants producing lignocellulosic biomass are considered to be one of the most promising feedstocks for the production of advanced biofuels. Its cultivation provides relatively high yields, requiring low inputs such as pesticides, fertilizers or soil tillage and is considered to have beneficial effects on the environment, especially in comparison to rapeseed or oil palms (Alalwan et al., 2019).

According to the data published in the Biomass Supply 2019 report, the area of perennial non-food energy crops in the European Union countries is estimated to be over 117,400 ha, including 63,907 ha short rotation coppice (SRC) willow and poplar cultivations. In Poland, there is approximately 17 824 ha within energy crops cultivation, including 16 320 ha under willow or poplar SRC. Poland is one of the leading countries in the SRC willow and poplar feedstock production, next to Sweden (10,932 ha), Denmark (8,896 ha) and Germany (6,600 ha). It is estimated, that due to the large area of wasteland, accounting for over 15% of EU-28 land, the potential to increase biomass production is high (Calderón et al., 2019). Marginal lands, unsuitable for traditional row crops may be appropriate for biomass crop production, especially lignocellulosic feedstock, due to its ability to tolerate environmental stresses and lower input requirements (Blanco-Canqui, 2016; Shortall, 2013; Stolarski et al., 2019).

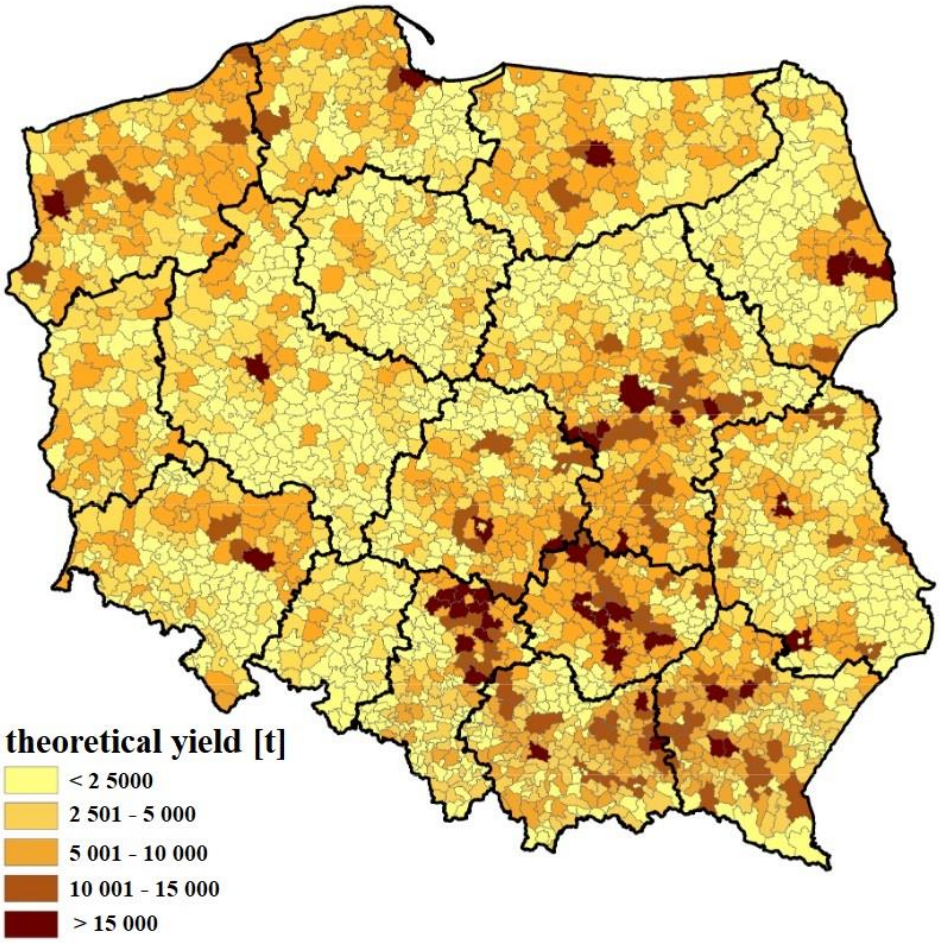


Figure 2. The theoretical yield potential of non-food perennial plants (from: Bioproducts from lignocellulosic biomass derived from marginal lands to fill the gap in the current national bioeconomy (BioMagic), Agreement No. BIOSTRATEG3/344253/2/NCBR/2017).

For Poland, the theoretical yield potential of non-food perennial plants cultivated specifically to provide feedstock for energy production is estimated at 9.6 million tons per year. It is high for the Mazowieckie, Łódzkie, Śląskie, Małopolskie and Podkarpackie voivodships (Fig. 1) (Jędrejek et al., 2021). The production of lignocellulosic biomass will increase with the rising demand, mainly by extending energy crops acreage on marginal lands.

2.3. Characteristics and potential of willow use in the model of sustainable agriculture

There are over 450 species of willow in the world, taking various forms - from small shrubs to trees, reaching over 40 meters in height. Willow trees used for energy purposes belong to the subgenus Caprisalix (Vetrix), containing over 125 species, growing in various parts of the world (Volk et al., 2004). In Poland, the most frequently cultivated for energy purposes is the so-called “energy willow” (Jezierska-Thöle et al., 2016; M. J. Stolarski et al., 2019a). This

term is most often used to describe the common osier, also known as basket willow (*Salix viminalis*), as well as its clones - i.e. hybrid forms with other willow species such as, for example, "INGER" (*Salix triandra* × *Salix viminalis*) or "TORDIS" (*Salix schwerinii* × *Salix viminalis*) (Scriba et al., 2021). Under natural conditions, common osier forms riparian willow forests (Salicetum albae Issler 1926), typical mainly for wet river valleys or on the shores of lakes (Matuszkiewicz, 2008). Also in the plantations established for energy purposes, this species prefers moist soils, on the other hand, willow copes with poor soil quality (Frédette et al., 2019) or heavy contamination, which is why it is often used in bioremediation (Dickinson and Pulford, 2005; Greger and Landberg, 1999; Kacálková et al., 2015; Mleczek et al., 2018; Pandey et al., 2016). Once established, willow plantations can be harvested for over 25 years (M. J. Stolarski et al., 2019b), with an average annual yield of 11-13 t ha^{-1} (dry mass) (Krasuska and Rosenqvist, 2012). Compared to perennial herbaceous crops, willow has a longer production cycle, being harvested every 3-4 years in the SRC technology, and 4 to 6 (or, sometimes more) years in the Eco-Salix technology (Stolarski et al., 2010, 2011). Plantations require a small number of agrotechnical treatments (Sage, 1998), especially maintained in the highly extensive Eco-Salix system (M. Stolarski et al., 2019; Stolarski et al., 2011). In the first year of cultivation, willows grow at a fast rate up to 3.5 cm per day. Harvesting takes place in the third year of cultivation when the coppice reaches approximately 5-7 meters. All clones called "energy willow" are characterized by rapid growth and high biomass production, with an energy value of up to 18,810-20,480 kJ / kg (Finch et al., 2009, Scriba et al., 2021). Compared to traditional row plants, willows are generally resistant to pests. By shedding their leaves in the fall, willows increase the cyclical, seasonal flow of detritus in the area, they are planted.

It is believed that the environmental impact of different types of energy crops varies significantly (Groom et al., 2008; Mohr and Raman, 2013; Saladini et al., 2016). Perennial energy crops, including willow, can contribute to reducing competition for land and water resources with traditional row crops (Liu et al., 2014). One of the ways to increase the mosaic pattern in the agricultural landscape is to introduce energy willow plantations, especially on marginal lands, unsuitable for food production. This not only contributes to the diversification of the range of habitats but also, is beneficial from a socio-economic point of view. It is considered, that plantations may bring income to farmers cultivating low-quality soils, ensuring the development of rural areas (Shortall, 2013; Sobczyk and Sobczyk, 2019; M. Stolarski et al., 2019; Stolarski et al., 2011).

2.4. Dedicated lignocellulosic crops alternative to willow

In addition to willow, in our country, to produce biomass, perennial herbaceous plants and grasses are increasingly used, such as giant miscanthus (*Miscanthus* × *giganteus*), cup plant (*Silphium perfoliatum*), or virginia mallow (*Sida hermaphrodita*). Giant miscanthus is a sterile hybrid of *Giant miscanthus sacchariflorus* and *Giant miscanthus sinensis*, rhizome grasses from East Asia. It is highly adaptive and can be successfully grown in our climate zone (Lewandowski et al., 2000). Due to C4 photosynthesis, it can reach heights of 3–4 metres in one season (Shepherd et al., 2020). It can yield 17-19 tones of dry weight per hectare (Banks et al., 2021). It has the ability to grow on marginal land, with poor soil and water conditions. Its water use efficiency is one of the highest of any crop. It is widely used in bioremediation, especially in soils contaminated with heavy metals (Nebeská et al., 2021).

The cup plant is a species of flowering plant in the family Asteraceae, native to North America (Peni et al., 2020). It achieves the best growth results in moderately moist soil, reaching up to 3 meters in height. It does not require a large amount of agrotechnical treatments (Frölich et al., 2016). The lifetime of the cup plant crops is estimated to be at least 15 years (Matthews et al., 2015). The annual biomass yield can reach 12 to 20 tones of dry weight per hectare (PPO / PRI AGRO Field Technology Innovations et al., 2018). Virginia mallow (Banks et al., 2021; Nahm and Morhart, 2018), like the cup plant, is a plant native to North America. Its' natural habitat is wetlands flooded for most of the year. Plants can reach 3 meters in height and, depending on the type of soil, a yield of 9 to 20 t of dry weight per hectare (Šiaudinis et al., 2015; "Virginia Fanpetals (Sida hermaphrodita Rusby) Cultivated on Light Soil; Height of Yield and Biomass Productivity, "2009). Virginia mallow can grow on less fertile soils (Borkowska and Molas, 2012), including wastelands, or heavily polluted soils, excluded from agricultural use ("Some Effects of Sida hermaphrodita R. Cultivation on Sewage Sludge," 2003). Despite their advantages, cup plant and virginia mallow have a high potential to be invasive (Banks et al., 2021; Gansberger et al., 2015;).

Especially the cup plant, producing large amounts of seeds planted on humid soils, can compete strongly with native plants (Ende et al., 2021; Matthews et al., 2015; PPO / PRI AGRO Field Technology Innovations et al., 2018; Raghu, 2006; Stanford, 1990). Therefore, introducing these plants into the agricultural landscape should be carried out with extreme caution. Virginia mallow and cup plant are characterized by a long flowering period and abundant blooming, which provides a rich forage source for pollinators (Fiedler and Landis, 2007; SPOONER et al., 1985). Cup plant, blooming between June and September, yields enough nectar to make 150 and 560 kg of honey per hectare (Gansberger et al., 2015; Jabłoński and Koltowski, 2005;

PPO / PRI AGRO Field Technology Innovations et al., 2018) For virginia mallow, flowering from June to August, it is even 230 kg per hectare (Jabłoński and Koltowski, 2005). It is worth noting that the blooming period of the virginia mallow, as well as the cup plant, is the time when the rapeseed is about to finish flowering. Therefore, the presence of these crops may contribute to the continuity of flowering plant distribution and provide the food base and habitat for pollinators, especially if biomass is harvested after the end of the vegetation period (Borkowska and Molas, 2012; Chmelikova and Wolfrum, 2019; Dauber et al., 2016; Gansberger et al., 2015; Jabłoński and Koltowski, 2005; Mueller et al., 2020b, 2020a; Mueller and Dauber, 2016; PPO / PRI AGRO Field Technology Innovations et al., 2018).

2.5. Potential of willow dendromass as a feedstock for the sustainable bioeconomy

Lignocellulosic biomass can be processed using thermal and biochemical methods. Depending on the type of technology applied, it is possible to obtain specific final products, such as bioethanol, biodiesel, hydrogen or methane (Anwar et al., 2014). The most developed sectors are biomass co-combustion with fossil fuels and direct biomass combustion. Co-combustion not only provides efficient heat and power production but also CO2 and other greenhouse gases abatement – while growing, plants - being the source of biomass - capture almost equal amount of carbon dioxide as it is released in cofiring (Tillman, 2015; Variny et al., 2021). Currently, the most common use of lignocellulosic biomass produced by perennial energy crops, including willow (*Salix* spp.), is heat and electricity generation, but also the production of second-generation biofuels is an emerging sector with broad prospects for the future (Dey et al., 2020)

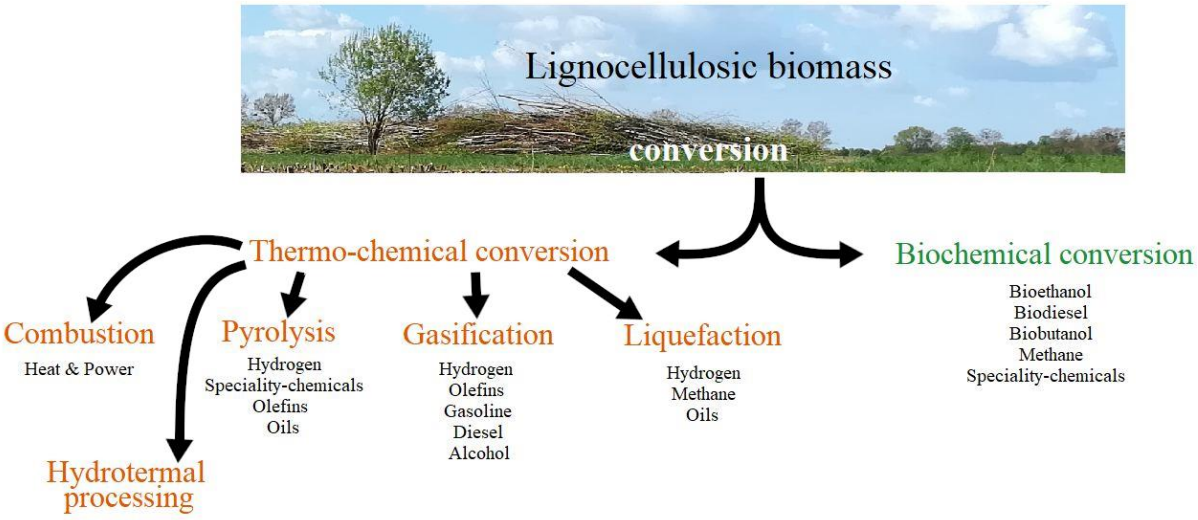


Figure 3. Conversion methods of the lignocellulosic biomass (the chart was made on the basis of (Anwar et al., 2014)

The production of energy from biomass is a rapidly growing industry. According to data from the World Bioenergy Association (WBA), in 2019, the energy obtained from renewable sources accounted for 17.2% of the gross final energy consumption (total final consumption of all energy sources including the electricity and heat consumption at all end-use sectors), with the share of energy obtained from biomass at the level of 12% of total consumption (WBA, 2021). Moreover, International Energy Agency (IEA) forecasts, that under the current policies, annual global demand for biofuels will increase by 28% in 2026, reaching 186 billion litres (IEA, 2019).

Currently, four generations of biofuels are distinguished. Their classification is based on the type of feedstock and the associated conversion method used. First-generation biofuels are generally made from food crops. The first group used for biofuel production are plants containing large amounts of carbohydrates – they can serve as a feedstock, from which bioethanol is obtained. This group includes, for example, corn (*Zea mays*), wheat (*Triticum spp*.), sugar beet (*Beta vulgaris*), and sugarcane (*Saccharum spp*.). The second group are oil plants from which biodiesel is obtained in the transesterification process. This group includes Guinea oilseed (*Elaeis guineensis*), sunflower (*Helianthus annuus*) and rapeseed (*Brassica spp*.) (Alalwan et al., 2019). There are rising controversies about the influence that first-generation fuels have on the natural environment. Firstly, there are some inconsistencies about their impact on the climate, and some authors claim, that emissions from the production and transport of first-generation biofuels frequently exceed those of traditional fossil fuels (Dahman et al., 2019; Lark et al., 2022). Moreover, they require good quality soils and intensification of their production can lead to competition with food resources (the food versus fuel debate) (Mohr and Raman, 2013; Saladini et al., 2016; Valentine et al., 2012). Second-generation biofuels are produced from lignocellulosic biomass, obtained e.g. from perennial industrial crops, including willow (*Salix* spp.), Giant miscanthus (*Miscanthus x giganteus*), cup plant (*Silphium perfoliatum*) and virginia mallow (*Sida hermaphrodita*) (Alalwan et al., 2019). These crops are characterized by lower soil requirements and can be planted on sites unsuitable for food production. Additionally, they can be cultivated in an extensive, low-input cropping system (Stolarski et al., 2019; Stolarski et al., 2011). Currently, the environmental impact of perennial industrial crops is considered more beneficial than in the case of food crops grown with biofuel feedstocks (Mohr and Raman, 2013; Saladini et al., 2016; Valentine et al. ., 2012). Second-

generation biofuels can also be obtained from agricultural and forest residues. Third-generation biofuels are produced from algae, while fourth-generation fuels are made of genetically modified microorganisms (Alalwan et al., 2019; Liu et al., 2014).

Willow can also be used directly as a solid fuel in the form of wood chips, briquettes and pellets (Stolarski et al., 2009; Szczukowski et al., 2006). Compared to biomass obtained from other energy plants, willow biomass is characterized by a small amount of ash and a large carbon amount, which is beneficial in the combustion process (Stolarski et al., 2008). The ash content, depending on the willow clone, harvest date and plant age, is 1-2%, and it can also be used as an element of plant fertilization. In terms of the emission of harmful gases, not only the carbon dioxide emission balance is favourable, but also the sulfur dioxide emission balance. For fine coal, it can reach the level of 10%, while for willow chips it is only 0.05% (Jakubiak, 2010).

2.6. The influence of willow plantations on abiotic and biotic factors

As an energy source, biomass can help reduce dependence on fossil fuels and contribute to mitigating global warming (Demirbas et al., 2009). On the other hand, the exact impact of energy plantations on the environment is not fully understood. According to Liu et al., energy crops can cause environmental degradation, and also can significantly increase the risk of habitat fragmentation, extinction of native species and spread of invading alien species (Liu et al., 2014). In the case of large-scale energy crop production in monoculture, other unfavourable processes such as a simplification of food webs, disruption of ecosystem services and, as a result, a decline in biodiversity are also observed. However, it is estimated that due to the more extensive cultivation system, lignocellulosic crops can have a beneficial effect on agrocenoses concerning other types of energy crops (Dauber et al., 2010).

The influence of short rotation coppice willow plantations on abiotic factors has been extensively researched. Due to the rapid growth of biomass, and hence the incorporation of substances taken from the soil into plant tissues, willow can be used for soil remediation in regions with a high degree of contamination (Jensen et al., 2009; Kacálková et al., 2015; Pulford, 2003; Ruttens et al., 2011). Due to its ability to grow despite extremely unfavourable edaphic conditions, willow is used as a phytoextractor in areas contaminated with Cd, Zn and Cu (D. Riddell-Black, 1994; Dickinson et al., 1994; Greger and Landberg, 1999; Pilipović et al., 2019; Punshon et al., 1995; Vysloužilová et al., 2011; Yang et al., 2018), and also on soils after application of sewage sludge (Aronsson and Perttu, 2001; Börjesson and Berndes, 2006; Dimitriou et al., 2006, 2012a; Urbaniak et al., 2017) to reduce phytotoxicity.

There are some controversies around the potential of SRC plantations for carbon sequestration. Some studies show that soil carbon sequestration is significantly higher in willow and similar poplar plantations than in other crops (Dimitriou et al., 2012b; Mao et al., 2010; McIvor and Douglas, 2012). Others - that it is equal or even lower (Coleman et al., 2004; Lockwell et al., 2012; Mao et al., 2010; Mukherjee and Coleman, 2020). In general, however, most studies show that the soil carbon sequestration potential of willows in short-rotation coppice (SRC) is high. It is also known that willow plantations can contribute to improving the mechanical properties of the soil (Mickovski et al., 2009). They can provide reinforcement to low-stability soils, e.g. on steep slopes (Kuzovkina and Quigley, 2005; McIvor and Douglas, 2012; Wall et al., 1997; Wilkinson, 1999). Additionally, when used as cover crops, hedgerows or winds strips can protect agricultural land against wind erosion and leaching (Börjesson, 1999; Börjesson and Berndes, 2006; Kuzovkina and Quigley, 2005; Whisenant, 2005).

Willow SRC crops also affect surface runoff. They can contribute to water retention and prevent flooding (Acharya and Blanco-Canqui, 2018; Dimitriou et al., 2012a; Langeveld et al., 2012). On the other hand, by increasing the transport of water from the deeper layers of the soil and evaporating it through transpiration, willow plantations may contribute to lowering the groundwater table, which may have a negative impact on water relations in regions with poor water supplies. This threat may be partially eliminated by choosing cultivars with more efficient, low water use (Busch, 2009; Dimitriou et al., 2009; Perry et al., 2001; Richard et al., 2019; Zalesny et al., 2019). Moreover, numerous studies point out that because herbaceous and woody perennial crops require far less use of fertilizers and pesticides than conventional crops, they do not deteriorate water quality (Acharya and Blanco-Canqui, 2018; Dimitriou et al., 2009; Dimitriou and Mola-Yudego, 2017; Joslin and Schoenholtz, 1997; Schmidt-Walter and Lamersdorf, 2012). Moreover, these plantations can increase the availability of soil nitrogen and reduce the amount of nitrates in groundwater, which is of great importance, especially in intensively used agricultural areas with poor, sandy soils.

Due to the small number of agrotechnical treatments, the impact of willow cultivation on accompanying flora is considered positive – there are many studies indicating that SRC plantations can increase farmland flora diversity compared with arable crops. In the United Kingdom, 151 plant species have been found on willow crops in the SRC system, a number much larger than in average lowland farms (Caslin et al., 2015). According to Sage & Robertson (Sage and Robertson, 1994), in the initial growth stage, plantations are covered with agricultural weeds and ruderal species, characteristic of disturbed habitats. In older plantations, however, colonization by less common forest species may occur (Dauber et al., 2010; Sage and

Robertson, 1994). In these plantations, the species diversity of herbaceous plants is lower than in old mixed forests. However, it may exceed the diversity recorded in coniferous forests (Baum, 2012). The influence of cultivation age on the occurrence of various types of weeds is also emphasized by other authors (Chwastek, 2009; Marks et al., 2014; Trąba et al., 2009; Wojciechowski et al., 2009). In the first years after the plantation was established, mainly annual plants are observed as an accompanying flora, such as *Echinochloa crusgalli* L, *Galinsoga parviflora* Cav., *Veronica persica* L., *Galium aparine* L. (Borkowska and Molas, 2010; Piórek et al., 2009; Wojciechowski et al., 2009). In the following years, as a result of increasing canopy density, and shading of the understorey, the development of weeds becomes limited (Borkowska and Molas, 2010; Reddersen, 2001), and in consequence, annual species are replaced with perennial forms, including *Cirsium arvense* (L .) Scop., *Taraxacum officinale* Weber, *Agropyron repens* (L .) P. Beau., *Poa trivialis* L ., *Poa pratensis* L. (Kościk and Ziemińska-Smyk, 2009; Krechowski et al., 2009; Kutyna et al., 2009; Marks et al., 2014; Siciński, 2009; Skrajna et al., 2009; Trąba et al., 2009). The diversity of flora also depends on the land use prior to the plantation establishment. Plantations established in meadow habitats are richer in accompanying flora than those on post-agricultural lands (Aniol-Kwiatkowska et al., 2009; Caslin et al., 2015; Chwastek, 2009; Krechowski et al., 2009; Kutyna et al., 2009; Marks et al., 2014; Siciński, 2009; Trąba et al., 2009). Similarly, the floristic composition is influenced by soil moisture and fertility, which is positively connected with the enrichment of plant communities (Kutyna et al., 2009; Skrajna et al., 2009; Trąba et al., 2009; Wróbel et al., 2011). Willow, as a native species, does not have the potential to be invasive in Europe. However, it may contribute to a greater dispersion of invasive plants in the landscape, creating environmental corridors for them (Feledyn-Szewczyk et al., 2019). Moreover, there is a risk of hybridization of willow cultivars planting for short rotation coppicing with local willow species (Börjesson, 1999). Therefore, plantations should not be located in areas of high nature value.

Summing up, the factors influencing the diversity of herbaceous plants in plantations are the following: the age of the plantation, the age of the stand and the availability of light, the shape and size of the plantation, the previous use of the land on which the plantation was established, soil properties, the intensity of agrotechnical treatments and the type of habitats adjacent to the plantation (Baum, 2012; Dauber et al., 2010; Marks et al., 2014). It is also proven that properly managed (Sage, 1998; Vanbeveren and Ceulemans, 2019) SRC willow plantations can significantly contribute to the growth of herbaceous plant diversity in agricultural areas (S. Baum et al., 2009; Baum et al., 2012; Dauber et al., 2010; Rowe et al., 2009; Zitzmann and Rode, 2021) and their effect on weeds diversity is considered more

favourable than for most plants grown for the production of lignocellulosic biomass (Feledyn-Szewczyk et al., 2019; Radzikowski et al., 2020; Schulz et al., 2009; Sobisz and Ratuszniak, 2009).

Providing a place for accompanying flora growth, willow plantations constitute a habitat and source of forage for invertebrates, including those providing valuable ecosystem services (Caslin et al., 2015; Czachorowski et al., 2015; Rowe et al., 2011; Schulz et al., 2009). One of the groups that can particularly benefit from willow plantations are pollinators. Willow, flowering in temperate climates from mid-March, provides an early source of pollen and nectar, especially important for bees and bumblebees (Apidae). Especially for species specialized in willow pollination, SRC plantations may enable survival in monoculture-rich agrocenoses (Hass et al., 2012; Mueller et al., 2018; Ostaff et al., 2015; Reddersen, 2001; Tumminello et al., 2018). Moreover, it was found that SRC plantations can also be a refuge for predatory hymenopterans of the Vespidae and Apidae families, hunting for beetle larvae and parasitic aphids on willow crowns. They can also use honeydew produced by aphids as an additional source of food (Rowe et al., 2011).

The ends of the field (the so-called headlands) and the technical roads crossing the plantation are also of great importance to biodiversity, as they can overgrow with herbaceous vegetation thanks to greater access to light. In addition, the edges of the field can act as ecotones, and due to the lack of pesticide applications in SRC plantations, they can create a favourable environment for invertebrates (S. Baum et al., 2009; Baum, 2012; Czachorowski et al., 2015; Feledyn-Szewczyk et al., 2019; Graham and Nassauer, 2019; Rowe et al., 2011; Sage and Robertson, 1994; Schulz et al., 2009). It has been found that headlands and technical roads have a greater abundance of butterflies than areas located inside the plantations (Czachorowski et al., 2015; Landis and Werling, 2010; Sage and Robertson, 1994).

Another group of insects delivering important ecosystem services on willow plantations are predatory beetles of the Carabidae and Staphylinidae families, contributing to the control of pest populations, both on the plantation itself and adjacent farmlands (Jimenez-Sanchez et al., 2009; Konieczna et al., 2013; Müller-Kroehling et al., 2020; Piotrowska et al., 2020; Rowe et al., 2013; Williams and Feest, 2022). This role is also played by spiders (Al Hussein et al., 2014; Radzikowski et al., 2020; Williams and Feest, 2022) and predatory insects, such as some heteropterans (Heteroptera), ladybirds (Coccinellidae), and green lacewings (Chrysopidae). Good conditions enable the maintenance of the predatory entomofauna population in energy willow plantations and, as a result, biological pest control. Therefore, there is usually no need

to apply pesticides to SRC willow plantations (Fiedler and Jaworska, 2009; Stephan et al., 2016).

Lack of ploughing, no pesticide applications, a large influx of detritus from falling leaves and the higher moisture buffering capacity provided by willow roots create conditions favourable for the soil invertebrates populations. Compared to conventional crops, plantations have a positive effect on decomposition processes in soil, improving most of its biological parameters. They create an environment beneficial for the functioning of the soil microbiome, including mycorrhizal fungi. Therefore, in most cases, soil entomofauna and mycoflora observed in SRC plantations, especially the old ones, are richer than for other agricultural crops (C. Baum et al., 2009; Czachorowski et al., 2015; Rowe et al., 2013, 2009; Stauffer et al., 2014; Vanbeveren and Ceulemans, 2019). A consequence of the increase in the number of soil organisms, such as nematodes (Lumbricidae), mites (Acari), springtails (Collembola) or centipedes (Isopoda) is the increase in the population of predatory insects that forage on them, e.g. beetles from the Carabidae family (C. Baum et al., 2009).

The presence of herbaceous plants and the well-developed entomofauna of the SRC plantation are factors promoting the presence of birds, the second most studied group of organisms, after arthropods, in willow cultivation (Baxter et al., 1996; Berg, 2002; Christian et al., 1998; Coates and Say, 1999; Cunningham et al., 2004; Czachorowski et al., 2015; Dhondt et al., 2004; Kay, 1985; Londo et al., 2005; Rowe et al., 2009; Sage et al., 2006, 1994; Sage and Robertson, 1996, 1996; Sage and Tucker, 1998; Schulz et al., 2009). The number of birds associated with SRC plantations is estimated, depending on the parameters of the studied plantation, at 8 to even 60 species. It is also higher compared to other conventional crops (Berg, 2002; Sage et al., 2006). Depending on the age of the stand, plantations may constitute feeding or nesting sites for various bird species (Sage et al., 2006; Schulz et al., 2009). As in the case of insects, beneficial effects of plantation edges on bird populations have been reported (Cunningham et al., 2004).

There is still no more comprehensive research on the mammals inhabiting SRC willow plantations. However, it has been found that these plantations (as well as SRC poplar plantations), especially the older ones, provide small mammals with an environment more beneficial than traditional row crops (Christian et al., 1998; Coates and Say, 1999; Moser et al., 2002). The presence of larger, herbivorous mammals, including European hare (*Lepus europaeus*), wild boar (*Sus scrofa*), roe deer (*Capreolus capreolus*) and red deer (*Cervus elaphus*) have also been noted in plantations (Christian, 1997; Christian et al., 1998; Rowe et al., 2009; Schulz et al., 2009; Zitzmann et al., 2021; Zitzmann and Reich, 2022, own

observations). In an agricultural landscape dominated by monoculture food crops, plantations constitute a valuable shelter and feeding place for these animals, which can contribute to the protection of their populations in areas subjected to high anthropopressure (Bergström and Guillet, 2002). There are also traces of the presence of carnivorous species on plantations, such as red foxes (*Vulpes vulpes*) (Zitzmann and Reich, 2022, own observations).

2.7. Ground beetles (Coleoptera, Carabidae)

2.7.1. General characteristics of the ground beetles (Coleoptera, Carabidae)

Carabidae (Coleoptera: Carabidae) are the largest group of adephaga beetles (Holland, 2002; Schulz et al., 2009). Currently, over 40,000 species have been described, including over 2,700 for Europe and over 2,000 for North America (Kromp, 1999). In Poland, over 500 species of beetles from this family have been described (Burakowski et al., 1974, 1973; Burakowski, 2000). In comparison to other insects groups, Carabidae are relatively well known (in the Northern Hemisphere) (Holland, 2002; Homburg et al., 2014, 2019; Kotze et al., 2011; Lindroth, 1986; McCravy and Lundgren, 2011; Niemelä et al., 2002; Thiele, 1977a). The status of the assemblages description is estimated at nearly 90% (Aleksandrowicz, 2004). Due to the fact that Carabidae are taxonomically and ecologically well-studied the assessment of the anthropogenic influence, affecting their communities, and habitats is possible (Luff, 1996; Niemelä, 2001; Serap and Luff, 2010). Due to their high plasticity, Carabidae can colonize a wide variety of habitats – even the disturbed ones, like urban habitats (Aleksanov et al., 2022) or intensively managed crops (Holland and Luff, 2000; Langmaack et al., 2001). This ecological success is related to the great diversity of this group. The ground beetles occurring in Poland reach a size from 1.2 mm (*Paratachys bistriatus*) to over 40 mm (*Carabus coriaceus*) (Aleksandrowicz, 2004; Watała, 1995). The largest European representative of this family, *Carabus gigas*, can reach up to 70mm (Trautner and Geigenmüller, 1987), and some tropical species of the genus *Mormolyce* – even over 1000mm (Ober and Heider, 2010).

According to the Polish name (the name of this group is „biegaczowate" in Polish, which means „runners"), the majority of European beetles from the Carabidae family are adapted to move quickly, mainly on the surface of the earth. One of the species of Australian tiger beetles, *Cicindela hudsoni* can reach the cursorial velocity of 2.5 metres per second – equal to about 350km/h on a human scale and is the World's fastest running insect recorded to date (Kamoun and Hogenhout, 1996). Very rapid terrestrial locomotion is possible due to the morphological traits, especially those connected with the hind legs, in particular the size of the metatrochanters (Ribera et al., 1999; Talarico et al., 2011). All species have evolved slender,

running-type legs ended in five-segmented, clawed feet (Barševskis and Huruk, 2014; Lindroth, 1986; Thiele, 1977a; Watała, 1995). According to Evans and Forsythe, three main types of locomotion are recognized. 'Group I" – light built body species with short metatrochanters and long, narrow leg segments, having the ability to fast-running, like the genera *Cicindela, Nebria, Leistus, Notiophilus* or *Loricera*. `Group II' – species with long metatrochanters with broad femora and body shape generally more robust than in group I species, adapted to strong wedge-pushing, but being not so fast, for example genus *Harpalus, Amara* or *Carabus*. `Group III' species with short and narrow hind legs, long and pedunculate bodies, and usually front legs with special adaptations for digging, being adapted to strong horizontal-pushing for example genus *Clivina* or *Dyschirius* (Evans, 2009; Evans and Forsythe, 2009; T. Forsythe, 2009; Trevor Forsythe, 2009).

The basic body structure of Carabidae is fairly uniform - only a few species of the genera *Omophoron, Dromius, Tachyta, and Mormolyce* differ in shape and are flattened or rounded. If any, morphological variations are generally connected with nutritional specialisation. For example snail predators from the genus *Cychrus* have much narrowed and elongated thorax and head, enabling them to crawl into the snail shell (Thiele, 1977a). The pronotum plays an important role in species identification. It can have various shapes - square, rectangular, trapezoidal, heart-shaped, oval, almost flat or convex. Except for *Brachinini* the number of sternits is always six, and the thighs of the hindlegs are fused with the first sternites. Part of the Carabidae developed flightlessness - the elytra may be fused, and the membranous wings may be completely reduced. This is the case, for example, in the genus Carabus (except for a few species). The colour, shape and surface of the elytra can be very varied and marked with various kinds of folds, grooves or pits (Barševskis and Huruk, 2014). Black or brown colour is the most common in this group of beetles. It is related to the nocturnal lifestyle of most European Carabidae. Diurnal species are usually more colourful and iridescent, sometimes even bright and contrasting, such as *Omophron limbatum* or *Diachromus germanus* (Czechowski, 1981; Hůrka, 1996; Szyszko, 2002; Watała, 1995; Wolender, 2013). Among metallic-coloured species, particular individuals may differ significantly - for example, *Carabus granulatus*, predominantly greenish bronze can also be green or occasionally almost black. Camouflage is part of the Carabidae defence strategy, allowing them to avoid predators (Fukuda and Konuma, 2019; Hasegawa and Taniguchi, 1996; Schultz, 2001).

An additional form of protection against predators are the repellent secretions from paired abdominal pygidial glands, located on the ventral side of the abdomen. In case of danger, Carabidae can release from them a mixture of carboxylic acids, quinones, hydrocarbons,

phenols, aldehydes and esters. This adaptation was found in 150 species belonging to 43 subfamilies, including *Bembidiini, Pterostichini, Amarini, Carabini, Nebriini, Harpalini,* and *Agonini* (Giglio et al., 2021). The most notable for their defence mechanism are the bombardier beetles (tribe Brachinini), which can eject noxious chemical spray, heated to temperatures reaching around 100 ° C (Sugiura, 2018). These adaptations allow Carabidae not only to be effective hunters but also to avoid larger predators such as frogs and birds.

2.7.2. Phenological types

Carabidae, like all beetles, belong to holometabola – insects which undergo complete metamorphosis. Their campodeiform larvae are overwhelmingly active predators, with well-developed thoracic legs and conspicuous head with chewing mouthparts. In this stage, ground beetles forage (in the majority on the soil surface) and grow intensively (Suenaga and Hamamura, 1998). After the histolysis, occurring in the pupal stage, they are ready for dispersal and mating. Due to the reproduction time, they can be divided into two types - spring and autumn breeders. They have different reproduction rhythms, and overwintering in different development stages (Larsson, 1939). “Spring breeders” hibernate as adults with undeveloped gonads and reproduce from spring to early summer. After that, the majority of adults die off. “Autumn breeders” reproduce at the end of summer or in autumn and usually hibernate as larvae. Therefore, they can be also called “adult hibernators” and “larval hibernators” (Lindroth, 1986; Thiele, 1977a). Larsson's classification became broadly accepted and is still used in scientific publications, as it is simple and rather clear. It was broadened by Thiele, who distinguished seven types of reproductive rhythms, due to different dormancy types (facultative or obligatory) and external factors influencing annual rhythm (photoperiod, temperature). Numerous attempts at expanding and modifying Larssons and Thiele classifications were made, and to date, 30 variants of life cycles in ground beetles from the western Palaearctic have been established (Matalin, 2007).

According to Larsson's classification, it was found, that Carabidae with different breeding strategies differ also in their habitat preferences. Species with an autumn reproduction type of development predominate in forests (Czechowski, 1981). However, their occurrence is also dependent on the age of the stand. Mature forest habitats, as well as open areas, are typical for autumn-breeders, while young forests and peat bogs are more likely to be inhabited by spring-breeders. Summing up, in general, species with an autumn reproduction type are characteristic of well-balanced environments, and species with a spring reproduction type - for environments with a disturbed structure (Nietupski et al., 2008; Walerys et al., 2008).

2.7.3. Trophic preferences

Another way to divide Carabidae is through trophic types. In this group, different trophic preferences were distinguished (Barševskis and Huruk, 2014), nevertheless, ground beetles in general are carnivores. It accounts not only for adult Carabidae but also their larvae, at most highly predatory. Many adaptations toward hunting were seen in this group. In species of the genus *Carabus* L. and *Calosoma* WEB. there is a possibility of extra-oral digestion – they can regurgitate gut enzymes to cover their victim, and eat their prey partially digested. *Carabus coriaceus* L., in case of danger, can use this liquid as a defensive substance and eject it at a distance of up to 1 m (Kozlowski, 2015). There are also specializations in hunting a specific type of invertebrate. Apart from the aforementioned Cychrini, represented by *Cychrus caraboides*, with a body shape adapted to hunting snails, also several species feeding on springtails have interesting predatory specialisations. There are several strategies, chosen by them (Baulechner et al., 2022). Nocturnal hunters, from the genera *Leistus* use setal traps located on the ventral side of their head, and mostly olfactory cues (Bauer, 1985). Adult ground beetles from the *Loricera* genus form a similar apparatus from hair-covered antennae, and their larvae have exceptionally long mandibles (Hintzpeter and Bauer, 1986). On the other hand, species from the genera *Nothiopilus*, being visual predators, have a perfectly developed organ of sight (Bauer, 1981; Ernsting and Jansen, 1978). Interestingly, analogous adaptations were already visible in beetles living in the Mesozoic, which indicated that they are evolutionarily very old (Yin et al., 2017). An interesting adaptation is also the chemical mimicry of the larvae of the African Sahara species, *Thermophilum sexmaculatum*. It is a myrmecophage, reproducing in the ant nests. *T. sexmaculatum* larvae can move freely in them after starting to feed – hydrocarbons of ants were implemented to their cuticula (Dinter et al., 2002).

Most Carabidae species, however, are non-specialised predators - feeding on the most available prey at a given moment (Górny, 1971; Hengeveld, 1980). Hemizoophages, which have the ability to forage on both, plant and animal matter are in the minority (Barševskis and Huruk, 2014). These include representatives of the genera *Harpalus* and *Amara*, as well as *Pterostichus, Poecilus, Synuchus,* and *Nebria*. Herbivorous species feed on seedlings, flowers and leaves (Carbonne et al., 2019; Honek et al., 2006, 2003; Hurst and Doberski, 2003). There are relatively few of them and they are mainly grouped in the taxa *Acinopus*, *Ophonus*, and *Zabrus*. Some of them, such as *Zabrus tenebrionides* can cause agricultural damage (Bassltt, 1978). According to (Kosewska et al., 2007) we can classify Carabidae in terms of nutrition into particular groups:

- ➔ Large carnivores (body size over 12 mm)
- ➔ Medium carnivores (body size between 5mm, and 12 mm)
- ➔ Small carnivores (body size under 5 mm)
- ➔ Hemizoophages
- ➔ Phytophages

There is a strong correlation between the arrangement of particular trophic groups in a ground beetles assemblage and the condition of the ecosystem. A disturbed trophic structure, with the lack of smooth transitions between particular classes, may indicate an influence of anthropogenic (or other) factors, leading to an imbalance in the ecosystem (Allegro and Sciaky, 2003; Kosewska et al., 2011; Thiele, 1977a; Walerys et al., 2008; Wolender, 2013). In addition, the presence of large ground carnivores, especially of the *Carabus* genus, indicates the stability of the ecosystem (Szyszko, 1997), while the predominance of medium and small carnivores, is a sign of habitat disturbance. Similarly, a sign of high anthropopressure is the presence of a large proportion of herbivorous species (Huruk, 2006; Nietupski et al., 2006). Moreover, large carnivores inhabit rather sites with fertile, unpolluted soils (Leśniak, 1987) and favourable water conditions (Poole et al., 2003). In contrast, herbivorous species inhabit areas with lower humidity (Kirichenko-Babko et al., 2020).

2.7.4. Habitat preferences and hygropreferences

Most of the ground beetles found in Poland are adapted to a specific type of habitat. The basic division of Carabidae species according to environmental preferences was made by (Flis and Skłodowski, 1998). They distinguished three types:

- ➔ Forest species
- ➔ Open area species
- ➔ Eurytopic species

A more detailed division, including also species associated with humid habitats, has been developed by (Kosewska et al., 2007):

- ➔ Forest species
- ➔ Open area species
- ➔ Eurytopic species
- ➔ Wetlands
- ➔ Peat-bogs

The presence of species belonging to a given type depends not only on the type of habitat but also on its age (Piotrowska et al., 2020) or the level of anthropopressure (Koivula, 2011; Butovsky za Vician et al., 2018). Particular types also differ in their resistance to environmental changes. If a catastrophe occurs in a habitat, seriously changing its properties, it should be expected that the number of forest species will decrease proportionally, and they will be replaced by eurytopic species (Czechowski, 1981; Sklodowski and Zdzioch, 2005). Many forest species have reduced, vestigial wings, and thus do not have the ability for dispersal flights. As a result, these species are more vulnerable to environmental changes than stenotopic species or species preferring open areas, with greater dispersibility. Also, they will react more strongly to habitat fragmentation (Koivula, 2019; Koivula and Niemelä, 2002; Teofilova et al., 2015; Venn, 2016). Depending on the factors affecting the environment, dynamic changes in the shape of Carabidae assemblages are observed. Forest species will predominantly inhabit fully mature or maturing forests (Koivula, 2019; Riley and Browne, 2011; Sklodowski, 2021; Skłodowski, 1997), however, in old stands, they will be replaced with other species (Szyszko, 2000). It is related to changes in the vegetation cover and the soil properties, occurring with the growth of the trees (J. Skłodowski, 2014; J. J. Skłodowski, 2014; Vician et al., 2018). These processes are also observed on plantations of energy crops (C. Baum et al., 2009; S. Baum et al., 2009; Briones et al., 2019; Kahle and Janssen, 2020; Mueller-Kroehling et al., 2020). With increasing age, they create a specific microclimate, changing water and soil conditions (Londo et al., 2004; Makeschin, 1994; Perry et al., 2001; Zalesny et al., 2019). Due to the fact that the majority of ground beetles are geophiles, i.e. soil-related organisms, soil parameters have a great influence on the shape of their assemblages (Huruk, 2002, 1993; Szyszko, 1974; Vician et al., 2018). Soil conditions are important, especially for larvae, which require appropriate moisture and soil structure (Mueller-Kroehling et al., 2020). Carabidae are believed to be indicators of soil processes (Szyszko, 1991; Vician et al., 2018). Good soil conditions promote large, predatory forest species and increase the density and richness of Carabidae species in general. Species with the autumn type of breeding are more numerous in rich soils and they occur more frequently on heavy soils. Whereas, light soils, usually considered less fertile, are preferred by medium ground beetles and species with a spring reproduction type (Szyszko, 1974).

The type of preferred habitat is related to the Carabidae hygropreference. As a group, these beetles are tolerant to a wide spectrum of humidity, being able to inhabit both extremely dry and highly humid areas, such as swamps and stream banks. Some of them can even periodically inhabit the aquatic environment and hunt in the water. Such species include, for example, *Oodes heliopoides*, *Carabus variolosus* or *Carabus clathratus* (Sienkiewicz, 2003;

Thiele, 1977a). According to the division proposed by Aleksandrowicz et al. (Aleksandrowicz, 2008), there are five hygropreference classes:

- ➔ Hygrophiles
- ➔ Mesohygrophiles
- ➔ Mesophiles
- ➔ Mesoxerophiles
- ➔ Xerophiles

Polish indigenous species are most often mesophilic. They are characterized by a wide range of moisture tolerance (Thiele, 1977a). Most likely, it is related to the transitional nature of Poland's climate (Wolender, 2013). Xerophiles are the most common among Carabidae that prefer open areas. Hygrophiles are largely related to the swamps and the shores of water reservoirs.

2.7.5. Carabidae as indicators of the natural environment conditions and as providers of ecosystem services

In environments subjected to strong anthropopression, biodiversity is decreasing. One of its determinants is the condition of zoocoenoses in the study area. It can be assessed using indicator species, which population and functioning can reflect the qualitative status of the environment (Hodkinson and Jackson, 2005; Montgomery et al., 2021). The group of animals used extremely often in bioindication are insects (Parikh et al., 2021). This is due to the fact that many species from this group fulfil the conditions of ideal bioindicators:

1. Insects are very common and numerous in the environment, which allows for a good statistical analysis and the exclusion of the random factor;
2. Insects populations are relatively stable and well studied;
3. Insects are sensitive to factors influencing the environment, therefore can reflect the state of the habitat, and the response of their population is proportional to the changes in the habitat;
4. Additionally, many insects can be also used as model organisms;
5. Research using insects are generally not technically difficult and relatively inexpensive (Holt and Miller, 2010).

Many studies show the usefulness of Carabidae beetles as an indicator of ecosystem health (Allegro and Sciaky, 2003; Cameron and Leather, 2012; Ghannem et al., 2018; Koivula, 2011; Ludwiczak et al., 2020; Magura et al., 2017; Rainio and Niemelä, 2003). Carabidae are

abundantly represented in many environments, and the differences in the composition of their assemblages, depending on environmental conditions, are relatively well known. Different species are characteristic of areas in different succession stages and with different types of environments (Tarwacki, 2012).

In dynamically changing environments, the number of species is greater, but specialized and more sensitive species - such as large zoophages and brachypterous species - are disappearing (Barševskis and Huruk, 2014; Koivula, 2011). The information obtained from the analysis of the ground beetles communities is a valuable description of many environmental parameters. Carabidae assemblages analysis enables the comparison of a selected habitat with others, similar ones, and the assessment of the human impact on them (Holland and Luff, 2000; Niemelä et al., 2000; Pizzolotto et al., 2018; Serap and Luff, 2010). Carabidae are sensitive to soil contamination with heavy metals and pesticides. Therefore they can serve as an "early warning system" when negative changes in the ecosystem occur. Many studies also suggest that they may be key indicators for a given ecosystem (keystone indicators) (Koivula, 2011).

Moreover, Carabidae performs a very important function in the areas where they live, providing valuable ecosystem services (Tarwacki, 2012). Predatory ground beetles, especially large species of the genus *Carabus*, contribute to the control of the pest population, both in the area where they live and in adjacent crops (Holland, 2002; Kromp, 1999; Lövei and Sunderland, 1996; Menalled et al., 2007; Teofilova, 2021). This is important, especially in a model of sustainable agriculture, in which the integrated pest management (IPM) system should be implemented. In sustainable agriculture, pest control should depend largely on the activities of the pest's natural enemies, not on the plant protection products. Many laboratory and field studies indicated the significant influence of Carabidae on various types of pests (Bohan et al., 2000; Eskelson et al., 2011; Mair et al., 2001; Reich et al., 2020; Renkema et al., 2014; Scheller, 2009; Weseloh, 1985) as well as weed seeds (Ali et al., 2022; Frei et al., 2019; Honek et al., 2006, 2003; Hurst and Doberski, 2003; Kulkarmi et al., 2015; Kulkarni et al., 2015) making them one of the most important biocontrol agents on agricultural lands.

3. MATERIALS AND METHODS

3.1. Study area

Two field experiments, belonging to the Department of Genetics, Plant Breeding and Bioresource Engineering were located in the vicinity of two small villages: Leginy (54˚0’2.75’’N, 21°7’55.92’’E) and Kocibórz (54°0’42.57’’N, 21°11’2.58’’E), located in the southern part of the commune of Reszel (Warmian-Masurian Voivodeship), in north-eastern Poland. Both experimental sites were located in the area owned by the Experimental Station of Warmia and Mazury University in Olsztyn (UWM).



Figure 4. Location of the research area on the map of Poland

The research area was located in the physiographic mesoregion of the Mrągowskie Lake District, belonging to the Eastern Baltic-Belarusian Lowland. The Mrągowskie Lake District covers an area of about 1830 km² and occupies the central part of the macroregion called the Masurian Lake District. It is extending from the Sępopolska Lowland in the north to the Masurian Plain in the south. At its western end, it borders the Olsztyn Lake District, and the Land of the Masurian Lakes at the east (Kondracki, 2002).

The Mrągowskie Lake District is situated in the young glacial landscape. It is more elevated than the surrounding mesoregions and in some places exceeds the altitude of 200 m

above sea level. A distinctive feature of this region is the characteristic depositional landforms, created by the retreating glacier. The landscape is rolling and partly hilly, with valleys sloping down towards the northwest. Moraine uplands are arranged latitudinally, whereas valleys, streams and the ribbon of lakes are arranged longitudinally. Winding ridges of eskers and regular clusters of kames are paralleled to valleys, formed by glacial throughs and meltwater streams. The abundant hydrographic network was formed after the last glaciation. The Mrągowskie Lakeland is characterized by an exceptionally large number of lakes – they represent 5% (90 km²) of the total area. Also in the vicinity of investigated area, Leginy and Kocibórz, groups of small lakes are situated: Legińskie, Widryńskie, Trzcinno, Pastrzewo, Klawój and Mutek. Waters of those lakes are drained by rivers Sajna and Leginka to the north, into the catchment basin of the Pregola. Uplands are composed mostly of clay, deposited by the retreating glacier. Glaciofluvial sands occur in terrains located between the moraines of the Poznań phase and the moraines of the Pomeranian phase south of Mrągowo, which are also the only larger forest areas in the Mrągowskie Lakeland (Kondracki, 2002).

3.2. Structure of the field experiment

3.2.1. Experimental plots in Leginy

The experiment was carried out on four plots. In the three of them, herbaceous energy crops: cup plant (*Silphium perfoliatum* L.), virginia mallow (*Sida hermaphrodita* Rusby L.), giant miscanthus (*Giant miscanthus* × *giganteus* J.M.Greef & M.Deuter) were cultivated. In the last one a woody energy crop - willow (*Salix viminalis* L.) was grown. The experimental area was located in the terrain descended at no more than a 2% slope. The soil was classified as sandy clay, with an acidity of 5.5 (pH KCl 5.5). The average humus content was 2.7%. The groundwater table was below 150 cm. Investigated plantations were established in 2013. Each plot covered an area of 720 m². The distance between the particular plots was 4 m. In early April, before the start of plant vegetation, mineral and biogas digestate fertilisation was applied. There were no pesticides applied during the time of the experiment.

Cup plant (*Silphium perfoliatum* L.) plantation

The density of cup plant crops at the time of planting was 20 thousand plants per ha. A spacing of 0.75 m × 0.67 m was applied. From the beginning of June, plants formed a dense canopy, practically without patches, overgrown by other vegetation. The plants were harvested each year in September.



Figure 5. The crop of cup plant (*Silphium perfoliatum* L.), in the study site „Leginy", spring 2019



Figure 6. The crop of cup plant (*Silphium perfoliatum* L.), in the study site „Leginy", summer 2019

Virginia mallow (*Sida hermaphrodita* Rusby L.) plantation

The density of virginia mallow crop at the time of planting was 20 thousand plants per ha. A spacing of 0.75 m × 0.67 m was applied. From the beginning of June, plants formed a dense canopy, practically without patches, overgrown by other vegetation. The plants were harvested each year in September.



Figure 7. The crop of virginia mallow (*Sida hermaphrodita* Rusby L.), in the study site „Leginy", spring 2019



Figure 8. The crop of virginia mallow (*Sida hermaphrodita* Rusby L.), in the study site „Leginy", summer 2019

Giant miscanthus (*miscanthus* × *giganteus* J.M.Greef & M.Deuter) plantation

The density of the giant miscanthus crop at the time of planting was 10 thousand plants per ha. A spacing of 1 m × 1 m was applied. Canopy closed about three weeks later than in the cup plant or virginia mallow plantation, at the end of June. Vegetation was dense, covering the entire field without patches where establishment had failed. The plants were harvested each year in September.



Figure 9. The crop of giant miscanthus (*miscanthus* × *giganteus* J.M.Greef & M.Deuter), in the study site „Leginy", spring 2019



Figure 10. The crop of giant miscanthus (*miscanthus* × *giganteus* J.M.Greef &M.Deuter), in the study site „Leginy", summer 2019

Willow (*Salix spp.* L.) plantation

The density of the willow crop at the time of planting was 20 thousand plants per ha. Twin row planting was applied with a space of 0.75 m between two rows in a stripe and the stripes were spaced every 1.5 m. Harvesting was carried out in a three-year cycle.



Figure 11. The crop of willow (*Salix* spp. L.), in the study site „Leginy", spring 2019



Figure 12. The crop of willow (*Salix* spp. L.) in the study site "Leginy", summer 2019

3.2.2. Experimental plots in Kocibórz

The distance from the study site "Leginy" was about 3 km in a straight line. Plantations belonging to the University of Warmia and Mazury in Olsztyn, supervised by the Department of Genetics, Plant Breeding and Bioresource Engineering were selected as research plots. There were willow plantations (*Salix* spp.), cultivated in two coppicing systems - SRC (short-rotation coppice) and Eco-Salix. In addition, arable row crops and fallow land were used as comparative plots.

Willow cultivated in the short rotation coppice (SRC) system

The plantation was established in 2014. The density of the willow crop at the time of planting was 11.1 thousand plants per ha. Row planting was applied with a space of 1.5 m between the stripes. Harvesting was carried out in a four-year cycle. The experiment presented in this study began in spring 2019 after the plants were harvested – it was the beginning of the new rotation cycle. Plant protection products were not used.



Figure 13. Willow cultivated in the short rotation coppice (SRC) system, Kocibórz, at the beginning of summer 2019



Figure 14. Willow cultivated in the short rotation coppice (SRC) system, Kocibórz, at the end of summer 2020

Willow cultivated in the Eco-Salix system

The plantation was established in 2010. The density of the willow crop at the time of planting was 4.5 thousand plants per ha. Row planting was applied with a space of 2.2 m between the stripes. Plant protection products, as well as fertilisers, were not applied.



Figure 15. Willow cultivated in the Eco-Salix system, Kocibórz, at the beginning of summer 2019



Figure 16. Willow cultivated in the Eco-Salix system, Kocibórz, at the end of summer 2020

The fallow land and the arable crops

The fallow land was established over 15 years before the beginning of the experiment. In the arable land, common wheat (*Triticum aestivum*) was grown in 2019, and in the following year 2020 - faba bean (*Vicia faba)*. Nitrogen fertilizer was applied - for wheat 180 kg of nitrogen per hectare and faba bean 30 kg of nitrogen per hectare.



Figure 17. The fallow land, Kocibórz, at the beginning of summer 2019



Figure 18. The fallow land, Kocibórz, at the end of summer 2020



Figure 19. The arable field, planted with wheat (*Triticum aestivum*), Kocibórz, at the beginning of summer 2019



Figure 20. The arable field, planted with faba bean (*Vicia faba*), Kocibórz, at the beginning of spring 2020

3.3. Sampling design

In plantations located in the vicinity of Leginy Carabid communities were sampled from June to October 2019. In Kocibórz research was carried out from May to October in both seasons (2019 and 2020). In Leginy, at each sampling site, five pitfall traps were placed alongside the transect line, located 2 meters from the crop edge. In each of the perennial plants, five traps per one trapping interval were used. Only for willow number of the traps has been doubled (ten traps per one trapping interval). To avoid interference, the distance between the traps was about 10 meters. Due to the larger acreage of research plots in Kocibórz, two linear transects were determined on each of the research plots. In each line, five traps spaced at 10 meters were set (10 traps per plot, 40 traps in total). The distance between the transects was about 50 meters. Each transect was located in the centre of the investigated plot. In both localisations, pitfalls were emptied twice a month (excluding May) and the preserving solution was replaced. The location of the traps in Kocibórz was the same in each year of the study.

Carabids were collected using modified Barber pitfall traps (Barber, 1931). Each trap consisted of a polyethylene cup (ø 90 mm) with a capacity of 500 ml. Traps were dug in level with the ground surface and filled up to 1/3 with a solution of ethylene glycol used as a killing agent and preservative. Each trap was covered with a roof made of bark to prevent excessive rain and litter from reaching it.



Figure 21. Hidden modified Barber's trap, covered with a roof made of bark



Figure 22. Hidden modified Barber's trap, covered with a roof made of bark

3.4. Analyses

3.4.1. Biodiversity indicators and species ecological traits

Collected Carabid beetles were identified using standard keys (Hůrka, 1996; Watała, 1995) and follow the nomenclature in Aleksandrowicz (Aleksandrowicz, 2004). The correctness of identifications has been verified by prof. Agnieszka Kosewska and prof. Mariusz Nietupski from the Department of Entomology, Phytopathology and Molecular Diagnostics, Faculty of Environmental Management and Agriculture, UWM Olsztyn. Species diversity and Carabidae abundance were expressed as the total number of species and specimens caught per study site. For each study site the dominance value was calculated as a percentage share of the individuals of the respective species on the total number of individuals collected at the investigated site. Dominance structure was expressed using the Balogh equation (Balogh, 1958):

$$D_i = \frac{n_i}{N} \cdot 100\%$$

where:

Di – dominance of *i*th species,

ni – the total number of specimens belonging to the *i*th species,

N – the total number of specimens (population size) in the dataset;

Dominance classes were established according to the classification established by (Kasprzak and Niedbała, 1981):

→ eudominants (> 10,0%),

→ dominants (> 5,0-10,0%),

→ subdominants (> 2,0 – 5,0%),

→ recedents (> 1,0-2,0%),

→ subrecedents (< 1,0)%.

Besides individuals number and dominance structure, the Carabidae were analyzed with respect to richness-evenness biodiversity indices:

● Shannon-Wiener index of species diversity (H') (Shannon and Weaver, 1949), given by the expression:

$$H' = -\sum_{i=1}^{S} p_i (\log_2 p_i)$$

where:

H' – Shannon-Wiener index,

S – the total number of species (species richness) in the dataset,

pi - the proportion of individuals belonging to the *i*th species in the dataset,

● Simpson's Index of Diversity (Simpson, 1949), defined as:

$$D = 1 - \sum p_i^2$$

where:

D – Simpson's index,

pi – the proportion of individuals belonging to the *i*th species in the dataset,

● Pielou's evenness index (J') (Pielou, 1966), calculated as follows:

$$J' = \frac{H'}{\log_2 S}$$

where:

J' – Pielou's evenness index (J'),

H' – Shannon-Wiener index,

S – the total number of species (species richness) in the dataset.

Collected beetles were characterised in terms of their ecology (Aleksandrowicz, 2004; Larsson, 1939; Lindroth, 1986; Thiele, 1977b), using the following ecological traits:

→ breeding type (phenology): spring breeders (Sb), autumn breeders (Ab) (Larsson, 1939; Thiele, 1977b),

→ habitat preferences: open area (OA), eurytopic (Eu), forest (F), wetland (We) (Aleksandrowicz, 2004; Flis and Skłodowski, 1998; Kosewska et al., 2007),

→ hygropreferences: xerophilous (x), mesophilous (m), hygrophilous (h) (Aleksandrowicz, 2008; Aleksandrowicz et al., 2008; Kosewska et al., 2007; Thiele, 1977b),

→ dispersion capability: brachypterous (B), dipterous (D), macropterous (Mac) (Hůrka, 1996),

→ body size and trophic preferences: phytophages (Ph), hemizoophages (Hz), small carnivores (Sc - body length <5mm), medium carnivores (Mc- body length 5-12mm), large carnivores (Lc- body length >12mm) (Aleksandrowicz, 2004; Hůrka, 1996; Kosewska et al., 2007).

In classifications used in this dissertation peat-bogs species were classified as a wetland species.

3.4.2. Data arrangement

All analyses were conducted for Kocibórz and Leginy separately. However, statistical methods used throughout the study were identical for both localisations, to provide valid and reliable results. Except for the functional traits analyses, performed with Kruskal-Wallis one-way ANOVA, data for each study site were pooled. Each sample used for PCA and NMDS analysis consisted of data obtained from all observations done in the studied season. The number of traps for the sites located in Kocibórz and in Leginy differed, which is described in the chapter "3.3. Sampling design". To evaluate biological characteristic of Carabidae assemblages each individual trap at every trapping interval was used as a sample. As some traps were damaged, the full set of 40 (for Kocibórz) or 25 (for Leginy) samples per trapping interval were not obtained in all cases. In particular, several of the traps were damaged by foxes or wild boars, whose tracks have been found at both locations In the "Kocibórz" investigation area, all traps set in set-aside land (KU1- KU10) and part of the traps set in the farmland (KP6-KP10) could not be collected during the second trapping interval; thus, third collection covered both intervals for those traps.

3.4.3. Statistical analyses

In the first step, the data were bias tested regarding such parameters as: the number of species, the number of individuals, composition of functional traits in the Carabidae assemblages due to different habitats. In order to do so, the collected data were compared between four investigated plots in Kocibórz (KP, KU, KW, KES), as well as between four investigated plots in Leginy (SP, SH, MG, SV). The following analyses were conducted using PAST v. 4.03 software (Oslo, Norway) (Hammer et al., 2001). As normal distribution was rejected by Shapiro-Wilk test, nonparametric Kruskal-Wallis one-way ANOVA was used to determine the *p* values. To identify the specific sample pairs for stochastic dominance, Dunn's multiple comparisons test with Bonferroni correction was carried out. Those analyses were performed for two-year sampling period.

In the second step patterns in the distribution of ground beetle assemblages among the sites were analysed using principal component analysis (PCA). Analyses were performed using Canoco for Windows 4.56 and CanoDraw for Windows 4.14 (Lepš and Šmilauer, 2003; ter Braak et al., 2002). In order to select the appropriate statistical model Detrended Correspondence Analyses (DCA) were first applied. Based on the length of the longest gradient (< 2.0) Principal Components Analyses (PCA) were employed in each case (Lepš and Šmilauer, 2003). Inter-sample distance scaling was applied. Data were log-transformed and centred by species.

Indirect gradient analysis was applied to illustrate the structure patterns of Carabidae assemblages at the study sites. Both, species composition and ecological characteristic have been analysed. This was done first for two years of the study (2019, 2020) separately and then after pooling the data from observations conducted in 2019 and 2020 together. Restriction of the number of species in the final graph was implemented for analyses covering single year of the study (2019, 2020 separately). To achieve a reasonable number of species in the biplot "Species Fit Range" has been adjusted in such a manner that the 20 species with the highest fit into the ordination space were displayed (ter Braak and Šmilauer, 2002). For the analyses covering two years of the study the ranges of the sampling plots of the respective study sites were visualized by constructing polygons enclosing the corresponding point set.

In addition to PCA analyses, indirect ordination of the Carabidae assemblages recorded in the examined transects was performed using non-metric multidimensional scaling (NMDS). In order to determine the variability in the Carabidae assemblages in different years NMDS analyses were performed for two research periods (years 2019 and 2020) separately. NMDS was calculated in PAST v. 4.03 software (Oslo, Norway) using a Bray-Curtis similarity matrix

(Hammer et al., 2001; Kruskal, 1964). The significance of the multivariance differences among ground beetles assemblages was assessed using the one-way ANOSIM non-parametric statistical test (Anderson, 2001; Clarke, 1993; Kenkel and Orloci, 1986) with Bonferroni corrected p-values (9,999 permutations).

3.5. Climatic conditions and weather during the research period

Insects ecological traits, behaviours and geographic ranges are highly dependent on climatic factors. Temperatures determine the survival rate of insects and influence the changes, whichtook place during their development. Especially for holometabolic Carabidae, weather changes have significant impact on seasonal dynamics and hence reproductive and metamorphosis cycles. The viability of early instars is highly dependent on temperature and precipitation, conditioning soil moisture and plant cover growth.

Evaluation of meteorological conditions was based on measurements and observations carried out at the Meteorological Station in Łężany (belonging to Experimental Station of Warmia and Mazury University in Olsztyn). The data included values of mean monthly temperatures (Tab. 1) and the monthly sum of atmospheric precipitation (Tab.2.) during the 2 years of the study as well as the average values in period 1998-2021.

Table 1. Average air temperature expressed in ˚C for Meteorological Station in Łężany (belonging to Experimental Station of Warmia and Mazury University in Olsztyn).

Month	2019	2020	1998-2021
January	-3	2.7	-2.5
February	2.9	3.1	-1.3
March	4.7	3.9	2.5
April	9.1	7.6	8.4
May	12.4	10.5	13.3
June	20.8	18.2	16.9
July	17.6	17.8	18.9
August	19	18.6	18.3
September	14.1	16	13.9
October	10.1	10.4	8.3
November	6.4	5	4.3
December	3.1	0.5	0
May-Sept	16.8	16.2	16.3
Jan-Dec	9.8	9.5	8.4

In the investigated area the growing season lasted between 212 and 217 days (Kozyra et al., 2013). Values of the average annual air temperature fluctuated only a little during the 2 years of the study, reaching the mean values approximately 9.5 ˚C. Average annual temperature in years 2019-2020 was about 1 ˚C higher than the mean for the period 1998-2021 (8.4 ˚C).

The average air temperature during the growing season (April-October) was similar for all periods and ranged from 13 to 14.7ºC. During the study the highest values of the average temperature were recorded in June (2019 – 20.8 ºC; 2020 – 18.2 ºC) and August (2019 – 19 ºC; 2020 – 18.6 ºC). The average annual precipitation in the period 1998-2021 was 681.8 mm and was higher than at the time of the experiment (2019 - 477mm; 2020 - 567.1mm). The total rainfall during the growing season (April-October) was lowest in 2019, and has reached 379 mm. In 2020 total rainfall has reached 427.6 mm, which was below the average for the years 1998-2021 (472.1 mm). Meanwhile, the highest precipitation for the period 1998-2021 was observed in July and August (100.4 mm; 88.3 mm). Average monthly precipitation differs a lot for years 2019 and 2020, for example in 2019 July had the highest rainfall, reaching 82.2 mm, while in 2020 it was only 33.4 mm.

Table 2. Average precipitation expressed in mm for Meteorological Station in Łężany (belonging to Experimental Station of Warmia and Mazury University in Olsztyn)

Month	2019	2020	1998-2021
January	25.2	38.9	35.9
February	3.8	26.2	31.5
March	31	21.6	43
April	3.4	2.8	38.7
May	68.4	75	61.4
June	81.8	134.4	85
July	82.2	33.4	100.4
August	48.4	86.8	88.3
September	62.8	16.2	41.4
October	32	79	56.9
November	18.6	28.4	54.6
December	19.4	24.4	44.7
May-Sept	343.6	345.8	376.4
Jan-Dec	477	567.1	681.6

4. RESULTS

In order to ensure clarity and transparency, it was decided to present the results for both research areas separately:

Leginy – where the Carabidae assemblages inhabiting the short-rotation coppice (SRC) willow plantation were compared to the Carabidae assemblages inhabiting plantations of perennial herbaceous energy plants: giant miscanthus (*Miscanthus x giganteus*), cup plant (*Silphium perfoliatum*) and virginia mallow (*Sida hermaphrodita*) (results included in point 4.1).

Kocibórz – where the Carabidae assemblages inhabiting two different types of willow plantation (SRC and Eco-Salix) as well as traditional row crops and fallow land were compared (results included in point 4.2).

4.1.Willow versus herbaceous perennial energy plants – study site "Leginy"

4.1.1. Species richness and abundance

In total, 2,177 individuals belonging to 42 species of Carabidae were caught in the study site "Leginy" **(Tab.3-4).** On the studied plantations, the following number of individuals were caught, respectively: miscanthus (MG) – 463 individuals, virginia mallow (SH) - 352 individuals, cup plant (SP) - 637 individuals, and willow (SV) – 725 individuals **(Fig. 23)**. As the number of traps on the willow plantation (SV) was doubled, the average number of individuals per trap noticed on this plot was not the highest as it was in terms of the total number of individuals. The average numbers of individuals per trap were as follows: MG = 10.5 indiv. per trap, SH = 8 indiv. per trap, SP = 14.5 indiv. per trap, SV = 9.1 indiv. per trap **(Tab.4)**.

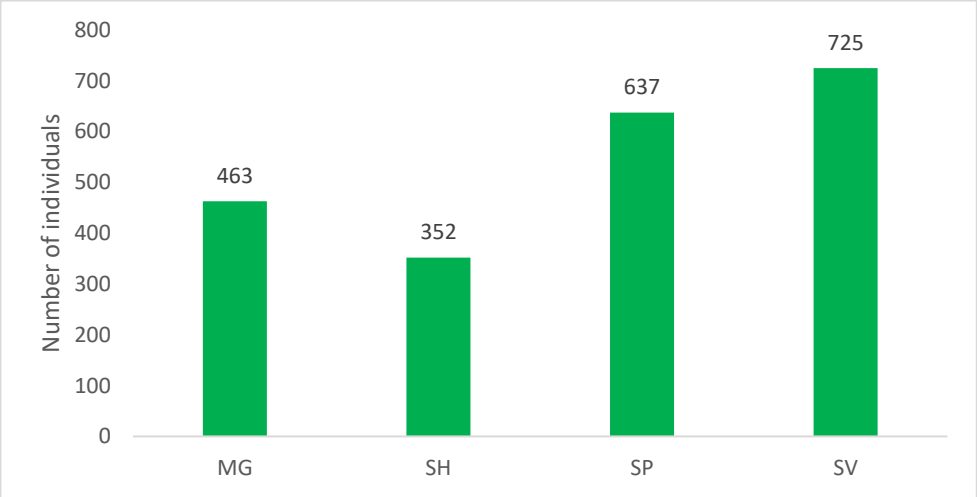


Figure 23. The number of Carabidae individuals captured in the study site "Leginy" in 2019. The abbreviation used on the graph mean respectively: MG – miscanthus, SH- virginia mallow, SP – cup plant, SV- willow; *the number of traps in the willow crop was doubled

The number of species was the highest (29) for the plot covered with the virginia mallow (SH). For the remaining plants, it was respectively: 23 for the miscanthus (MG) and willow (SV) and 25 for the cup plant (SP) **(Fig. 24)**. Based on the Kruskal-Wallis test, no significant differences in the number of individuals, as well as in the species number captured on each of the experimental plots were indicated.



Figure 24. The number of Carabidae species captured in the study site "Leginy" in 2019. The abbreviation used on the graph mean respectively: MG – miscanthus, SH- virginia mallow, SP – cup plant, SV- willow

Table 3. Species composition and abundance of Carabidae caught in the experimental plots in Leginy. The abbreviation used on the graph mean respectively: MG – miscanthus, SH- virginia mallow, SP – cup plant, SV- willow; *the number of traps in the willow crop was doubled

Species	MG	SH	SP	SV
Amara aenea (Degeer,1774)	13	1	9	1
Amara bifrons (Gyllenhal,1810)	12	10	36	-
Amara communis (Panzer,1797)	-	1	2	-
Amara similata (Gyllenhal,1810)	-	1	-	-
Badister bullatus (Schrank,1798)	-	-	-	1
Bembidion lampros (Herbst,1784)	-	4	1	-
Bembidion properans (Stephens,1828)	1	2	4	-
Bembidion pygmaeum (Fabricius,1792)	-	-	1	-
Bembidion quadrimaculatum (Linnaeus,1761)	-	-	-	1
Calathus ambiguus (Paykull,1790)	1	-	10	-
Calathus erratus (Sahlberg,1827)	-	-	34	41
Calathus fuscipes (Goeze,1777)	147	82	178	274
Calathus halensis (Schaller,1783)	3	8	12	-
Calathus melanocephalus (Linnaeus,1758)	1	2	2	3
Carabus cancellatus (Illiger,1798)	6	10	8	45

Carabus coriaceus (Linnaeus,1758)	-	1	-	1
Carabus marginalis (Fabricius,1794)	-	2	-	26
Carabus nemoralis (O.F.Muller,1764)	-	-	-	6
Carabus granulatus (Linnaeus,1758)	-	1	-	6
Cicindela campestris (Linnaeus,1758)	-	-	1	-
Clivina fossor (Linnaeus,1758)	1	-	-	-
Curtonotus aulicus (Panzer,1797)	1	1	10	-
Dyschiriodes globosus (Herbst,1784)	1	2	-	1
Harpalus affinis (Schrank,1781)	13	4	17	-
Harpalus griseus (Duftschmid,1812)	-	1	-	-
Harpalus latus (Linnaeus,1758)	-	1	-	-
Harpalus luteicornis (Duftschmid,1812)	1	11	-	-
Harpalus picipennis (Duftschmid,1812)	2	-	3	-
Harpalus rufipes (Degeer,1774)	127	84	234	65
Harpalus tardus (Panzer,1797)	3	1	-	2
Harpalus signaticornis (Duftschmid,1812)	-	-	-	1
Harpalus xanthopus winkleri (Schauberger,1923)	2	-	-	-
Leistus ferrugineus (Linnaeus,1758)	1	2	2	-
Microlestes minutulus (Goeze,1777)	-	-	3	-
Nebria brevicollis (Fabricius,1792)	-	4	1	37
Notiophilus palustris (Duftschmid,1812)	-	1	-	1
Platynus assimilis (Paykull,1790)	-	-	-	1
Poecilus cupreus (Linnaeus,1758)	2	5	7	4
Poecilus lepidus (Leske,1785)	5	1	19	4
Poecilus versicolor (Sturm,1824)	11	4	1	8
Pterostichus melanarius (Illiger,1798)	2	6	2	26
Pterostichus niger (Schaller,1783)	107	99	40	170
Total number of species: **42**	Total number of individuals: **2,177**			

4.1.2. Biodiversity indices and the dominance structure

There were no significant differences between the values of species diversity indices calculated for each field. The Shannon-Wiener species diversity index (H') attained low values for all of the studied plots, exceeding 2 (2.098) only for the virginia mallow (SH) crop. This indicator reaches high values for the assemblages characterized by stable structure and a lower number of individuals. It was, therefore, the result of the highest number of species in the plot covered with virginia mallow (SH) in combination with the lowest number of ground beetles per trap observed on this plantation. Correspondingly, the Pielou's evenness index (J') was not very differentiated and was noticeably lower only for the miscanthus crop (MG). Simpson's Index of Diversity (D) reached the highest values for the assemblages inhabiting miscanthus (MG) (0.231) and cup plant (SP) (0.225) plantations. The Simpson's diversity index is also

known as the dominance concentration index (D) because it recognizes species the most numerously represented in the dataset but attributes less importance to the rare ones **(Tab.4)**.

Table 4. The number of individuals, species and species diversity indices describing Carabidae assemblages in studied plots in Leginy. The abbreviation used on the graph mean respectively: MG – miscanthus, SH- virginia mallow, SP – cup plant, SV- willow; *the number of traps in the willow crop was doubled

Plant	**MG**	**SH**	**SP**	**SV**
Number of individuals	463	352	637	725*
The mean number of individuals per trap	10.5	8	14.5	9.1
Total number of individuals		2,177		
Number of species	23	29	25	23
Total number of species		42		
Shannon's (Log Base 2,718) (H')	1.812	2.098	1.994	1.948
Pielou's evenness index (J)	0.578	0.623	0.619	0.621
Simpson's Diversity (D)	0.231	0.192	0.225	0.217

It was reflected by the distribution of dominance classes on particular plantations. **(Tab.5, Fig.25)**. Miscanthus crop (MG), characterised by the lowest Pielou evenness index (J') and the highest Simpson's Index of Diversity (D), was also characterised by the largest disparities in shares of particular dominance classes. The class of eudominants comprised over 82% of all individuals in this assemblage. Moreover, there was no „dominants" class. The best-balanced assemblage was indicated for the willow plantation (SV), where no sharp transitions between the dominance groups were noticed **(Fig.25)**. Moreover, all dominance classes were present on this plantation. A well-balanced domination structure indicated that this crop had been subjected to the lowest anthropopressure level. The percentage distribution of the most common species was included in **Table 5**. , presenting the distribution of the dominance classes on particular crops.

Table 5. Carabidae dominance structure in the studied plots in Leginy – species belonged to the particular dominance classes. The abbreviation used on the graph mean respectively: MG – miscanthus, SH- virginia mallow, SP – cup plant, SV- willow;

Dominance group	PLANT			
	MG	**SH**	**SP**	**SV**
Eudominants	*Calathus fuscipes* (31.7%) *Harpalus rufipes* (27.4%) *Pterostichus niger* (23.1%)	*Pterostichus niger* (28.1%) *Harpalus rufipes* (23.9%) *Calathus fuscipes* (23.3%)	*Harpalus rufipes* (36.7%) *Calathus fuscipes* (27.9%)	*Calathus fuscipes* (38.8%) *Pterostichus niger* (23.4%)
Dominants	none	none	*Pterostichus niger* (6.3%) *Amara bifrons* (5.7%) *Calathus erratus* (5.3%)	*Harpalus rufipes* (9.0%) *Carabus cancellatus* (6.2%) *Calathus erratus* (5.7%) *Nebria brevicollis* (5.1%)
Subdominants	*Amara aenea* (2.8%) *Harpalus affinis* (2.8%) *Amara bifrons* (2.6%) *Poecilus versicolor* (2.4%)	*Harpalus luteicornis* (3.1%) *Amara bifrons* (2.8%) *Carabus cancellatus* (2.8%) *Calathus halensis* (2.3%)	*Poecilus lepidus* (3.0%) *Harpalus affinis* (2.7%)	*Pterostichus melanarius* (3.6%) *Carabus marginalis* (3.6%)
Recedents	*Carabus cancellatus* (1.3%) *Poecilus lepidus* (1.1%)	*Pterostichus melanarius* (1.7%) *Poecilus cupreus* (1.4%) *Harpalus affinis* (1.1%) *Poecilus versicolor* (1.1%) *Bembidion lampros* (1.1%) *Nebria brevicollis* (1.1%)	*Calathus halensis* (1.9%) *Calathus ambiguus* (1.6%) *Curtonotus aulicus* (1.6%) *Amara aenea* (1.4%) *Carabus cancellatus* (1.3%) *Poecilus cupreus* (1.1%)	*Poecilus versicolor* (1.1%)
Subrecedents	14 other species (4.8%)	16 other species (6.0%)	12 other species (3.6%)	14 other species (4.6%)

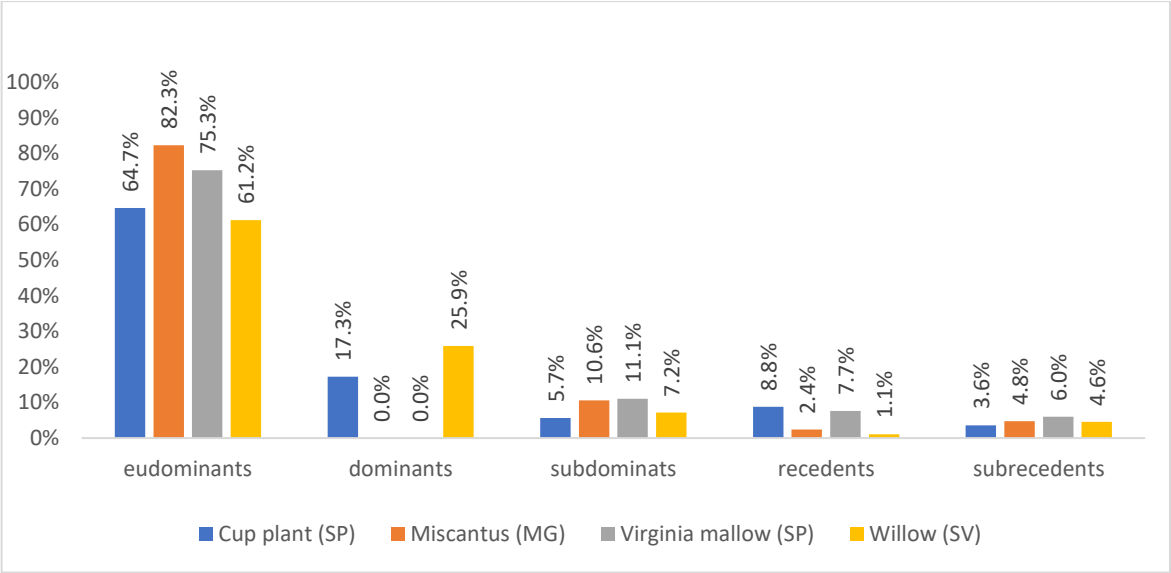


Figure 25. Carabidae dominance structure in the studied plots in Leginy – percentage share of particular dominance classes. The abbreviations used on the graph mean respectively: MG – miscanthus, SH- virginia mallow, SP – cup plant, SV- willow;

Significant differences between the Carabidae assemblages inhabiting particular crops were indicated, moreover, they were further confirmed by the non-metric multidimensional scaling (NMDS) analysis (**Fig.26**). The analysis of similarities (ANOSIM) revealed significant differences in the species compositions of the carabid assemblages, recorded on the particular plots (R: 0.4333; p: 0.001). The most significant differences were indicated between the willow crop (SV) and the cup plant crop (SP) (p=0.003), as well as between the willow crop (SV) and the miscanthus crop (MG) (p=0.0072) (ANOSIM, Bonferroni corrected p-values), which confirmed the hypothesis H1 about the distinctiveness of willow plantations. The analysis showed a large assemblage of ground beetles common to the miscanthus (MG) and the virginia mallow (SH) plantations (**Fig.26**). The good fit of the model to the studied assemblages was confirmed by the stress factor of 0.1862.

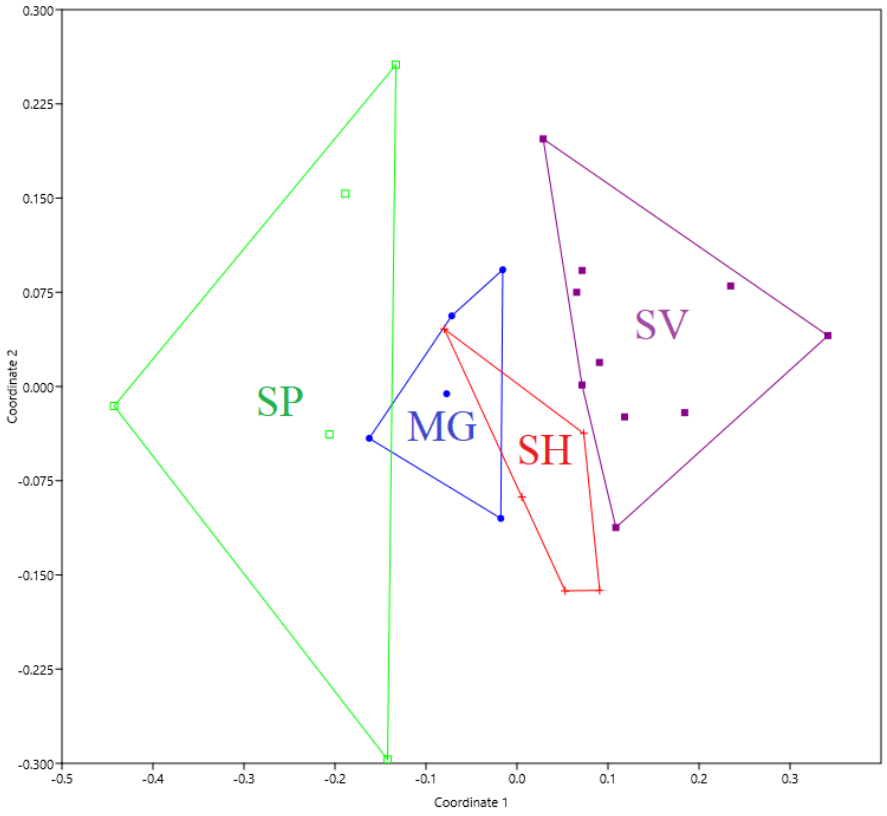


Figure 26. Diagram of non-metric multidimensional scaling (NMDS) for studied ground beetle assemblages. The abbreviations used on the graph mean respectively: MG – miscanthus, SH- virginia mallow, SP – cup plant, SV- willow

4.1.3. Characteristics of ecological traits in the Carabidae assemblages

Depending on the type of environment, determining factors such as a type of vegetation, humidity or the level of anthropopressure in a given habitat, the Carabidae assemblages inhabiting them differ in the level of displayed functional traits. In this study, the following features were analyzed (along with the classification used): breeding strategy (autumn breeders; spring breeders), habitat preferences (open area, forest, eurytopic, wetlands), hygropreferences (mesophilous, hygrophilous, xerophilous), body size and trophic preferences (phytophages, hemizoophages, small zoophages, medium zoophages, large zoophages) as well as dispersion capability (macropterous, brachypterous, dimorphic) (**Tab. 6-7**). The overmentioned ecological traits were described in further parts of this subsection.

Table 6. The number of the Carabidae species attributed to the particular functional traits in the studied plots in Leginy. The abbreviations used on the graph mean respectively: MG – miscanthus, SH- virginia mallow, SP – cup plant, SV- willow

Functional trait	PLANT				Total number of species
	MG	SH	SP	SV	
Autumn breeders	10	13	12	8	15
Spring breeders	13	16	13	15	27
Open Area	18	20	18	12	27
Forest	3	4	3	5	7
Eurytopic	2	4	4	5	7
Wetlands	0	1	0	1	1
Mesophilous	15	21	15	15	26
Hygrophilous	1	2	0	3	3
Xerophilous	7	6	10	5	13
Phytophages	1	2	1	1	2
Hemizoophages	8	9	6	3	12
Small zoophages	3	4	4	3	8
Medium zoophages	7	7	10	9	12
Large zoophages	4	7	4	7	8
Macropterous	13	17	14	9	23
Brachypterous	3	5	3	6	8
Dimorphic	7	7	8	8	11

Table 7. The number of Carabidae individuals attributed to the particular functional traits in the studied plots in Leginy. The abbreviation used on the graph mean respectively: MG – miscanthus, SH- virginia mallow, SP – cup plant, SV- willow;

Functional trait	PLANT				Total number of individuals
	MG	SH	SP	SV	
Autumn breeders	402	301	561	617	1,881
Spring breeders	61	51	76	108	296
Open Area	345	226	547	365	1,483
Forest	110	104	76	239	529
Eurytopic	8	21	14	115	158
Wetlands	0	1	0	6	7
Mesophilous	668	504	331	413	1,916
Hygrophilous	8	0	3	1	12
Xerophilous	49	18	133	49	249
Phytophages	13	2	9	1	25
Hemizoophages	161	114	302	68	645
Small zoophages	1	7	9	2	19
Medium zoophages	170	102	255	374	901
Large zoophages	118	127	62	280	587
Macropterous	190	143	345	120	798
Brachypterous	9	16	13	85	123
Dimorphic	264	193	279	520	1,256

Breeding strategy (phenology)

The total number of indicated species was 15 (1,181 individuals) for autumn breeders and 27 (296 individuals) for spring breeders (**Tab. 6, Tabl. 7, Fig. 27**). Therefore in quantitative terms dominance of autumn breeders was observed, however in the qualitative terms the spring breeders were more numerous (**Fig. 28-31**). However, statistical analysis indicated no significant differences in the number of beetles representing those two development types (spring and autumn breeders) between the studied plots. In all plantations, a high prevalence of autumn breeders was observed (**Fig. 28**). In quantitative terms, they accounted for over 85% of all examined Carabidae assemblages (**Fig. 29**). Interestingly, in the qualitative context, the proportions of both types were opposite (**Fig. 28-31**). Species with the spring type of reproduction were more numerous in all study plots (**Fig. 30, Fig. 31**).

It was shown that eudominant species, such as *Pterostichus niger*, *Harpalus rufipes* and *Calathus fuscipes*, belonged to the group "autumn breeders" (**Tab. 5**). As a result, the number of individuals in this group was higher (**Fig. 28**).

AUTUMN BREEDERS	SPRING BREEDERS	
Amara bifrons	*Amara aenea*	*Dyschiriodes globosus*
Calathus ambiguus	*Amara communis*	*Harpalus affinis*
Calathus erratus	*Amara similata*	*Harpalus luteicornis*
Calathus fuscipes	*Badister bullatus*	*Harpalus picipennis*
Calathus halensis	*Bembidion lampros*	*Harpalus signaticornis*
Calathus melanocephalus	*Bembidion properans*	*Harpalus tardus*
Carabus coriaceus	*Bembidion pygmaeum*	*Harpalus xanthopus winkleri*
Curtonotus aulicus	*Bembidion quadrimaculatum*	*Microlestes minutulus*
Harpalus griseus	*Carabus cancellatus*	*Notiophilus palustris*
Harpalus latus	*Carabus granulatus*	*Platynus assimilis*
Harpalus rufipes	*Carabus marginalis*	*Poecilus cupreus*
Leistus ferrugineus	*Carabus nemoralis*	*Poecilus lepidus*
Nebria brevicollis	*Cicindela campestris*	*Poecilus versicolor*
Pterostichus melanarius	*Clivina fossor*	
Pterostichus niger		
15	27	

Figure 27. Species number and composition of Carabidae with different breeding strategies

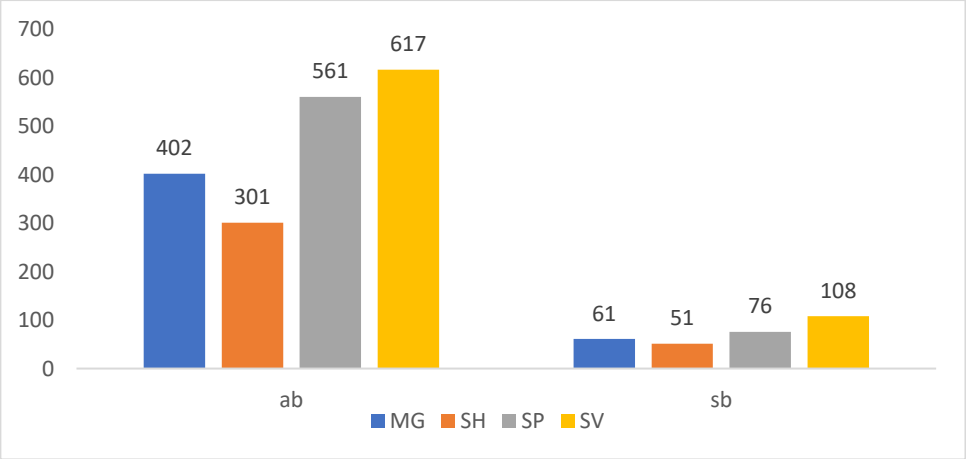


Figure 28. The number of Carabidae individuals with different breeding strategies (ab – autumn breeders, sb – spring breeders). The abbreviations used on the graph mean respectively: MG – miscanthus, SH- virginia mallow, SP – cup plant, SV- willow

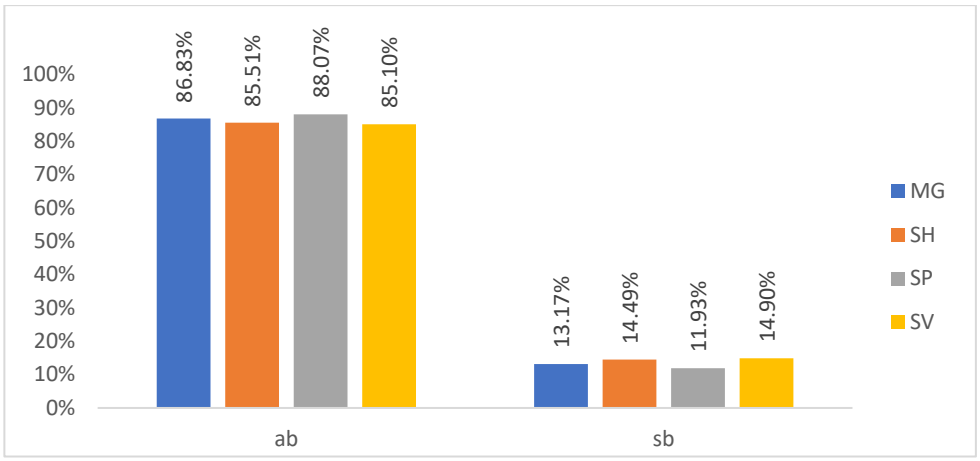


Figure 29. Percentage of Carabidae individuals with different breeding strategies (ab – autumn breeders, sb – spring breeders). The abbreviations used on the graph mean respectively: MG – miscanthus, SH- virginia mallow, SP – cup plant, SV- willow

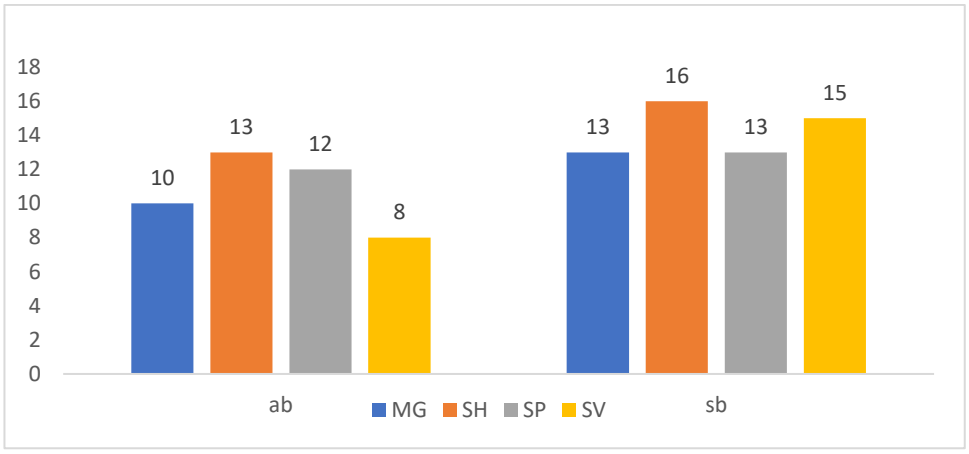


Figure 30. The number of Carabidae species with different breeding strategies (ab – autumn breeders, sb – spring breeders). The abbreviations used on the graph mean respectively: MG – miscanthus, SH- virginia mallow, SP – cup plant, SV- willow

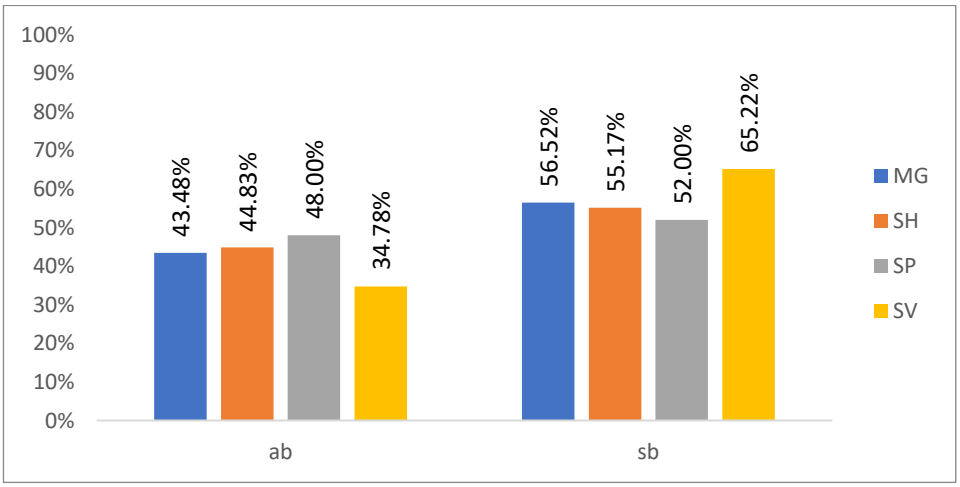


Figure 31. Percentage of Carabidae species with different breeding strategies (ab – autumn breeders, sb – spring breeders). The abbreviations used on the graph mean respectively: MG – miscanthus, SH- virginia mallow, SP – cup plant, SV- willow

Body size and trophic preferences

In terms of quality, the most numerously represented groups on the study site "Leginy" were hemizoophages and medium carnivores (**Tab. 6, Fig. 32**). These species were the most numerous also in terms of quantity (**Tab. 7).** The last numerous group in both, quantitative and qualitative terms were phytophages; therefore, they were excluded from the further ecological traits analysis. (**Tab. 6-7**).

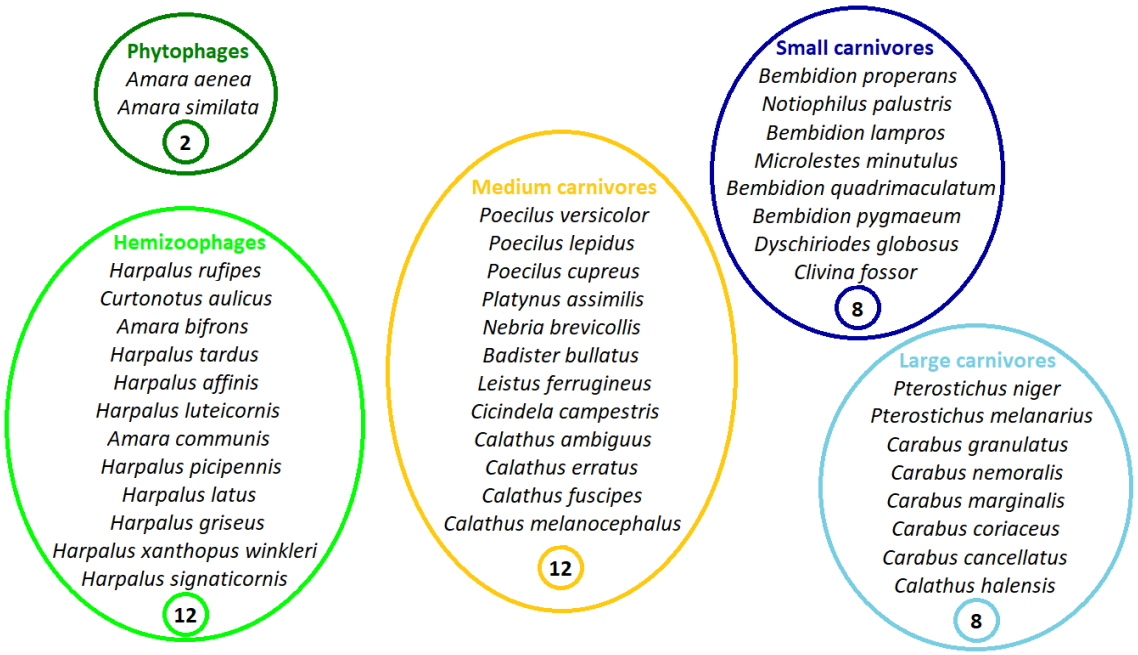


Figure 32. Species number and composition of Carabidae with different size and trophic preferences

Phytophages

There were two phytophagous species (25 individuals) (**Tab. 6-7)** There were no significant differences in the number of phytophages between particular plots (**Tab. 8**).

Table 8. Results of the Kruskal-Wallis significance test for size and trophic preferences of Carabidae inhabiting crops in the study site "Leginy"

Functional trait	*p*
Phytophages (Ph)	n.s.
Hemizoophages (Hz)	7.512E-07
Small carnivores (Sc)	0.009187
Medium carnivores (Mc)	n.s.
Large carnivores (Lc)	8.415E-07

Phytophages were the most numerous on the miscanthus crop (MG); however, even on this plantation, their number did not exceed 3% of the studied assemblage (**Fig. 34-37**). According

to the low number of individuals captured, this group was excluded from further functional traits analysis. In all study plots, only two phytophagous species were captured (*Amara aenea* and *Amara similata*) (**Fig. 33**).

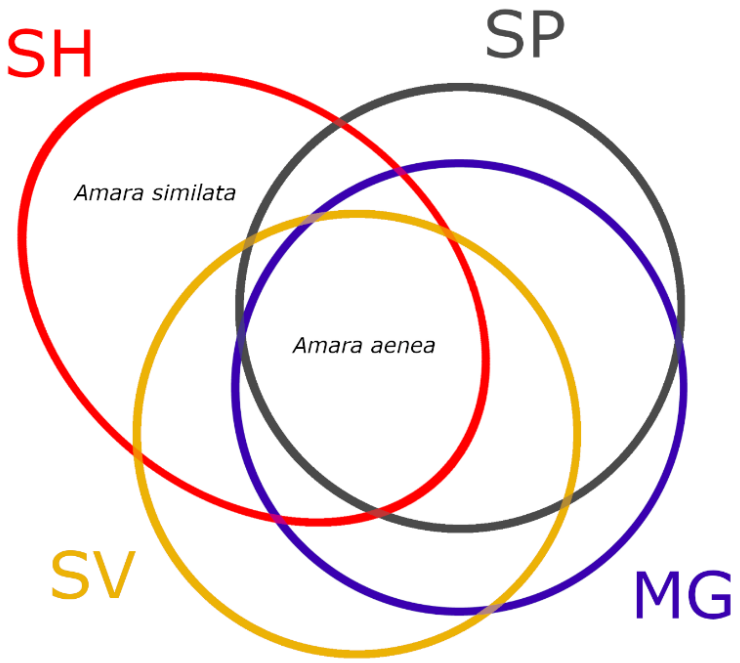


Figure 33. Phytophagous species presence on the particular plots in the study site: ”Leginy”
The abbreviations used on the graph mean respectively: MG – miscanthus, SH- virginia mallow, SP – cup plant, SV- willow;

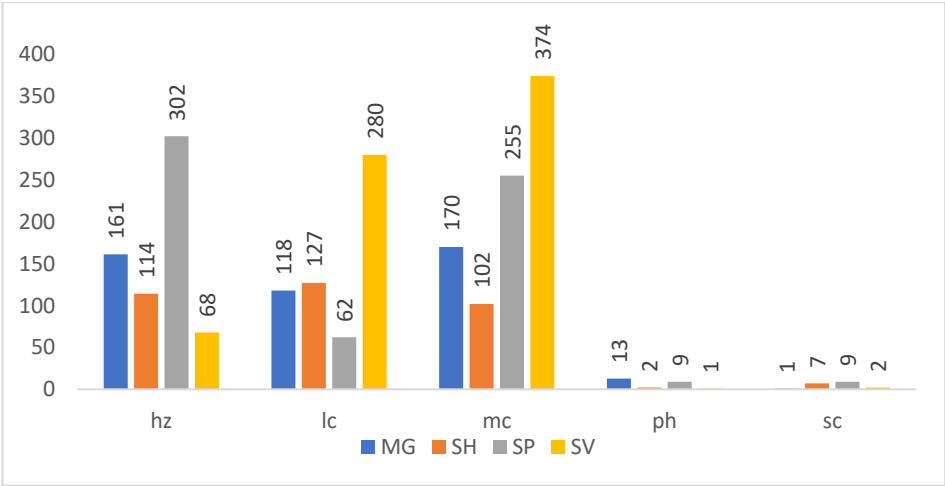


Figure 34. The number of Carabidae individuals with different size and trophic preferences (hz –hemi-zoophages, lc – large carnivores, mc – medium carnivores, ph – phytophages, sc – small carnivores;).
The abbreviations used on the graph mean respectively: MG – miscanthus, SH- virginia mallow, SP – cup plant, SV- willow

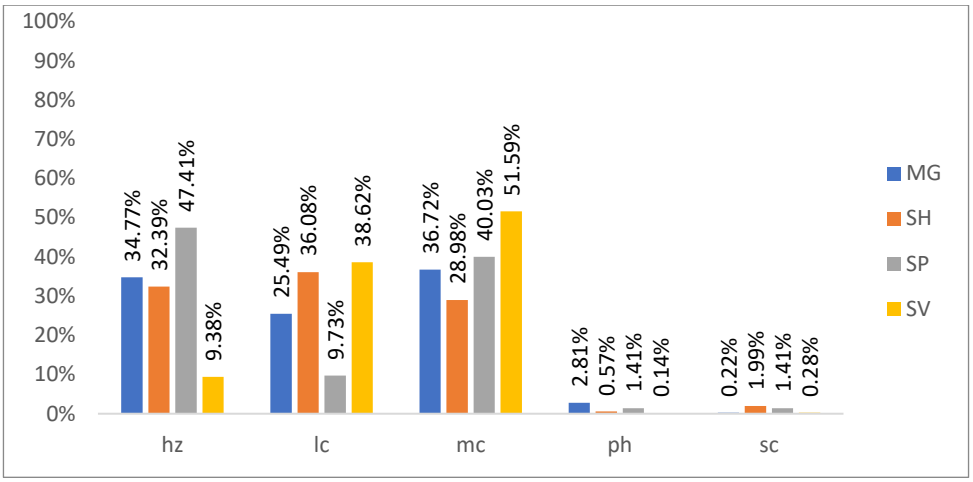


Figure 35. Percentage of Carabidae individuals with different size and trophic preferences (hz –hemizoophages, lc – large carnivores, mc – medium carnivores, ph – phytophages, sc – small carnivores;). The abbreviations used on the graph (MG, SH, SP, SV) as in Fig. 34

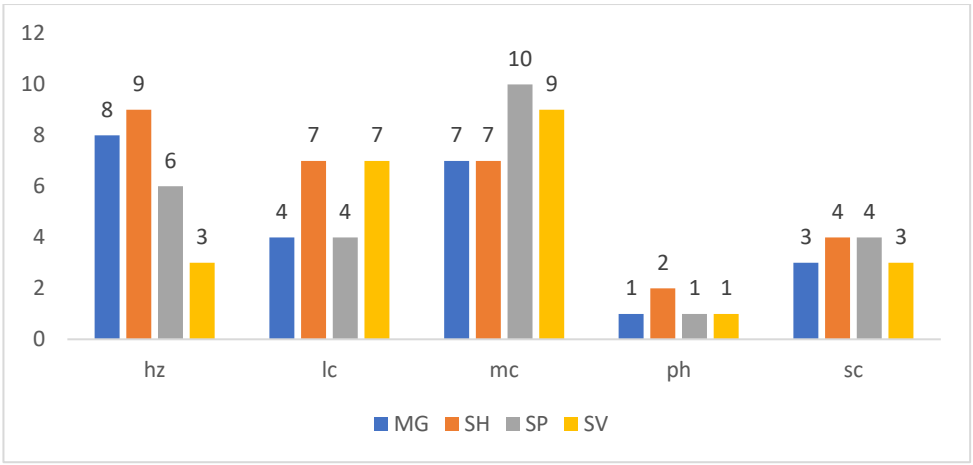


Figure 36. The number of Carabidae species with different size and trophic preferences (hz –hemizoophages, lc – large carnivores, mc – medium carnivores, ph – phytophages, sc – small carnivores;). The abbreviations used on the graph (MG, SH, SP, SV) as in Fig. 34

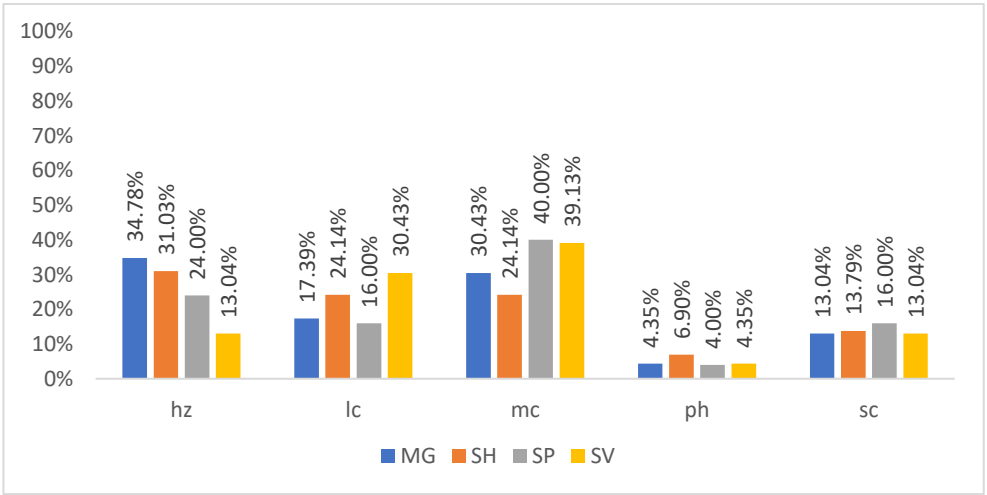


Figure 37. Percentage of Carabidae species with different size and trophic preferences (hz –hemizoophages, lc – large carnivores, mc – medium carnivores, ph – phytophages, sc – small carnivores;). The abbreviations used on the graph (MG, SH, SP, SV) as in Fig. 34

Hemizoophages

There were 12 hemizoophagous species comprising 645 individuals (**Tab. 6-7**). Statistical analysis indicated that there were significant differences in the number of beetles representing this group between studied plots (*p-value* = 7.512E-07) (**Tab.8)**. The number of hemizoophages, captured in the willow SRC crop (SV) was significantly lower than in the rest of the plantations (**Fig. 38)**

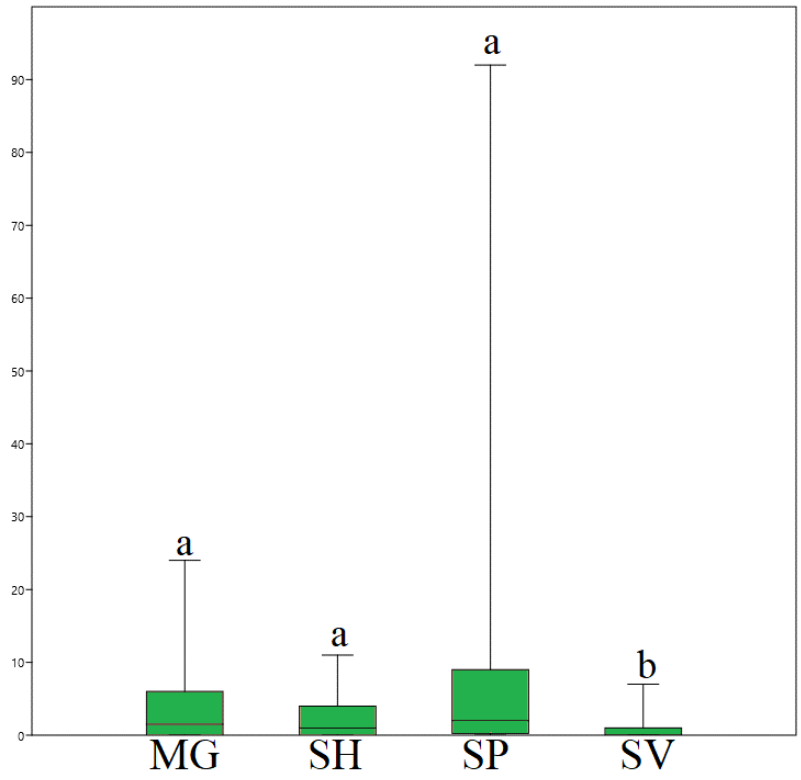


Figure 38. Rarefied hemizoophagous Carabidae individuals abundance for different crop types (Dunn's post hoc; p-value with Bonferroni correction). Mean values per trap are shown for the particular crops (MG – miscanthus, SH- virginia mallow, SP – cup plant, SV- willow) planted in the study site "Leginy". Different letters above the boxplots indicate significant differences between the habitats ($p < 0.05$)

It was reflected by the percentage share of this group in particular crops. Hemizoophages were the last numerous on willow crop (SV) in both quantitive and qualitative terms. There were 68 hemizoophagous individuals indicated on this plantation (9.38% of the assemblage) (**Fig. 34- 35**). Similarly, the number of hemizoophages on this plantation was the lowest – they were represented only by three *Harpalinae* species (13.04% of the assemblage): *Harpalus signaticornis, Harpalus tardus* and *H. rufipes* (**Fig. 36-37, Fig. 39).** There were no significant differences in the number of hemizoophages recorded in the other plantations (MG, SH,

SP) (**Fig. 38**). Hemizoophages were the most numerous on the cup plant crop (SP). There were 302 individuals from this group (47.41% of the assemblage) (**Fig. 34- 35**). In qualitative terms, it was 6 species (24.00% of the assemblage) (**Fig. 36-37**). On the miscanthus crop (MG) 161 individuals from this group (34.77% of the assemblage) were indicated (**Fig. 34-35**). In qualitative terms, it was 8 species (34.78% of the assemblage) (**Fig. 36-37**). On virginia mallow crop (SH) 114 individuals from this group (32.39% of the assemblage) were indicated (**Fig. 34-35**). In qualitative terms, it was 9 species (31.03% of the assemblage) (**Fig. 36-37**). The most numerous hemizoophagous species on all plantations was *H. rufipes* (**Tab.3, Tab.5**, **Fig. 39**).

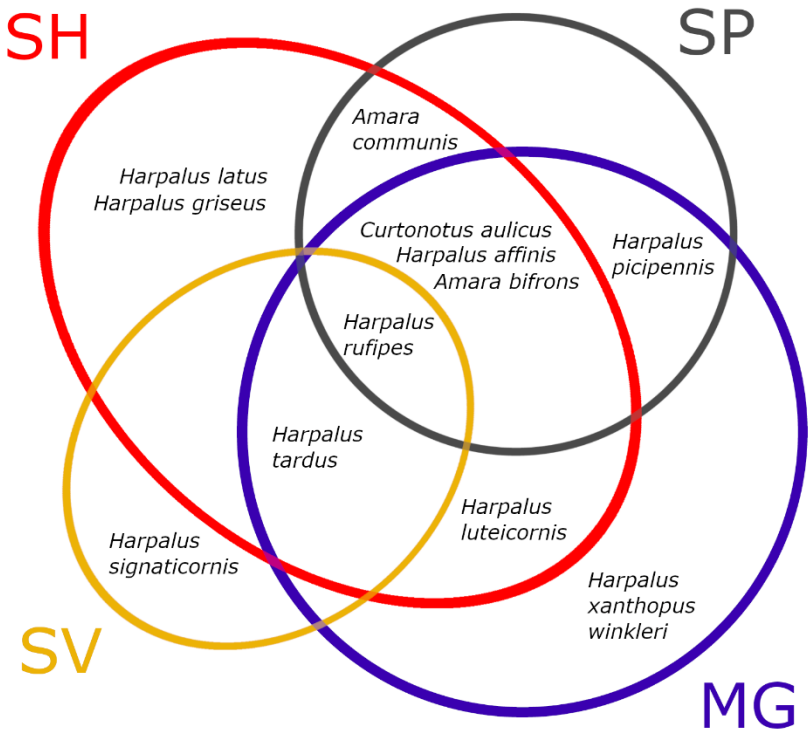


Figure 39. Hemizoophagous species presence on the particular plots in the study site: ”Leginy”
The abbreviations used on the graph mean respectively: MG – miscanthus, SH- virginia mallow, SP – cup plant, SV- willow

Small carnivores

Small carnivores, similar to phytophages, were represented in the low numbers in all studied plantations. They were the last numerously represented among all trophic groups. In this group, only eight species (19 individuals) were indicated (**Tab. 6-7, Fig. 39**). According to the low number of specimens captured, this group was excluded from the further functional traits analysis.

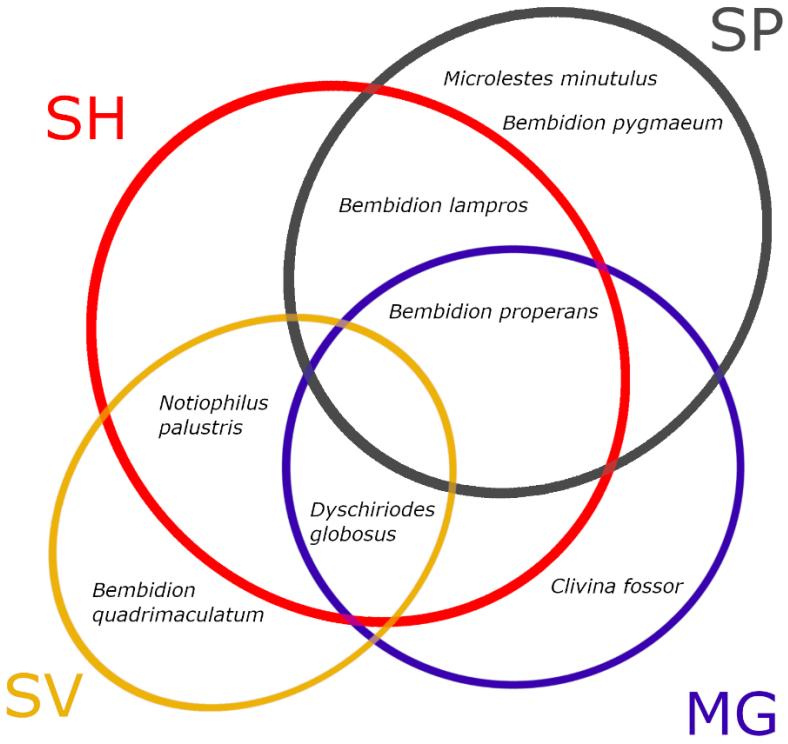


Figure 40. Small carnivorous species presence on the particular plots in the study site: ”Leginy” The abbreviations used on the graph mean respectively: MG – miscanthus, SH- virginia mallow, SP – cup plant, SV- willow

Medium carnivores

Medium carnivores were the best represented among all of the studied groups. There were 12 medium carnivorous species (901 individuals) (**Tab.6-7**). Statistical analysis indicated, that there were no significant differences in the number of beetles representing this group in particular plots (**Tab.8**). In quantitative terms, medium carnivores were the most numerous group on the miscanthus (MG) and the willow plantations (SV). On the virginia mallow plantation (SH), they were outnumbered by large zoophages and hemizoophages. On the cup plant (SP) crop they were outnumbered by the hemizoophages (**Tab. 7**). In the miscanthus crop (MG), there were 170 individuals, constituting 36.72%, of the assemblage (**Fig. 34-35**). In qualitative terms, it was 7 species, constituting 30,43% of the assemblage (**Fig. 36-37**). In the virginia mallow crop (SH), there were 102 individuals, constituting 28.98%, of the assemblage (**Fig. 34-35**). In qualitative terms, it was also 7 species, constituting 27.59% of the assemblage (**Fig. 36-37**). In the cup plant crop (SP), there were 255 individuals, constituting 40.03%, of the assemblage (**Fig. 34-35**). In qualitative terms, it was 10 species, constituting 40.00% of the assemblage (**Fig. 36-37**). In the willow crops (SV), there were 374 individuals, constituting 51.59% of the assemblage (**Fig. 34-35**). In qualitative terms, it was 9 species, constituting 39,13% of the assemblage (**Fig. 36-37**). *C. fuscipes* was the most numerous medium carnivore,

indicated on all studied crops. *C. erratus* and *Nebria brevicollis* were well represented on the willow plantation (SV). Similarly, *C. erratus* and *P. lepidus* were numerous on cup plant crop (SP) (**Tab. 5, Fig. 41**).

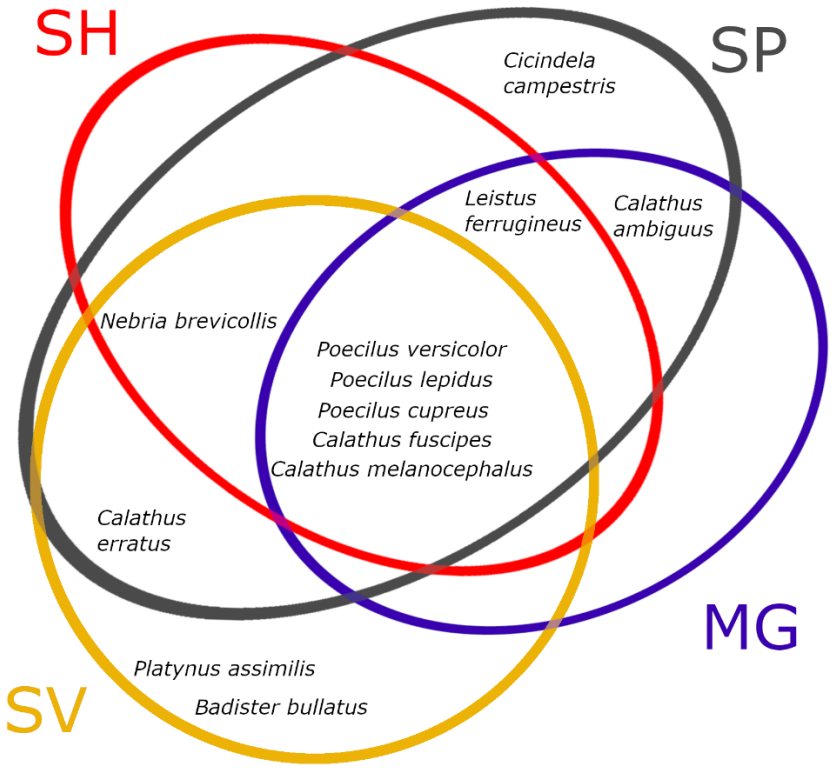


Figure 41. Medium carnivorous species presence on the particular plots in the study site: ”Leginy” The abbreviations used on the graph mean respectively: MG – miscanthus, SH- virginia mallow, SP – cup plant, SV- willow

Large carnivores

In total, there were eight large carnivore species. There were 587 individuals indicated on all studied crops (**Tab. 6-7**). Statistical analysis indicated that there were significant differences in the number of beetles representing this group (*p-value*=8.415E-07) (**Tab. 8**). Differences were indicated between: a) miscanthus crop (MG) and willow plantation (SV), b) cup plant crop (SP) and virginia mallow crop (SH), c) cup plant crop (SP) and willow plantation (SV) (**Fig. 42**).

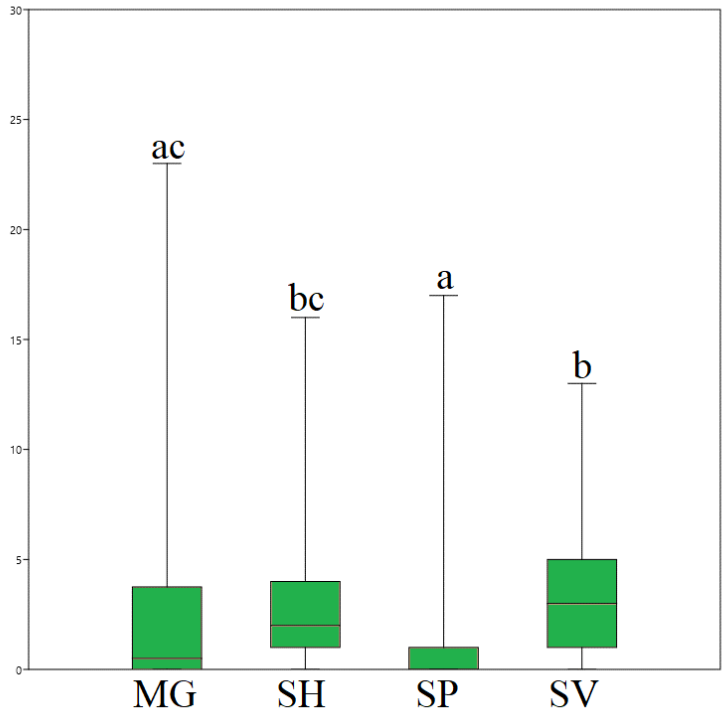


Figure 42. Rarefied large carnivorous Carabidae individuals abundance for different crop types (Dunn's post hoc; p-value with Bonferroni correction). Mean values per trap are shown for the particular crops (MG – miscanthus, SH- virginia mallow, SP – cup plant, SV- willow) planted in the study site "Leginy". Different letters above the boxplots indicate significant differences between the habitats (P<0.05).

In quantitative terms, this group was the most numerous in the willow plantation (SV) and was the second most numerous group in the assemblage. In this crop, large zoophages were represented by 280 individuals, constituting 38.62% of the assemblage (**Fig. 34-35**). They belonged to 7 species (30.43% of the assemblage) (**Fig. 36- 37**). On the willow plantation (SV) large carnivores group included members of the Carabus genus. It was represented by eurytopic *Carabus nemoralis* and *Carabus cancellatus*, forest *Carabus marginalis* and *Carabus coriaceus* as well as *Carabus granulatus* preferring wetlands (**Tab. 3, Fig. 43**). Members of this genus provide valuable ecosystem services and are considered to be an indicator of good environmental status. The number of species from this group was significantly lower in perennial herbaceous plant crops. *P. niger*, preferring the forest environment, was the most abundant in all crops, investigated in the study site "Leginy" (**Tab. 5, Fig. 43**). Willow plantation (SV) significantly differed from the miscanthus (MG) and the cup plant (SP) crops, where 118 individuals (25.49% of the assemblage) and 62 individuals (9.73% of the assemblage) were caught, respectively (**Fig. 34- 35**). In both of those plantations, 4 species were indicated, constituting respectively 17.39% of the assemblage in the miscanthus crop (MG) and 16.00%, of the

assemblage in the cup plant crop (SP) (**Fig. 36-37**). In the virginia mallow (SH) crop 127 individuals (36.08% of the assemblage) (**Fig. 34-35**), belonging to 7 species (24.14% of the assemblage) were indicated (**Fig. 36- 37**).

Differences in the distribution of trophic preferences between the Carabidae assemblages inhabiting particular crops revealed the considerable distinctiveness of the willow plantation (SV). In this crop, the lowest number of hemizoophages and the highest number of large carnivores have been shown, indicating a lower anthropopressure level than in other plantations. It confirms hypothesis **H1**, showing that Carabidae assemblages inhabiting the willow plantations differ significantly from assemblages inhabiting other plantations in terms of body size and trophic preferences.

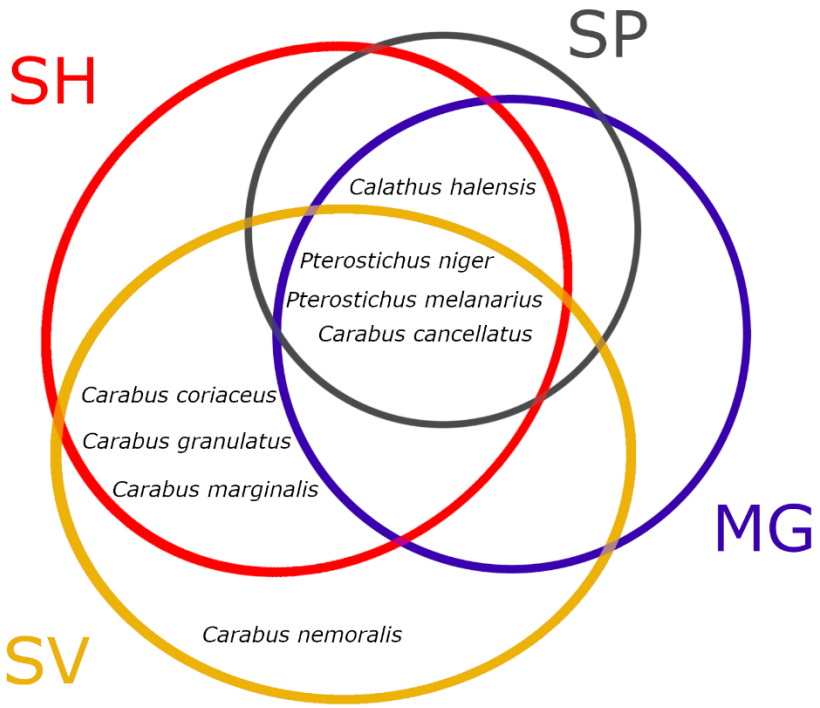


Figure 43. Large carnivorous species presence on the particular plots in the study site: ”Leginy”
The abbreviations used on the graph mean respectively: MG – miscanthus, SH- virginia mallow, SP – cup plant, SV- willow;

Habitat preferences

Species preferring open areas were the most numerous in both quantitative and qualitative terms. In terms of quantity, forest species were also numerously represented.
Wetland species were the last numerous – they were infrequent in the study site “Leginy”, which excluded them from further functional traits analyses (**Fig. 44**).

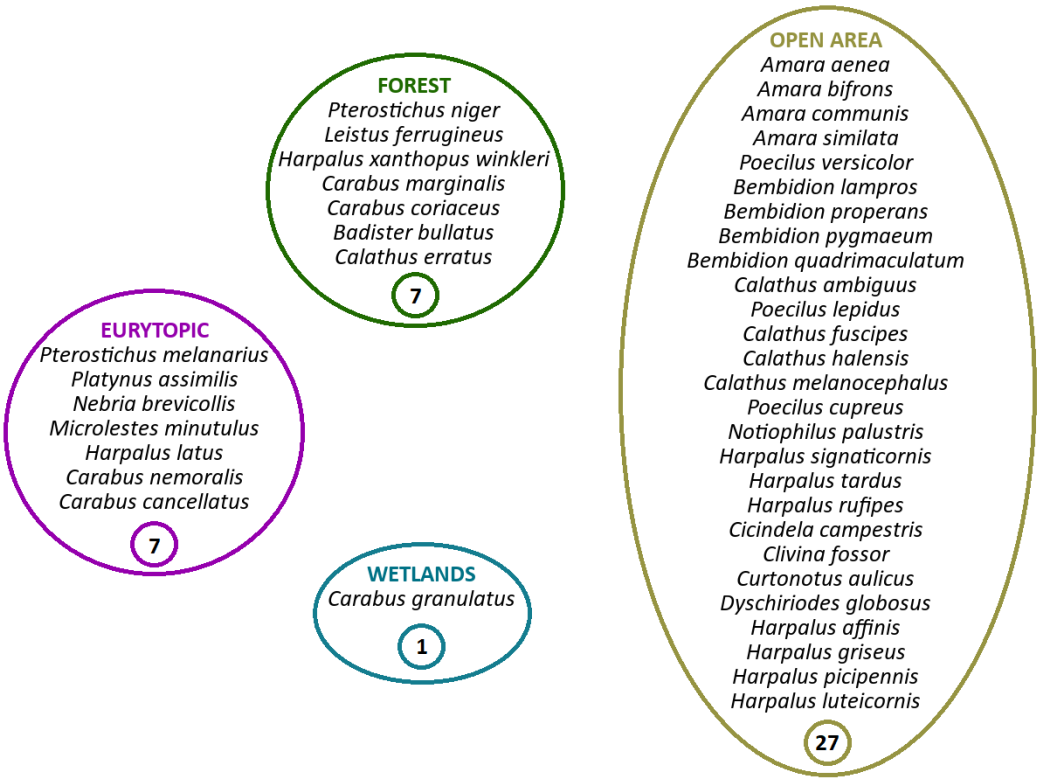


Figure 44. Species number and composition of Carabidae with different habitat preferences

Table 9. Results of the Kruskal-Wallis significance test for habitat preferences of Carabidae inhabiting crops in the study site "Leginy"

Functional trait	***p***
Open area (OA)	0.006772
Eurytopic (Eu)	6.593E-06
Forest (F)	0.0121
Wetland (W)	n.s.

Open area species

Carabidae belonging to species preferring open areas constituted the largest group in terms of quantity (number of individuals) and quality (number of species). The total number of individuals from this group was 1,483. They belonged to 27 species (**Tab.6-7**). Statistical analyses indicated significant differences (*p-value*= 0.006772) in the number of individuals between investigated plots (**Tab. 9**). Differences were indicated between miscanthus (MG) and willow (SV) crops (**Fig. 45**).

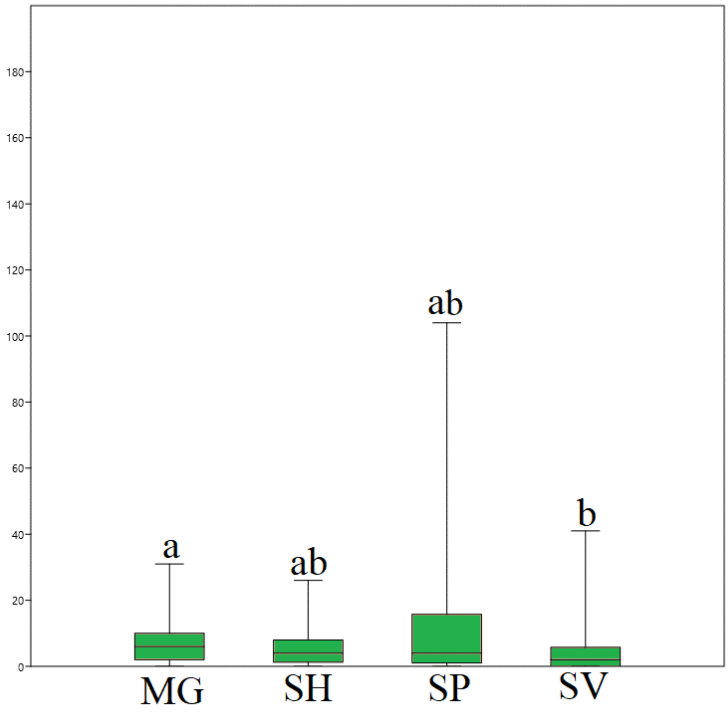


Figure 45. Rarefied open area Carabidae individuals abundance for different crop types (Dunn's post hoc; p-value with Bonferroni correction). Mean values per trap are shown for the particular crops (MG – miscanthus, SH- virginia mallow, SP – cup plant, SV- willow) planted in the study site "Leginy". Different letters above the boxplots indicate significant differences between the habitats ($p < 0.05$)

Carabidae preferring open areas constituted the highest percentage of beetles caught on all research plots, regarding the number of individuals caught and species presence. While in quantitative terms, open area species were the most numerous on the cup plant crop (SP), in qualitative terms, the highest number of species from this group was found on the virginia mallow crop (SH). The cup plant crop (SP) was indicated as the most abundant in terms of individuals number, 547 individuals, constituting 85.87% of the assemblage (**Fig. 46- 47**). In qualitative terms, there were 18 species in this crop (72.00% of the assemblage) (**Fig. 48-49).** The same number of species was indicated on the miscanthus crop (MG). They constituted 78.26% of the assemblage there (**Fig. 48-49).** On the miscanthus crop (MG), 345 individuals were indicated (74.51% of the assemblage) (**Fig. 46-47).**

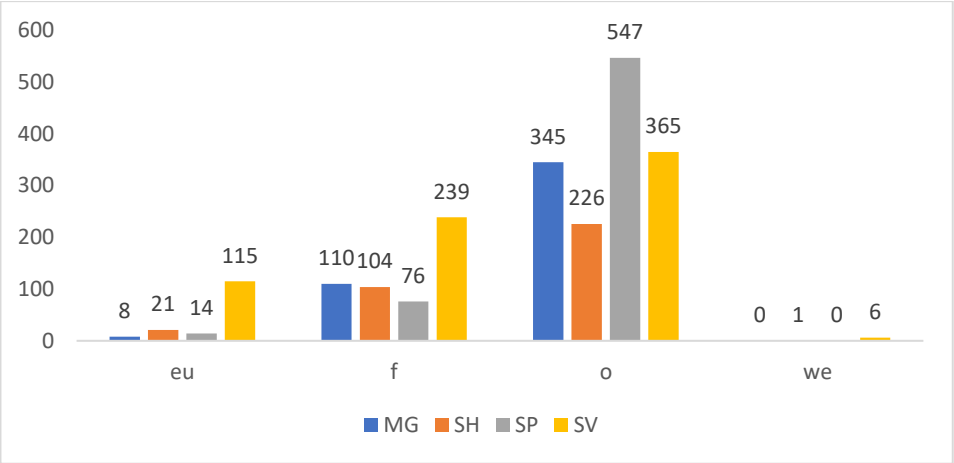


Figure 46. The number of Carabidae individuals with different size and trophic preferences (eu-eurytopic, f – forest, o – open area, we - wetland). The abbreviations used on the graph mean respectively: MG – miscanthus, SH- virginia mallow, SP – cup plant, SV- willow

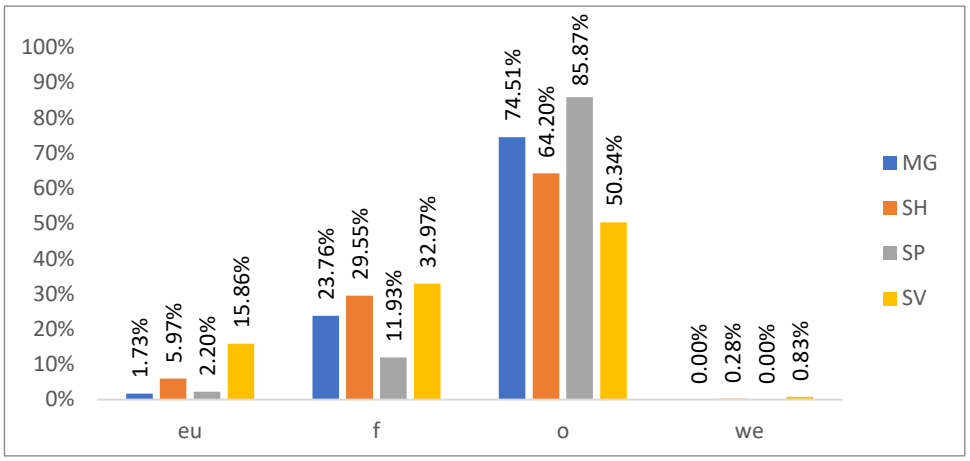


Figure 47. Percentage of Carabidae individuals with different size and trophic preferences (eu-eurytopic, f – forest, o – open area, we - wetland). The abbreviations used on the graph mean respectively: MG – miscanthus, SH- virginia mallow, SP – cup plant, SV- willow

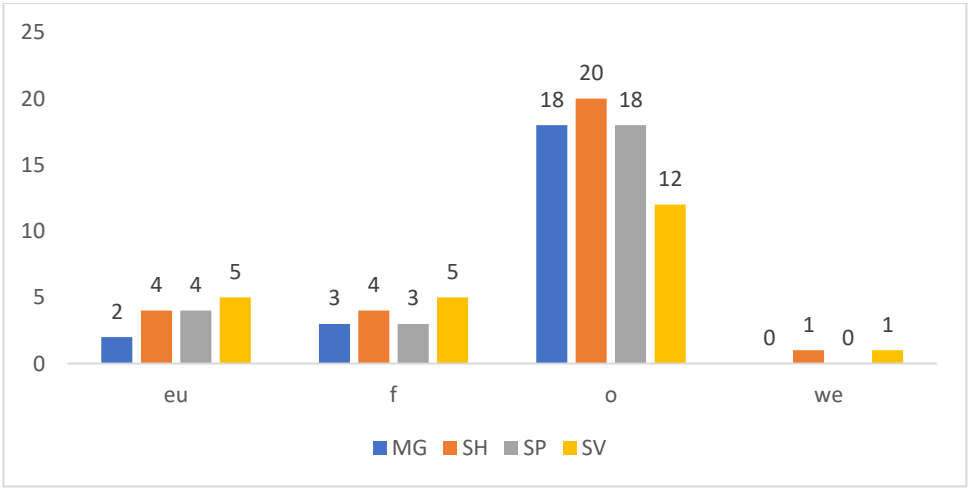


Figure 48. The number of Carabidae species with different size and trophic preferences (eu-eurytopic, f – forest, o – open area, we - wetland). The abbreviations used on the graph mean respectively: MG – miscanthus, SH- virginia mallow, SP – cup plant, SV- willow

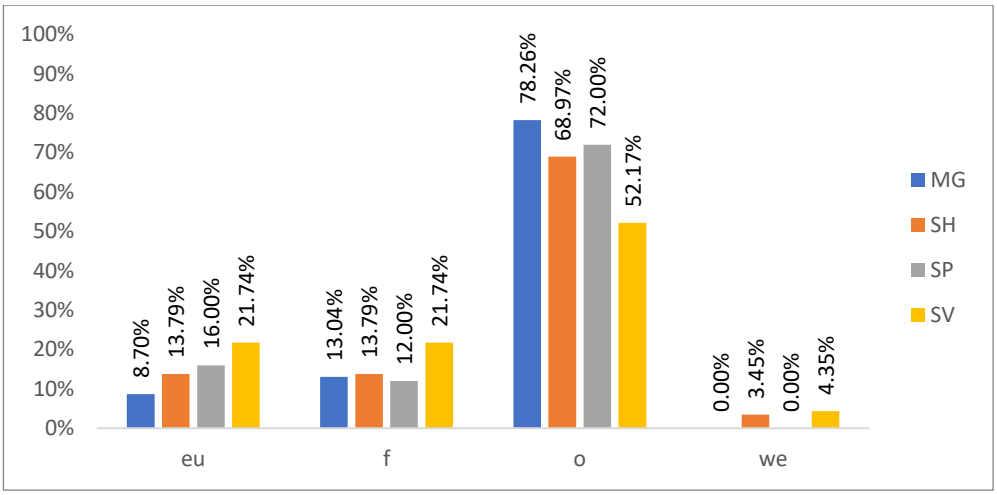


Figure 49. Percentage of Carabidae species with different size and trophic preferences (eu-eurytopic, f – forest, o – open area, we - wetland). The abbreviations used on the graph mean respectively: MG – miscanthus, SH- virginia mallow, SP – cup plant, SV- willow

There were 226 individuals on the virginia mallow crop (SH), constituting 64.20% of all individuals in the assemblage (**Fig. 46-47).** In qualitative terms, it was 20 species on this crop (68.97% of the assemblage) (**Fig. 48-49).** Open area species were the last numerous in the willow crop (SV) in both, quantitative, and qualitative terms. There were 365 individuals on the willow crop (SV), constituting 50.34% of all individuals in the assemblage **Fig. 46-47).** In qualitative terms, it was 20 species on this crop (52.17% of the assemblage) (**Fig. 48-49).** In all investigated plantations the most numerous species were *C. fuscipes* and *H. rufipes* (**Tab. 5, Fig. 50**).

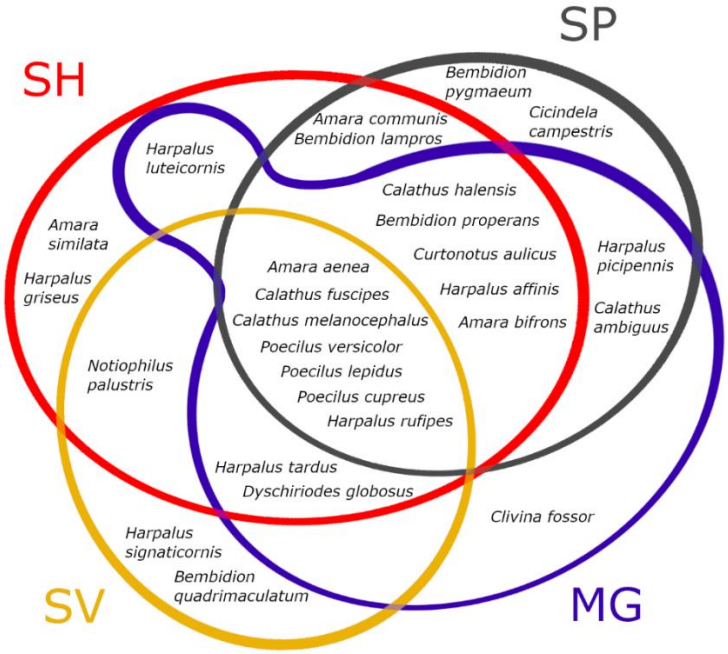


Figure 50. Open area species presence on the particular plots in the study site: ”Leginy”
The abbreviations used on the graph mean respectively: MG – miscanthus, SH- virginia mallow, SP – cup plant, SV- willow

Eurytopic species

The total number of eurytopic ground beetles was 158. They belonged to 7 species (**Tab. 6-7**). Statistical analyses indicated significant differences (p-value = 6.593E-06) in the number of individuals between the investigated plots (**Tab.9**). Differences were indicated between willow plantation (SV) and all other crops (MG, SH, SP) (**Fig. 51**).

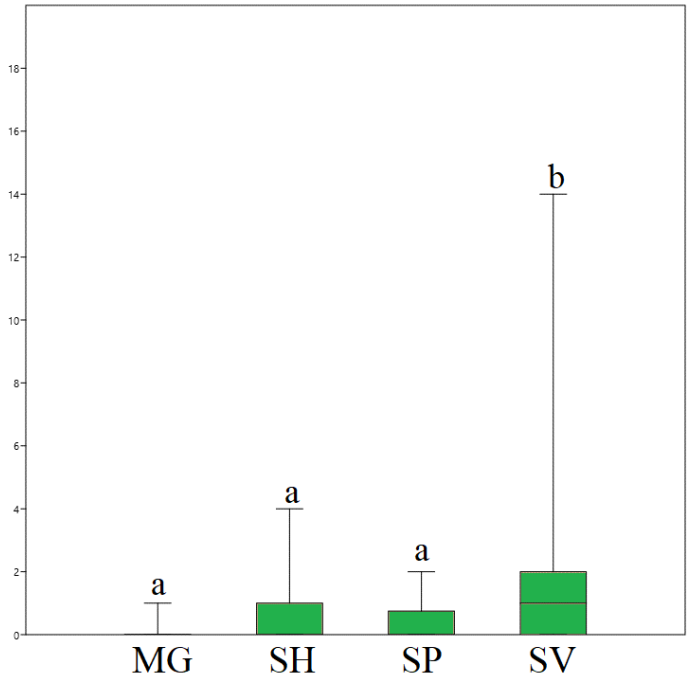


Figure 51. Rarefied eurytopic Carabidae individuals abundance for different crop types (Dunn's post hoc; p-value with Bonferroni correction). Mean values per trap are shown for the particular crops (MG – miscanthus, SH- virginia mallow, SP – cup plant, SV- willow) planted in the study site "Leginy". Different letters above the boxplots indicate significant differences between the habitats (p <0.05)

Eurytopic species were the most numerous in willow plantation, both quantitative and qualitative. It was 115 individuals caught there (15.86% of the assemblage) (**Fig. 46-47)**. There were 5 eurytopic species recorded on this crop (SV), constituting over 21.7% of the assemblage in terms of habitat preference (**Fig. 48-49)**. The most numerous represented species, recorded on this crop were: *C. cancellatus*, *N. brevicollis* and *P. melanarius* (**Tab.3, Tab. 5**). On the rest of the studied plantations, the number of eurytopic ground beetles was significantly lower. They were noticed in the lowest number, both in quantitative and qualitative terms on the miscanthus plantation (MG), where they were represented only by 2 species (8 individuals) (**Fig. 46, 48, 52**). According to the low number of individuals collected on those plantations, they were excluded from the further functional traits analyses.

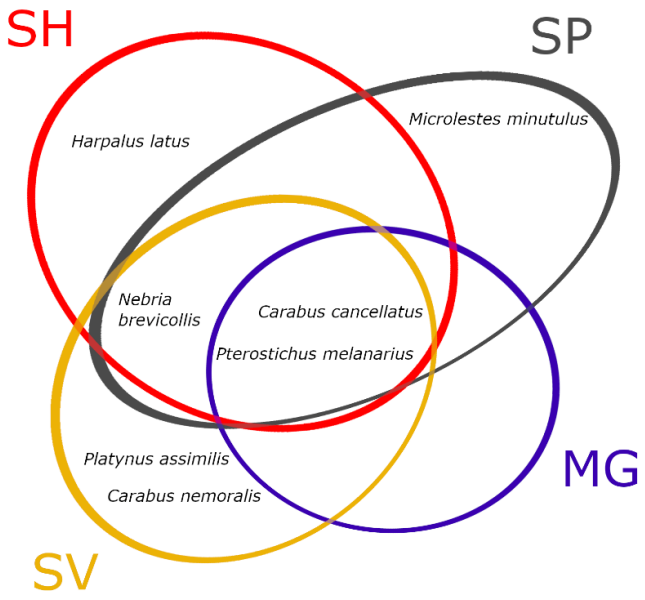


Figure 52. Eurytopic species presence on the particular plots in the study site: ”Leginy”
The abbreviations used on the graph mean respectively: MG – miscanthus, SH- virginia mallow, SP – cup plant, SV- willow

Forest species

The total number of collected forest ground beetles was 529, belonging to 7 species. (**Tab. 6-7**). Statistical analyses indicated significant differences (*p-value* = 0.0121) in the number of individuals between the investigated plots (**Tab.9**). Differences were indicated between the willow plantation (SV) and the cup plant crop (SP) (**Fig. 53**).

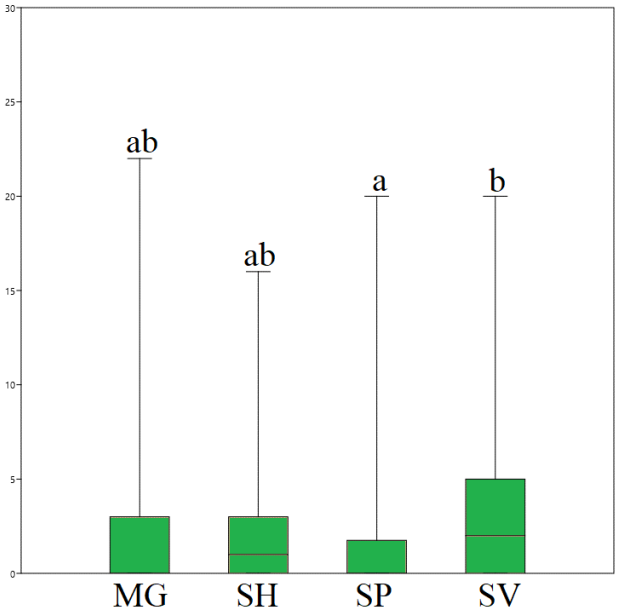


Figure 53. Rarefied forest Carabidae individuals abundance for different crop types (Dunn’s post hoc; p-value with Bonferroni correction). Mean values per trap are shown for the particular crops (MG – miscanthus, SH- virginia mallow, SP – cup plant, SV- willow) planted in the study site “Leginy”. Different letters above the boxplots indicate significant differences between the habitats ($p<0.05$)

Forest ground beetles were the most abundant on the willow plantation (SV). Individuals from this group constituted almost 33% of the assemblage recorded on this plantation (239 individuals (**Fig. 46-47)**. Correspondingly, the willow plantation (SV) was the most abundant in the qualitative term. There were 5 forest species recorded on this plantation: the most numerous *P. niger*, numerously represented *Calathus erratus* and *C. marginalis*, as well as *C. coriaceus* and *Badister bullatus* represented by single individuals (**Tab.3, Tab. 5**). They constituted 21.74% of all assemblage (**Fig. 48-49).** *C. marginalis* indicated on this crop is a rare species in Poland, occurring more numerous locally in the Warmia region. Forest species were the last abundant on the cup plant crop (SP). There were 76 individuals indicated on this plantation (**Fig. 46).** In quantitative terms, forest species constituted 11.93% of the assemblage on this plantation (**Fig. 47).** In qualitative terms, it was 3 species (12.00% of the assemblage) (**Fig. -47).** The most abundant were *P. niger* and *C. erratus* (**Tab.5**). Miscanthus (MG) and virginia mallow (SH) plantations were the most similar. On these plantations, 110 individuals and 104 individuals were indicated, respectively (**Fig. 46)**. In quantitative terms, they constituted 23.76% of the assemblage in the miscanthus (MG), and 29.55% of the assemblage in the virginia mallow (SH) crops, respectively (**Fig. 47)**. In the miscanthus crop (MG) 3 species (13.04% of the assemblage) were indicated and for virginia mallow (SH) there were 4 species (13.79% of the assemblage (**Fig. 48-49, Fig. 54).** On the miscanthus crop (MG), as well as on virginia mallow crop (SH), *P. niger* was the most numerous forest species (**Tab.5**).

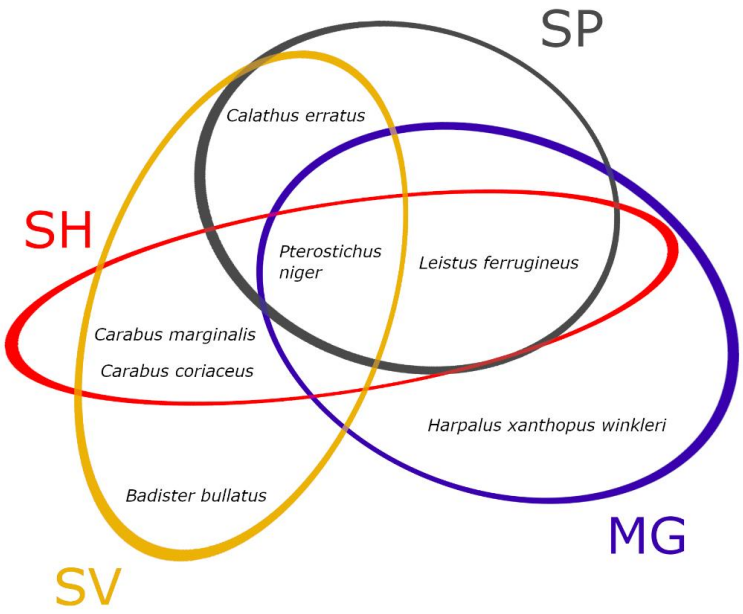


Figure 54. Forest species presence on the particular plots in the study site: ”Leginy”
The abbreviations used on the graph mean respectively: MG – miscanthus, SH- virginia mallow, SP – cup plant, SV- willow

Wetland species

Carabidae from this group were extremely rare in the study site "Leginy" – there was only one species: *C. granulatus*. It was noticed on willow crop (SV) (6 individuals – 0.83% of all individuals recorded on this crop) and on virginia mallow crop (SH) (1 specimen – 0.28% of all individuals recorded on this crop) (**Fig. 46-47, Fig. 55**). The low number of wetland Carabidae specimens does not allow to obtain statistically significant results for this group.

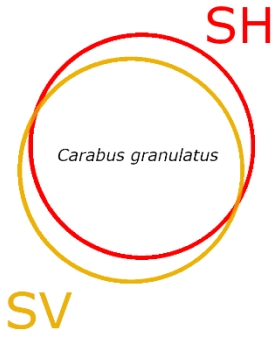


Figure 55. Wetland species presence on the particular plots in the study site: "Leginy"
The abbreviation used on the graph mean respectively: MG – miscanthus, SH- virginia mallow, SP – cup plant, SV- willow

Also, in the case of the distribution of habitat preferences, willow plantation (SV) differs significantly from other crops. In this crop, the lowest number of species preferring open areas and the highest number of forest species were indicated. Similarly, the number of eurytopic species was the highest for this plantation. It confirms hypothesis **H1**, showing that Carabidae assemblages inhabiting the willow plantations differ significantly from assemblages inhabiting other plantations also in terms of habitat preferences. Additionally, it creates the best conditions for species preferring forests, which partially confirms hypothesis **H2.**

Hygropreferences

The most numerously represented group were mesophiles, most abundant in all investigated plots, in quantitative, as well as qualitative terms. Moreover, hygrophilous species were extremely rare in the study site "Leginy" and were excluded from the further ecological traits analyses (**Tab. 6-7, Fig. 56**).

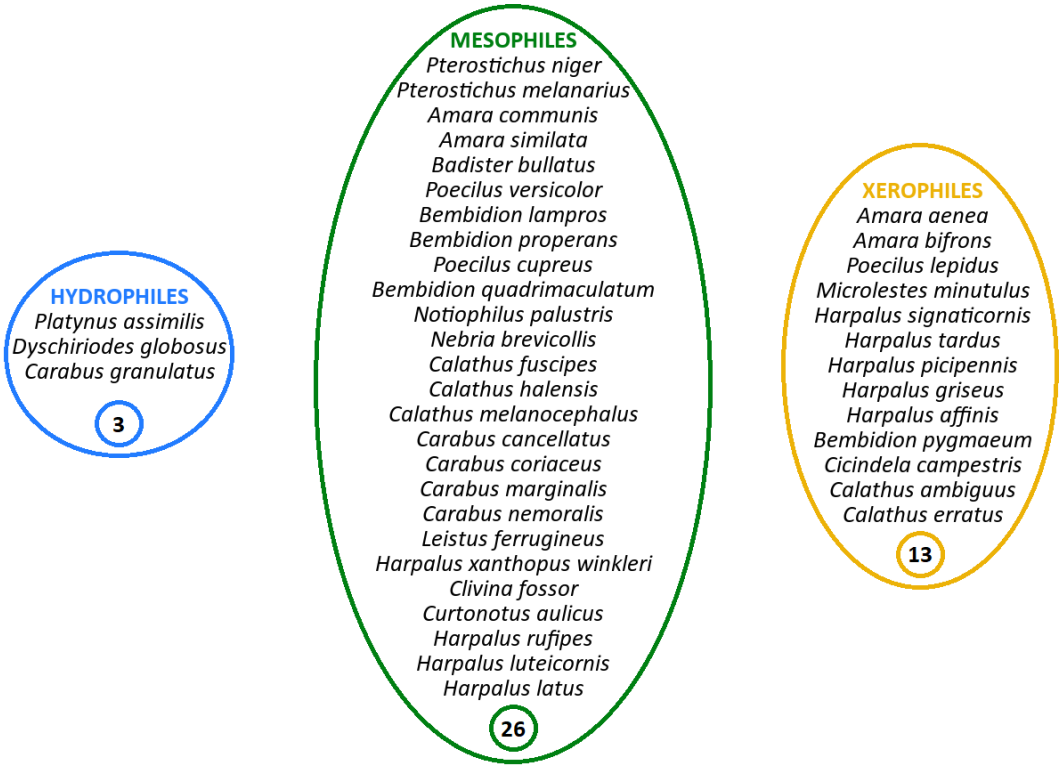


Figure 56. Species number and composition of Carabidae with different hygropreferences

In total, there were 13 xerophilous (249 individuals), 26 mesophilous (1,916 individuals) and 3 hygrophilous (12 individuals) species indicated (**Tab. 6-7**). Statistically significant differences in the number of ground beetles individuals with different hygropreference were indicated only for xerophilous species (*p-value*= 0.0001992) (**Tab.10**).

Table 10. Results of the Kruskal-Wallis significance test for hygropreferences of Carabidae inhabiting crops in the study site "Leginy"

Functional trait	***p***
Xerophilous (X)	0.0001992
Mesophilous (M)	n.s.
Hygrophilous (H)	n.s.

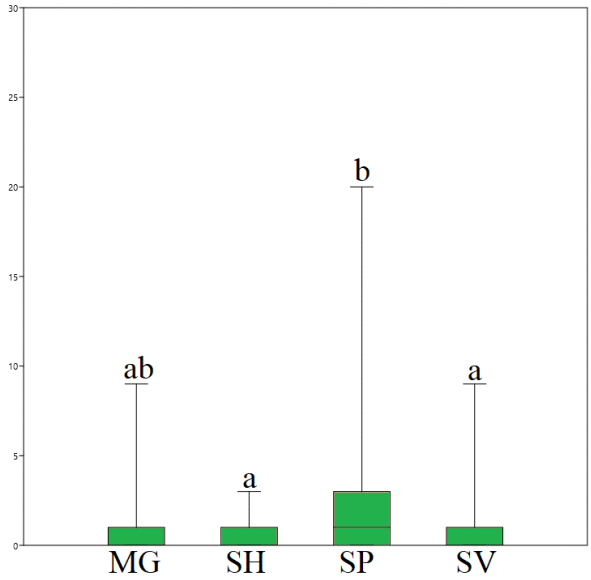


Figure 57. Rarefied xerophilous Carabidae individuals abundance for different crop types (Dunn's post hoc; p-value with Bonferroni correction). Mean values per trap are shown for the particular crops (MG – miscanthus, SH- virginia mallow, SP – cup plant, SV- willow) planted in the study site "Leginy". Different letters above the boxplots indicate significant differences between the habitats ($p < 0.05$)

Hygrophilous

Similarly to the overmentioned wetland species, hygrophilous species were very rare in all of the studied crops. There were only three species from this group recorded: *Platynus assimilis*, *Dyschiriodes globosus*, and *C. granulatus* (**Tab. 6, Fig. 58)**. There were no species from this group recorded on the cup plant crop (SP). Hygrophilous species were indicated on willow (SV) (8 individuals – 1.10% of all individuals recorded on this crop), virginia mallow (3 individuals – 0.85% of all individuals recorded on this crop) and miscanthus crops (1 individual – 0.22% of all individuals recorded on this crop) (**Tab. 59- 60**). A low number of specimens from this group does not allow us to obtain statistically significant results for hygrophilous Carabidae.

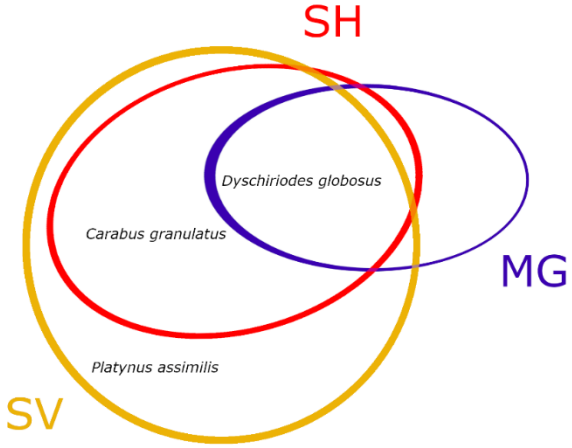


Figure 58. Hygrophilous species presence on the particular plots in the study site: "Leginy"
The abbreviations used on the graph mean respectively: MG – miscanthus, SH- virginia mallow, SP – cup plant, SV- willow

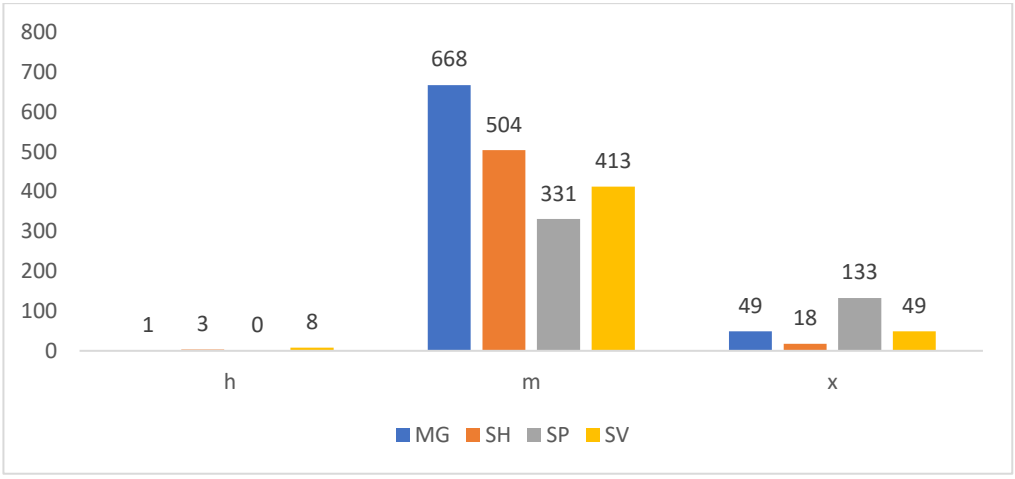


Figure 59. The number of Carabidae individuals with different hygropreferences (h – hygrophilous, m – mesophilous, x - xerophilous). The abbreviations used on the graph mean respectively: MG – miscanthus, SH- virginia mallow, SP – cup plant, SV- willow

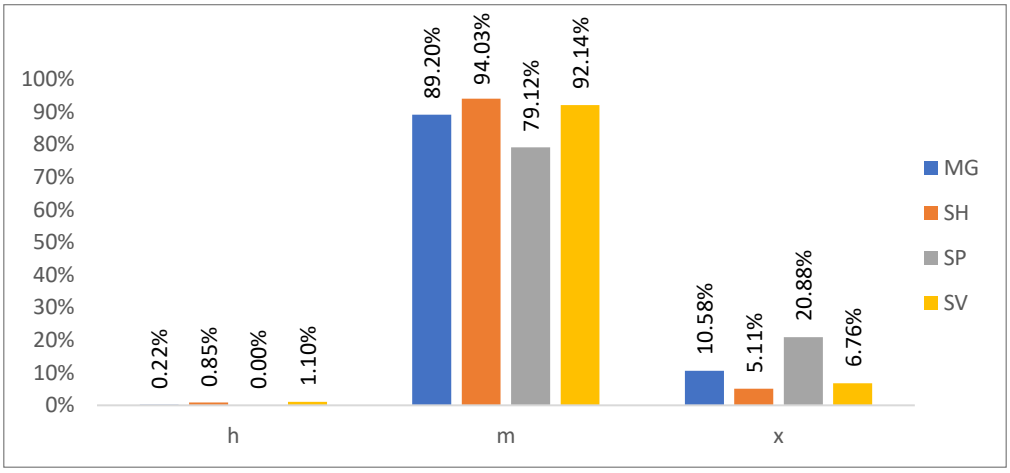


Figure 60. Percentage of Carabidae individuals with different hygropreferences (h – hygrophilous, m – mesophilous, x - xerophilous). The abbreviations used on the graph mean respectively: MG – miscanthus, SH- virginia mallow, SP – cup plant, SV- willow

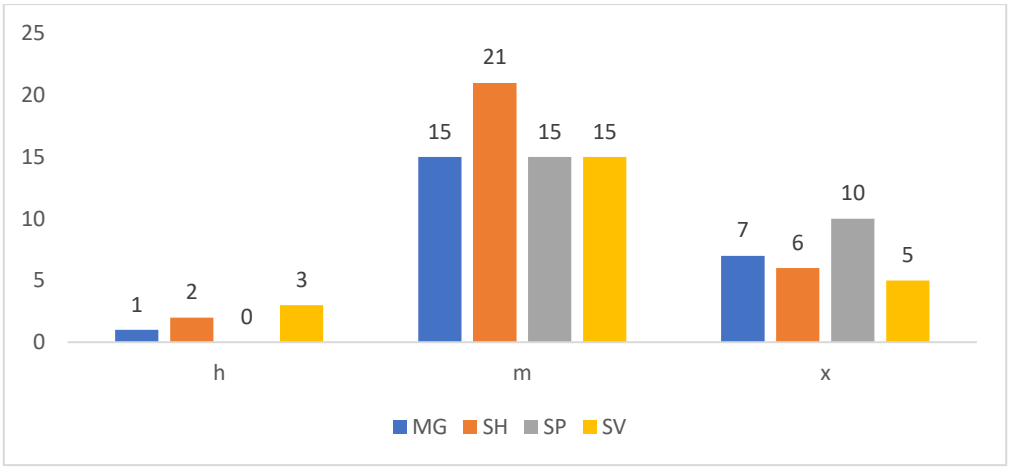


Figure 61. The number of Carabidae species with different hygropreferences (h – hygrophilous, m – mesophilous, x - xerophilous). The abbreviations used on the graph mean respectively: MG – miscanthus, SH- virginia mallow, SP – cup plant, SV- willow

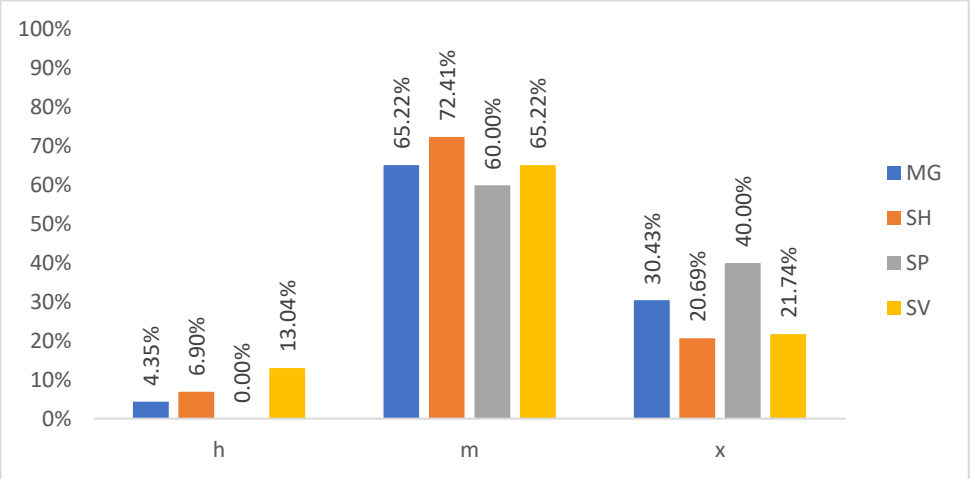


Figure 62. Percentage of Carabidae species with different hygropreferences (h – hygrophilous, m – mesophilous, x - xerophilous). The abbreviations used on the graph mean respectively: MG – miscanthus, SH- virginia mallow, SP – cup plant, SV- willow

Mesophilous species

There were no statistically significant differences in the number of individuals representing mesophilous species (**Tab. 10**). It was the most numerous group in all studied plantations – all eudominants belonged to it (**Tab. 3, 5, Fig. 56**). In both, qualitative and quantitative terms, the percentage of the species from this group was the highest in the virginia mallow crop (SH). There were 504 individuals from this group (94.03% of the assemblage), representing 21 species (72.41% of the assemblage) (**Tab. 59-60**). On the willow crop (SV) there were 413 individuals indicated (92.14% of the assemblage), representing 15 species (65.22% of the assemblage) (**Tab. 59- 61)**. On the miscanthus crop (MG) there were 668 individuals indicated (89.20% of the assemblage), representing 15 species (65.22% of the assemblage) (**Tab. 59-60)**. Mesophilous species were the last numerous on the cup plant crop (SP). There were 331 individuals from this group indicated (79.12% of the assemblage), representing 15 species (60.00% of the assemblage) (**Tab. 59-60)**. There was a large group of mesophilous species common for all studied crops (**Fig. 63**).

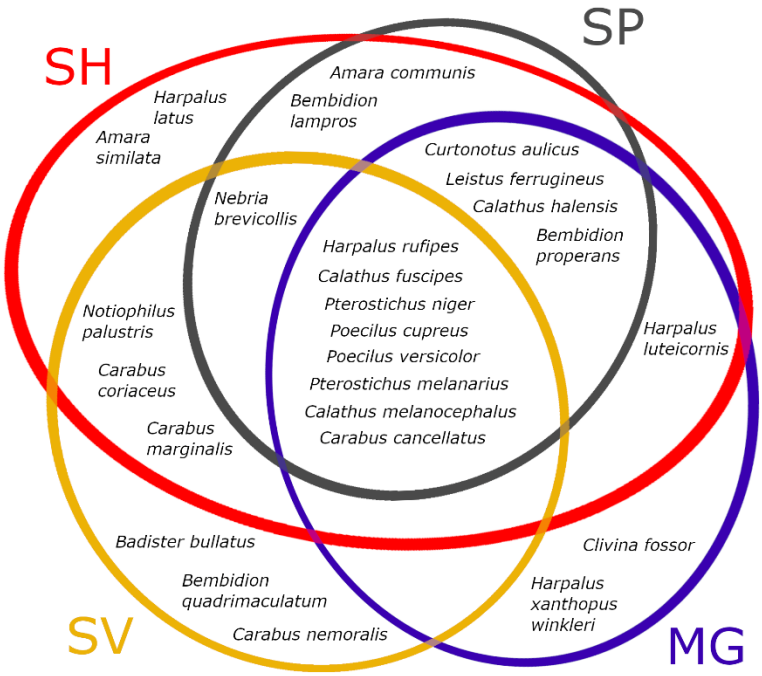


Figure 63. Mesophilous species presence on the particular plots in the study site: ”Leginy”
The abbreviations used on the graph mean respectively: MG – miscanthus, SH- virginia mallow, SP – cup plant, SV- willow

Xerophilous species

Statistical analyses indicated significant differences between the number of individuals recorded on the particular crops (*p-value* = 0.0001992) (**Tab. 10**). Differences were indicated between a) the cup plant (SP) and willow (SV) crops as well as b) the cup plant (SP) and virginia mallow (SH) crops (**Fig. 57**). Xerophilous species were the most numerous in the cup plant crop (SP) – there were 10 species belonging to this type, constituting 40% of the assemblage in qualitative terms. In quantitative terms, there were 133 individuals (20.88% of the assemblage) (**Tab. 59-60)**. In the willow plantation (SV) were 5 species, constituting 21.74% of the assemblage in qualitative terms. There were 49 individuals from this group (6.76% of the assemblage in quantitative terms) (**Tab. 59-60)**. In the miscanthus plantation (MG), 7 xerophilous species constituted 30.43% of the assemblage in qualitative terms. There were 49 individuals from this group (10.58% of the assemblage in quantitative terms) (**Tab. 59-60)**. Xerophilous species were the last numerous on the virginia mallow plantation (SH). There were 6 xerophilous species, which constituted 20.69% of the assemblage in qualitative terms. There were 18 individuals from this group (5.11% of the assemblage in quantitative terms) (**Tab. 59-**

60). The most numerous xerophilous species indicated on the cup plant crop (SP) were *A. bifrons* and *C. erratus*, belonging to the group of dominants, as well as *P. lepidus* and *H. affinis*, belonging to the group of subdominants. On the willow plantation (SV) it was *C. erratus* from the group of subdominants. The most numerous xerophilous species indicated on the miscanthus crop (MG) were *H. affinis*, *A. aenea* and *A. bifrons* belonging to the group of subdominant (**Tab. 3, Tab. 5, Fig. 64**).

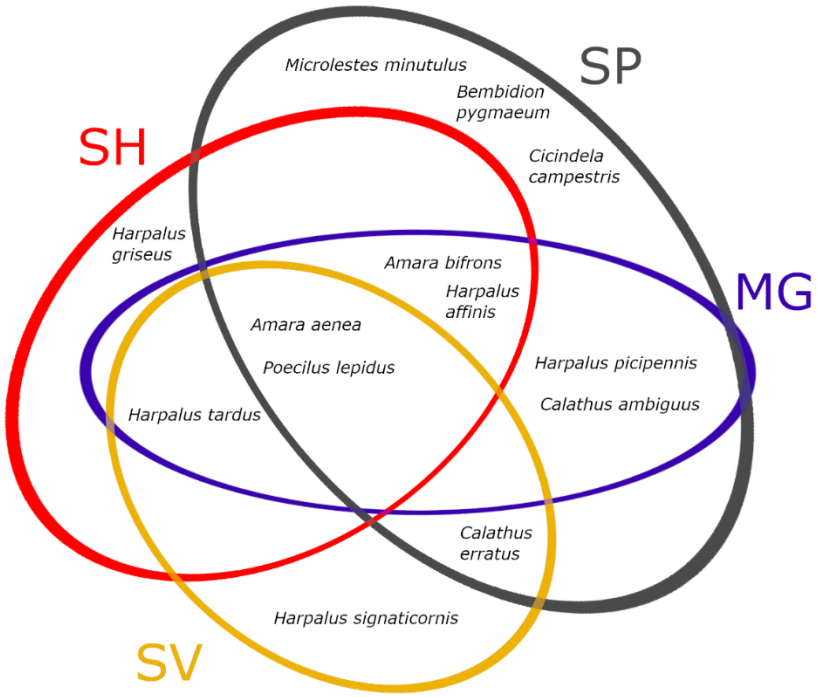


Figure 64. Xerophilous species presence on the particular plots in the study site: ”Leginy”
The abbreviations used on the graph mean respectively: MG – miscanthus, SH- virginia mallow, SP – cup plant, SV- willow

Mesophiles were the most numerously represented group on all crops in the study site “Leginy”. It was particularly evident, especially in the quantitive terms. Significant differences between the plots were indicated only for xerophilous species, the most numerously represented on the cup plant crop.

Dispersion capability

The most numerous group in quantitative terms were dimorphic species. However, in qualitative terms, those species were the last numerous. In qualitative terms, macropterous species were the most numerous group (**Tabl. 6, Fig. 65**).

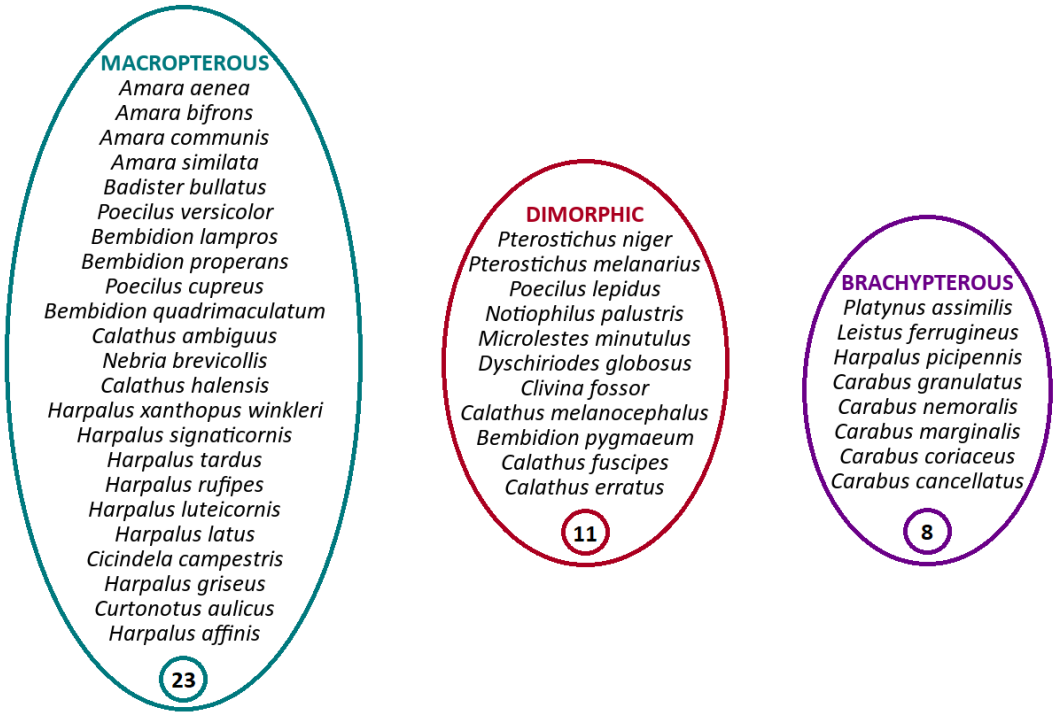


Figure 65. Species number and composition of Carabidae with different dispersion capabilities

In total, there were 8 brachypterous species (123 individuals), 11 dimorphic species (1,256 individuals) and 23 macropterous species (798 individuals) indicated (**Tab. 6-7**). There were statistically significant differences in the number of individuals of ground beetles with different dispersion abilities (brachypterous *p-value*=1.091E-05; macropterous *p-value*=3.631E-05), except for the dipterous ones (**Tab. 11**). It was indicated, that in terms of brachypterous species number, willow plantation (SV) differed from all other crops (**Fig. 66**).

Table 11. Results of the Kruskal-Wallis significance test for dispersion capacity of Carabidae inhabiting crops in the study site "Leginy"

Functional trait	***p***
Brachypterous (B)	1.091E-05
Dimorphic (D)	n.s.
Macropterous (Mac)	3.631E-05

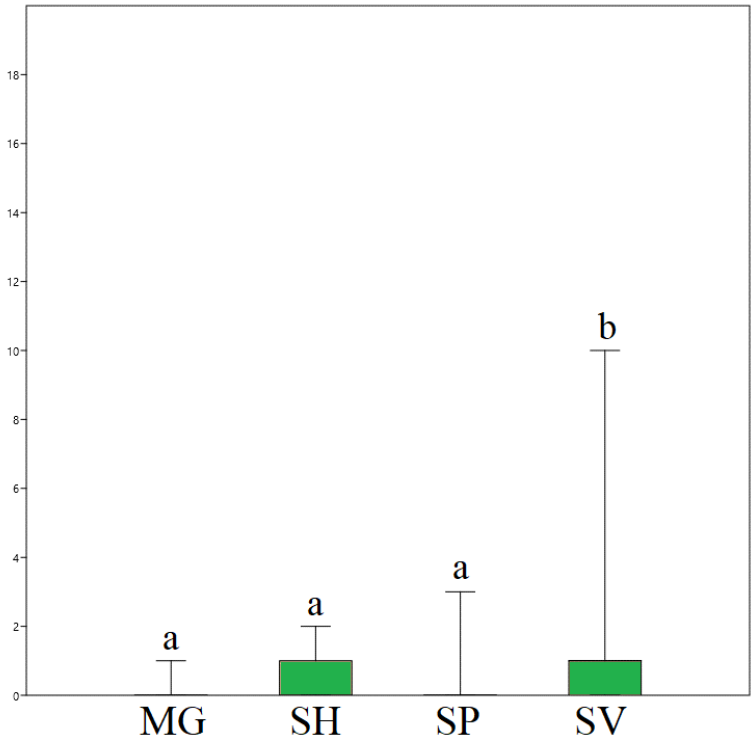


Figure 66. Rarefied brachypterous Carabidae individuals abundance for different crop types (Dunn's post hoc; p-value with Bonferroni correction). Mean values per trap are shown for the particular crops (MG – miscanthus, SH- virginia mallow, SP – cup plant, SV- willow) planted in the study site "Leginy". Different letters above the boxplots indicate significant differences between the habitats ($p < 0.05$)

Willow plantation (SV) was the most abundant in brachypterous species, in both, qualitative (26.09% of the assemblage) and quantitive (11.72% of the assemblage) terms (**Fig. 69, Fig. 71**). There were 6 brachypterous species, indicated in this crop (85 individuals) **Fig. (68, Fig. 70**). In this plantation brachypterous species recorded were: *P. assimilis, C. nemoralis, C. marginalis, C. coriaceus, C. granulatus* and *C. cancellatus* (**Tab. 6, Fig. 72**). Except for *P. assimilis* all of them were large carnivores, and none of them belonged to open area species. Also in the case of brachypterous species abundance, miscanthus (MG) and cup plant (SP) crops differ the most from willow crop (SV). In those crops, brachypterous species constituted respectively 1.94% (9 individuals) and 2.04% (13 individuals) of the assemblage in quantitative (**Fig. 68-69**) as well as 13.04% (3 species) and 12.00% (3 species) in qualitative terms (**Fig. 70-71**). On virginia mallow plantation (SH) brachypterous species constituted 4.55% of the assemblage in quantitive terms (16 individuals) (**Fig. 68-69**) and 17.24% of the assemblage in qualitative terms (5 species) (**Fig. 70-71**).

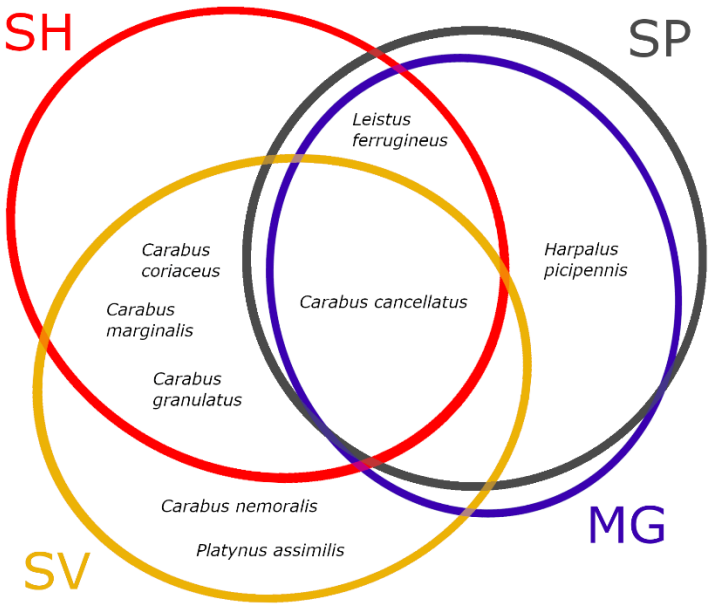


Figure 67. Brachypterous species presence on the particular plots in the study site: ”Leginy”
The abbreviations used on the graph mean respectively: MG – miscanthus, SH- virginia mallow, SP – cup plant, SV- willow

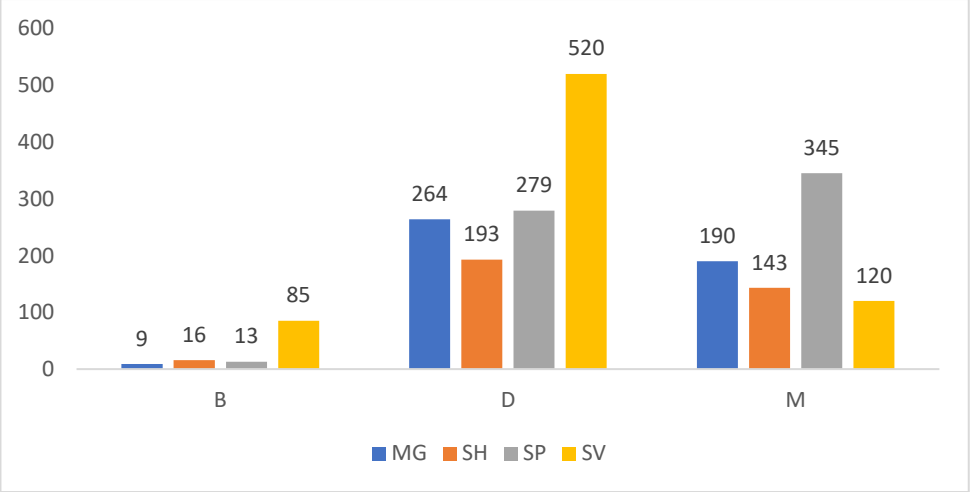


Figure 68. The number of Carabidae individuals with different dispersion capacities (B - brachypterous, D – dimorphic, M - macropterous). The abbreviations used on the graph mean respectively: MG – miscanthus, SH- virginia mallow, SP – cup plant, SV- willow

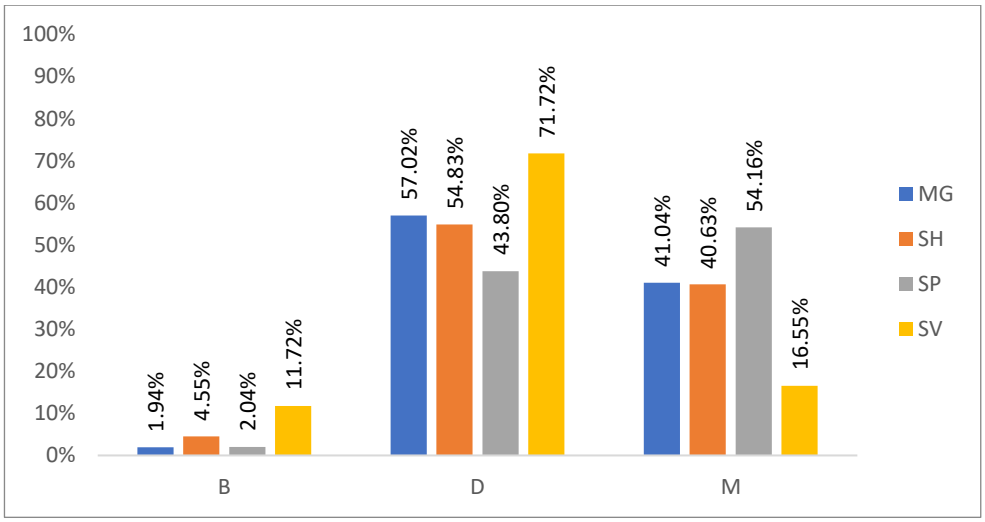


Figure 69. Percentage of Carabidae individuals with different dispersion capacities (B - brachypterous, D – dimorphic, M - macropterous). The abbreviations used on the (MG, SH, SP, SV) as in Fig. 68

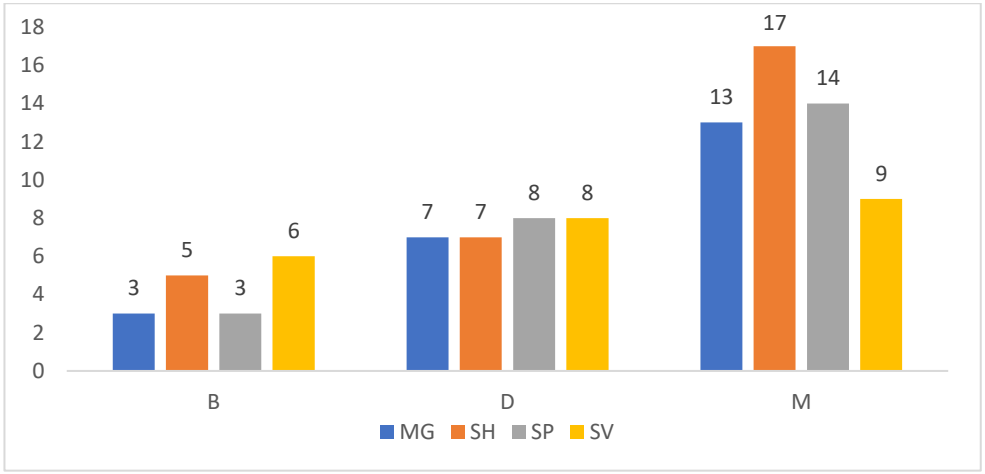


Figure 70. Percentage of Carabidae individuals with different dispersion capacities (B -brachypterous, D – dimorphic, M - macropterous). The abbreviations used on the (MG, SH, SP, SV) as in Fig. 68

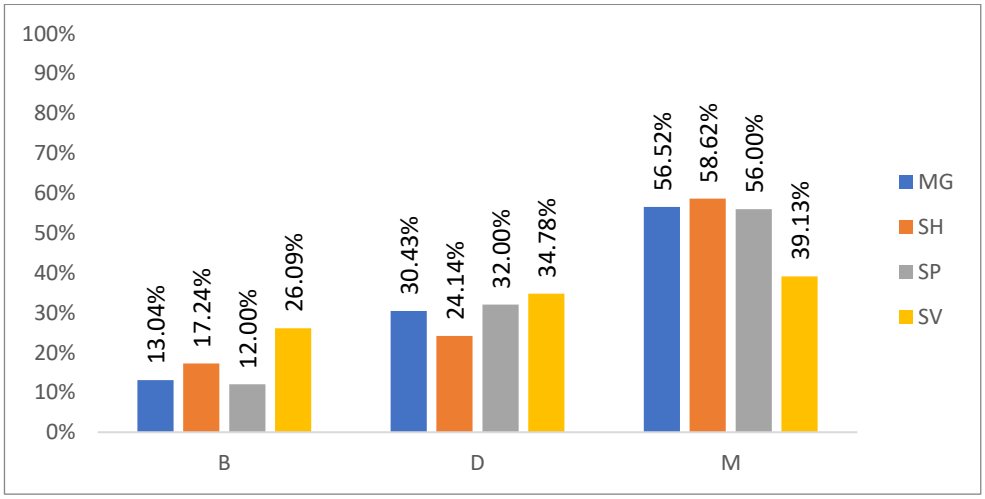


Figure 71. Percentage of Carabidae individuals with different dispersion capacities (B - brachypterous, D – dimorphic, M - macropterous). The abbreviations used on the (MG, SH, SP, SV) as in Fig. 68

In willow plantation (SV), in which the number of macropterous individuals was the lowest, dimorphic species constituted the largest part of the assemblage, in both, quantitative, as well as in qualitative terms (71.72% of individuals in the assemblage, 34.78% of species in the assemblage) (**Fig. 69, Fig. 71**). However, there were no statistical differences in the number of dimorphic individuals, between the particular plots (**Tab. 11)**. In the willow plantation (SV) 520 dimorphic Carabidae individuals, represented by 8 species were indicated (**Fig. 68-7**). Similar values were received for other plantations. On the miscanthus crop (MG) were 264 dimorphic Carabidae individuals (57.02% of the assemblage), represented by the 7 species (30.43% of species in the assemblage(**Fig. 68-71**). On the virginia mallow crop (SH) were 193 dimorphic Carabidae individuals (54.83% of the assemblage), represented by the 7 species (24.14% of species in the assemblage) (**Fig. 68-71**). On the cup plant crop (SP) were 279 dimorphic Carabidae individuals (43.80% of the assemblage), represented by the 8 species (32.00% of species in the assemblage) (**Fig. 68-71**). *C. fuscipes* and *P. niger* were the most numerous species from this group in all investigated plantations. *C. erratus* was also numerous in cup plant (SP) and willow (SV) crops, as well as *P. melanarius* in willow crop (SV) (**Tab. 3, 5, Fig. 72**).

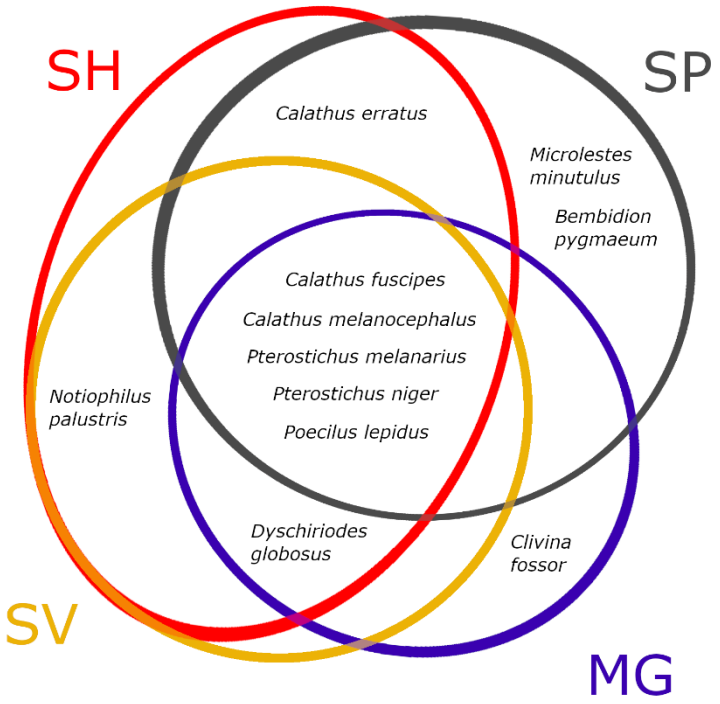


Figure 72. Dimorphic species presence on the particular plots in the study site: ”Leginy”
The abbreviations used on the graph mean respectively: MG – miscanthus, SH- virginia mallow, SP – cup plant, SV- willow

The number of macropterous species, with high dispersion capacity, was significantly lower on willow plantation (SV) (**Fig. 73**). On this crop, only 9 species from this group were indicated, and they were represented by 120 individuals. (**Fig. 68, Fig. 70**). They accounted for 39.13% of the assemblage in qualitative terms and only 16.55% in quantitive (**Fig. 69, Fig.71**).

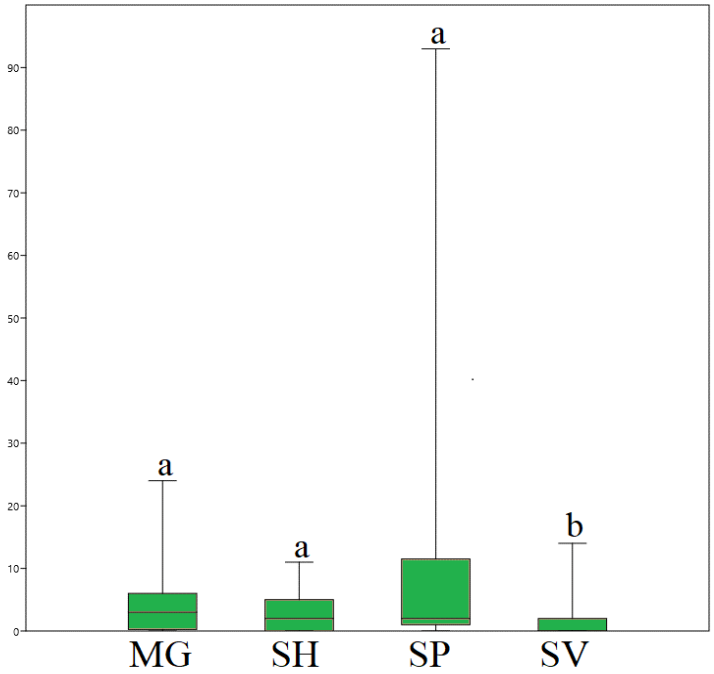


Figure 73. Rarefied macropterous Carabidae individuals abundance for different crop types (Dunn's post hoc; p-value with Bonferroni correction). Mean values per trap are shown for the particular crops (MG – miscanthus, SH- virginia mallow, SP – cup plant, SV- willow) planted in the study site "Leginy". Different letters above the boxplots indicate significant differences between the habitats ($p < 0.05$)

It was a significantly lower number, in comparison to other crops: miscanthus (MG) (13 species, which gave 56.52% of the assemblage in qualitative terms and 41.04% in quantitive terms) virginia mallow (SH) (17 species, which gave 58.62% of the assemblage in qualitative terms and 40.63% in quantitive terms) and a cup plant (SP) (14 species, which gave 56.00% of the assemblage in qualitative terms and 54.16% in quantitive terms) (**Fig. 68-71**). Most of the macropterous species were hemizoophages or small carnivores, only *Calathus halensis* was a large carnivore. There was a group of macropterous species common for all of the investigated plantations. Additionally, there was the second group, common for the perennial herbaceous energy crops (MG, SH, SP) (**Fig. 74**). The highest number of brachypterous species, as well as the lowest abundance of macropterous ones, was noticed in the willow crop (SV). It proves, that this plantation provides the best conditions for this group. It confirmed hypothesis **H1**, as well as **H2** (partially).

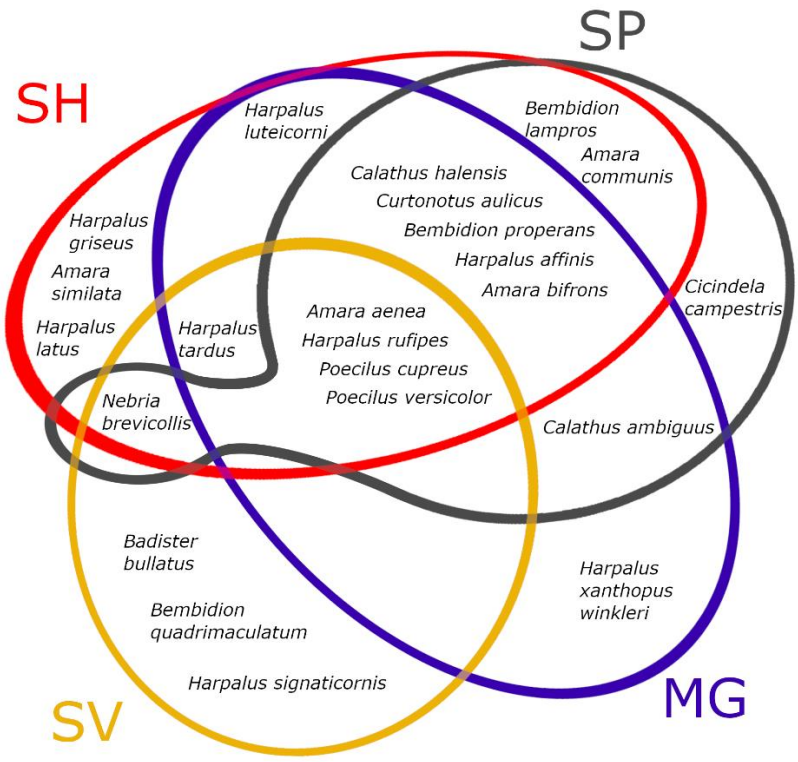


Figure 74. Macropterous species presence on the particular plots in the study site: ”Leginy”
The abbreviations used on the graph mean respectively: MG – miscanthus, SH- virginia mallow, SP – cup plant, SV- willow

In the PCA based on the species assemblages, the first and the second ordination axes explained 28.5 and 17.2 % of the variation in the dataset, respectively. In the case of the PCA based on functional traits, the first and the second ordination axis explained 43.1% and 17.8% of the variation in the dataset, respectively (**Fig. 75, Fig. 76**) The assemblages from the different study plots were located on the different sites of the diagram. Assemblages recorded in the cup plant crop (SP) were located on the diagram side opposite to the assemblages recorded in the willow crop (SV). The assemblage recorded in the miscanthus (MG) was located adjacent to the assemblage recorded in the virginia mallow (SH), but the assemblage recorded in the miscanthus (MG) was somewhat shifted in the cup plant (SP) assemblage direction (**Fig. 75)**.

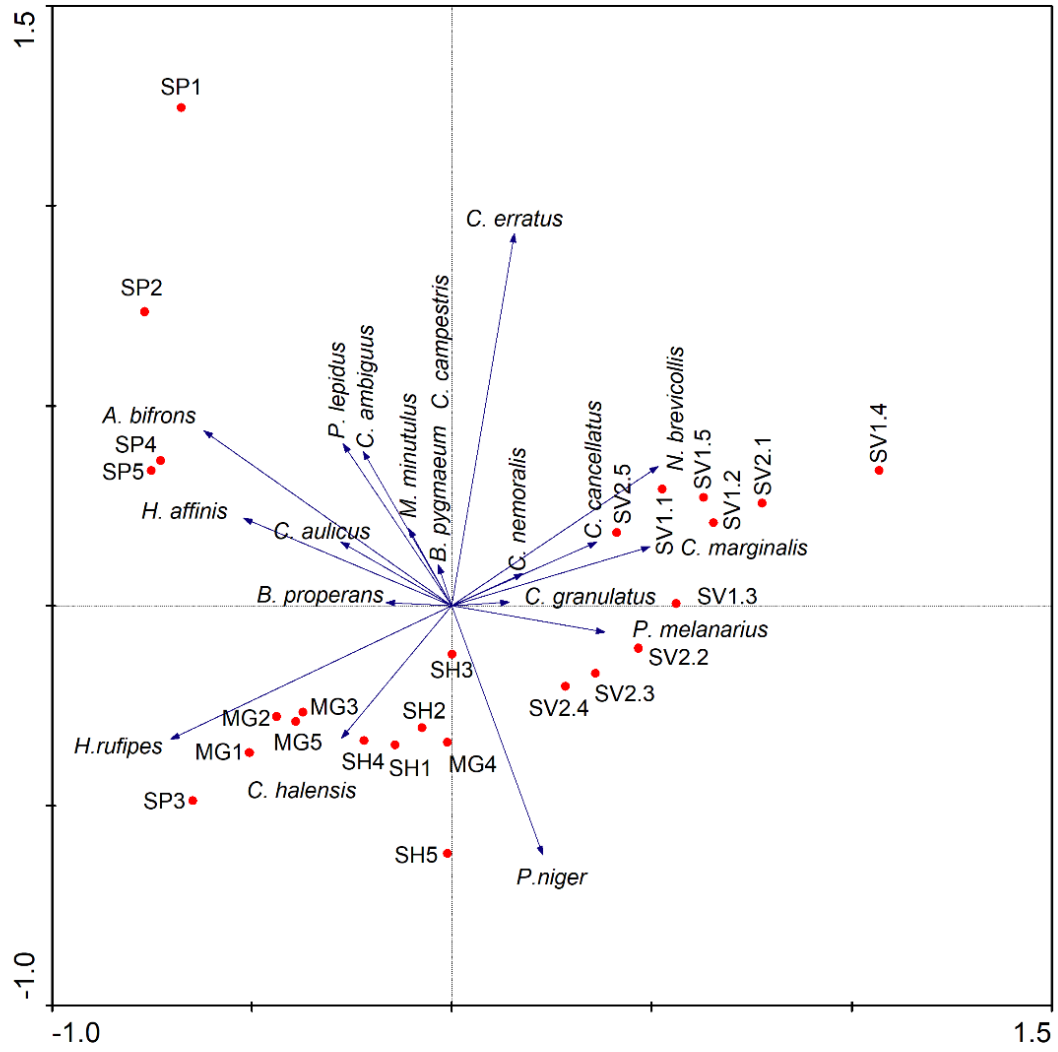


Figure 75. Ordination plot based on Principal Component Analysis (PCA) of the Carabidae assemblages (species information) inhabiting investigated study plots (MG – miscanthus, SH- virginia mallow, SP – cup plant, SV- willow) in the study site "Leginy"

The plot covered with the cup plant (SP) seemed to be characterized more by open area species, preferring dry conditions, such as *A. bifrons*, *H. affinis*, *P.s lepidus* and *Calathus ambiguus*. Similarly, assemblage recorded in the miscanthus crop (MG) was characterized by open area species, but preferred rather mesophilic conditions, like *H. rufipes* and *C. halensis.* This assemblage was connected also with the assemblage inhabiting the virginia mallow crop (SH).

Also, the PCA based on functional traits showed the tendency that the xerophilous, macropterous, phytophagous and hemizoophagous, as well as open area species, were more strongly connected with the miscanthus (MG) and the cup plant (SP). Whereas, willow plantation (SV) seemed to be characterized more by brachypterous and eurytopic species, as well as by species preferring wetlands, and hygrophilous ones. Similarly, forest species and large carnivores were more connected with willow plantation (SV). Regarding these groups, species directed towards willow plantation (SV) were: eurytopic *N. brevicollis*, *C. cancellatus* and *P. melanarius*, wetland *C. granulatus* and forest *C. marginalis* (**Fig. 76**).

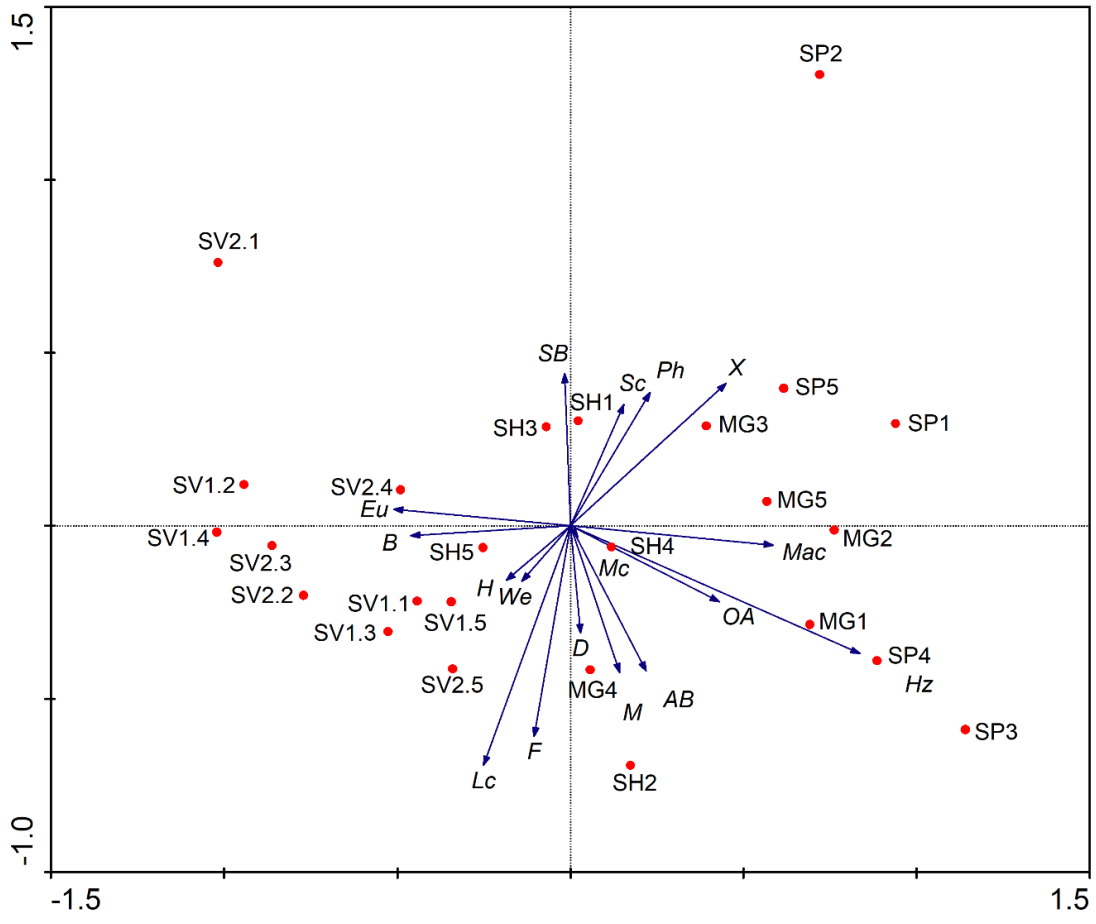


Figure 76. Ordination plot based on Principal Component Analysis (PCA) of the functional traits of Carabidae assemblages inhabiting investigated study plots (MG – miscanthus, SH- virginia mallow, SP – cup plant, SV- willow) in the study site "Leginy"

4.2. Willow versus other habitats in agricultural landscape - study site "Kocibórz"

4.2.1. Species richness and abundance

During the 2-year study, 11,248 individuals representing 86 species of Carabidae were caught in the study site "Kocibórz". In the first year of the study 6,434 individuals, belonging to 75 species were caught. In 2020 total number of collected individuals (4,814 individuals), as well as the number of collected species (63 species) decreased (**Tab. 12-13**).

On the studied sites, the following number of individuals were caught in the study years 2019-2020, respectively: Eco-Salix plantation (KES) - 1,395 and 1,537 individuals, agricultural crop (KP) - 1,233 and 1,400 individuals, fallow land (KU) - 2,363 and 1,295 individuals, short rotation coppice willow plantation (KW) - 1,443 and 582 individuals (**Fig. 77**). During the 2-year study, significant differences between the individuals number were indicated only between the willow planted in the Eco-Salix (KES) and SRC (KW) systems (*p-value*=0.02374) (**Fig. 79**) The number of species in study years 2019-2020 was between 30 – 49 and was the highest (49) for the arable crop (KP) in the study year 2019 (**Fig. 78).** Based on the Kruskal-Wallis test, no significant differences in the species number captured on each of the experimental plots were indicated.

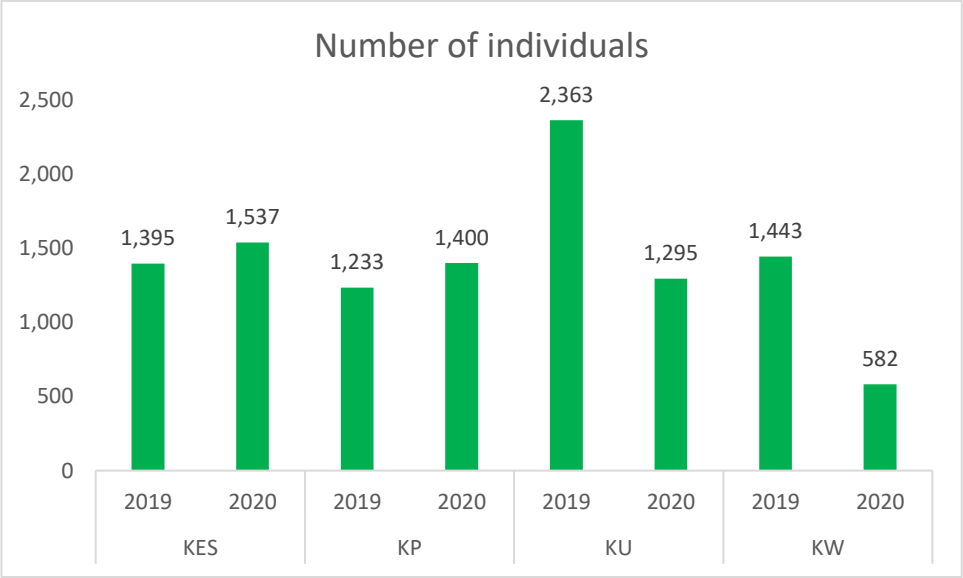


Figure 77. The number of Carabidae individuals captured in the study site "Kocibórz" in the years 2019 and 2020. The abbreviations used on the graph mean respectively: KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow

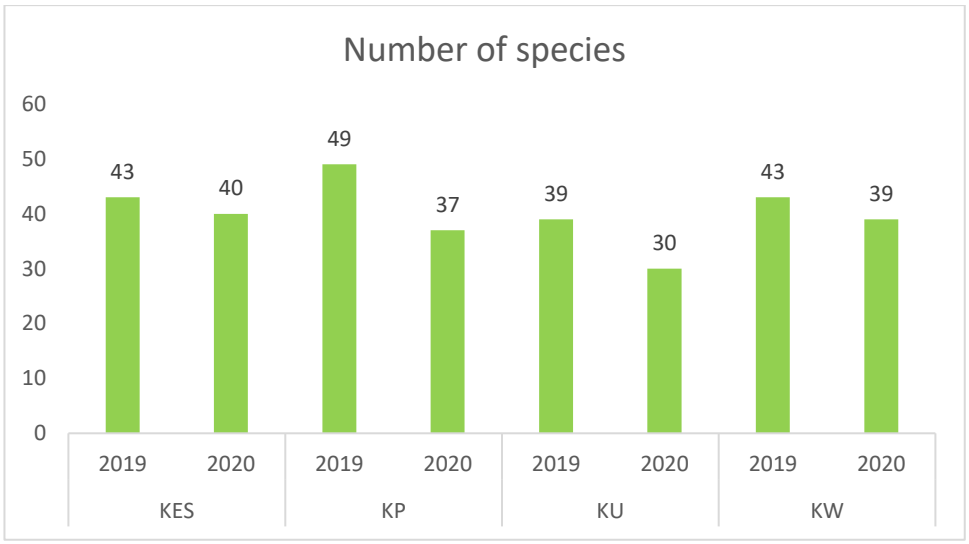


Figure 78. The number of Carabidae species captured in the study site "Kocibórz" in the years 2019 and 2020. The abbreviations used on the graph mean respectively: KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow

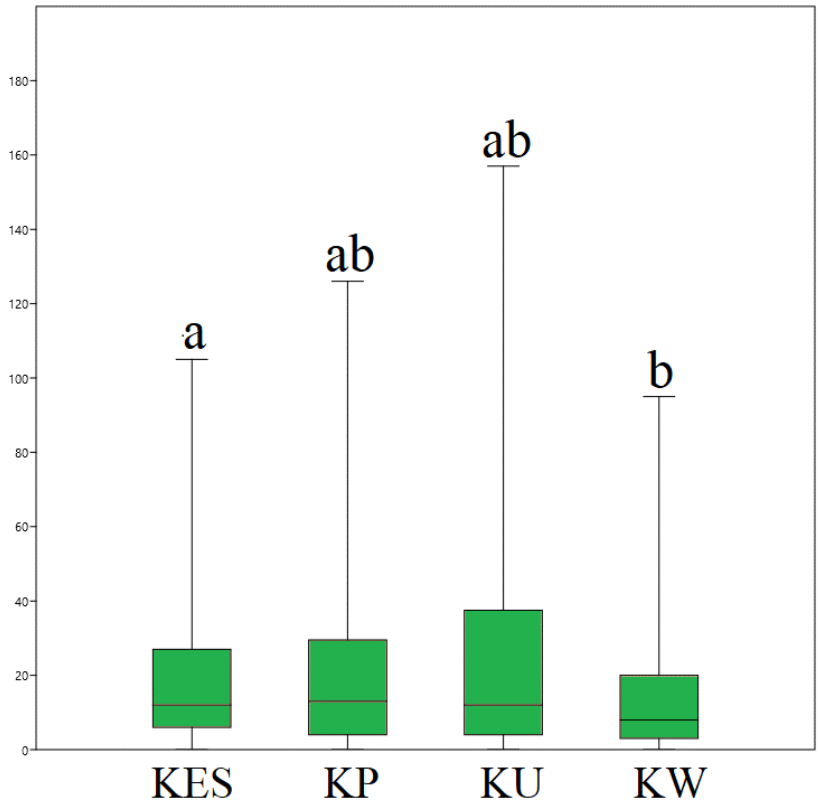


Figure 79. Rarefied Carabidae individuals abundance for different plots (Dunn's post hoc; p-value with Bonferroni correction). Mean values per trap are shown for the particular plots (KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow;) in the study site "Kocibórz". Different letters above the boxplots indicate significant differences between the habitats ($p < 0.05$)

Table 12. Species composition and abundance of Carabidae caught in the experimental plots in Kocibórz. The abbreviations used on the graph (KES, KP, KU, KW) as in Tab. 3

Species	KES		KP		KU		KW	
	2019	2020	2019	2020	2019	2020	2019	2020
Agonum fuliginosum (Panzer, 1809)	-	4	-	-	-	-	1	-
Agonum gracilipes (Duftschmid, 1812)	-	-	4	-	1	-	1	-
Agonum sexpunctatum (Linnaeus, 1758)	-	-	1	1	-	-	3	-
Agonum viduum (Panzer, 1796)	6	-	-	-	-	-	-	-
Amara aenea (Degeer,1774)	2	4	1	7	67	32	12	1
Amara bifrons (Gyllenhal, 1810)	1	-	3	16	16	66	3	8
Amara communis (Panzer, 1797)	6	19	-	-	1	-	-	5
Amara consularis (Duftschmid, 1812)	-	-	2	3	2	2	1	-
Amara convexior (J.F. Stephens, 1828)	-	-	2	-	9	-	1	-
Amara familiaris (Duftschmid, 1812)	-	1	-	2	-	1	-	1
Amara fulva (Degeer, 1774)	-	-	1	-	-	-	-	-
Amara lunicollis (Schiødte, 1837)	-	-	2	-	-	-	-	-
Amara majuscula (Chaudoir, 1850)	-	-	1	-	-	-	-	-
Amara montivaga (Sturm, 1825)	-	-	-	-	-	-	1	-
Amara ovata (Fabricius, 1792)	-	-	1	7	-	2	6	4
Amara plebeja (Gyllenhal, 1810)	-	-	1	-	-	-	-	-
Amara similata (Gyllenhal, 1810)	-	1	3	6	1	-	22	-
Amara tibialis (Paykull, 1798)	-	-	-	-	1	1	-	-
Anchomenus dorsalis (Pontoppidan, 1763)	-	-	6	2	-	-	2	1
Anisodactylus binotatus (Fabricius, 1787)	-	-	1	-	1	-	3	-
Anisodactylus nemorivagus (Duftschmid, 1812)	-	1	-	-	-	3	-	1
Badister bullatus (Schrank, 1798)	3	5	-	-	-	-	2	-
Badister lacertosus (Sturm, 1815)	1	1	-	-	-	-	3	-
Badister sodalist (Duftschmid, 1812)	-	1	-	-	-	-	-	-
Bembidion gilvipes (Sturm, 1825)	1	32	-	1	-	-	-	2
Bembidion guttula (Fabricius, 1792)	1	-	4	-	-	-	2	-
Bembidion lampros (Herbst, 1784)	27	29	3	8	2	3	1	10
Bembidion properans (Stephens, 1828)	6	9	4	6	6	-	12	3
Bembidion quadrimaculatum (Linnaeus, 1761)	-	1	3	9	1	-	4	-
Broscus cephalotes (Linnaeus, 1758)	-	-	1	1	-	-	-	-
Calathus ambiguus (Paykull, 1790)	1	-	13	-	21	24	-	-
Calathus cinctus (Motschulsky, 1850)	-	-	3	3	12	8	-	-
Calathus erratus (Sahlberg, 1827)	2	-	40	13	1,380	622	12	1
Calathus fuscipes (Goeze, 1777)	38	1	260	253	264	268	246	14
Calathus halensis (Schaller, 1783)	-	1	1	11	-	-	2	1
Calathus melanocephalus (Linnaeus, 1758)	3	-	40	14	90	21	14	42
Carabus cancellatus (Illiger, 1798)	3	-	5	1	-	-	2	1
Carabus granulatus (Linnaeus, 1758)	298	365	6	2	-	1	32	32
Carabus hortensis (Linnaeus, 1758)	134	113	-	-	1	-	1	4
Carabus nemoralis (Muller, 1764)	42	21	2	2	-	-	1	7
Chlaenius nigricornis (Fabricius, 1787)	-	1	-	-	-	-	-	-
Clivina fossor (Linnaeus, 1758)	-	2	-	-	-	-	-	-

Curtonotus aulicus (Panzer, 1797)	19	13	2	18	-	1	-	4
Cymindis angularis (Gyllenhal, 1810)	-	-	-	-	-	1	-	-
Dyschiriodes globosus (Herbst, 1784)	5	1	-	1	1	-	2	-
Epaphius secalis (Paykull, 1790)	9	5	-	1	-	-	6	3
Harpalus affinis (Schrank, 1781)	-	-	7	7	22	4	8	2
Harpalus anxius (Duftschmid, 1812)	-	-	-	-	-	16	-	-
Harpalus autumnalis (Duftschmid, 1812)	-	-	-	-	1	-	-	-
Harpalus calceatus (Duftschmid, 1812)	3	-	18	-	38	-	-	-
Harpalus distinguendus (Duftschmid, 1812)	-	-	-	-	1	-	-	-
Harpalus griseus (Duftschmid, 1812)	2	-	15	2	4	6	2	-
Harpalus laevicollis (Duftschmid, 1812)	-	-	1	-	-	-	-	-
Harpalus laevipes (Zetterstedt, 1828)	-	-	2	-	12	-	-	-
Harpalus latus (Linnaeus, 1758)	-	1	-	-	9	-	-	2
Harpalus luteicornis (Duftschmid, 1812)	4	-	1	-	13	-	4	-
Harpalus picipennis (Duftschmid, 1812)	3	-	1	-	7	-	-	-
Harpalus pumilus (Sturm, 1818)	-	-	-	-	3	-	-	1
Harpalus rubripes (Duftschmid, 1812)	-	-	2	-	71	-	1	-
Harpalus rufipes (Degeer, 1774)	36	2	247	426	17	19	204	38
Harpalus signaticornis (Duftschmid, 1812)	-	-	-	6	-	-	-	2
Harpalus smaragdinus (Duftschmid, 1812)	-	-	6	-	80	99	-	-
Harpalus tardus (Panzer, 1797)	10	6	15	5	44	15	29	10
Harpalus xanthopus winkleri (Schauberger, 1923)	-	1	-	-	-	-	-	1
Leistus ferrugineus (Linnaeus, 1758)	4	7	-	1	-	1	-	1
Leistus terminatus (Panzer, 1793)	1	-	-	-	-	-	-	-
Masoseus wetterhallii (Gyllenhal, 1813)	-	-	-	-	-	2	-	-
Microlestes minutulus (Goeze, 1777)	1	-	1	-	1	-	-	-
Nebria brevicollis (Fabricius, 1792)	23	2	-	6	-	-	-	3
Notiophilus palustris (Duftschmid, 1812)	4	2	-	-	-	-	-	-
Oxypselaphus obscurus (Herbst, 1784)	-	9	-	-	-	-	1	-
Panagaeus bipustulatus (Fabricius, 1775)	-	-	-	-	-	-	2	-
Platynus assimilis (Paykull, 1790)	1	-	-	-	-	-	-	-
Poecilus cupreus (Linnaeus, 1758)	6	5	226	254	16	2	79	1
Poecilus lepidus (Leske, 1785)	-	-	61	23	104	40	47	-
Poecilus versicolor (Sturm, 1824)	72	118	173	251	36	14	463	188
Pterostichus diligens (Sturm, 1824)	-	-	-	-	-	-	1	1
Pterostichus melanarius (Illiger, 1798)	354	234	20	24	5	11	109	50
Pterostichus niger (Schaller, 1783)	221	458	17	6	2	8	92	125
Pterostichus oblongopunctatus (Fabricius, 1787)	11	17	1	-	-	-	-	1
Pterostichus strenuus (Panzer, 1796)	15	27	1	-	-	-	-	3
Pterostichus vernalis (Panzer, 1796)	6	5	-	-	-	-	-	5
Stomis pumicatus (Panzer, 1796)	8	10	-	-	-	-	-	-
Syntomus truncatellus (Linnaeus, 1761)	-	2	-	1	-	2	3	2
Synuchus vivalis (Illiger, 1798)	1	-	-	-	-	-	1	1
Trechus quadristriatus (Schrank von Paula, 1781)	1	-	2	-	-	-	-	-
Total number of species: **86**	Total number of individuals: **11,248**							

4.2.2. Biodiversity indices and the dominance structure

There were significant differences between the values of species diversity indices calculated for each field. In the first year of the study, the Shannon-Wiener species diversity index (H') was the highest for the agricultural crop (KP) (2.379). It was similar to the Eco-Salix crop (KES) (2.366) and SRC willow crop (KW) (2.275). Also, the Pielou's evenness index was similar for those three crops (0.6292 for Eco-Salix, 0.6114 for agricultural crop and 0.6049 for SRC willow). Only fallow land (KU) was characterised by Shannon's H' index value below 2 (1.778). Additionally, Pielou's index (J') was significantly lower for this plot (0.4854), and the Simpson's diversity index (D), was the highest for this plot (0.3611). It proves, that the assemblage inhabiting this plot was the least evenly distributed. Simpson's index (D) was similar for the arable crop (KP) (0.1437), Eco-Salix willow plantation (KES) (0.1506) and SRC willow crop (KW) (0.1674) (**Tab.13**). Also in the second year of the study, there were similarities between Shannon-Wiener (H') index values for the agricultural crop (KP) (2.054), Eco-Salix crop (KES) (2.153) and SRC willow crop (KW) (2.319). Shannon-Wiener (H') index was lower only for the fallow land (KU) (1.84), which, as in the previous year, was characterised by the highest dominance concentration index (D) and the lowest evenness (J'). In 2020 the highest values of the Shannon-Weiner index (H'), as well as the Pielou's evenness index (J') were recorded in the SRC plantation (KW), which was, moreover, characterised by the lowest Simpson's diversity index (D) (**Tab.13**). However, high Pielou's index (J') most likely was connected with the lowest number of individuals, recorded on this plantation, during the second year of the study.

Table 13. The number of individuals, species and species diversity indices describing Carabidae assemblages in studied plots in Kocibórz. The abbreviations used on the graph mean respectively: KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow

	KES		**KP**		**KU**		**KW**	
Plant	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**
Number of individuals	1395	1537	1233	1400	2363	1295	1443	582
The mean number of indiv. per trap	18.8		19.4		25.8		14.6	
Total number of indiv. in 2019/20	6,434 / 4,814							
Number of species	43	40	49	37	39	30	43	39
Total number of species in 2019/20	75 / 63							
Shannon's (Log Base 2,718)(H')	2.366	2.153	2.379	2.054	1.778	1.84	2.275	2.319
Pielou's evenness index (J)	0.6292	0.5835	0.6114	0.5688	0.4854	0.5411	0.6049	0.6329
Simpson's Diversity (D)	0.1506	0.1815	0.1437	0.1917	0.3611	0.285	0.1674	0.1723

Studied plots differed in the distribution of dominance classes, which may give information about the condition of the habitat (**Fig. 80- 83**). The largest disparities in shares of particular dominance classes were observed in the arable field (KP). During the 2-years study, the share of eudominants was the highest for this plot, and the dominants class was absent (**Fig. 81**). The lowest disparities between the dominance classes were recorded for both willow plantations (KES & KW), where no sharp transitions between the particular dominance classes were indicated (**Fig. 80, Fig. 83**).

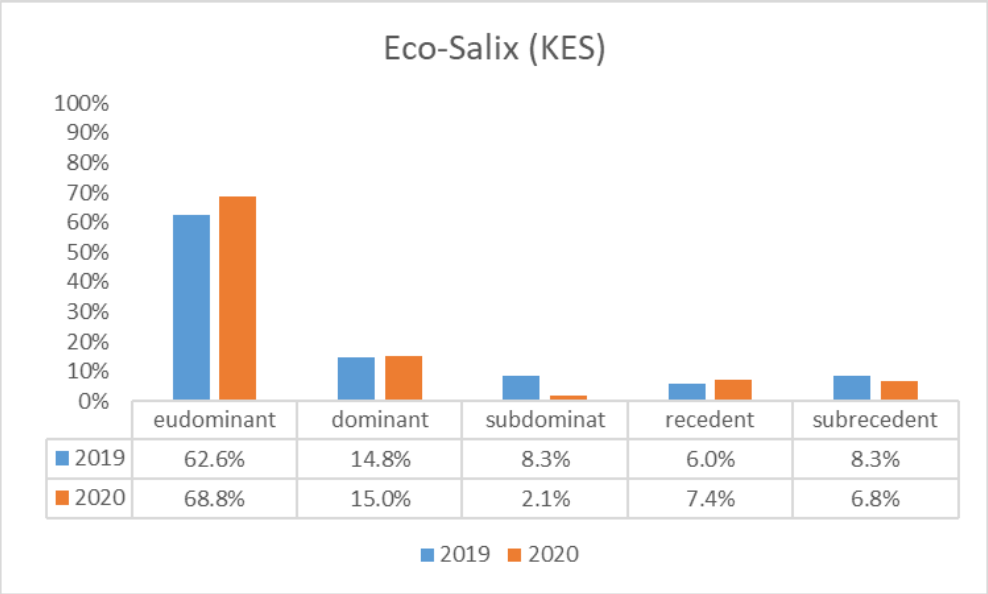


Figure 80. Carabidae dominance structure in the Eco-Salix crop (KES) in Kocibórz – percentage share of particular dominance classes

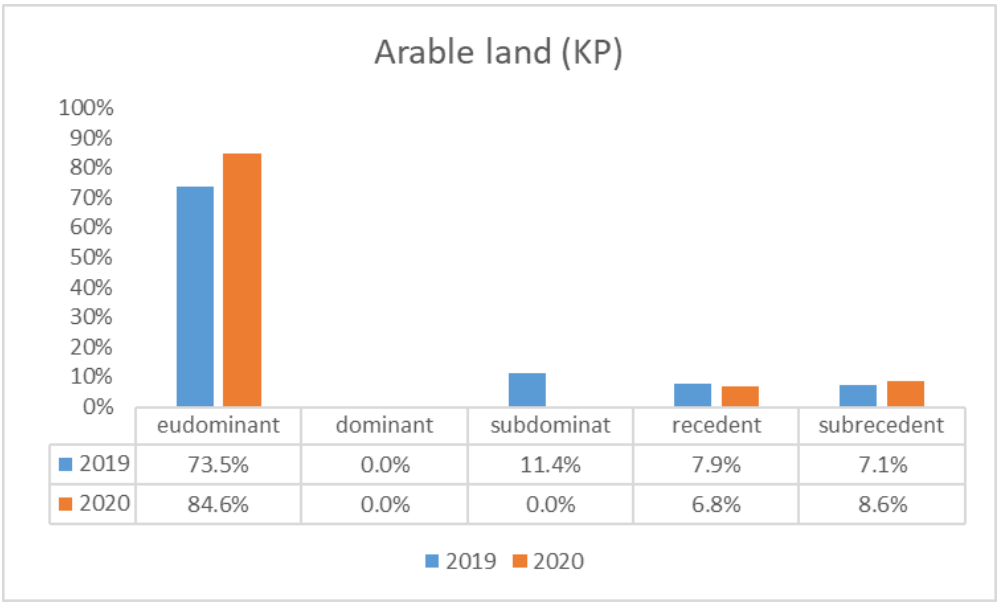


Figure 81. Carabidae dominance structure in the arable field (KP) in Kocibórz – percentage share of particular dominance classes

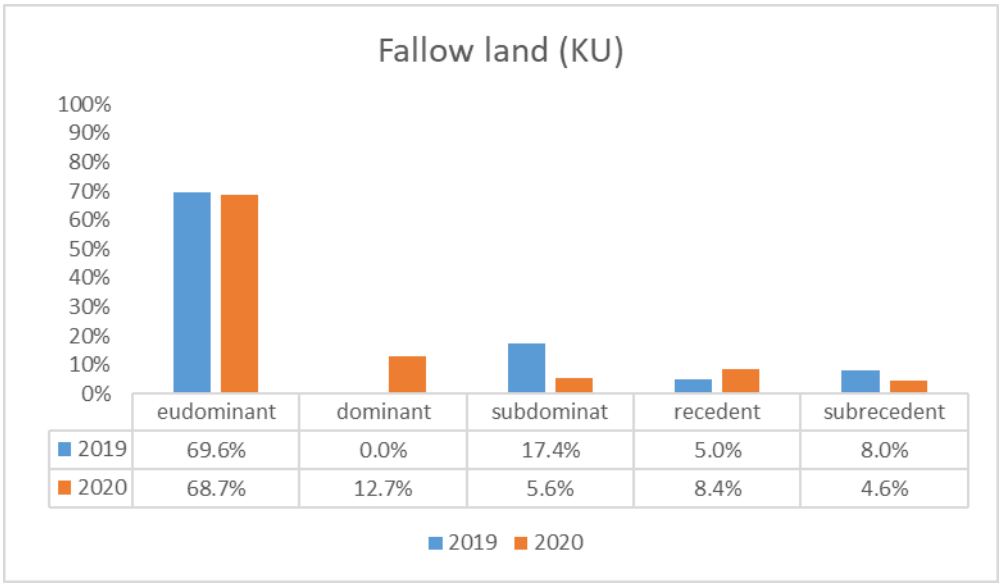


Figure 82. Carabidae dominance structure in the fallow land (KU) in Kocibórz – percentage share of particular dominance classes

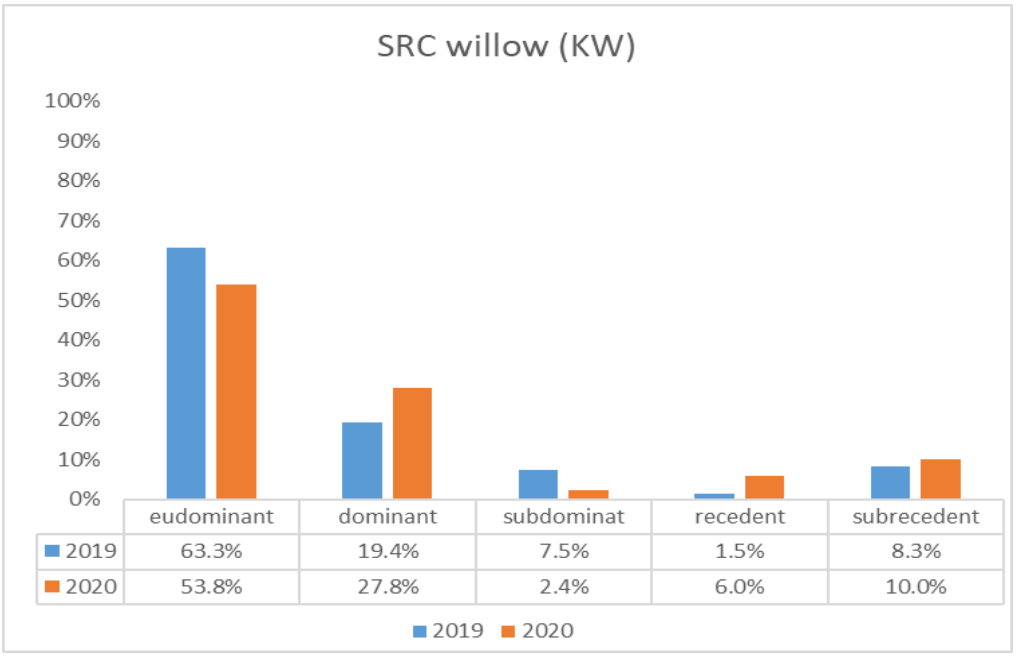


Figure 83. Carabidae dominance structure in the SRC willow crop (KW) in Kocibórz – percentage share of particular dominance classes

There were large differences in the species composition of eudominants class between study plots. The eudominant species in Eco-Salix (KES) plantation in all years of the study were the large carnivores: wetland *C. granulatus*, eurytopic *P. melanarius* and forest *P. niger*. A significant shift in the species composition of the eudominants class was observed in the SRC willow plantation (KW). In 2019 it was constituted by the three open area species: *Poecilus versicolor*, *H. rufipes*, and *C. fuscipes* noticed in this dominance class also on the arable crop (KP). However, in the following year, in the eudominants group only one species preferring open areas – *P. versicolor*, and *P. niger* characteristic of forest areas, appeared. During this time, the willows on the plantation reached about 3 m in height, and the canopy was very dense. It was worth noticing, that in both years of study, *C. erratus*, forest xerophilous species was recorded in the greatest number on fallow land (KU). In this plot, *C. erratus* shared the eudominants group with only one species, open area *C. fuscipes*. As was mentioned earlier, this species was also recorded on the arable field (KP), where it shared the eudominants group with other open area species: *H. rufipes, C. fuscipes, P. cupreus*. The percentage distribution of the most common species was included in **Table 14,** presenting the distribution of the dominance classes on particular plots.

Table 14. Carabidae dominance structure in the studied plots in Kocibórz– species belonged to the particular dominance classes. The abbreviations used on the graph mean respectively: KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow

	PLANT							
	KES		KP		KU		KW	
	2019	2020	2019	2020	2019	2020	2019	2020
Eudominants	*Pterostichus melanarius* (25.38%) *Carabus granulatus* (21.36%) *Pterostichus niger* (15.84%)	*Pterostichus niger* (29.80%) *Carabus granulatus* (23.75%) P*terostichus melanarius* (15.22%)	*Calathus fuscipes* (21.09%) *Harpalus rufipes* (20.03%) *Poecilus cupreus* (18.33%) *Poecilus versicolor* (14.03%)	*Harpalus rufipes* (30.43%) *Poecilus cupreus* (18.14%) *Calathus fuscipes* (18.07%) *Poecilus versicolor* (17.93%)	*Calathus erratus* (58.40%) *Calathus fuscipes* (11.17%)	*Calathus erratus* (48.03%) *Calathus fuscipes* (20.69%)	*Poecilus versicolor* (32.09%) *Calathus fuscipes* (17.05%) *Harpalus rufipes* (14.14%)	*Poecilus versicolor* (32.30%) *Pterostichus niger* (21.48%)
Dominants	*Carabus hortensis* (9.61%) *Poecilus versicolor* (5.16%)	*Poecilus versicolor* (7.68%) *Carabus hortensis* (7.35%)	none	none	none	*Harpalus smaragdinus* (7.64%) *Amara bifrons* (5.10%)	*Pterostichus melanarius* (7.55%) *Pterostichus niger* (6.38%) *Poecilus cupreus* (5.47%)	*Pterostichus melanarius* (8.59%) *Calathus melanocephalus* (7.22%) *Harpalus rufipes* (6.53%) *Carabus granulatus* (5.50%)

Subrecedents	Recedents	Subdominants
31 other species (10.90%)	*Bembidion lampros* (1.94%) *Nebria brevicollis* (1.65%) *Curtonotus aulicus* (1.36%) *Pterostichus strenuus* (1.08%)	*Carabus nemoralis (*3.01%) *Calathus fuscipes* (2.72%) *Harpalus rufipes* (2.58%)
29 other species (7.35%)	*Bembidion lampros* (1.89%) *Pterostichus strenuus* (1.76%) *Carabus nemoralis* (1.37%) *Amara communis* (1.24%) *Pterostichus oblongopunctatus* (1.11%)	*Bembidion gilvipes* (2.08%)
36 other species (13.06%)	*Pterostichus melanarius* (1.62%) *Harpalus calceatus* (1.46%) *Pterostichus niger* (1.38%) *Harpalus griseus* (1.22%) *Harpalus tardus* (1.22%) *Calathus ambiguus* (1.05%)	*Poecilus lepidus* (4.95%) *Calathus erratus* (3.24%) *Calathus melanocephalus* (3.24%)
28 other species (5.79%)	*Pterostichus melanarius* (1.71%) *Poecilus lepidus* (1.64%) *Curtonotus aulicus* (1.29%) *Amara bifrons* (1.14%) *Calathus melanocephalus* (1.00%)	none
29 other species (6.39%)	*Harpalus tardus* (1.86%) *Harpalus calceatus* (1.61%) *Poecilus versicolor* (1.52%)	*Poecilus lepidus* (4.40%) *Calathus melanocephalus* (3.81%) *Harpalus smaragdinus* (3.39%) *Harpalus rubripes* (3.00%) *Amara aenea* (2.84%)
18 other species (5.56%)	*Calathus ambiguus* (1.85%) *Calathus melanocephalus* 1.62%) *Harpalus rufipes* (1.47%) *Harpalus anxius* (1.24%) *Harpalus tardus* (1.16%) *Poecilus versicolor* (1.08%)	*Poecilus lepidus* (3.09%) *Amara aenea* (2.47%)
33 other species (15.11%)	*Amara similata* (1.52%)	*Poecilus lepidus* (3.26%) *Carabus granulatus* (2.22%) *Harpalus tardus* (2.01%)
28 other species (12.03%)	*Bembidion lampros* (1.72%) *Harpalus tardus* (1.72%) *Amara bifrons* (1.37%) *Carabus nemoralis* (1.20%)	*Calathus fuscipes* (2.41%)

The non-metric multidimensional scaling (NMDS) analysis has indicated significant differences between the Carabidae assemblages recorded on particular study plots. In 2019 analysis of similarities (ANOSIM) revealed significant differences in the species compositions of the carabid assemblages, recorded on the particular plots (R: 0.4311; p: <0.001). Differences were noticed between all plantations (**Fig.84)**. Similarly, in 2020 differences were indicated between all of the plots (R: 0.448; p: <0.001). The analysis showed, that the Eco-Salix (KES) crop differs the most from the others. In the diagram, it was located closest to the SRC willow crop (KW), especially in the second year of studies, which confirmed hypothesis H1 (**Fig.85)**. In 2019 SRC willow crop (KW) was strongly shifted towards an arable crop (KP), which changed in 2020 (**Fig.84-85).** The good fit of the model to the studied assemblages was confirmed by the stress factor, reaching the value of 0.1251 in 2019 and 0.1341 in 2020.

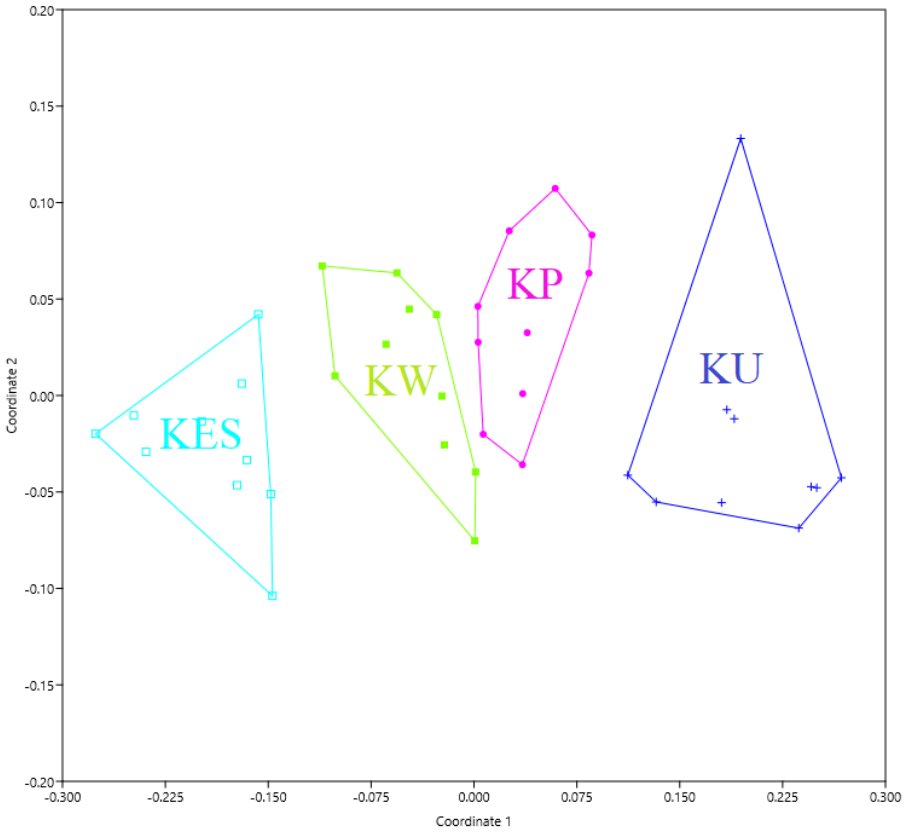


Figure 84. Diagram of non-metric multidimensional scaling (NMDS) for studied ground beetle assemblages in the study year 2019. The abbreviations used on the graph mean respectively: KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow

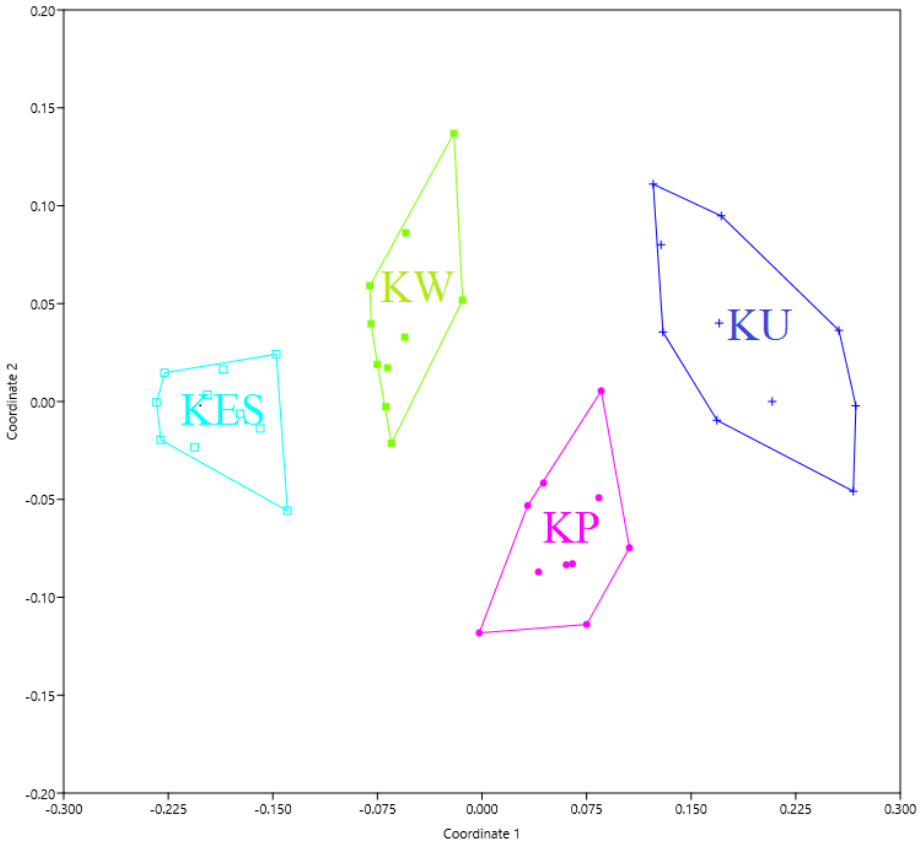


Figure 85. Diagram of non-metric multidimensional scaling (NMDS) for studied ground beetle assemblages in the study year 2020. The abbreviations used on the graph mean respectively: KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow

4.2.3. Characteristics of ecological traits in the Carabidae assemblages

The same classification of ecological traits as for plantations located in the study site "Leginy" was used to assess the assemblages of Carabidae inhabiting the study site in Kocibórz (**Tab. 15-16**).

Table 15. The number of Carabidae species attributed to the particular functional traits in the studied plots in Kocibórz. The abbreviations used on the graph mean respectively: KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow

Functional trait	PLANT / YEAR								Total number of species
	KES		KP		KU		KW		
	2019	2020	2019	2020	2019	2020	2019	2020	
Autumn breeders	19	13	19	17	15	16	13	16	30
Spring breeders	24	27	30	20	24	14	30	23	56
Open Area	23	18	35	25	31	22	29	20	52
Forest	8	10	6	4	3	5	6	9	13
Eurytopic	8	8	7	6	5	2	7	7	14
Wetlands	4	4	1	2	0	1	1	3	7
Mesophilous	24	27	30	22	22	16	24	25	45
Hygrophilous	10	10	5	5	1	1	8	6	24
Xerophilous	9	3	14	10	16	13	11	8	17
Phytophages	1	2	3	2	2	1	2	1	3
Hemizoophages	10	8	19	10	20	12	13	12	31
Small zoophages	9	11	6	7	5	2	8	6	15
Medium zoophages	17	13	13	11	9	12	13	13	28
Large zoophages	6	6	7	7	3	3	7	7	8
Undetermined	0	1	0	0	0	0	0	0	1
Macropterous	20	23	33	22	27	18	27	23	53
Brachypterous	9	8	4	5	2	3	6	6	21
Dimorphic	14	9	12	10	10	9	10	10	12

Table 16. The number of Carabidae individuals attributed to the particular functional traits in the studied plots in Kocibórz. The abbreviations used on the graph mean respectively: KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow;

Functional trait	PLANT / YEAR								Total number of individuals
	KES		KP		KU		KW		
	2019	2020	2019	2020	2019	2020	2019	2020	
Autumn breeders	861	848	688	800	1,873	1,061	693	298	7,122
Spring breeders	534	689	545	600	490	234	750	284	4,126
Open Area	257	221	1,130	1,334	952	646	1174	339	6,053
Forest	396	644	61	27	1,383	636	115	141	3,403
Eurytopic	436	273	36	36	28	12	122	67	1,010
Wetlands	306	399	6	3	0	1	32	35	782
Mesophilous	1,033	1,075	1,031	1,312	502	365	1,278	511	7,107
Hygrophilous	337	450	18	7	1	1	45	44	903
Xerophilous	25	12	184	81	1,860	929	120	27	3,238
Phytophages	2	5	5	13	68	32	34	1	160
Hemizoophages	87	48	329	492	352	232	265	78	1,883
Small zoophages	50	90	17	26	10	5	29	21	248
Medium zoophages	204	202	829	822	1,925	1,006	876	262	6,126
Large zoophages	1,052	1,192	52	47	8	20	239	220	2,830
Undetermined	0	0	1	0	0	0	0	0	1
Macropterous	245	247	769	1,054	493	310	872	293	4,283
Brachypterous	502	531	14	7	8	3	43	48	1,156
Dimorphic	648	759	450	339	1,862	982	528	241	5,809

Breeding strategy (phenology)

In 2019 the total number of indicated species was 27 (4,115 individuals) for autumn breeders and 48 (2,319 individuals) for spring breeders. In 2020 it was 27 (3,007 individuals) for autumn breeders and 48 (1,807 individuals) for spring breeders, respectively (**Tab. 15-16, Fig. 86**). Statistical analysis indicated significant differences in the number of ground beetles representing two development types between the studied plots (spring breeders *p-value*= 0.04128; autumn breeders *p-value*= 2.655E-06) (**Tab. 17**).

AUTUMN BREEDERS	SPRING BREEDERS	
Amara bifrons	*Agonum fuliginosum*	*Clivina fossor*
Amara consularis	*Agonum gracilipes*	*Dyschiriodes globosus*
Amara familiaris	*Agonum sexpunctatum*	*Harpalus affinis*
Amara fulva	*Agonum viduum*	*Harpalus anxius*
Amara majuscula	*Amara aenea*	*Harpalus autumnalis*
Broscus cephalotes	*Amara communis*	*Harpalus distinguendus*
Calathus ambiguus	*Amara convexior*	*Harpalus laevicollis*
Calathus cinctus	*Amara lunicollis*	*Harpalus luteicornis*
Calathus erratus	*Amara montivaga*	*Harpalus picipennis*
Calathus fuscipes	*Amara ovata*	*Harpalus pumilus*
Calathus halensis	*Amara plebeja*	*Harpalus rubripes*
Calathus melanocephalus	*Amara similata*	*Harpalus signaticornis*
Carabus hortensis	*Amara tibialis*	*Harpalus smaragdinus*
Curtonotus aulicus	*Anchomenus dorsalis*	*Harpalus tardus*
Cymindis angularis	*Anisodactylus binotatus*	*Harpalus xanthopus winkleri*
Epaphius secalis	*Anisodactylus nemorivagus*	*Microlestes minutulus*
Harpalus calceatus	*Badister bullatus*	*Notiophilus palustris*
Harpalus griseus	*Badister lacertosus*	*Oxypselaphus obscurus*
Harpalus laevipes	*Badister sodalis*	*Panagaeus bipustulatus*
Harpalus latus	*Bembidion gilvipes*	*Platynus assimilis*
Harpalus rufipes	*Bembidion guttula*	*Poecilus cupreus*
Leistus ferrugineus	*Bembidion lampros*	*Poecilus lepidus*
Leistus terminatus	*Bembidion properans*	*Poecilus versicolor*
Masoseus wetterhallii	*Bembidion quadrimaculatum*	*Pterostichus diligens*
Nebria brevicollis	*Carabus cancellatus*	*Pterostichus oblongopunctatus*
Pterostichus melanarius	*Carabus granulatus*	*Pterostichus strenuus*
Pterostichus niger	*Carabus nemoralis*	*Pterostichus vernalis*
Stomis pumicatus	*Chlaenius nigricornis*	*Syntomus truncatellus*
Synuchus vivalis		
Trechus quadristriatus		
2019 27 2020 24	2019 48 2020 39	

Figure 86. Species number and composition of Carabidae with different breeding strategies

Table 17. Results of the Kruskal-Wallis significance test for breeding strategies of Carabidae inhabiting crops in the study site "Kocibórz"

Functional trait	*p*
Spring breeders (SB)	p = 0.04128
Autumn breeders (AB)	p = 655E-06

The number of spring breeders differed for the Eco-Salix crop (KES) and the fallow land (KU) (**Fig. 87)**. For autumn breeders differences between: a) Eco-Salix (KES) and SRC willow (KW); b) fallow land (KU) and SRC willow (KW); c) fallow land (KU) and arable field (KP) were noticed (**Fig. 88)**.

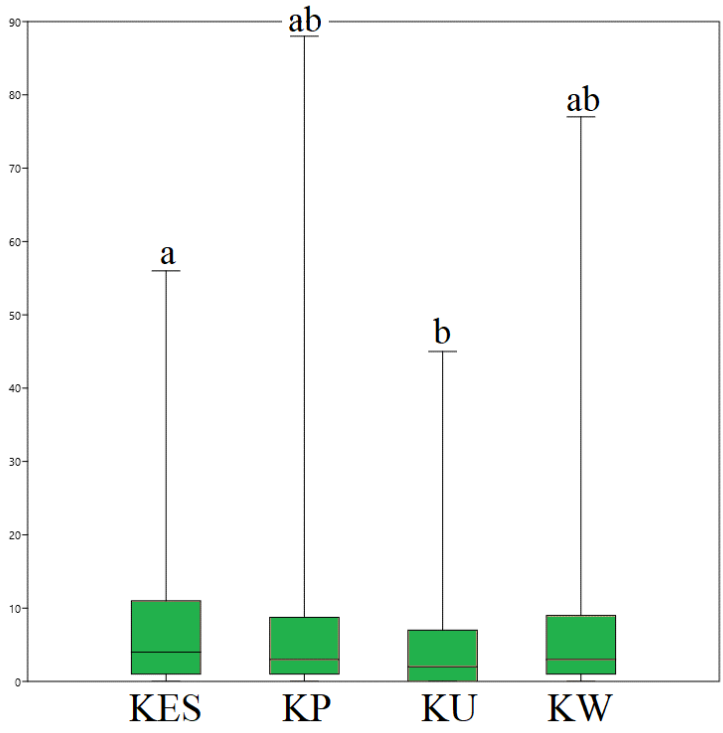


Figure 87. Rarefied spring breeders Carabidae individuals abundance for different plots (Dunn's post hoc; p-value with Bonferroni correction). Mean values per trap are shown for the particular plots (KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow;) in the study site "Kocibórz". Different letters above the boxplots indicate significant differences between the habitats ($p < 0.05$)

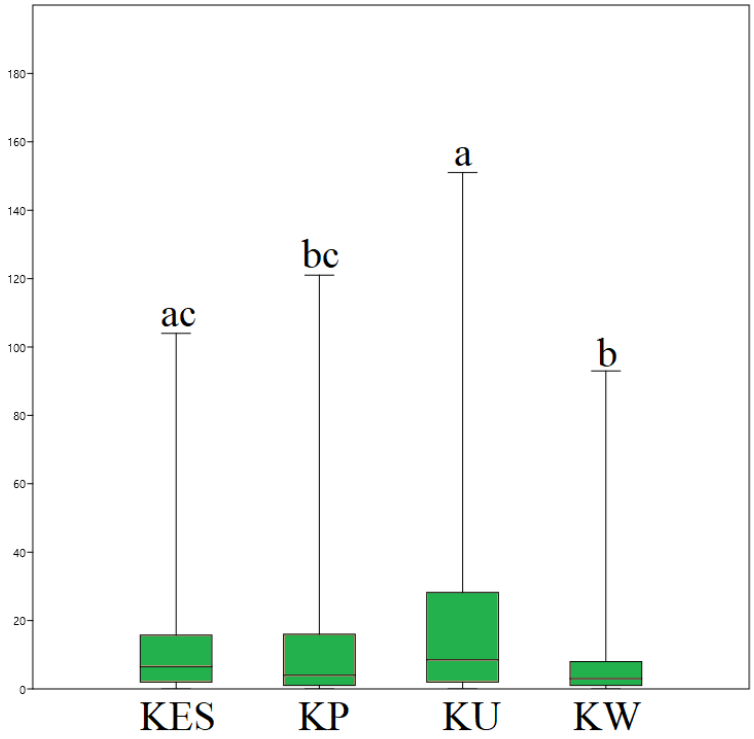


Figure 88. Rarefied autumn breeders Carabidae individuals abundance for different plots (Dunn's post hoc; p-value with Bonferroni correction). Mean values per trap are shown for the particular plots (KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow;) in the study site "Kocibórz". Different letters above the boxplots indicate significant differences between the habitats ($p<0.05$)

In quantitative terms, a higher prevalence of autumn breeders was observed in all study plots. In the qualitative context, the proportions of both types were opposite – there were more species with the spring reproduction type (**Fig. 89-92**).

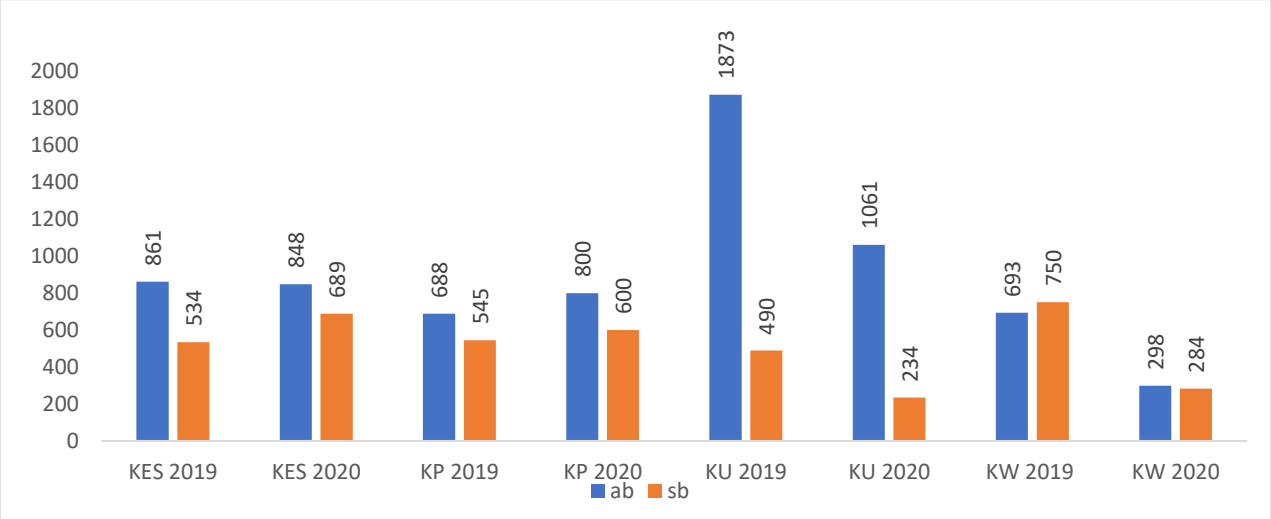


Figure 89. The number of Carabidae individuals with different breeding strategies. The abbreviations used on the graph mean respectively: KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow

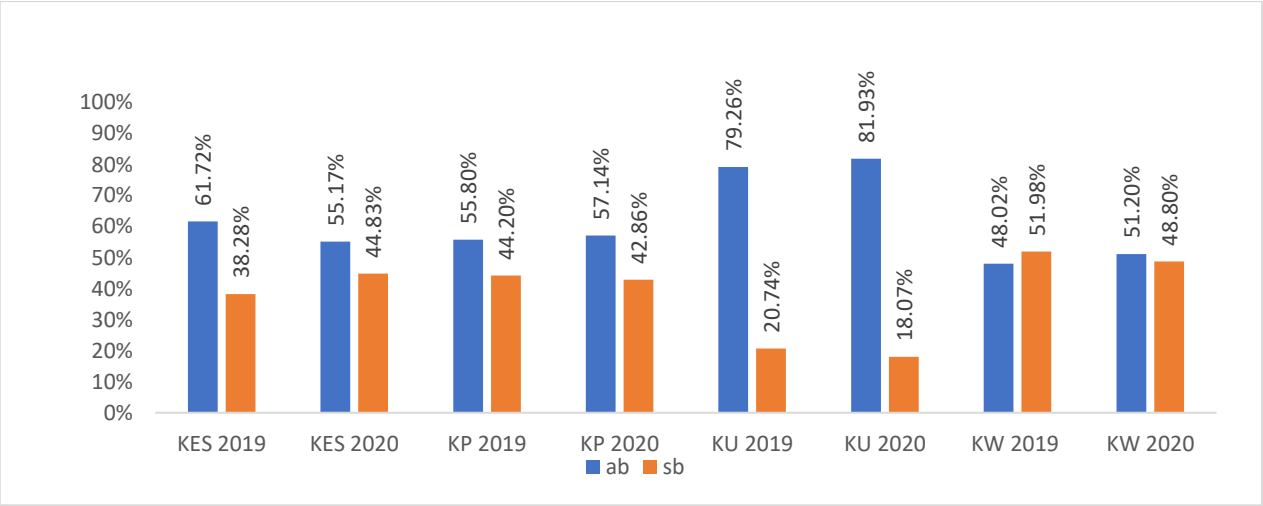


Figure 90. Percentage of Carabidae individuals with different breeding strategies. The abbreviations used on the graph (KES, KP, KU, KW) as in Fig. 89

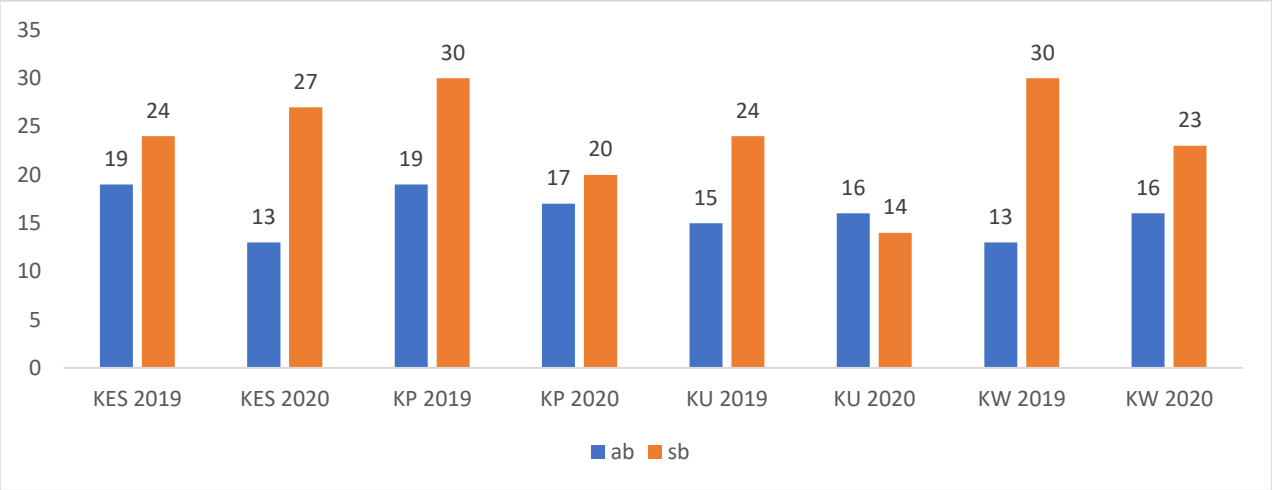


Figure 91. The number of Carabidae species with different breeding strategies. The abbreviations used on the graph (KES, KP, KU, KW) as in Fig. 89

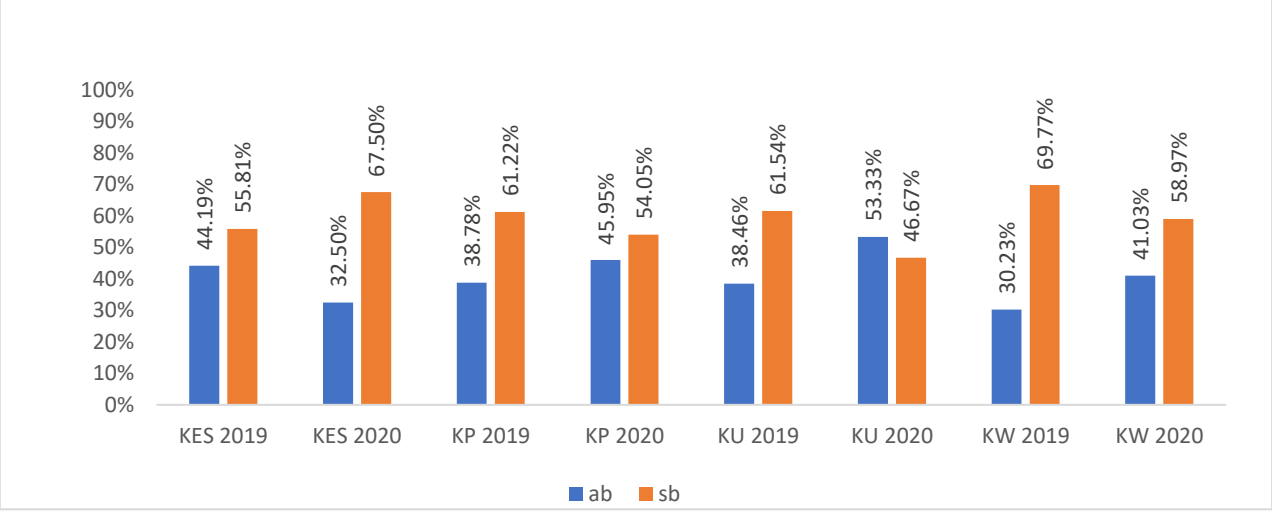


Figure 92. Percentage of Carabidae species with different breeding strategies. The abbreviations used on the graph (KES, KP, KU, KW) as in Fig. 89

Autumn breeders were the most numerous in the fallow land (KU), in both study seasons (1,873 individuals in 2019 and 1,061 individuals in 2020) (**Fig. 89**). They constituted 79.26 % and 81.93% of the assemblage, respectively (**Fig. 90**). However in qualitative terms they were not significantly more abundant than in other plantations. It was 15 autumn breeders species (38.46% of the assemblage) and 16 autumn breeders species (53.33% of the assemblage) in the years 2019 and 2020, respectively (**Fig. 91, Fig. 92**). Autumn breeders species, the most numerous in the fallow land (KU) during the 2-year study were: *C. erratus* and *C. fuscipes* (**Tab. 12**, **Tab. 14**).

The Eco-Salix crop (KES) was characterised by the most equal number of autumn breeders in both years: 861 (61.72% of the assemblage) in 2019 and 848 (55.17% of the assemblage) in 2020 (**Fig. 89-90**). In the first study year there were 19 species from this group (44.19% of the assemblage), in the second year their number decreased to 13 species (32.50% of the assemblage) (**Fig. 91-92**). *P. melanarius*, *P. niger* and *C. hortensis* were the autumn breeders species the most numerous on this plantation in both years of study (**Tab. 12**, **Tab. 14**). According to the autumn breeders number, Eco-Salix plantation (KES) was the most similar to the arable crop (KP), in which 688 individuals (55.80% of the assemblage) in 2019 and 800 individuals (57.14% of the assemblage) in 2020 were recorded (**Fig. 89-90**). Arable crop (KP) was also similar to Eco-Salix crops (KES) in the term of species number in 2019 (there were also 19 species, constituting 38.78% of the assemblage), but not in 2020 (there were 17 species, constituting 45.95% of the assemblage) (**Fig. 91-92**). *H. rufipes* and *C. fuscipes* were the autumn breeders most numerously represented in arable crop (KP) in seasons 2019 and 2020 (**Tab. 12**, **Tab. 14**).

Willow plantation (KW) was the last abundant in autumn breeders, in both, qualitative and quantitive terms. In the first study year, 693 individuals (48.02% of the assemblage) were indicated. In the second year of the study, it was the lowest among all study plants (298 individuals, 51.20% of the assemblage) (**Fig. 89-90**). Also the percentage of autumn breeders was one of the lowest – it was 13 species (30.23% of the assemblage) in 2019 and 16 species (41.03% of the assemblage) in 2020 (**Fig. 91-92**). In 2019 the most numerous autumn breeders on willow plantation (KW) were: *C. fuscipes, H. rufipes, P. melanarius* and *P. niger*, whereas in 2020 *C. fuscipes* was replaced by *C. melanocephalus* (**Tab. 12**, **Tab. 14**).

It is worth noticing, that for spring breeders differences in the individuals number between study seasons 2019 and 2020 were higher, than differences between particular experimental plots. Significant differences were indicated only for the Eco-Salix crop (KES) and the fallow land (KU) (**Fig.87**).

During the two-year study, the number of spring breeders was the highest for the Eco-Salix plantation (KES) – it was 534 individuals (38.28% of the assemblage) in 2019 and 689 individuals (44.83% of the assemblage) in 2020 (**Fig. 89-90**). They belonged to 24 (55.81% of the assemblage) and 27 (67.50% of the assemblage) species, respectively in 2019 and 2020 (**Fig. 91-92**). In both years of the study, the most numerous spring breeders in the Eco-Salix crop (KES) were *C. granulatus* and *P. versicolor* (**Tab. 12**, **Tab. 14**).

The total number of individuals collected in the arable field (KP) and SRC willow plantation (KW) was not differed significantly from Eco-Salix crop (KES), as well as from fallow land (KU). Differences between study seasons 2019 and 2020 were lowest for the arable crop (KP) – there were 545 (44.20% of the assemblage) and 600 (42.86% of the assemblage) individuals collected in the following years (**Fig. 89-90**). In qualitative terms, it was 30 (61.22% of the assemblage) and 20 (54.05% of the assemblage) species, respectively (**Fig. 91-92**). In both years of the study, the most numerous spring breeders in the arable field (KP) were *Poecilus cupreus* and *P. versicolor* (**Tab. 12**, **Tab. 14**).

Differences between study seasons 2019 and 2020 were the highest for SRC willow plantation (KW). In 2019, 750 (51.98% of the assemblage) individuals were recorded in this plant and in 2020 – only 284 individuals (48.80% of the assemblage) (**Fig. 89-90**). It was 30 (69.77% of the assemblage) and 23 (58.97% of the assemblage) species in qualitative terms, respectively (**Fig. 91-92**). In the willow plantation (KW), *P. cupreus* significantly outnumbered other spring breeders in both study seasons (**Tab. 12**, **Tab. 14**).

The lowest number of spring breeders was recorded on fallow land (KU). In this plot, spring breeders were the last numerous in both study seasons – 2019 (490 individuals, constituting 20.74% of the assemblage) and 2020 (234 individuals, constituting 18.07% of the assemblage) (**Fig. 89-90**). They belonged to 24 species (61.54% of the assemblage) in 2019 and 14 species (46.67% of the assemblage) in 2020, respectively (**Fig. 91-92**). In the first year of the study, more abundant in beetles, 4 spring breeders species, exceeded the number of 50 individuals were caught. There were: *Poecilus lepidus*, *Harpalus smaragdinus*, *Harpalus rubripes* and *A. aenea*. In the second year of the study, it was only one species: *H. smaragdinus* (**Tab. 12**, **Tab. 14**).

Body size and trophic preferences

In terms of quality, the most numerously represented groups on the study site "Kocibórz" were hemizoophages and medium carnivores (**Tab. 16, Fig. 93**). However, in the terms of quantity medium and large carnivores were the most numerous (**Tab. 15).** The last numerous group in both, quantitative and qualitative terms were phytophages. (**Tab. 15-16, Fig. 93**).

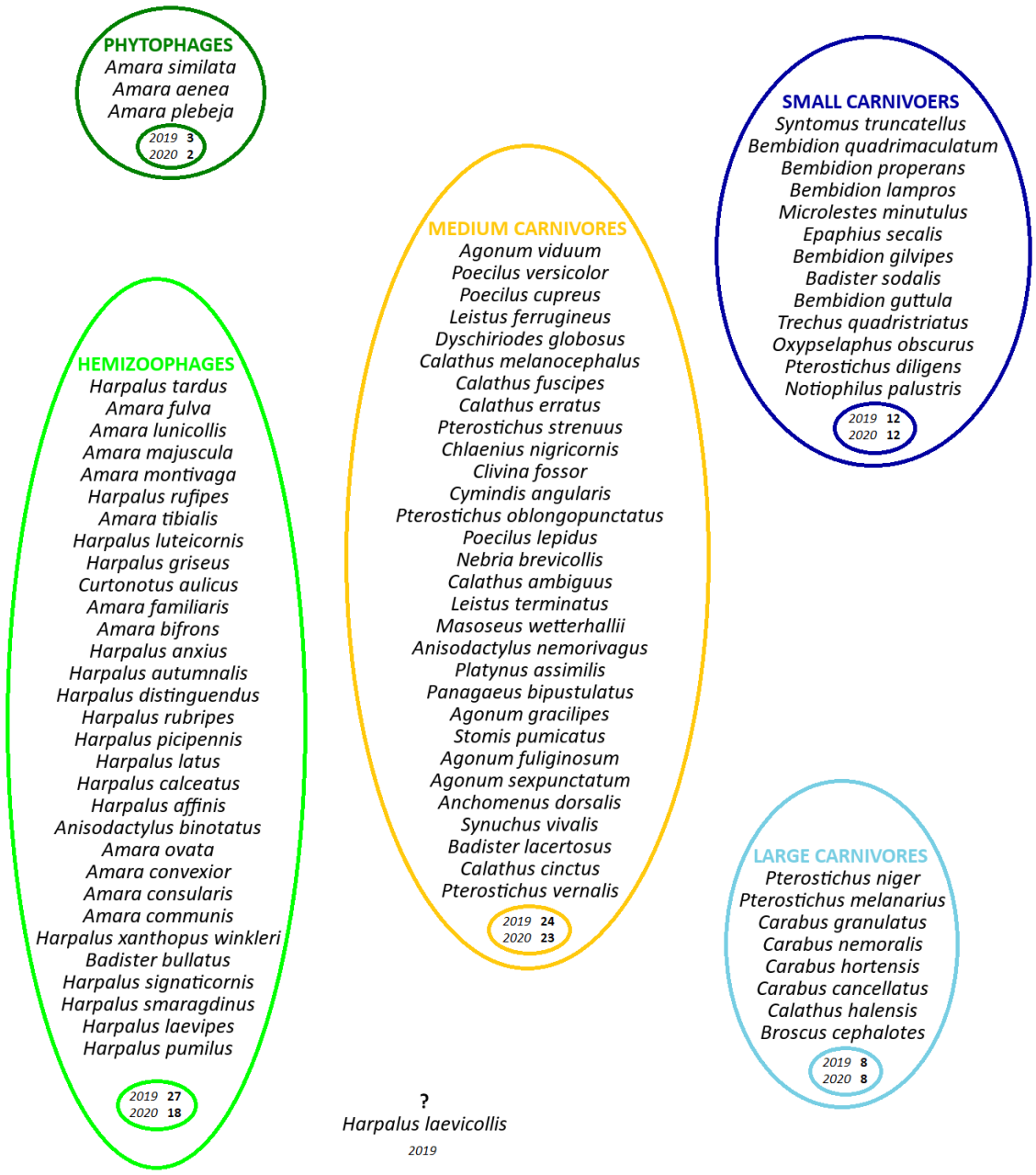


Figure 93. Species number and composition of Carabidae with different size and trophic preferences

Phytophages

Phytophages were the last numerous among all trophic groups. In 2019 there were 3 phytophages species (109 individuals) and in 2020 only two species (51 individuals) from this group were indicated (**Tab. 14-15, Fig. 93**). Statistical analysis indicated, that there were significant differences (*p-value*=1.998E-10) in the phytophages number between the investigated crops (**Tab. 18**).

Table 18. Results of the Kruskal-Wallis significance test for size and trophic preferences of Carabidae inhabiting crops in the study site "Kocibórz"

Body size and trophic preferences	***p***
Phytophages (Ph)	1.998E-10
Hemizoophages (Hz)	1.413E-16
Small carnivores (Sc)	2.187E-10
Medium carnivores (Mc)	1.099E-20
Large carnivores (Lc)	3.099E-64

Differences were indicated for: a) Eco-Salix crop (KES) and SRC willow crop (KW) and b) the fallow land (KU) and all other plots (KES, KP, KW) (**Fig. 94**).

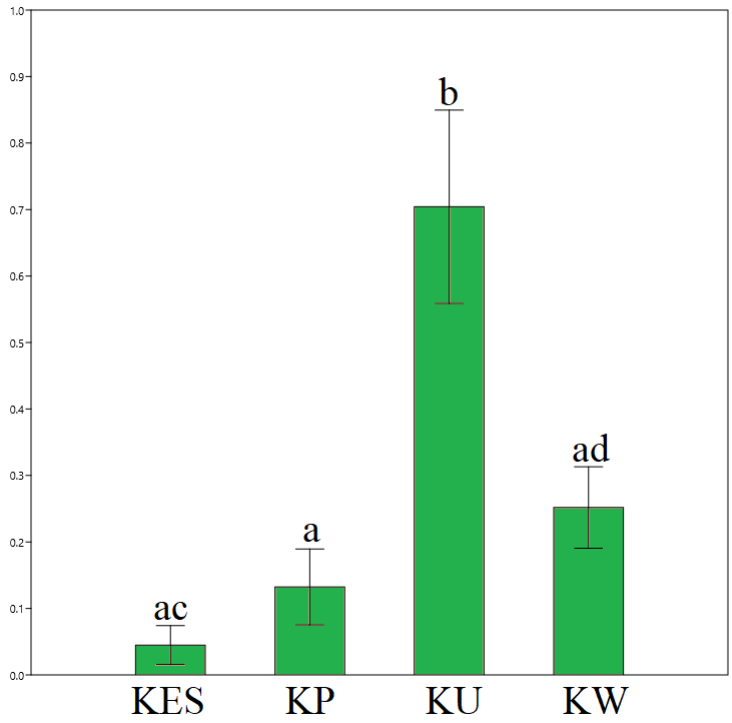


Figure 94. Rarefied phytophages Carabidae individuals abundance for different plots (Dunn's post hoc; p-value with Bonferroni correction). Mean values per trap are shown for the particular plots (KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow;) in the study site "Kocibórz". Different letters above the boxplots indicate significant differences between the habitats ($p < 0.05$)

Phytophages were the most numerous in the fallow land (KU) - there were 68 (2.88% of the assemblage) and 32 (2.47% of the assemblage) individuals indicated, respectively in 2019 and 2020 (**Fig. 95-96**). In the SRC willow plantation (KW) phytophages were more numerous in the first year of the growth cycle, after the coppicing when many herbaceous plants were present in the crop (there were 34 individuals, constituting 2.36% of the assemblage) (**Fig. 95-96**). In other plants, phytophages were not indicated in significant numbers (**Fig. 95-98**). Most common species were: *A. aenea* and *A. similata* (**Fig. 99**).

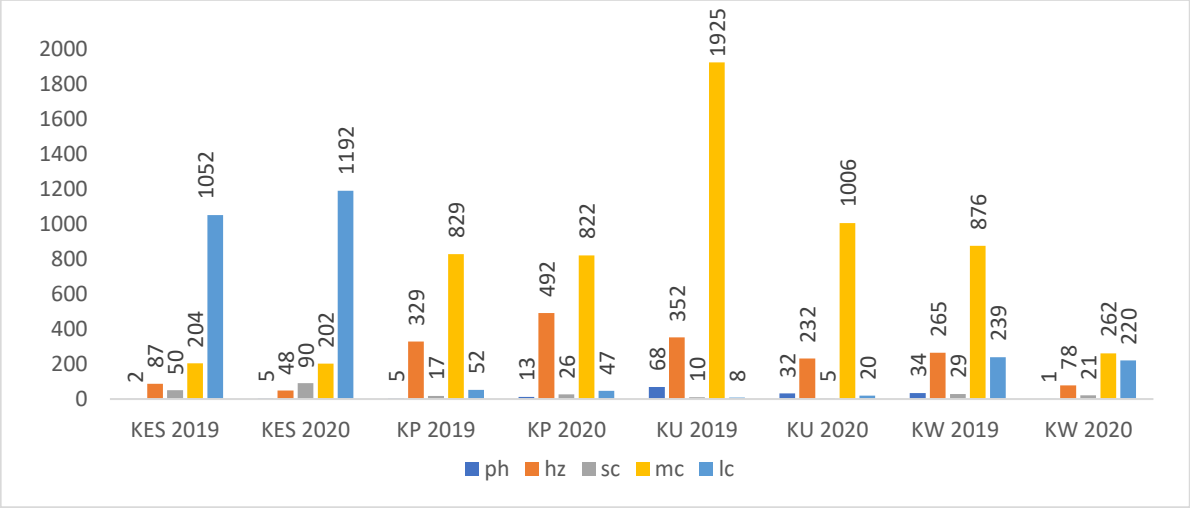


Figure 95. The number of Carabidae individuals with different size and trophic preferences (hz – hemizoophages, lc – large carnivores, mc – medium carnivores, ph – phytophages, sc – small carnivores;). The abbreviations used on the graph mean respectively: KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow

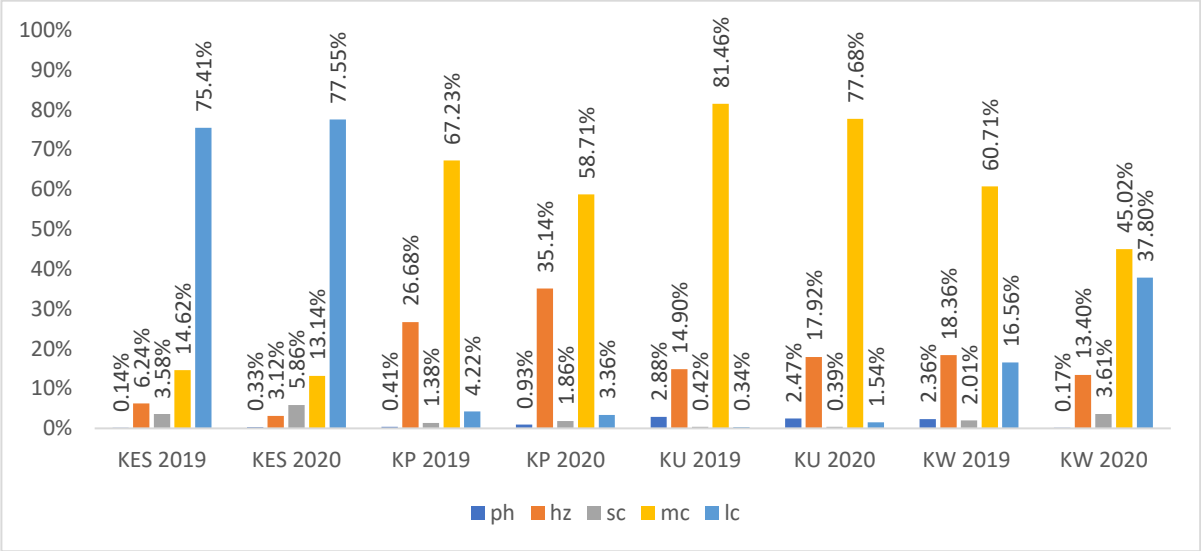


Figure 96. Percentage of Carabidae individuals with different size and trophic preferences (hz –hemizoophages, lc – large carnivores, mc – medium carnivores, ph – phytophages, sc – small carnivores;). The abbreviations used on the graph (KES, KP, KU, KW) as in Fig. 95

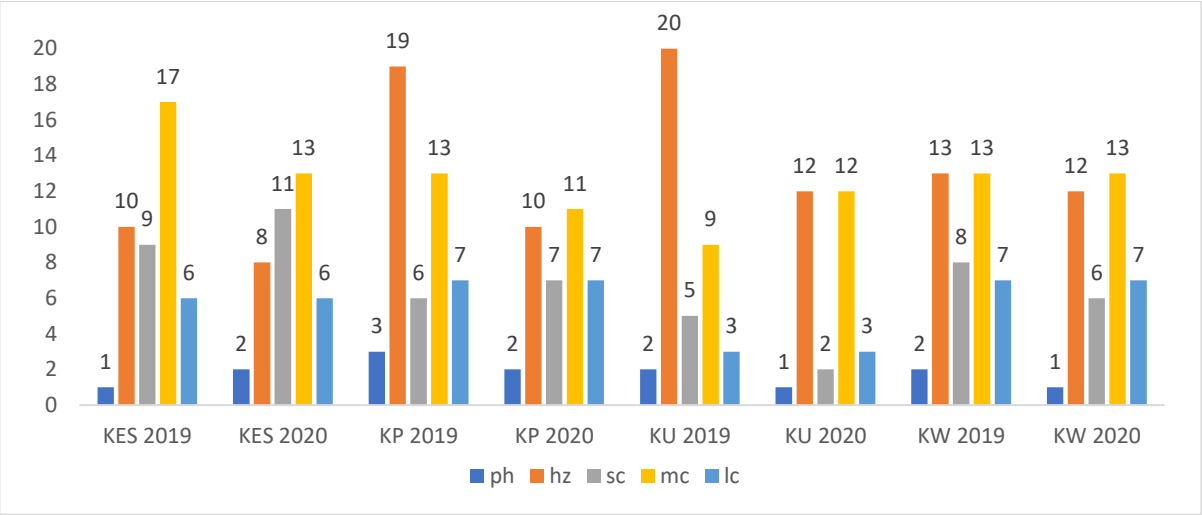


Figure 97. The number of Carabidae species with different size and trophic preferences (hz –hemizo-ophages, lc – large carnivores, mc – medium carnivores, ph – phytophages, sc – small carnivores;). The abbreviations used on the graph (KES, KP, KU, KW) as in Fig. 95

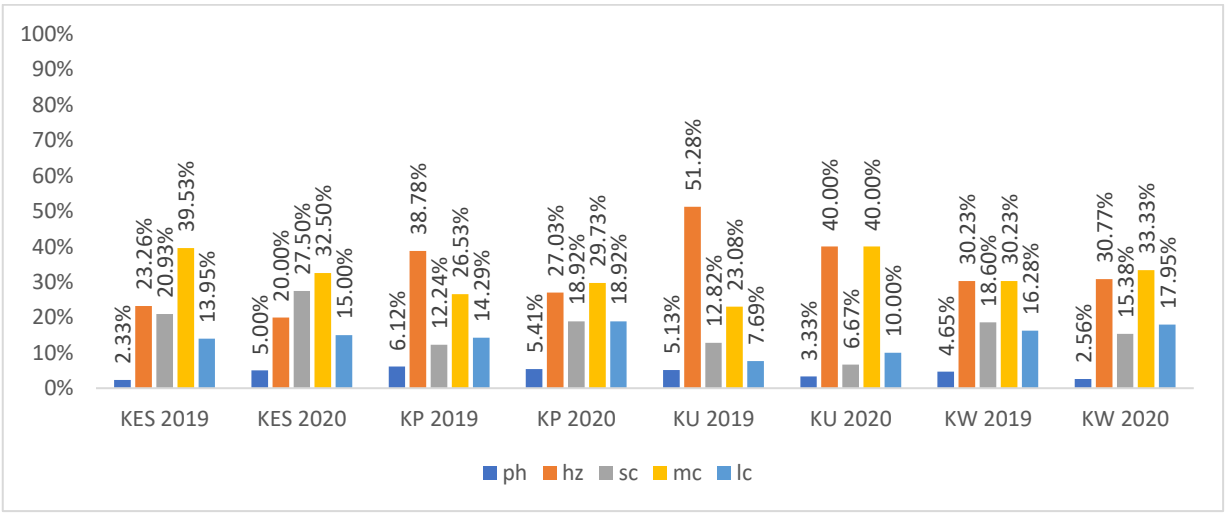


Figure 98. Percentage of Carabidae species with different size and trophic preferences (hz –hemizo-ophages, lc – large carnivores, mc – medium carnivores, ph – phytophages, sc – small carnivores;). The abbreviations used on the graph (KES, KP, KU, KW) as in Fig. 95

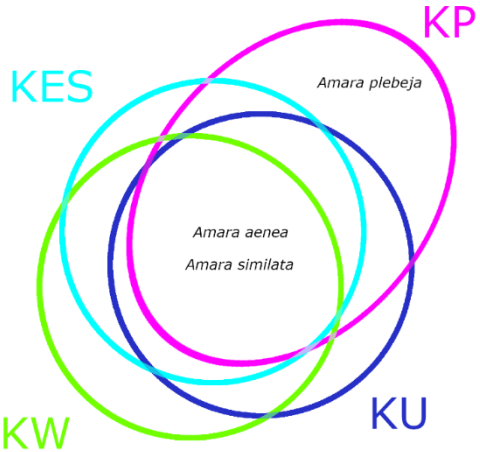


Figure 99. Phytophagous species presence on the particular plots in the study site: ”Kocibórz” The abbreviations used on the graph mean respectively: KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow

Hemizoophages

In 2019 the total number of indicated hemizoophages was 27 (1,033 individuals), in the next year it decreased to 18 species (850 individuals) (**Tab. 15-16, Fig. 93**). Statistical analysis indicated, that there were significant differences in the number of beetles representing the hemizoophages group between studied plots (*p-value*=1.413E-16) (**Tab. 18**). They were indicated between Eco-salix crop (KES) and all other study plots (KP, KU, KW) (**Fig. 100**).

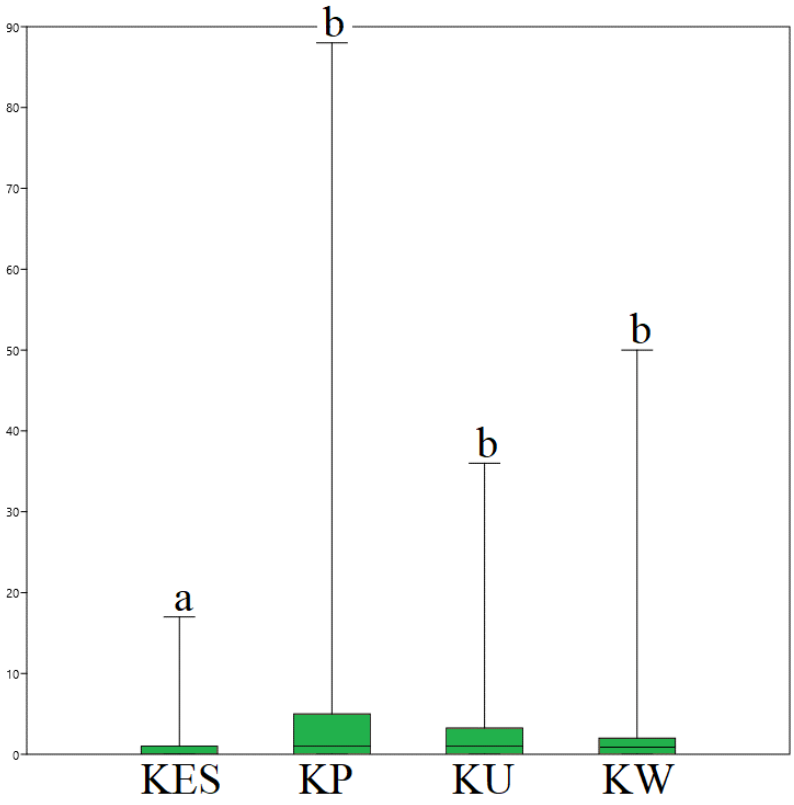


Figure 100. Rarefied hemizoophages Carabidae individuals abundance for different plots (Dunn's post hoc; p-value with Bonferroni correction). Mean values per trap are shown for the particular plots (KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow;) in the study site "Kocibórz". Different letters above the boxplots indicate significant differences between the habitats (p <0.05)

This group was the last numerous on Eco-salix crop (KES), in both, quantitive and qualitative terms. In 2019 there were 87 hemizoophages individuals indicated on this plantation, (6.24% of the assemblage) and in 2020 there were only 48 individuals (3.12% of the assemblage) (**Fig. 95-96**). In the first study year, 10 hemizoophages species (23.26% of the assemblage) were recorded on this plantation. In the second study year, there were 8 species (20.00% of the assemblage) (**Fig. 97-98**). In the first year of the study, more abundant in beetles, three hemizoophages species exceeded the number of 10 individuals caught. There were: *H. rufipes*,

Curtonotus aulicus and *H. tardus.* In the second year of the study, there were only two species: *A. communis* and *C. aulicus* (**Tab. 12, 14)**.

Also in the SRC willow plantation (KW), hemizoophages were relatively low represented, especially in the second year of the growth cycle. In 2019 there were 265 (18.36% of the assemblage) individuals from this group on SRC willow plantation (KW), which made SRC willow plantation (KW) similar to the arable crop (KP) and fallow land (KU). In 2020 it decreased to 78 individuals (13.40% of the assemblage) (**Fig. 95-96**). In qualitative terms, 13 species, constituting 30.23% of the assemblage were indicated in the first study season. In the second study season, it was 12 species, constituting 30.77% of the assemblage (**Fig. 97-98**). During 2-years study *H. rufipes* and *H. tardus* were the most numerous species. It is worth noticing, that *H. rufipes* was over 5 times more numerous in 2019 (204 versus 38 individuals) (**Tab. 12, 14**).

There were no statistically significant differences indicated, in individuals number between the SRC willow plantation (KW), arable crop (KP) and fallow land (KU). However, quantitively hemizoophages were the most numerous in the arable crop (KP) – there were 329 individuals from this group in 2019 (26.68% of the assemblage) and 492 individuals from this group in 2020 (35.14% of the assemblage) (**Fig. 95-96**). In qualitative terms it was, 19 (38.78% of the assemblage) and 10 (27.03% of the assemblage) species from this group, respectively (**Fig. 97-98**). The most numerous hemizoophagous species recorded on this plantation, during the two-year study was *H. rufipes*.

In fallow land (KU) were 352 individuals from this group in 2019 (14.90% of the assemblage) and 232 individuals from this group in 2020 (17.92% of the assemblage) (**Fig. 95-96**). In qualitative terms it was, 20 (51.28% of the assemblage) and 12 (40.00% of the assemblage) species from this group, respectively (**Fig. 97-98**). In 2019 the most numerous were the species from the Harpalinii genus: *H. smaragdinus, H. rubripes, H. tardus, Harpalus calceatus.* Also in 2020 Harplinii were very common on this plantation, The most numerous hemizoophages in 2020 were *H. smaragdinus* and *A. bifrons* (**Tab. 12, 14**). Species composition on particular plots was presented in **Figure 101**.

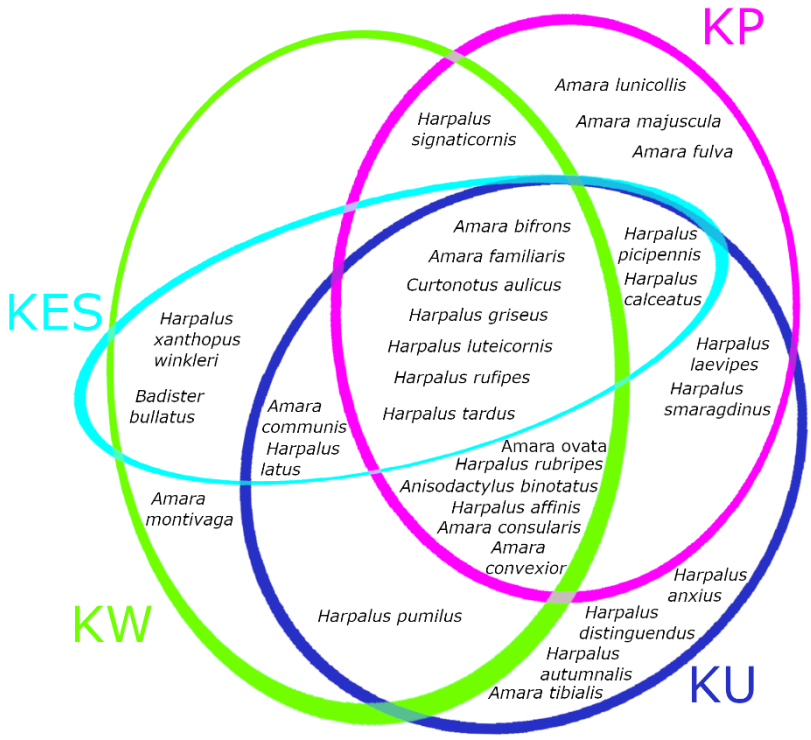


Figure 101. Hemizoophagous species presence on the particular plots in the study site: ”Kocibórz” The abbreviations used on the graph mean respectively: KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow

Small carnivores

Small carnivores, similar to phytophages, were represented in the low numbers in all studied plantations. In 2019 there were 12 small carnivore species (106 individuals). Also in 2020 twelve species (142 individuals) from this group were indicated (**Tab. 15-16, Fig. 93**). Statistical analysis indicated, that there were significant differences (*p-value* = 2.187E-10) in the number of small carnivores number between studied plots (**Tab. 18**). They were indicated between a) the Eco-Salix crop (KES) and other crops and b) fallow land (KU) and SRC willow crop (KW) (**Fig. 102**).

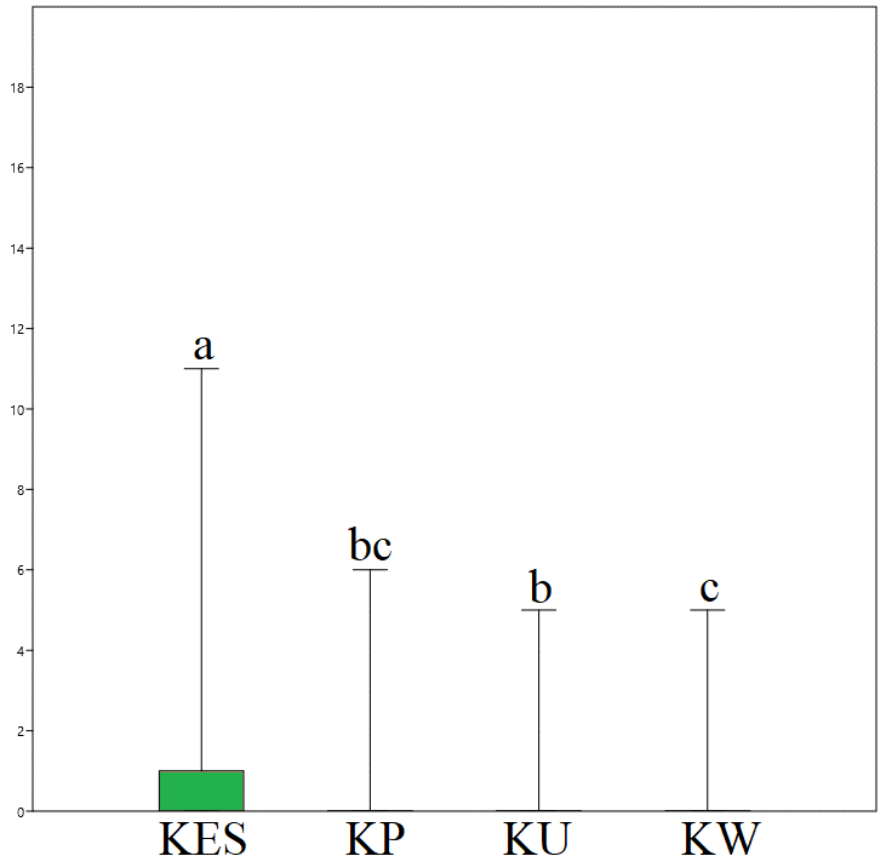


Figure 102. Rarefied small carnivorous Carabidae individuals abundance for different plots (Dunn's post hoc; p-value with Bonferroni correction). Mean values per trap are shown for the particular plots (KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow;) in the study site "Kocibórz". Different letters above the boxplots indicate significant differences between the habitats ($p < 0.05$)

This group was the most numerous in the Eco-Salix crop (KES), where there were 50 (3.58% of the assemblage) and 90 (5.86% of the assemblage) individuals indicated, respectively in 2019 and 2020 (**Fig. 95-96**). Also in qualitative terms, small carnivores were the most numerous on this plantation (9 species, constituting 20.93% of the assemblage in 2019 and 11 species, constituting 27.50% of the assemblage in 2020) (**Fig. 97-98**). In 2019 the most numerous species was *Bembidion lampros*, in 2020 there were *Bembidion gilvipes* and *B. lampros* – no more species accounted for over 10 individuals in the study years 2019-2020 (**Tab. 12.**).

The second most abundant assemblage was recorded on the SRC willow plantation (KW). In 2019 there were 29 individuals, constituting 2.01% of the assemblage, and in 2020 there were 21 individuals, constituting 3.61% of the assemblage. It significantly differs from the fallow land (KU) in which 10 individuals (0.42% of the assemblage) in 2019 and 5 individuals (0.39% of the assemblage) in 2020 were recorded (**Fig. 95-96**). There were 8 species

(18.60% of the assemblage) and 6 species (15.38% of the assemblage) recorded on the SRC willow plantation (KW) in the following years, and 5 species (12.82% of the assemblage) and 2 species (6.67% of the assemblage) recorded on the fallow land (KU) (**Fig. 97-98**). Apart from the willow plantation, only on this plantation number of recorded individuals exceeded 10 per year in the 2-year study. It was *Bembidion properans* in 2019 and *B. lampros* in 2020 (10 individuals) (**Tab. 12**).

On arable crop (KP) small carnivores were noticed in low numbers – there were 17 individuals in 2019 (1.38% of the assemblage) and 26 individuals in 2019 (1.86% of the assemblage) (**Fig. 95-96**). There were 6 species, constituting 12.24% of the assemblage and 7 species, constituting 18.92% of the assemblage, respectively, in study seasons 2019 and 2020 (**Fig. 97-98**). However, the number of small carnivores, recorded on those plants was too low, to give significant data. Nonetheless, it can show the trend, that this group was rather connected with Eco-Salix plantation (KES), not with open areas like fallow land (KU) or arable crop (KP) (**Tab. 12, Fig. 103**).

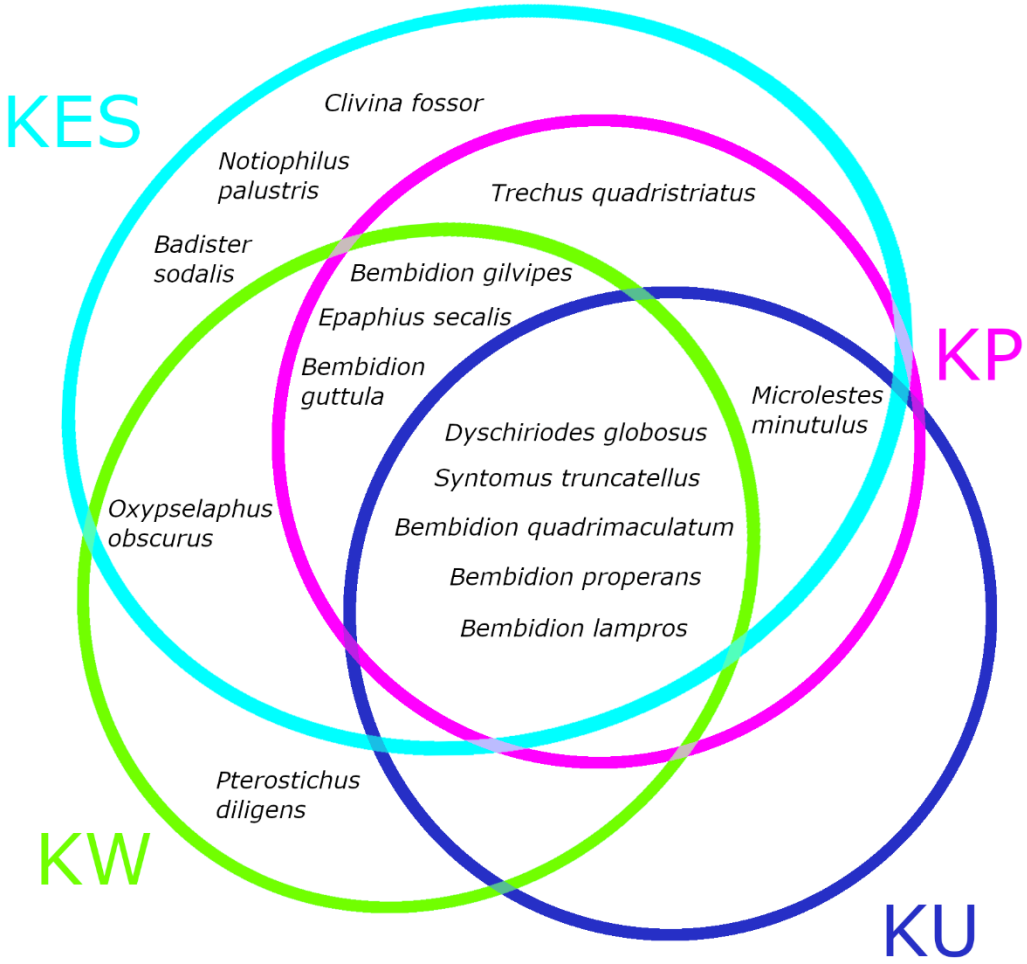


Figure 103. Small carnivorous species presence on the particular plots in the study site: ”Kocibórz” The abbreviations used on the graph mean respectively: KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow

Medium carnivores

There were, respectively, 24 and 23 medium carnivorous species in the study years 2019-2020. There were 3,834 and 2,292 individuals in the years 2019 and 2020, respectively, which made medium carnivores the most numerous among all trophic groups (**Tab. 15-16, Fig. 93**). Statistical analysis indicated, that there were significant differences in the number of beetles representing this group in particular plots (*p-value*=1.099E-20) (**Tab. 18**). They were indicated for: a) the Eco-salix crop (KES) and other study plots (KP, KU, KW); b) willow (KW) and other study plots (KES, KP, KU) (**Fig. 104**).

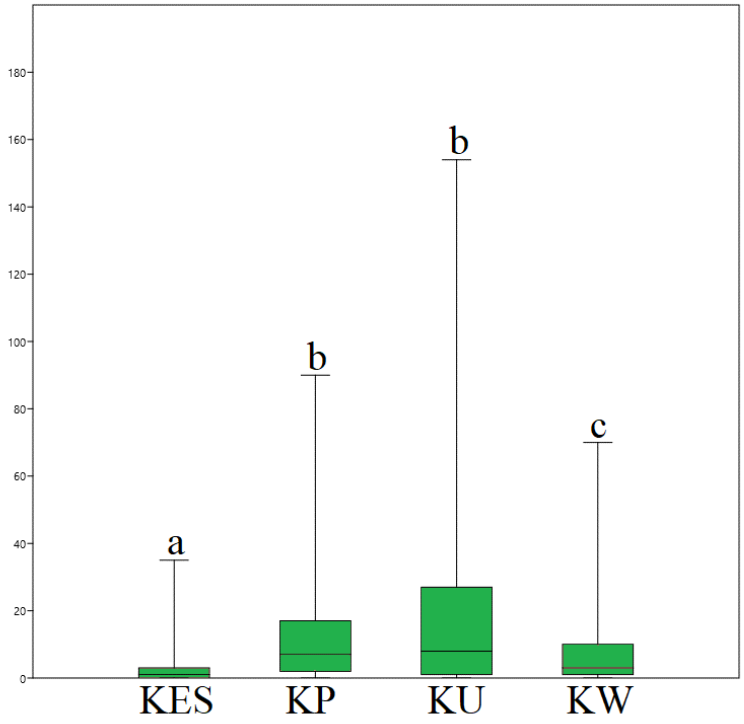


Figure 104. Rarefied medium carnivorous Carabidae individuals abundance for different plots (Dunn's post hoc; p-value with Bonferroni correction). Mean values per trap are shown for the particular plots (KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow;) in the study site "Kocibórz". Different letters above the boxplots indicate significant differences between the habitats (p <0.05)

Quantitively medium carnivores were the most numerous in the fallow land (KU). There were 1,925 individuals (constituting 81.46% of the assemblage) in 2019 and 1,006 individuals (constituting 77.68% of the assemblage) in 2020 (**Fig. 95-96**). Interestingly, medium carnivores were the last numerous in this crop in qualitative terms. There were 9 species (constituting 23.08% of the assemblage) in 2019 and 12 species (constituting 40.00% of the assemblage) in 2020 (**Fig. 97-98**). In 2019 *C. erratus* significantly outnumbered other species. Nevertheless,

there were other numerously represented species in this year, like *C. fuscipes, P. lepidus, C. melanocephalus, and P. versicolor*. A similar situation was noticed in 2020: the most numerous were *C. erratus, C. fuscipes* and *P. lepidus* (**Tab. 12, 14**).

The most similar to the fallow land (KU) was the arable crop (KP), and the SRC willow plantation (KW) in the first year of growth (2019). On the arable crop (KP) 829 medium carnivores individuals (constituting 67.23% of the assemblage) were collected in 2019 and 822 individuals (constituting 58.71% of the assemblage) were collected in 2020 (**Fig. 95-96**). They belonged to 13 species (constituting 26.53% of the assemblage) in 2019 and 11 species (constituting 29.73% of the assemblage) in 2020 (**Fig. 97-98**). The most numerous species were, in 2019: *C. fuscipes, P. cupreus, P. versicolor, P. lepidus* and in 2020*: P. cupreus, C. fuscipes, P. versicolor* (**Tab. 12, 14**).

There were significant differences in the number of small carnivores in study years 2019 and 2020 in SRC willow plantation (KW). In the first study season, there were 876 individuals (constituting 60.71% of the assemblage), and there were 262 individuals (constituting 45.02% of the assemblage) in the second study year (**Fig. 95-96**). In qualitative terms, it was, respectively 13 species (constituting 30.23% of the assemblage) in 2019 and 13 species (constituting 33.33% of the assemblage) in 2020 (**Fig. 97-98**). It made this plantation similar to fallow land (KU) and arable crops (KP) in the first year of study, and Eco-Salix crop (KES) in the second year. The most numerous species, indicated in 2019 were: *P. versicolor, C. fuscipes, P. cupreus* and *P. lepidus.* In 2020 the most numerous species were: *P. versicolor* and *C. melanocephalus* (**Tab. 12, 14**).

Quantitively medium carnivores were the last numerous in the Eco-Salix crop (KES). There were 204 individuals (constituting 14.62% of the assemblage) in 2019 and 202 individuals (constituting 13.14% of the assemblage) in 2020 (**Fig. 95-96**). Interestingly, this group was the most numerous in qualitative terms – there were 17 species (constituting 39.53% of the assemblage) in 2019 and 13 species (constituting 32.50% of the assemblage) in 2020. (**Fig. 97-98**). For this group, there was the tendency, that the plantations less abundant in quantitive terms, were more abundant in qualitative terms. The most numerous species, exceeding 20 individuals in 2019 were: *P. versicolor, C. fuscipes, N. brevicollis* and in 2020: *P. versicolor* and *P. strenuous* (**Tab. 12, 14)**.

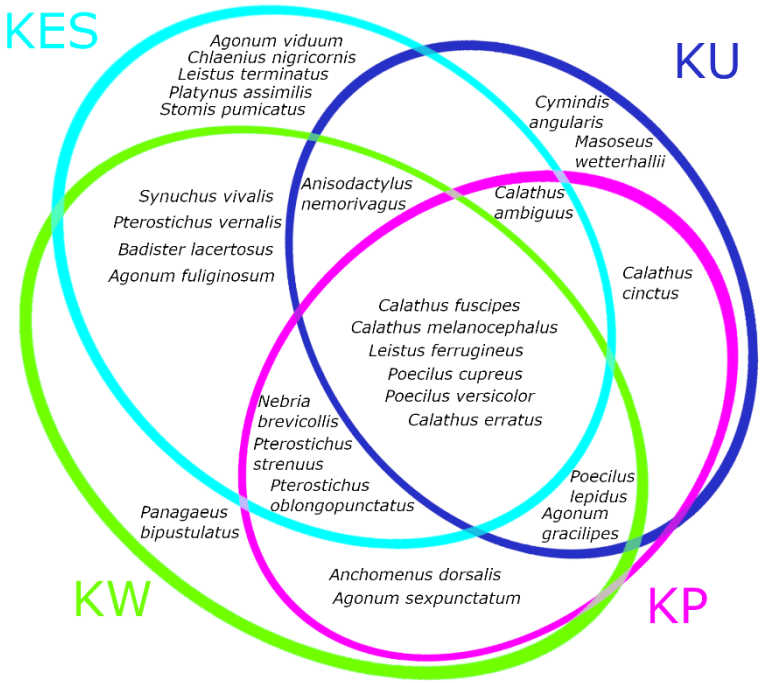


Figure 105. Medium carnivorous species presence on the particular plots in the study site: ”Kocibórz” The abbreviations used on the graph mean respectively: KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow

Large carnivores

In both years of the study, there were 8 large carnivorous species. There were 1,351 and 1,479 individuals in the years 2019 and 2020, respectively (**Tab. 15-16, Fig. 93**). Statistical analysis indicated, that there were significant differences in the number of beetles representing this group (*p-value*=3.099E-64) (**Tab. 18**). Those differences were indicated between all of the study plots (**Fig. 106**).

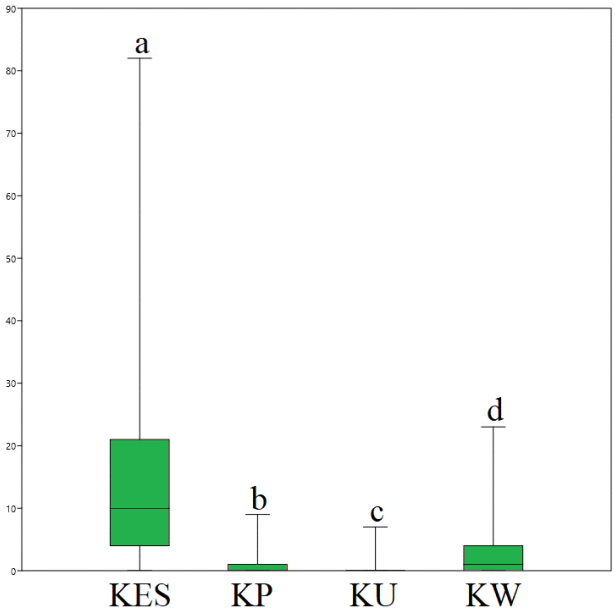


Figure 106. Rarefied large carnivorous Carabidae individuals abundance for different plots (Dunn’s post hoc; p-value with Bonferroni correction). Mean values per trap are shown for the particular plots (KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow;) in the study site “Kocibórz”. Different letters above the boxplots indicate significant differences between the habitats (p <0.05)

Large carnivores were the most numerous in the Eco-Salix plantation (KES). There were 1,052 individuals (constituting 75.41% of the assemblage) in 2019 and 1,192 individuals (constituting 77.55% of the assemblage) in 2020 (**Fig. 95-96**). There were 6 large carnivore species in both study seasons, constituting respectively 13.95% and 15.00% of the assemblage in the years 2019 and 2020 (**Fig. 97-98**). The most numerous species, inhabiting this plantation were: *P. melanarius C. granulatus P. niger* and *C. hortensis* in both study years. There were also *C. nemoralis* and *C. cancellatus* (**Tab. 12, 14)**.

A significant number of large carnivores was also indicated on the SRC willow crop (KW). There were 239 individuals (constituting 16.56% of the assemblage) in 2019 and 220 individuals (constituting 37.80% of the assemblage) in 2020 (**Fig. 95-96**). There were 7 large carnivore species in both study seasons, constituting respectively 16.28% and 17.95% of the assemblage in the years 2019 and 2020 (**Fig. 97-98**). Species indicated on this crop were: *P. melanarius, C. granulatus, P. niger* (more numerous) and *C. hortensis C. nemoralis C. cancellatus* and *C. halensis* (less numerous) (**Tab. 12, 14, Fig. 107**).

In quantitative terms, the number of large carnivores, indicated in open area habitats, such as fallow land (KU) and arable crop (KP) was significantly lower. Interestingly, these differences were not reflected in the qualitative terms – except for the fallow land (KU), the species number was similar in all plots. In the arable crop (KP) 52 individuals from this group (constituting 4.22% of the assemblage) were collected in 2019. In 2020, there were 47 large carnivores (constituting 3.36% of the assemblage) (**Fig. 95-96**). They were represented by 7 species in both study years, constituting 14.29% and 18.92%, in the years 2019 and 2020, respectively (**Fig. 97-98**). They were: *P. melanarius, C. halensis, P. niger, C. nemoralis, Broscus cephalotes* and *C. cancellatus* (**Tab. 12, 14, Fig. 107**).

Large carnivores were the last numerous in the fallow land (KU). There were only 8 individuals (constituting 0.34% of the assemblage) in 2019 and 20 individuals (constituting 1.54% of the assemblage) in 2020 (**Fig. 95-96**). There were 3 large carnivore species in both study seasons, constituting respectively 7.69% and 10.00% of the assemblage in the years 2019, and 2020 (**Fig. 97-98**). Species from this group, indicated on the fallow land were: *P. melanarius, P. niger, C.hortensis* in 2019 and *P. melanarius, P. niger, C. granulatus* in 2020 (**Tab. 12, 14, Fig. 107**).

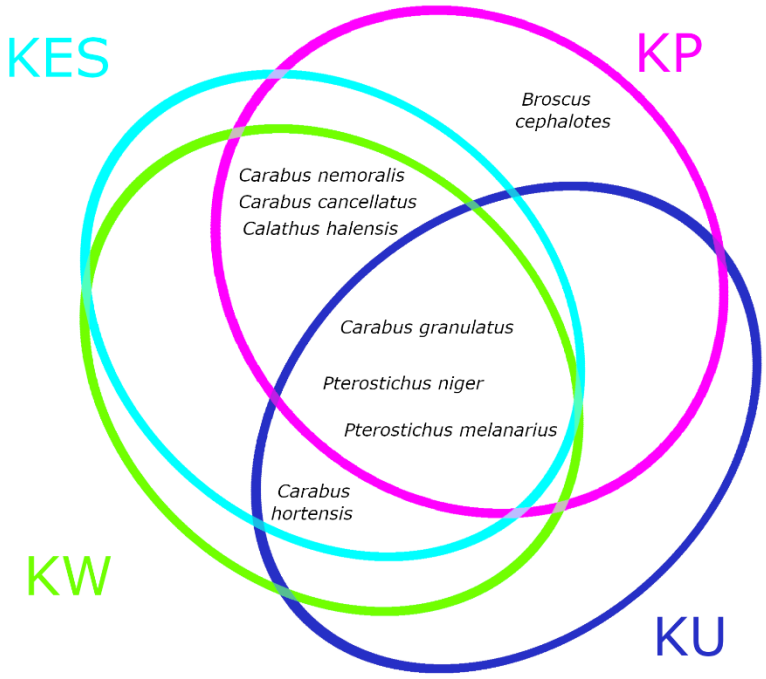


Figure 107. Large carnivorous species presence on the particular plots in the study site: ”Kocibórz”. The abbreviations used on the graph mean respectively: KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow

As in the case of other functional traits, also in the body size and trophic preferences of inhabiting Carabidae, willow plantations (KW, KES) were characterised by large distinctiveness, which confirmed hypothesis **H1**. It was evident, especially in the case of Eco-Salix plantation (KES), in which the high predominance of large carnivorous species was observed.

Habitat preferences

Species preferring open areas were the most numerous in both, quantitative and qualitative terms. In the terms of quantity, forest species were the second most numerously represented group. In the terms of quality, there were eurytopic species. In the study site "Kocibórz" species from all habitat preference groups were represented in significant numbers (**Fig. 108**).

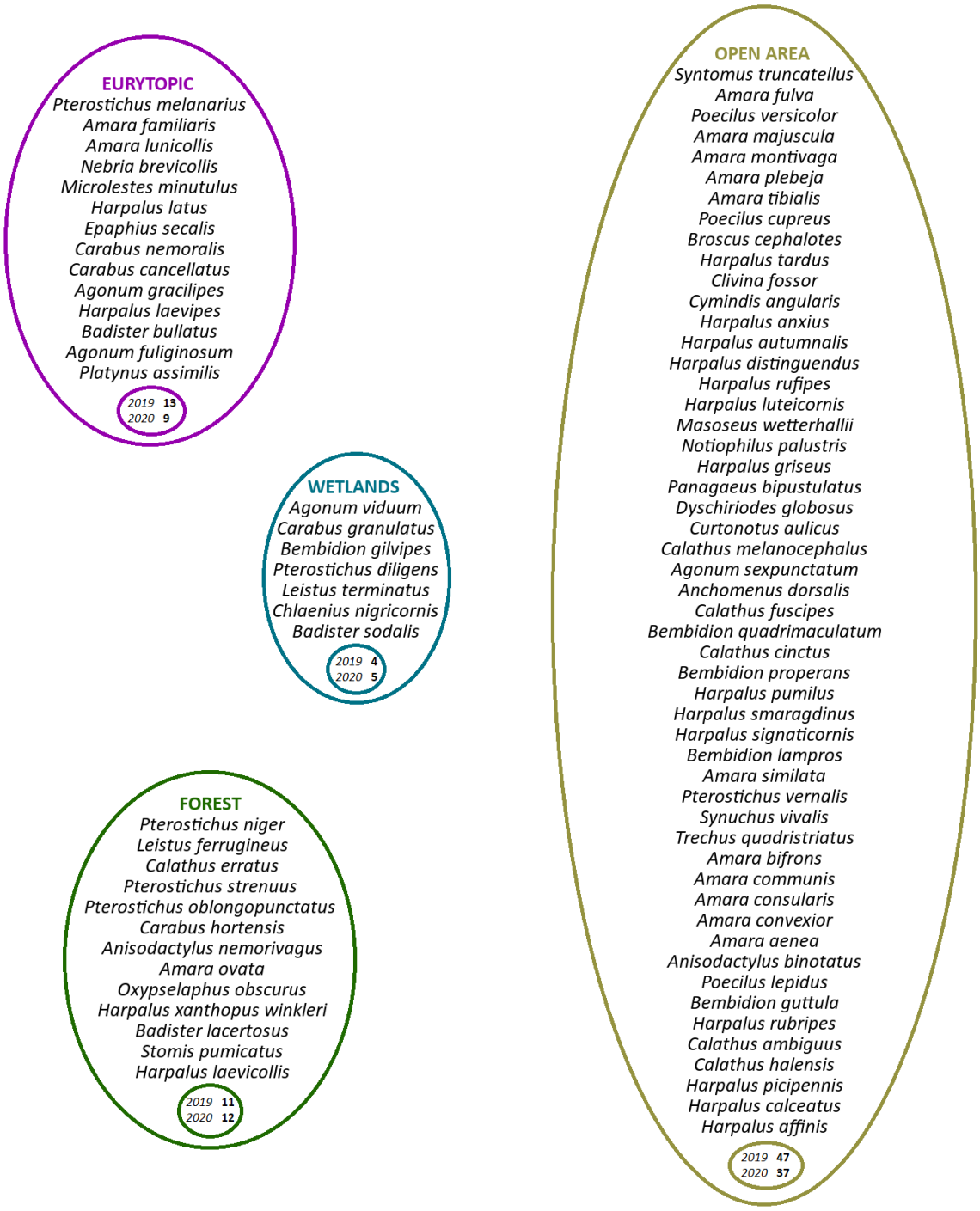


Figure 108. Species number and composition of Carabidae with different habitat preferences

Open area species

Open area species were the most numerous among all habitat preference groups. There were 47 species (3,513 individuals) and 37 species (2,540 individuals) in the years 2019 and 2020, respectively (**Tab. 15-16, Fig. 108**). Statistical analysis indicated, that there were significant differences in the number of ground beetles representing this group (*p-value*=6.973E-28) (**Tab. 19**). Differences were indicated between all study plots, except for the SRC willow plantation (KW) and the fallow land (KU) (**Fig. 109**).

Table 19. Results of the Kruskal-Wallis significance test for habitat preference of Carabidae inhabiting crops in the study site "Kocibórz"

Functional trait	***P***
Open area (OA)	6.973E-28
Eurytopic (Eu)	6.986E-29
Forest (F)	9.848E-34
Wetland (W)	1.503E-41

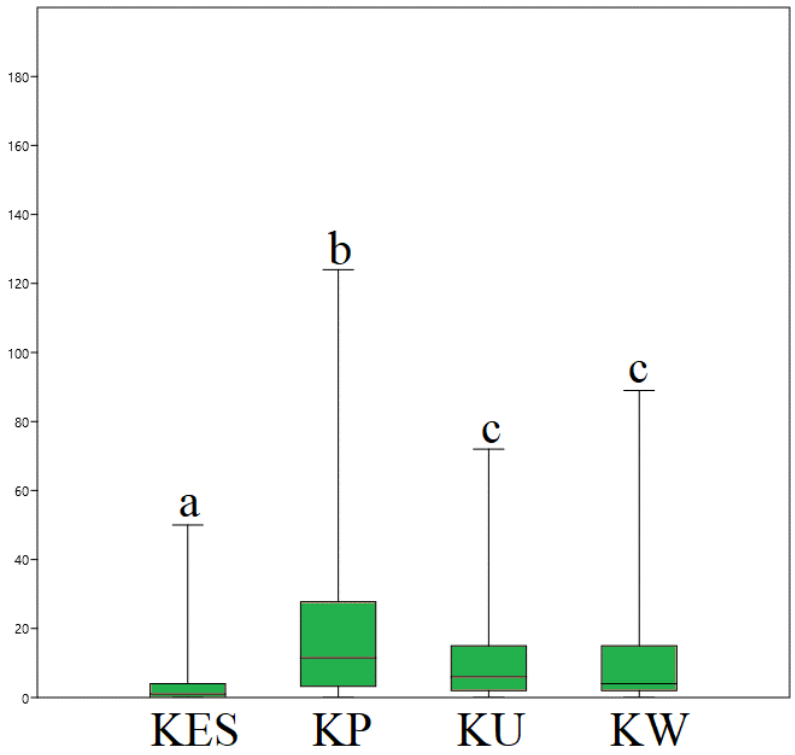


Figure 109. Rarefied open area Carabidae individuals abundance for different plots (Dunn's post hoc; p-value with Bonferroni correction). Mean values per trap are shown for the particular plots (KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow;) in the study site "Kocibórz". Different letters above the boxplots indicate significant differences between the habitats ($p < 0.05$)

In quantitative terms, open area species were the most numerous in the arable field (KP). There were 1,130 individuals (constituting 91.65% of the assemblage) in 2019 and 1,334 individuals (constituting 95.29% of the assemblage) in 2020 (**Fig. 110-111)**. They were also the most numerous in qualitative terms – there were 35 species (constituting 71.43% of the assemblage) in 2019 and 25 species (constituting 67.57% of the assemblage) in 2020 (**Fig. 112-113)**. During a 2-year study, the most numerous open area species noticed on arable crop were: *C. fuscipes*, *H.rufipes*, *P. cupreus*, and *P. versicolor* (**Tab. 12, Tab.14).**

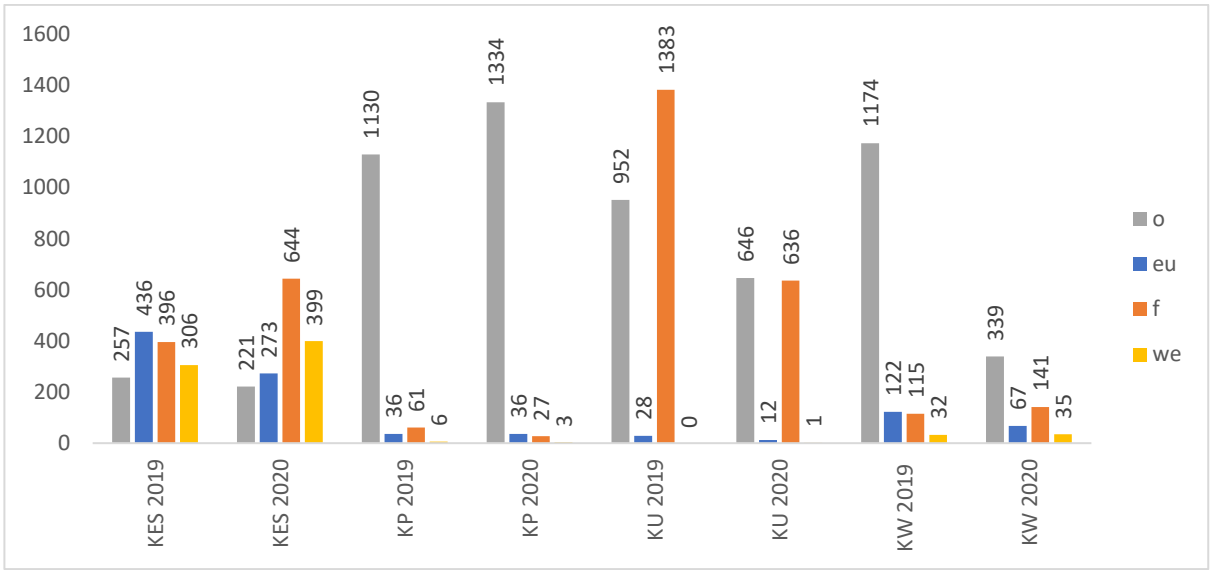


Figure 110. The number of Carabidae individuals with different habitat preferences (eu-eurytopic, f – forest, o – open area, we - wetland). The abbreviations used on the graph mean respectively: KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow

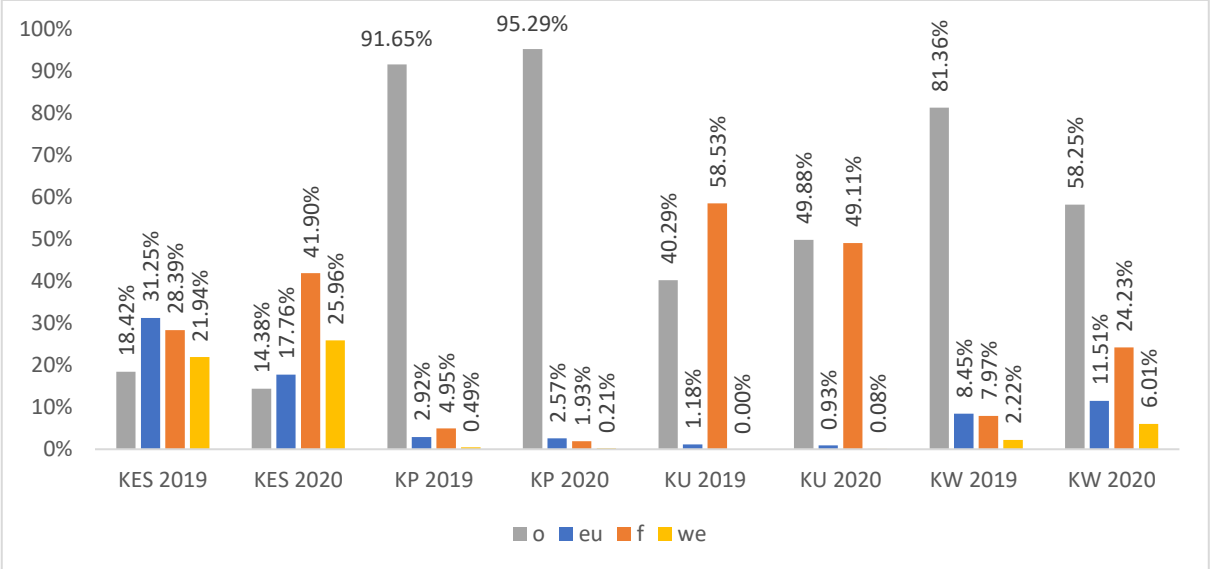


Figure 111. The percentage of Carabidae individuals with different habitat preferences (eu-eurytopic, f – forest, o – open area, we - wetland). The abbreviations used on the graph mean respectively: KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willo

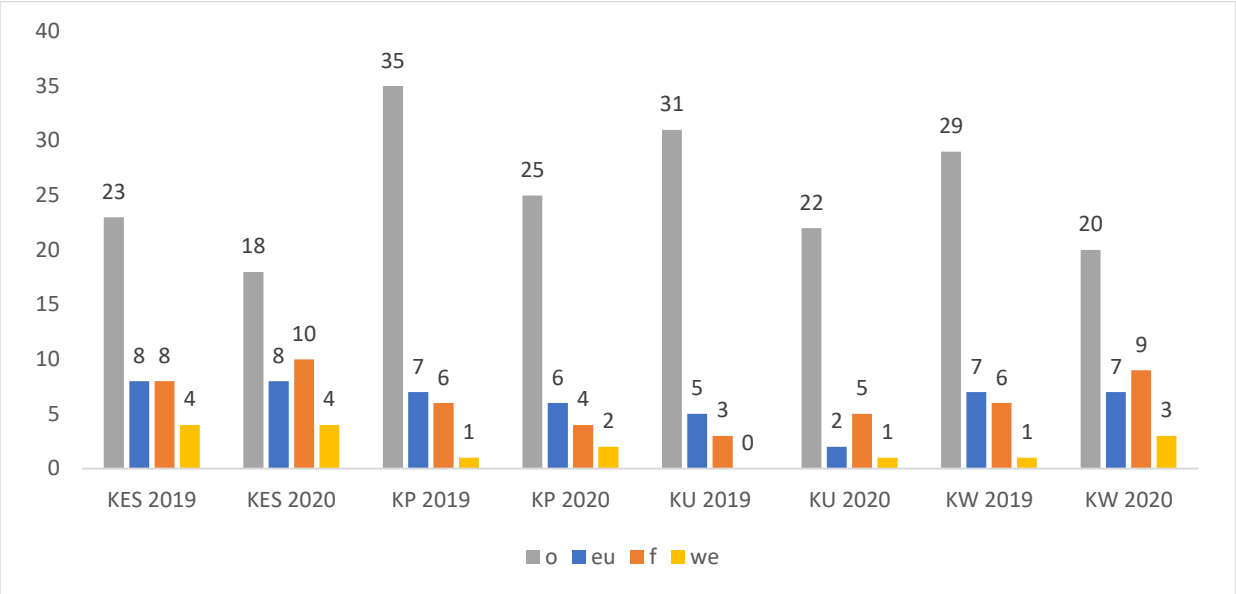


Figure 112. The number of Carabidae species with different habitat preferences (eu-eurytopic, f – forest, o – open area, we - wetland). The abbreviations used on the graph mean respectively: KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow

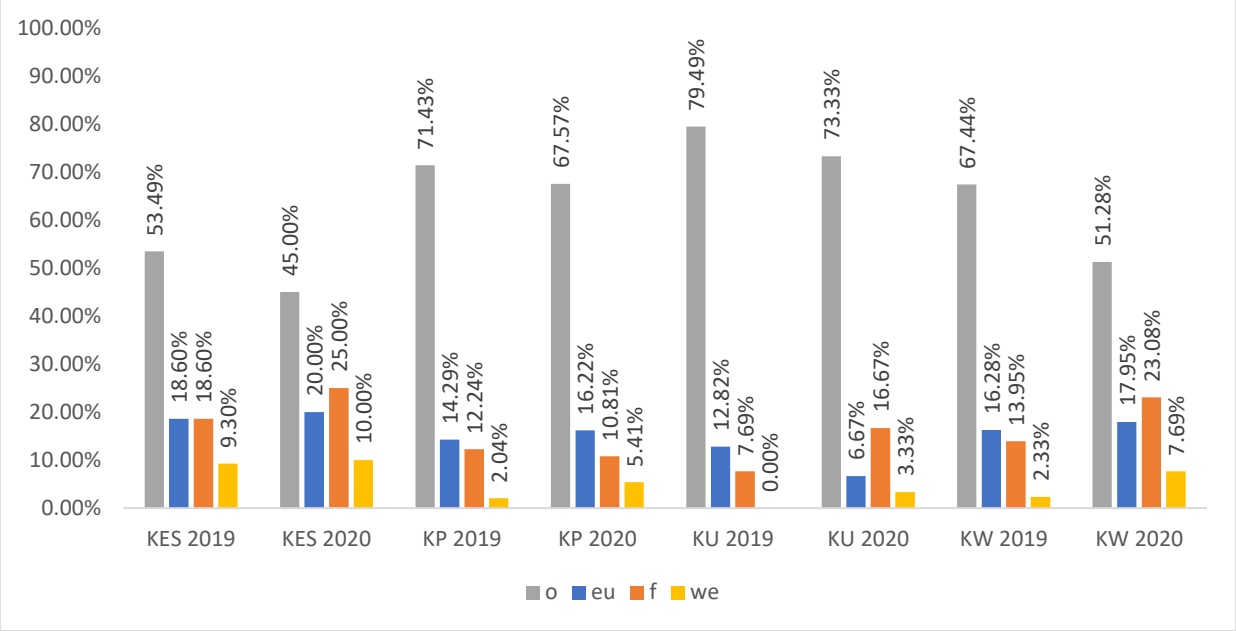


Figure 113. Percentage of Carabidae species with different habitat preferences (eu-eurytopic, f – forest, o – open area, we - wetland). The abbreviations used on the graph mean respectively: KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow

The most similar to the arable crop (KP) were: the fallow land (KU) and the SRC willow plantation (KW) in the first year of growth (2019). On fallow land (KU) 952 individuals of ground beetles preferring open areas (constituting 40.29% of the assemblage) were collected in 2019 and 646 individuals (constituting 49.88% of the assemblage) were collected in 2020 (**Fig. 110-111)**. They belonged to 31 species (constituting 79.49% of the assemblage) in 2019 and 22 species (constituting 73.33% of the assemblage) in 2020 (**Fig. 112-113)**.

The most numerous species, outnumbering 50 individuals, were in 2019: *C. fuscipes, P. lepidus, C. melanocephalus, H. smaragdinus, H. rubripes,* and *A. aenae.* In 2020 they were: *C. fuscipes, H. smaragdinus, A.bifrons* **(Tab. 12, Tab. 14)**.

There were significant differences in the number of open area species in study years 2019 and 2020 in SRC willow plantation (KW). In the first study season, there were 1,174 individuals (constituting 81.36% of the assemblage) and there were 339 individuals (constituting 58.25% of the assemblage) in the second study year (**Fig. 110-111)**. In qualitative terms, it was, respectively 29 species (constituting 67.44% of the assemblage) in 2019 and 20 species (constituting 51.28% of the assemblage) in 2020 (**Fig. 112-113)**. It made this plantation similar to fallow land (KU) and arable field (KP) in the first year of study, and to the Eco-Salix crop (KES) in the second year. The most numerous species, indicated in 2019 were: *P. versicolor, C.fuscipes* and *H. rufipes.* Only those species outnumbered 200 individuals. Also, *P. cupreus* and *P. lepidus* were numerous (> 30 individuals). In 2020 none of the species outnumbered 200 individuals. The most numerous were: *P. versicolor, C. melanarius, H. rufipes* (**Tab. 12, Tab.14).**

In both, quantitative and qualitative terms, open area species were the last numerous in the Eco-Salix crop (KES). There were 257 individuals (constituting 18.42% of the assemblage) in 2019 and 221 individuals (constituting 14.38% of the assemblage) in 2020 (**Fig. 110-111)**. They were also the last numerous in the number of species – there were 23 of them, (constituting 53.49% of the assemblage) in 2019 and 18 of them (constituting 45.00% of the assemblage) in 2020 (**Fig. 112-113)**. The most numerous species, exceeding 30 individuals in 2019 were: *P. versicolor, C. fuscipes* and *H. rufipes*. In 2020 only *P. versicolor* was recorded in the number greater than 30 individuals (**Tab. 12, Tab.14).** There was a large group of open area species common on all of the investigated plots **(Fig. 114).**

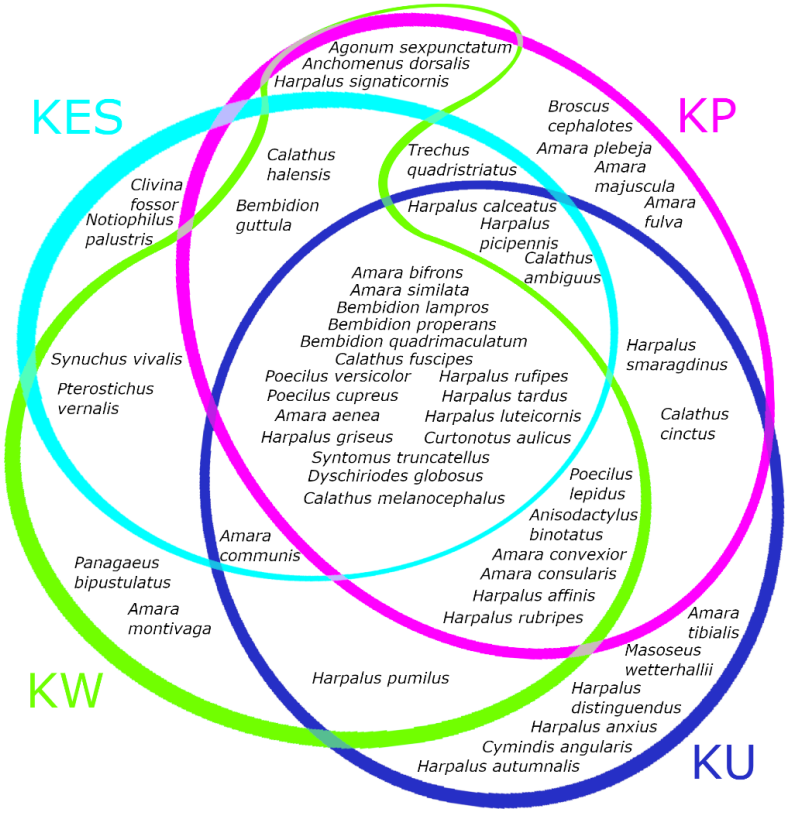


Figure 114. Presence of the open area species on the particular plots in the study site: ”Kocibórz”. The abbreviations used on the graph mean respectively: KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow

Eurytopic

Eurytopic species, similar to wetland species, were a not numerous group, recorded mainly on willow plantations (KES & KW). In 2019 there were 13 eurytopic species (622 individuals). In 2020, 9 species (388 individuals) from this group were indicated (**Tab.15-16, Fig. 108).** Statistical analysis indicated, that there were significant differences (*p-value* = 6.986E-29) in the number of eurytopic ground beetles between all of the studied plots (**Tab. 19, Fig. 115**).

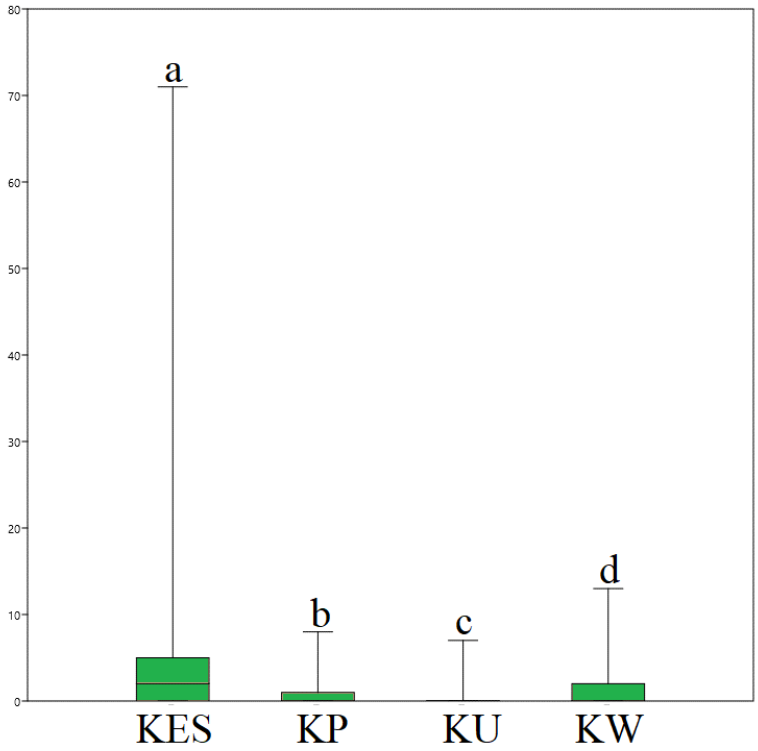


Figure 115. Rarefied eurytopic Carabidae individuals abundance for different plots (Dunn's post hoc; p-value with Bonferroni correction). Mean values per trap are shown for the particular plots (KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow;) in the study site "Kocibórz". Different letters above the boxplots indicate significant differences between the habitats ($p < 0.05$)

Eurytopic species were the most numerous in the Eco-Salix plantation (KES). There were 436 individuals (constituting 31.25% of the assemblage) in 2019 and 273 individuals (constituting 17.76% of the assemblage) in 2020 (**Fig. 110-111)**. There were 8 eurytopic species in both study seasons, constituting respectively 18.60% and 20.00% of the assemblage in the years 2019 and 2020 (**Fig. 112-113)**. In both study years, the most numerous species from this group, inhabiting Eco-Salix plantation (KES), was *P. melanarius*. Also, *C. nemoralis* was numerous.

A significant number of eurytopic species was also indicated on the SRC willow crop. There were 122 individuals (constituting 8.45% of the assemblage) in 2019 and 67 individuals (constituting 11.51% of the assemblage) in 2020 (**Fig. 110-111)**. There were 7 large carnivore species in both study seasons, constituting respectively 16.28% and 17.95% of the assemblage in the years 2019, and 2020 (**Fig. 112-113)**. In both study seasons, the most numerous eurytopic species indicated on this crop was *P. melanarius* (**Tab. 12, Tab. 14)**.

The number of eurytopic individuals, indicated in open area habitats, such as a fallow land (KU) and an arable crop (KP) was significantly lower. Interestingly, these differences were

not reflected in the qualitative terms – except for the fallow land (KU) in the second study season, the species number was similar in all plots. In both study seasons (2019 and 2020), there were 36 eurytopic individuals collected in the arable crop (KP), constituting 2.92% and 2.57% of the assemblage, respectively (**Fig. 110-111)**. They belonged to 7 species (constituting 14.29% of the assemblage) in 2019 and to 6 species (constituting 16.22% of the assemblage) in 2020 (**Fig. 112-113)**. Also in this plot, the most numerous eurytopic species in both years of the study was *P. melanarius* (**Tab. 12, Tab. 14)**.

Eurytopic species were the last numerous in the fallow land (KU). There were only 28 individuals (constituting 1.18% of the assemblage) in 2019 and 12 individuals (constituting 0.93% of the assemblage) in 2020 (**Fig. 110-111)**. This group was also the last numerous in qualitative terms. There were 5 eurytopic species in the first study season, and only 2 eurytopic species in the second study season, constituting respectively 12.82% and 6.67% of the assemblage, in the years 2019 and 2020 (**Fig. 112-113)**. The most numerous eurytopic species recorded on this plant in study season 2019 was *H. laevipes*. In 2020 it was *P. melanarius* (**Tab. 12, Tab. 14)**. Only two eurytopic species were present on all investigated plots – they were: subrecedent *A. familiaris* and numerously represented *P. melanarius* (**Fig. 116**).

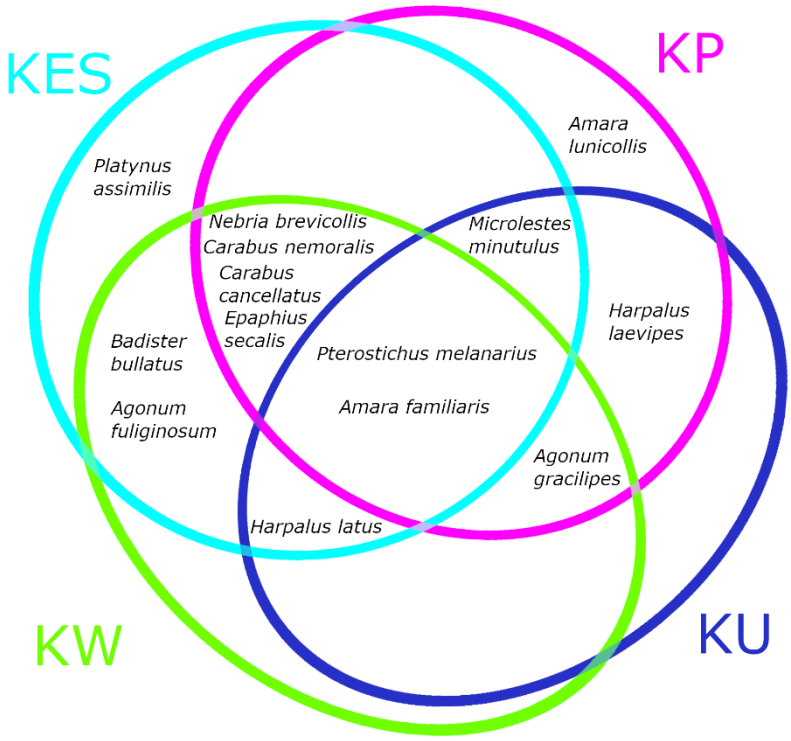


Figure 116. Presence of the eurytopic species on the particular plots in the study site: ”Kocibórz”. The abbreviations used on the graph mean respectively: KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow

Forest species

In 2019 eleven species (1,955 individuals) and in 2020 twelve species (1,448 individuals) from this group were indicated (**Tab. 15-16)**. Statistical analysis indicated, that there were significant differences (*p-value* = 2.187E-10) in the number of forest species individuals (**Tab. 19)**. Differences were indicated between all of the studied plots, except for the Eco-Salix crop (KES) and fallow land (KU), in which the median of collected individuals number was similar (**Fig. 117**).

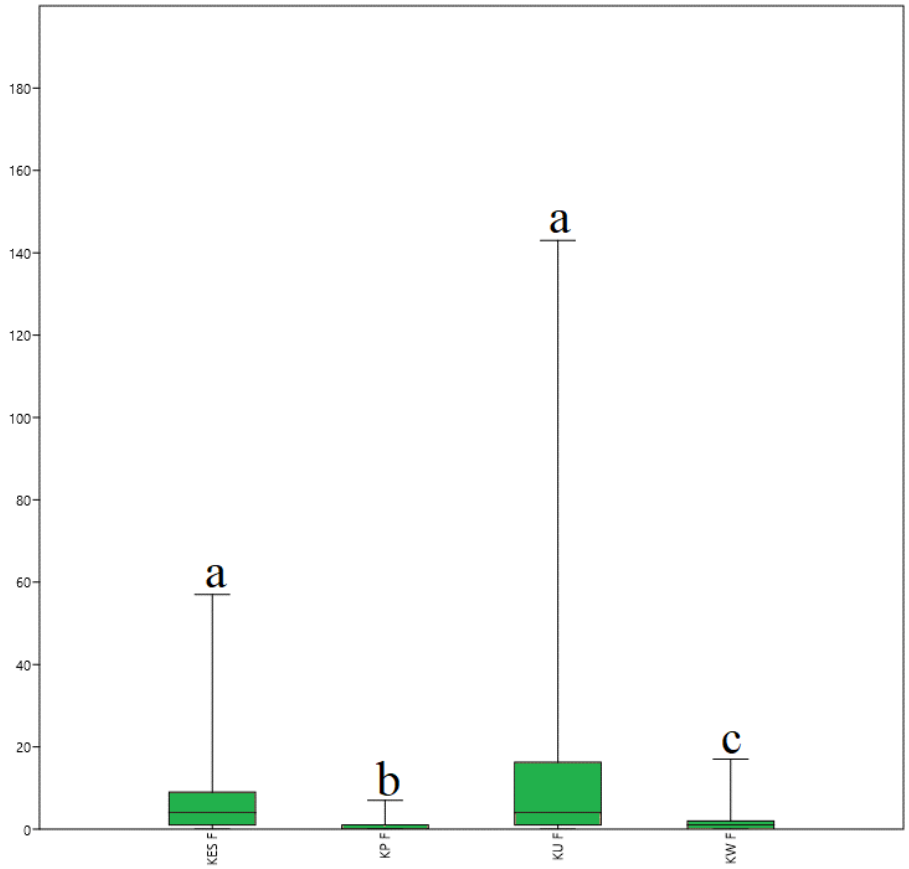


Figure 117. Rarefied forest Carabidae individuals abundance for different plots (Dunn’s post hoc; p-value with Bonferroni correction). Mean values per trap are shown for the particular plots (KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow;) in the study site “Kocibórz”. Different letters above the boxplots indicate significant differences between the habitats (p <0.05)

Fallow land (KU) was the most abundant in forest species in quantitative terms. There were 1,383 individuals (constituting 58.53% of the assemblage) in 2019 and 636 individuals

(constituting 49.11% of the assemblage) in 2020 (**Fig. 110-111)**. On the other hand, this plot was the last abundant in forest species in qualitative terms. There were only 3 forest species (constituting 7.69% of the assemblage) in study season 2019 and 5 forest species (constituting 16.67% of the assemblage) in study season 2020 (**Fig. 112-113)**. There was only one forest species, numerous on this plot - xerophilous eudominant, *C. erratus.* Other forest species were indicated on this plot only as single individuals (**Tab. 12, Tab. 14)**.

A significant number of forest species was also indicated on the Eco-Salix crop (KES). There were 396 individuals (constituting 28.39% of the assemblage) in 2019 and 644 individuals (constituting 41.90% of the assemblage) in 2020 (**Fig. 110-111)**. They belonged to 8 species (constituting 18.60% of the assemblage) in 2019 and to 10 species (constituting 25.00% of the assemblage) in 2020 (**Fig. 112-113)**. It made the Eco-Salix crop (KES) the most abundant in forest species in qualitative terms. The most numerous forest species, indicated on this plantation in both study seasons were *P. niger* and *C. hortensis*. Nonetheless, other species, like *P. strenuus* and *P. oblongopunctatus*, were also represented abundantly (**Tab. 12, Tab. 14)**.

There were no significant differences in the number of forest species individuals in study years 2019 and 2020 in SRC willow plantation (KW). However, the share of this species in the assemblage differs significantly between both study years. In the first study season, there were 115 individuals (constituting 7.97% of the assemblage) and there were 141 individuals (constituting 24.23% of the assemblage (!)) in the second year of study (**Fig. 110-111)**. In qualitative terms, it was 6 species (constituting 13.95% of the assemblage) in 2019 and 9 species (constituting 23.08% of the assemblage) in 2020 (**Fig. 112-113)**. It made the SRC willow plantation (KW), the second most abundant plot in qualitative terms (forest species). This plantation was similar to arable crops (KP) in the first year of growth, and to the Eco-Salix crop (KES) in the second year of a growth cycle. The most numerous species, indicated in the SRC willow plantation (KW) in both studied seasons, was *P. niger* (similarly to Eco-Salix (KES) (**Tab. 12, Tab. 14)**.

Quantitively, forest species were the last numerous in arable crops (KP). There were 61 individuals (constituting 4.95% of the assemblage) in 2019 and 27 individuals (constituting 1.93% of the assemblage) in 2020 (**Fig. 110-111)**. They were also not numerous in qualitative terms. Forest species, indicated in arable crops (KP), belonged to 6 species (constituting 12.24% of the assemblage) in 2019 and to 4 species (constituting 10.81% of the assemblage) in 2020 (**Fig. 112-113)**. The most numerously represented species in 2019 were *C. erratus* and *P. niger*, and in 2020 – also *C. erratus* (**Tab. 12, Tab. 14)**. Visualisation presented below illustrated (**Fig. 118**), that most of the forest species were shared by both willow plantations (KES, KW).

Additionally, forest species were the most abundant in those plantations. There were only 3 species common for all study plots: *C. erratus*, *P. niger* and *L. ferrugineus* (**Fig. 118**).

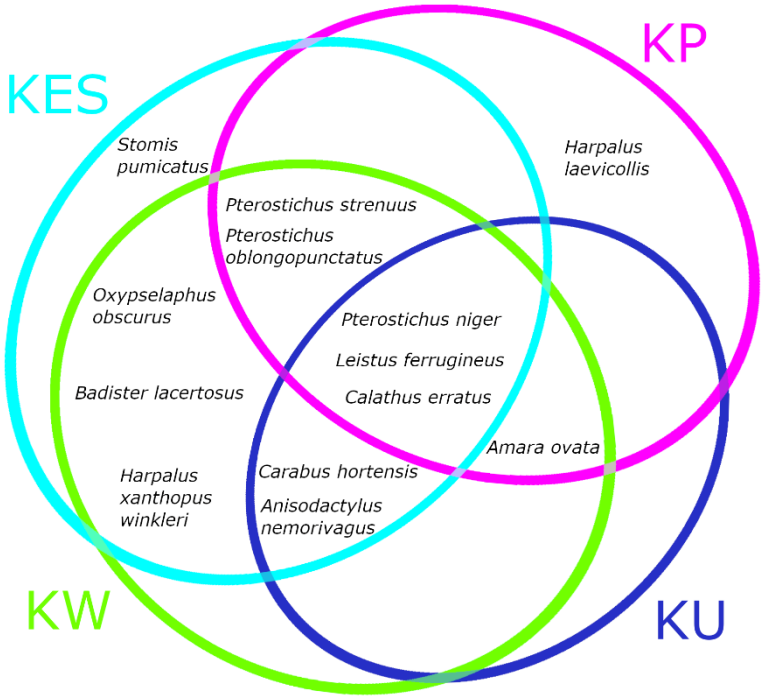


Figure 118. Presence of the forest species on the particular plots in the study site: ”Kocibórz”. The abbreviations used on the graph mean respectively: KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow

Wetland species

Wetland species were the last numerous among all habitat preference groups. In 2019 there were 4 wetland species (344 individuals). In 2020 5 species (438 individuals) from this group were indicated (**Tab. 15-16, Fig. 108)**, Statistical analysis indicated significant differences (*p-value* = 1.503E-41) in the number of Carabidae preferring wetland habitats between studied plots (**Tab. 19**). Differences were indicated for all of the study plots, except fallow land (KU) and arable crop (KP) (**Fig. 119**). In those two plots, wetland species were represented by single individuals, therefore those plots were excluded from further analysis (**Tab. 12**).

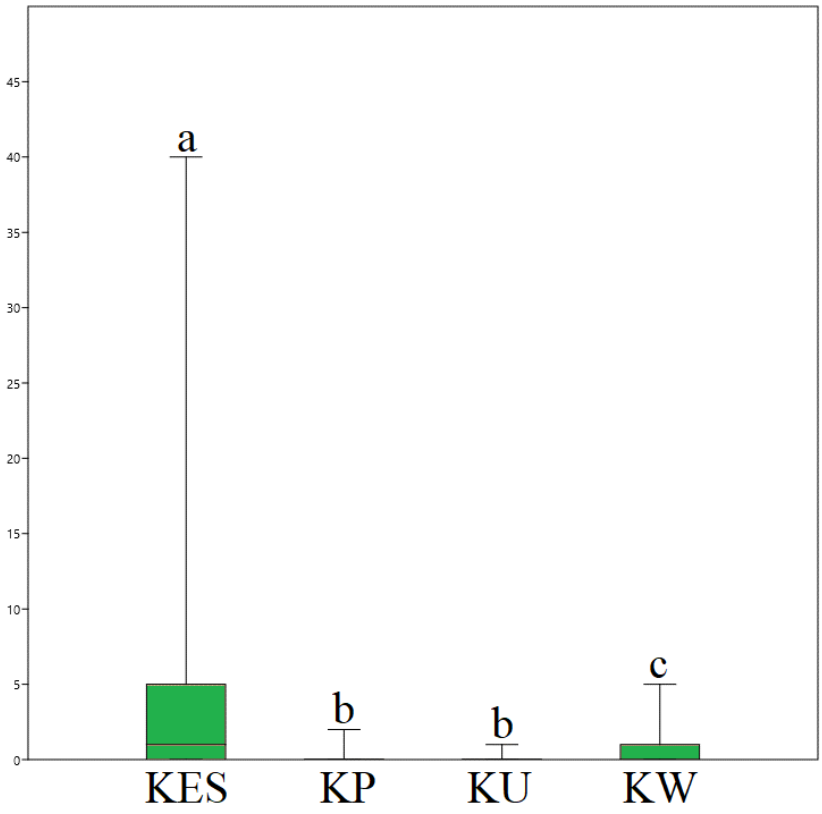


Figure 119. Rarefied wetland Carabidae individuals abundance for different plots (Dunn's post hoc; p-value with Bonferroni correction). Mean values per trap are shown for the particular plots (KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow;) in the study site "Kocibórz". Different letters above the boxplots indicate significant differences between the habitats ($p < 0.05$)

This group was the most numerous in the Eco-Salix crop (KES) (**Fig.120**). There were 306 individuals (21.94% of the assemblage) and 399 individuals (25.96% of the assemblage) indicated, respectively in 2019 and 2020 (**Fig. 110-111)**. In the study season 2019, as well as 2020, there were 4 species, constituting 9.30% and 10.00% of the assemblage, respectively (**Fig. 112-113)**. Species represented the most numerously on this plantation in both study seasons, was *C. granulatus*. In 2020, also *Bembidion gilvipes* was represented more numerously (**Tab. 12, Tab.14)**.

Ground beetles preferring wetland habitats were also present in a significant number in SRC willow plantation (KW). There were 32 individuals, constituting 2.22% of the assemblage in 2019 and 35 individuals, constituting 6.01% of the assemblage in 2020 (**Fig. 110-111)**. However, in qualitative terms, there was only 1 species in 2019 (2.33% of the assemblage) and 3 species in 2020 (7.69% of the assemblage) (**Fig. 112-113)**. In other plots number of wetland species was too low, to give significant data. In the study season 2019 only *C. granulatus* was

observed in the SRC willow plantation (KW). In the following season, there were also single individuals of *Bembidion gilvipes* and *Pterostichus diligens* recorded on this crop (**Tab. 12, Tab.14)**. The obtained results confirmed the **H1** hypothesis - willow plantations (especially Eco-Salix), differed from other studied plots. In the Eco-Salix (KES) willow plantation the lowest number of open area species was indicated. Meanwhile, the number of open area species was significantly higher on the row crop (KP) and fallow land (KU), and also in the SRC willow plantation (KW) in the first year after the harvest. Also, the number of eurytopic species and forest species was higher in willow plantations (KES, KW). It partially confirmed hypothesis **H2**. The number of forest species individuals was the highest for the fallow land (KU), but the general abundance (number of forest species) and ecological value of species from this group was higher for both willow plantations (KES, KW), especially for the Eco-Salix (KES), which large, brachypterous species from *Carabus* genera were indicated. Therefore hypothesis **H3** was also confirmed.

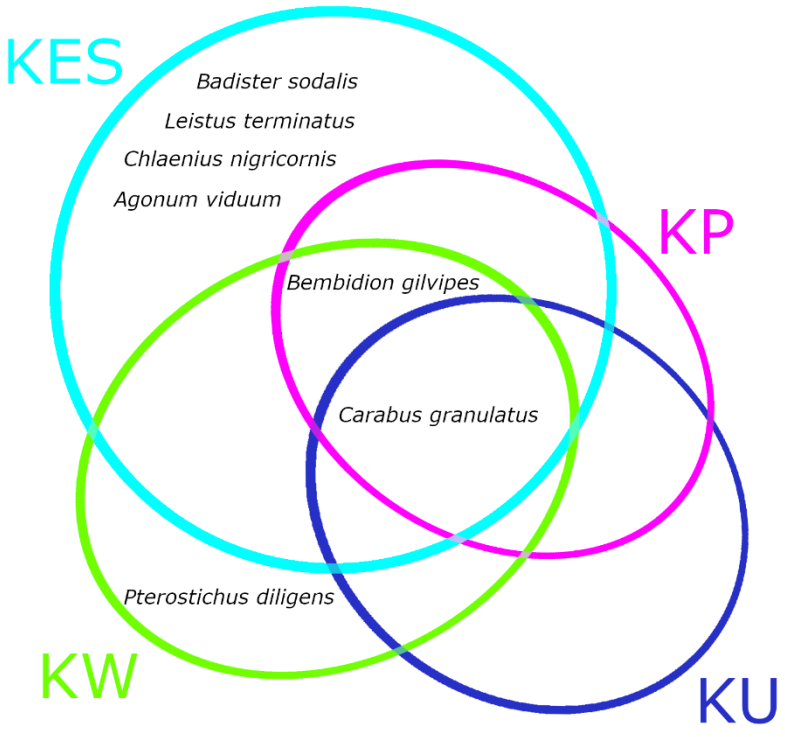


Figure 120. Presence of the wetland species on the particular plots in the study site: ”Kocibórz”. The abbreviations used on the graph mean respectively: KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow

Hygropreferences

The most numerously represented group were mesophiles, most abundant in all investigated plots, in quantitative, as well as qualitative terms. Large disparities between the number of hygrophilous and xerophilous species were observed for particular study plots (**Tab. 15-16, Fig. 121)**.

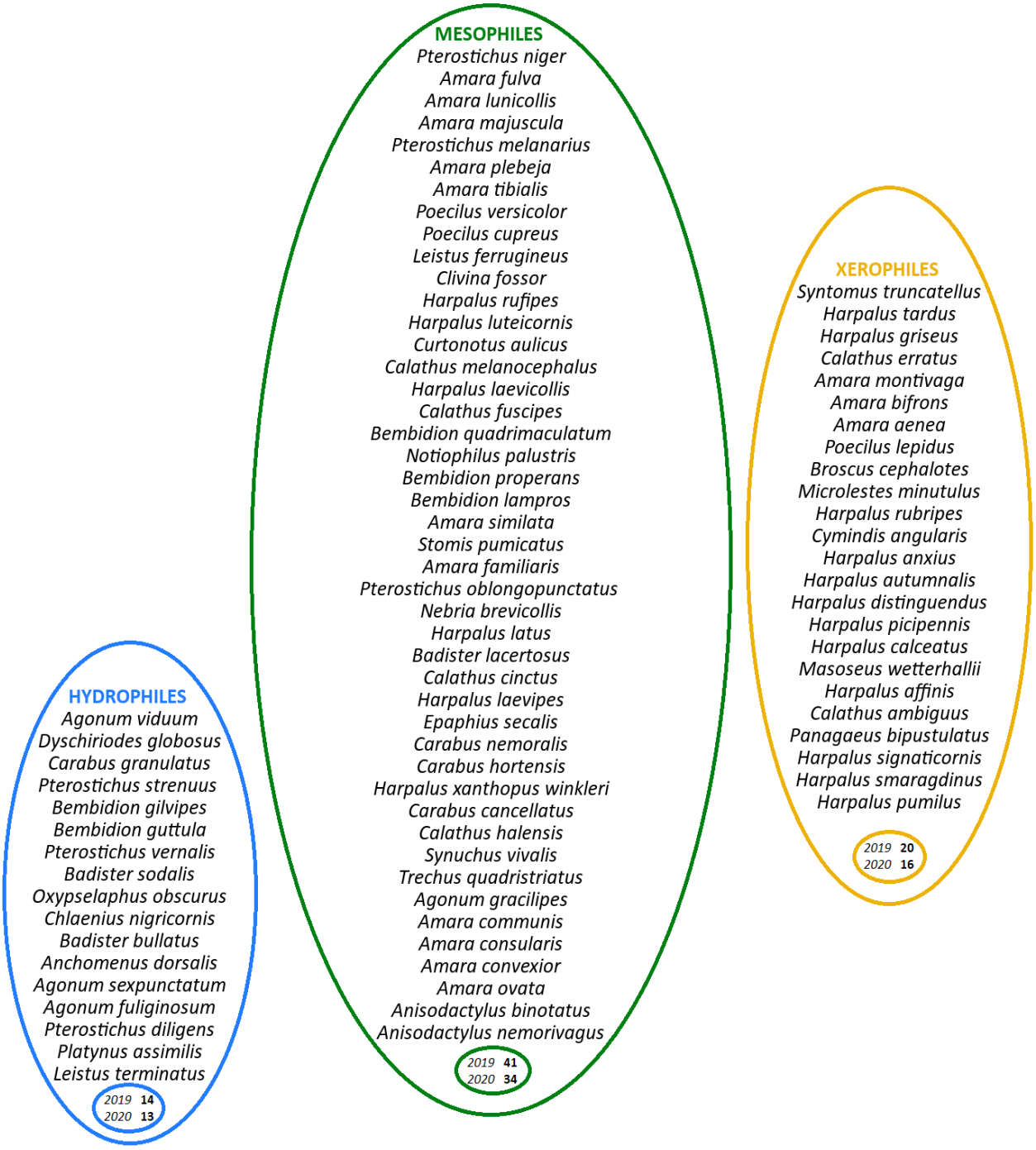


Figure 121. Species number and composition of Carabidae with different hygropreferences

Xerophilous species

There were 20 species (2,189 individuals) and 16 species (1,049 individuals) of xerophilous species in the years 2019 and 2020, respectively (**Tab. 15-16, Fig. 121)**. Statistical analysis indicated, that there were significant differences in the number of beetles representing this group (*p-value*=2.351E-57) (**Tab.20**). Differences were indicated between all studied plots, except for the SRC willow plantation (KW) and the arable field (KP) (**Fig. 122)**.

Table 20. Results of the Kruskal-Wallis significance test for hygropreference of Carabidae inhabiting crops in the study site "Kocibórz"

Functional trait	***p***
Xerophilous (X)	2.351E-57
Mesophilous (M)	1.271E-14
Hygrophilous (H)	2.205E-40

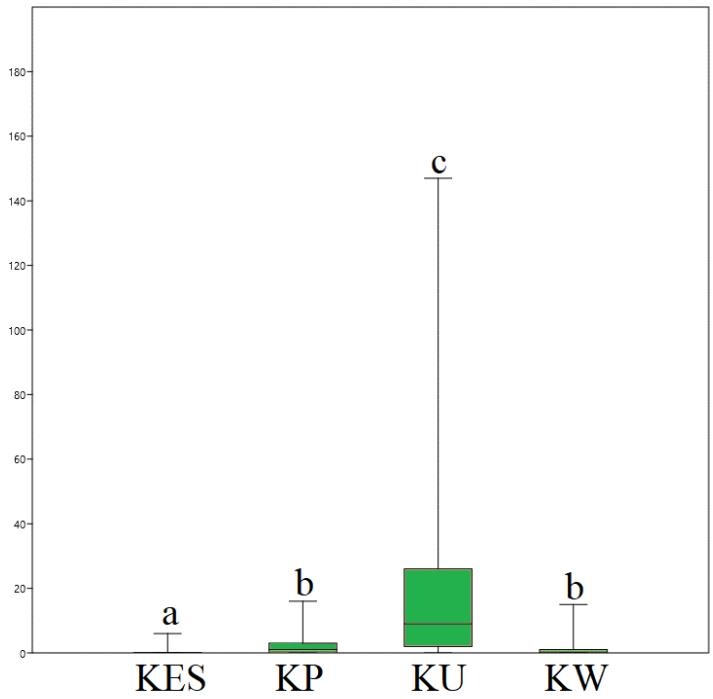


Figure 122. Rarefied xerophilous Carabidae individuals abundance for different plots (Dunn's post hoc; p-value with Bonferroni correction). Mean values per trap are shown for the particular plots (KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow;) in the study site "Kocibórz". Different letters above the boxplots indicate significant differences between the habitats (p <0.05)

In both, quantitative and qualitative terms xerophilous species were the most numerous in the fallow land (KU). There were 1,860 individuals (constituting 78.71% of the assemblage) in 2019 and 929 individuals (constituting 71.74% of the assemblage) in 2020 (**Fig. 123-124)**. They were also the most abundant in species number – there were 16 species (constituting 41.03% of the assemblage) in 2019 and 13 species (constituting 43.33% of the assemblage) in 2020 (**Fig. 125-126)**. During a 2-year study the most numerous xerophilous species were: *C. erratus,* significantly outnumbering other species. Also, *P. lepidus, H. smaragdinus, H. rubripes. A. aenea, H. tardus, H. calceatus, H. affinis, C. ambiguus* were numerously represented in 2019. In 2020 other numerously represented species were: *H. smaragdinus, A.bifrons, P. lepidus, A. aenea, and C. ambiguus* (**Tab. 12. Tab. 14. Fig. 127)**.

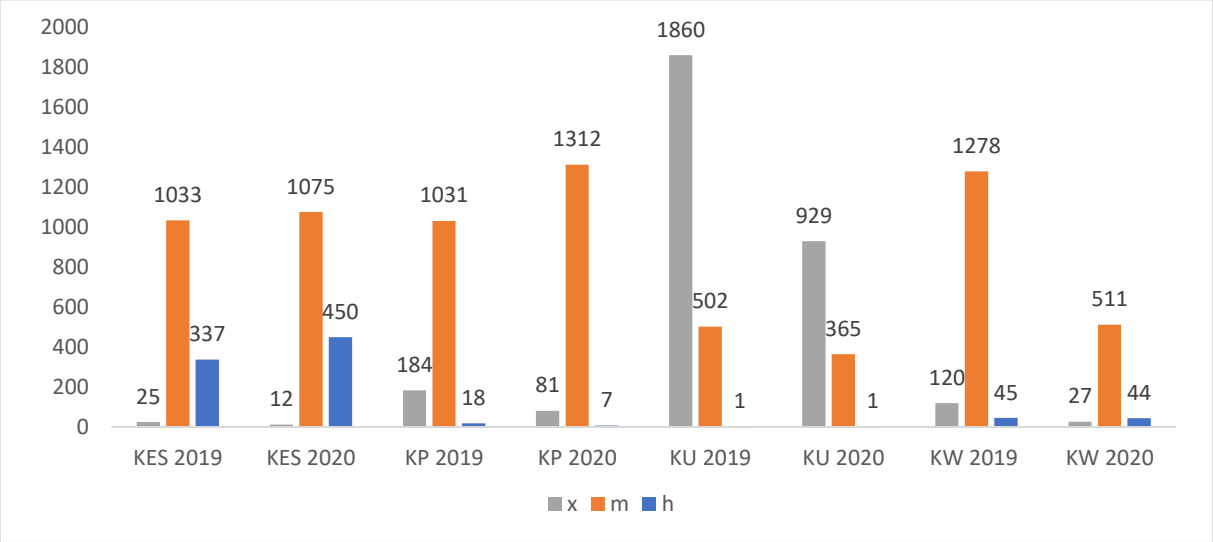


Figure 123. The number of Carabidae individuals with different hygropreferences (h – hygrophilous, m – mesophilous, x - xerophilous). The abbreviations used on the graph mean respectively: KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow

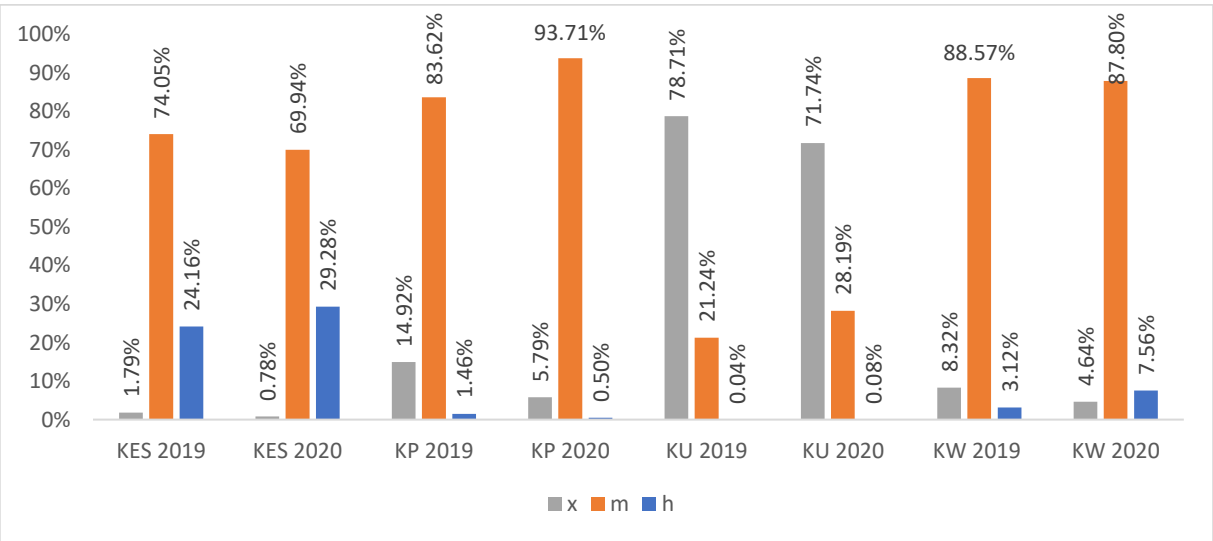


Figure 124. Percentage of Carabidae individuals with different hygropreferences (h – hygrophilous, m – mesophilous, x - xerophilous). The abbreviations used on the graph mean respectively: KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow

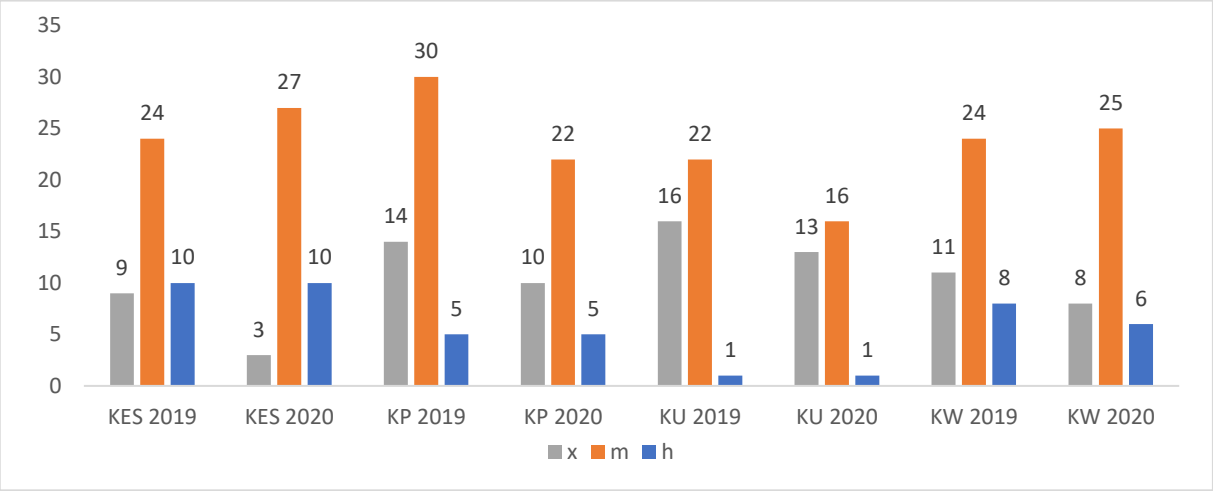


Figure 125. The number of Carabidae species with different hygropreferences (h – hygrophilous, m – mesophilous, x - xerophilous). The abbreviations used on the graph mean respectively: KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow

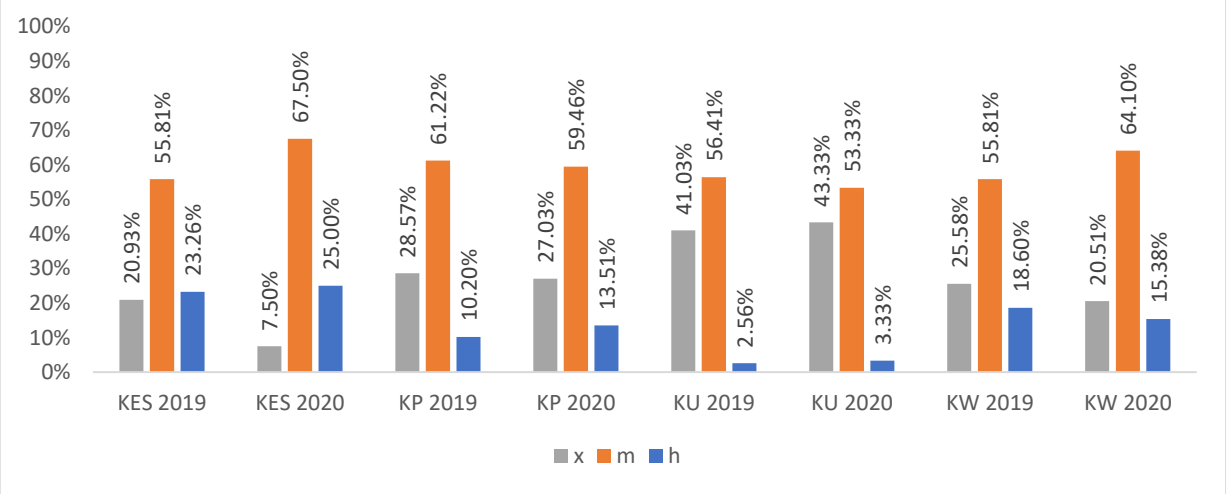


Figure 126. Percentage of Carabidae species with different hygropreferences (h – hygrophilous, m – mesophilous, x - xerophilous). The abbreviations used on the graph mean respectively: KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow

Other plantations differed significantly from the fallow land (KU), especially in quantitative terms. Xerophilous species were also numerous in the arable crop (KP) and SRC willow plantation (KW) in the first year of growth (2019), however, their number was significantly lower. On arable crop (KP) 184 individuals of xerophilous ground beetles (constituting 14.92% of the assemblage) were collected in 2019 and 81 individuals (constituting 5.79% of the assemblage) were collected in 2020 (**Fig. 123-124)**. They belonged to 14 species (constituting 28.57% of the assemblage) in 2019 and 10 species (constituting 27.03% of the assemblage) in 2020

(**Fig. 125-126)**. The most numerous xerophilous species, outnumbering 20 individuals, were in 2019: *C. erratus* and *P. lepidus.* In 2020 there was only *P. lepidus* (**Tab. 12. Tab. 14)**.

SRC willow plantation (KW) was the most similar to the arable crop (KP), especially in the first year of growth. In the first study season, there were 120 individuals (constituting 8.32% of the assemblage) and there were 27 individuals (constituting 4.64% of the assemblage) in the second experimental year (**Fig. 123-124)**. In qualitative terms, it was, respectively 11 species (constituting 25.58% of the assemblage) in 2019 and 8 species (constituting 20.51% of the assemblage) in 2020 (**Fig. 124-125)**. The most numerous xerophilous species, which outnumbered 20 individuals, were in 2019: *P. lepidus* and *H. tardus.* In 2020 none of the xerophilous species, indicated on this plant, have been represented by a large number of individuals (**Tab. 12. Tab. 14)**.

In both, quantitative and qualitative terms, xerophilous species were the last numerous in the Eco-Salix crop (KES). There were 25 individuals (constituting 1.79% of the assemblage) in 2019 and only 12 individuals (constituting 0.78% of the assemblage) in 2020 (**Fig. 123-124)**. In 2019, 9 species of xerophilous ground beetles were indicated on the Eco-Salix crop (KES) (constituting 20.93% of the assemblage). In 2020 there were only 3 of them (constituting 7.50% of the assemblage). In 2019, as well as in 2020 none of the xerophilous species, indicated on this plantation, have been represented by a large number of individuals. (**Fig. 125-126)**. *H. tardus* was the most numerous species in both study years (**Tab. 12. Tab. 14)**. The presence of xerophilous species on the particular plots is illustrated in **Figure 127.**

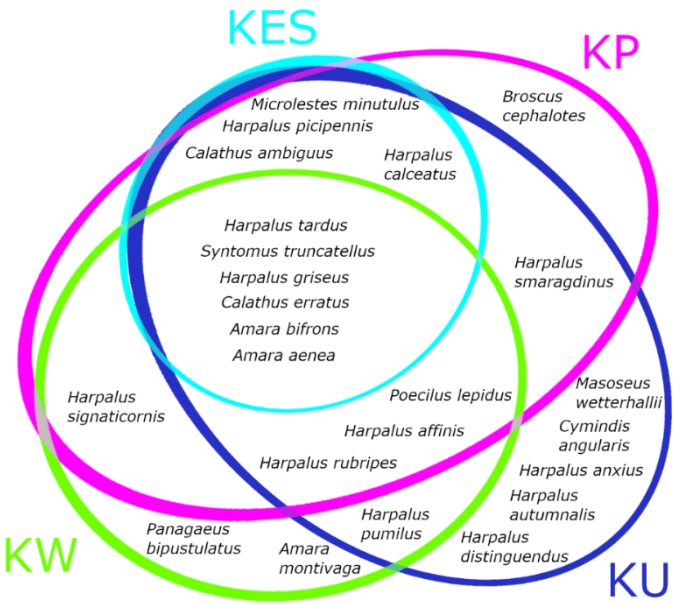


Figure 127. Presence of the xerophilous species on the particular plots in the study site: ”Kocibórz”. The abbreviations used on the graph mean respectively: KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow

Mesophilous species

Mesophilous species were the most numerous among all habitat preference groups. There were 41 species (3,844 individuals) and 34 species (3,263 individuals) in the years 2019 and 2020, respectively (**Tab. 15-16**). Statistical analysis indicated, that there were significant differences (*p-value*=1.271E-14) in the number of beetles representing this group. Differences were indicated between fallow land (KU) and all other plots (**Tab. 20, Fig. 128**).

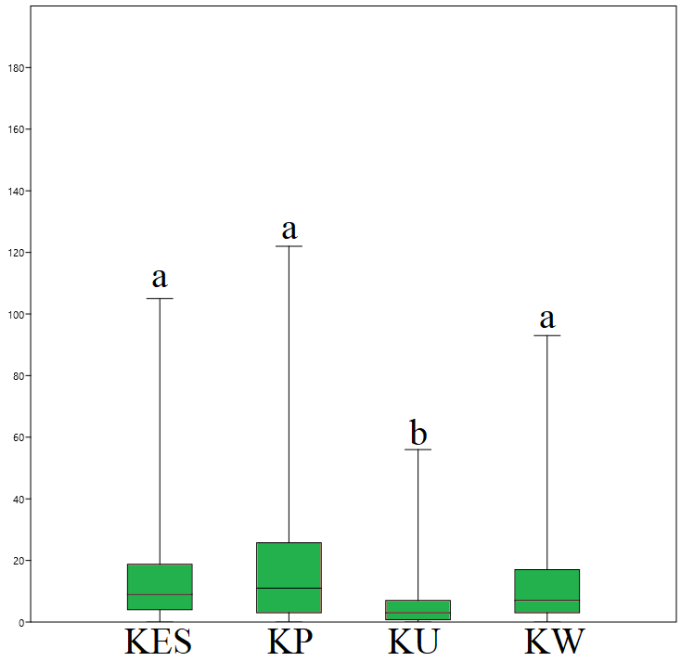


Figure 128. Rarefied mesophilous Carabidae individuals abundance for different plots (Dunn's post hoc; p-value with Bonferroni correction). Mean values per trap are shown for the particular plots (KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow;) in the study site "Kocibórz". Different letters above the boxplots indicate significant differences between the habitats (p <0.05)

Quantitively mesophilous species were the most numerous in the arable field (KP). There were 1,031 individuals (constituting 83.62% of the assemblage) in 2019 and 1,312 individuals (constituting 93.71% of the assemblage) in 2020 (**Fig. 123-124)**. They were also the most numerous in qualitative terms – there were 30 mesophilous species (constituting 61.22% of the assemblage) in 2019 and 22 mesophilous species (constituting 59.46% of the assemblage) in 2020 (**Fig. 125-126)**. During a 2-years study the most numerous mesophilous species noticed on arable crop were: *C. fuscipes, H.rufipes, P. cupreus,* and *P. versicolor* (**Tab. 12. Tab. 14)**.

The most similar to the arable crop (KP) were willow plantations (KW & KES). On the SRC willow plantation (KW) 1,278 individuals of mesophilous ground beetles (constituting 88.57% of the assemblage) were collected in 2019 and 511 individuals (constituting 87.80% of the assemblage) were collected in 2020 (**Fig. 123-124)**. They belonged to 24 species

(constituting 55.81% of the assemblage) in 2019 and 25 species (constituting 64.10% of the assemblage) in 2020 (**Fig. 125-126)**. The most numerous species, which outnumbered 50 individuals, were in 2019: *P. versicolor, C. fuscipes, H.rufipes, P. melanarius, P. niger, and P. cupreus.* In 2020 they were: *P. versicolor, P. niger, P. niger.* (**Tab. 12. Tab. 14)**.

On Eco-Salix plantation (KES) 1,033 individuals of mesophilous ground beetles (constituting 74.05% of the assemblage) were collected in 2019 and 1,075 individuals (constituting 69.94% of the assemblage) were collected in 2020 (**Fig. 123-124)**. They belonged to 24 species (constituting 55.81% of the assemblage) in 2019 and 27 species (constituting 67.50% of the assemblage) in 2020 (**Fig. 125-126)**. The most numerous species, outnumbering 100 individuals, were in 2019: *P. melanarius, P. niger, and C. hortensis.* In 2020 there was also *P. versicolor* (**Tab. 12. Tab. 14)**.

Fallow land (KU) differs the most from other plots. On fallow land (KU) 502 individuals of mesophilous ground beetles (constituting 21.24% of the assemblage) were collected in 2019 and 365 individuals (constituting 28.19% of the assemblage) were collected in 2020 (**Fig. 123-124)**. They belonged to 22 species (constituting 56.41% of the assemblage), collected in 2019 and 16 species (constituting 53.33% of the assemblage), collected in 2020 (**Fig. 125-126)**. On fallow land (KU), only one species outnumbered 100 individuals. In both study years, it was *C. fuscipes*. In 2019, also *C. melanocephalus* was numerously represented (**Tab. 12. Tab. 14)**.

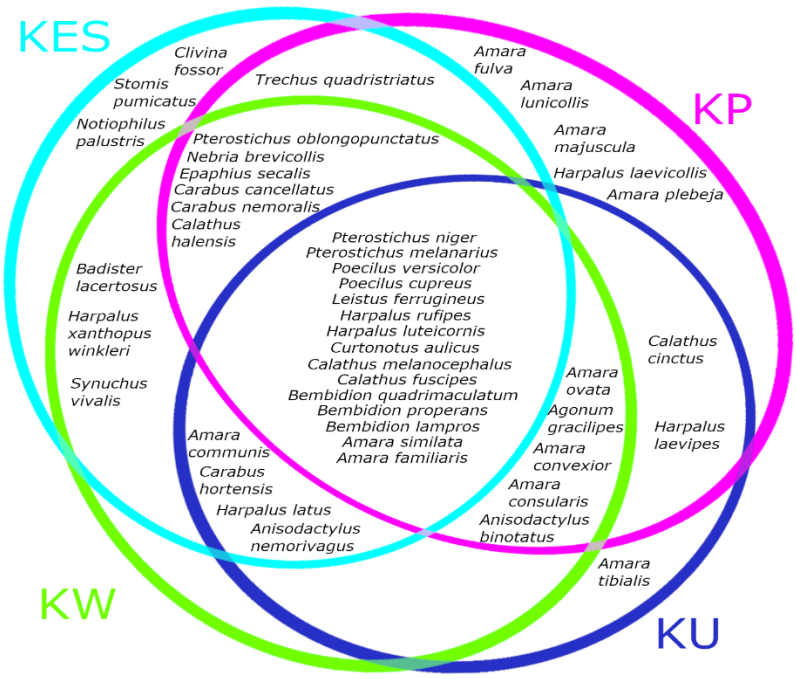


Figure 129. Presence of the mesophilous species on the particular plots in the study site: ”Kocibórz”. The abbreviations used on the graph mean respectively: KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow

Hygrophilous species

Hygrophilous species were the last numerous among all hygropreference groups. In 2019 there were 14 hygrophilous species (401 individuals). In 2020, 13 species (502 individuals) from this group were indicated (**Tab. 15-16)**. Statistical analysis indicated, that there were significant differences (*p-value* = 2.205E-40) in the number of hygrophilous Carabidae between all of the study plots (**Tab. 20**). On fallow land (KU), hygrophilous species were represented by single individuals, therefore this plot was excluded from further analysis (**Fig. 130**).

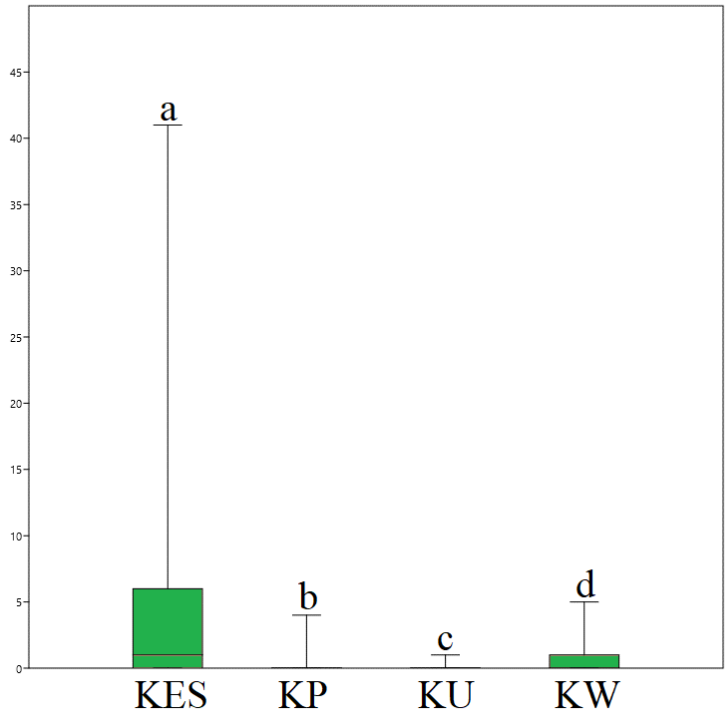


Figure 130. Rarefied hygrophilous Carabidae individuals abundance for different plots (Dunn's post hoc; p-value with Bonferroni correction). Mean values per trap are shown for the particular plots (KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow;) in the study site "Kocibórz". Different letters above the boxplots indicate significant differences between the habitats (p <0.05)

This group was the most numerous in the Eco-Salix crop (KES). There were 337 hygrophilous individuals (24.16% of the assemblage) and 450 individuals (29.28% of the assemblage) indicated, respectively in 2019 and 2020 (**Fig. 123-124)**. In 2019, 10 hygrophilous species (23.26% of the assemblage) were indicated. In 2020 it was also 10 species (25.00% of the assemblage) (**Fig. 125-126)**. Hygrophilous species represented the most numerously in both study seasons on this plantation, was *C. granulatus*. In 2020 also *B. gilvipes* and *P. strenuus* were numerous (**Tab. 12. Tab. 14)**.

Hygrophilous ground beetles were present in the SRC willow plantation (KW) more numerously in comparison to the arable field (KP) and fallow land (KU). There were 45 individuals, constituting 3.12% of the assemblage in 2019 and 44 individuals, constituting 7.56%

of the assemblage in 2020 (**Fig. 123-124)**. In 2019, 8 hygrophilous species (18.60% of the assemblage) were indicated. In 2020 it was 6 species (15.38% of the assemblage) (**Fig. 125-126)**. In both study seasons, *C. granulatus* was the most numerous hygrophilous species on the SRC willow plantation (KW) (**Tab. 12. Tab. 14)**.

In arable crop (KP) only 18 hygrophilous individuals were captured in 2019 (1.46% of the assemblage). In 2020 it was only 7 individuals (0.50% of the assemblage) (**Fig. 123-124)**. In qualitative terms, it was 5 species in both study seasons, 10.20% and 13.51% of the assemblage in the years 2019 and 2020, respectively. All hygrophilous species were represented in low numbers on this plot (**Fig. 125-126)**. Hygrophilous species distribution among all study plots was visualised in **Figure 131**.

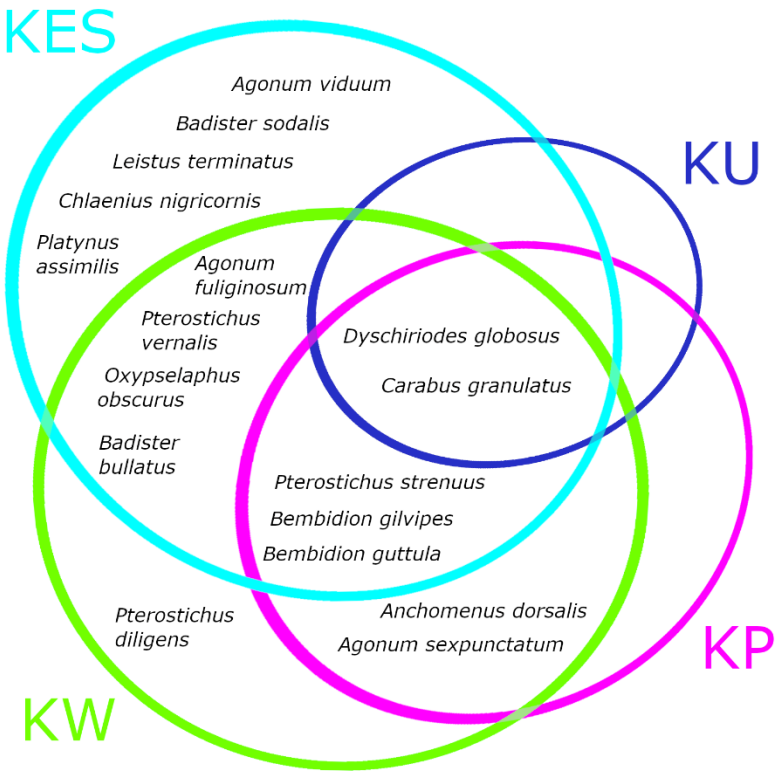


Figure 131. Presence of the hygrophilous species on the particular plots in the study site: ”Kocibórz”. The abbreviations used on the graph mean respectively: KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow

Compared to the other plots, fallow land (KU) was characterised by the highest number of xerophilous Carabidae individuals – in this plantation xerophiles were the most numerously represented group. On all other plots, mesophiles were the most numerous. Hygrophilous Carabidae species were represented more numerously in willow plantations, compared to fallow land (KU) and row crops (KP). It was particularly apparent in Eco-Salix plantation (KES), in which hygrophilous species were the second most numerous group of Carabidae.

Dispersion capability

The most numerous group in quantitative terms were dimorphic species. However, in qualitative terms, dimorphic species were the last numerous (**Fig. 132**).

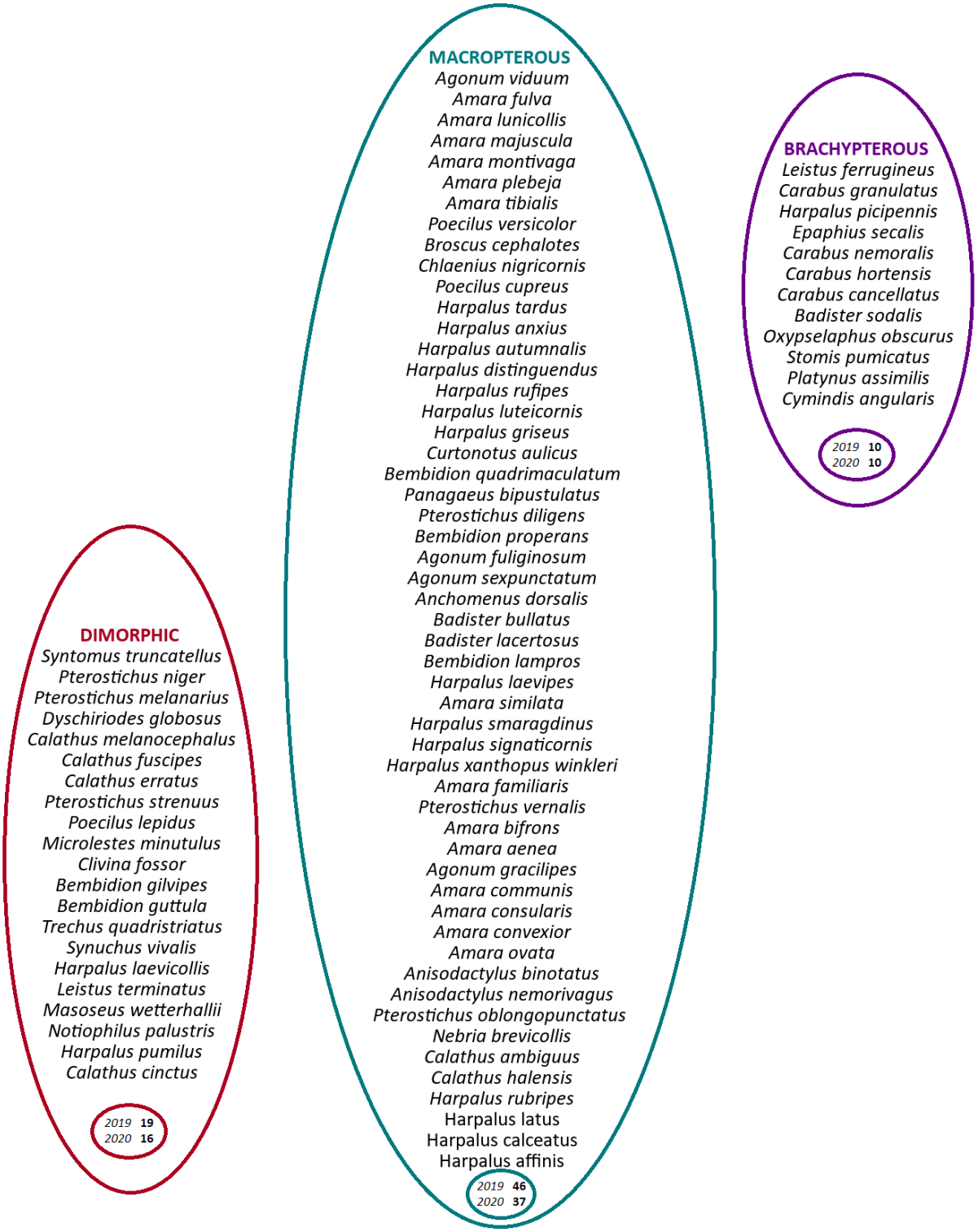


Figure 132. Species number and composition of Carabidae with different dispersion capabilities

Brachypterous species

Brachypterous species were the last numerous among all dispersion groups. In 2019 there were 10 brachypterous species (567 individuals). In 2020 also 10 species (589 individuals) from this group were indicated (**Tab. 15-16, Fig. 132**). Statistical analysis indicated, that there were significant differences (p-value = 3.7E-62) in the number of brachypterous Carabidae between investigated plots (**Tab. 21**).

Table 21. Results of the Kruskal-Wallis significance test for dispersion capacity of Carabidae inhabiting crops in the study site "Kocibórz"

Functional trait	***p***
Brachypterous (B)	3.7E-62
Dipterous (D)	1.675E-08
Macropterous (Mac)	5.957E-16

Differences were indicated for all of the study plots, except for the fallow land (KU) and arable crop (KP). On fallow land (KU), brachypterous species were represented by single individuals, therefore this plot was excluded from further analysis (**Fig. 133**).

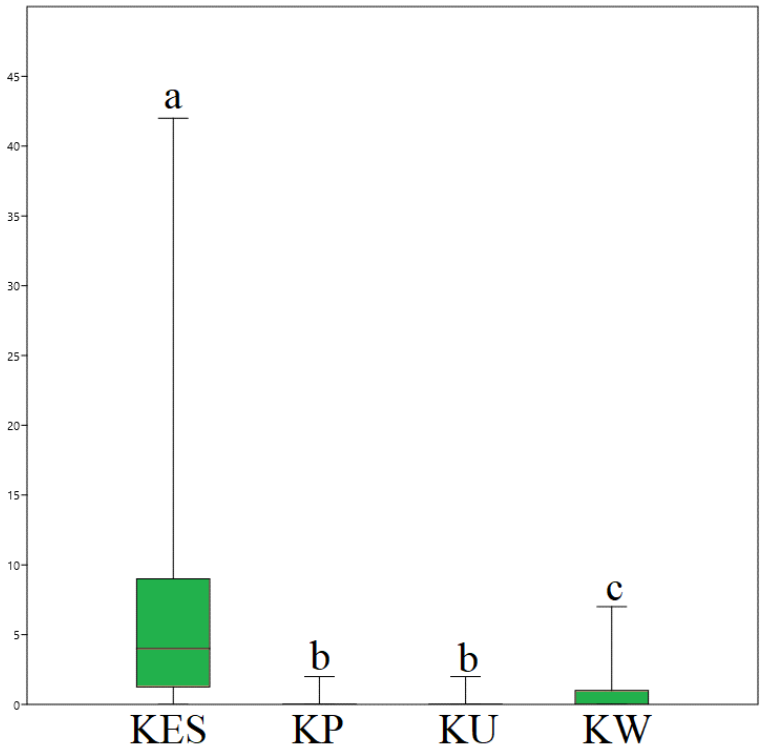


Figure 133. Rarefied brachypterous Carabidae individuals abundance for different plots (Dunn's post hoc; p-value with Bonferroni correction). Mean values per trap are shown for the particular plots (KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow;) in the study site "Kocibórz". Different letters above the boxplots indicate significant differences between the habitats (p <0.05)

This group was the most numerous in the Eco-Salix crop (KES). There were 502 brachypterous individuals (35.99% of the assemblage) and 531 individuals (34.55% of the assemblage) indicated, respectively in 2019 and 2020 (**Tab. 134-135**). In 2019, 9 brachypterous species (20.93% of the assemblage) were indicated. In 2020 it was 8 species (20.00% of the assemblage) (**Tab. 136-137**). Brachypterous species represented the most numerously in both study seasons on this plantation, were *C. granulatus, C.hortensis* and *C. nemoralis* (**Tab. 12. Tab. 14)**.

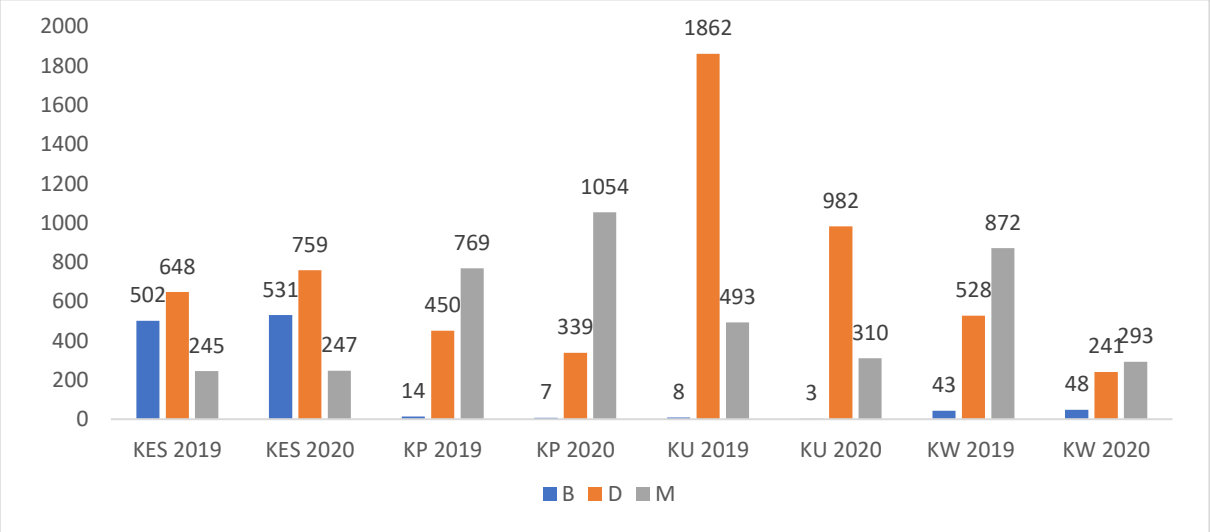


Figure 134. The number of Carabidae individuals with different dispersion capacities (B - brachypterous, D – dipterous, M – macropterous). The abbreviations used on the graph mean respectively: KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow

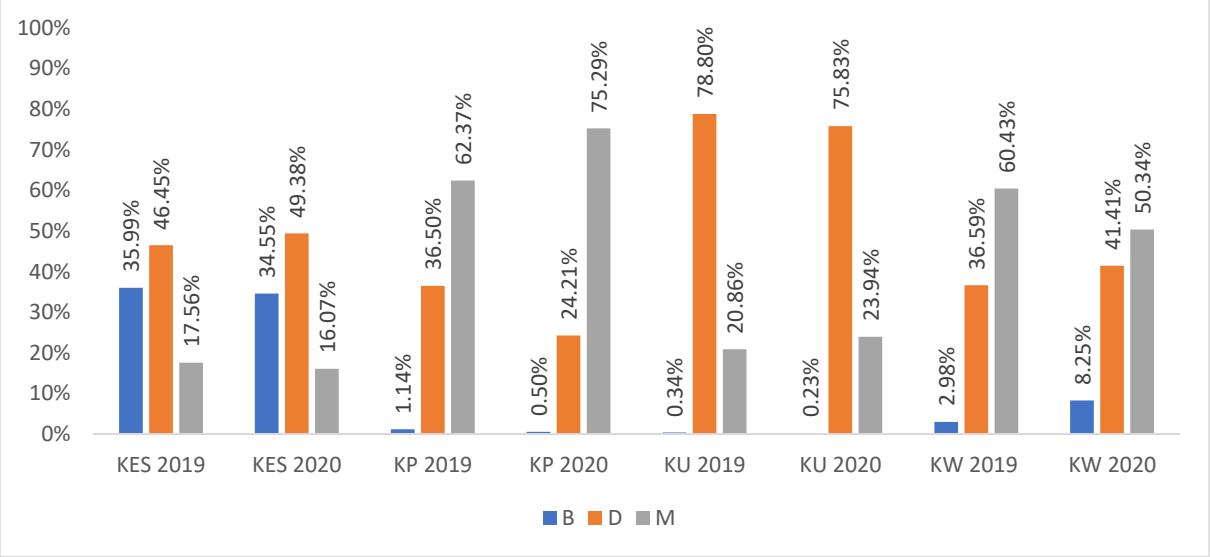


Figure 135. Percentage of Carabidae individuals with different dispersion capacities (B - brachypterous, D – dipterous, M – macropterous). The abbreviations used on the graph mean respectively: KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow

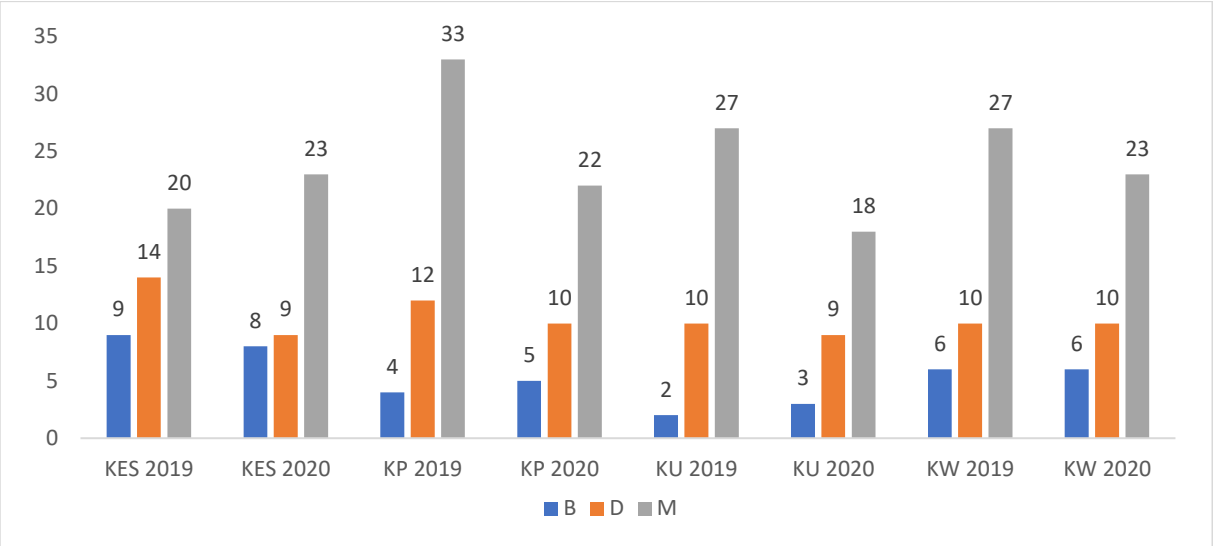


Figure136. The number of Carabidae species with different dispersion capacities (B - brachypterous, D – dipterous, M – macropterous). The abbreviations used on the graph mean respectively: KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow

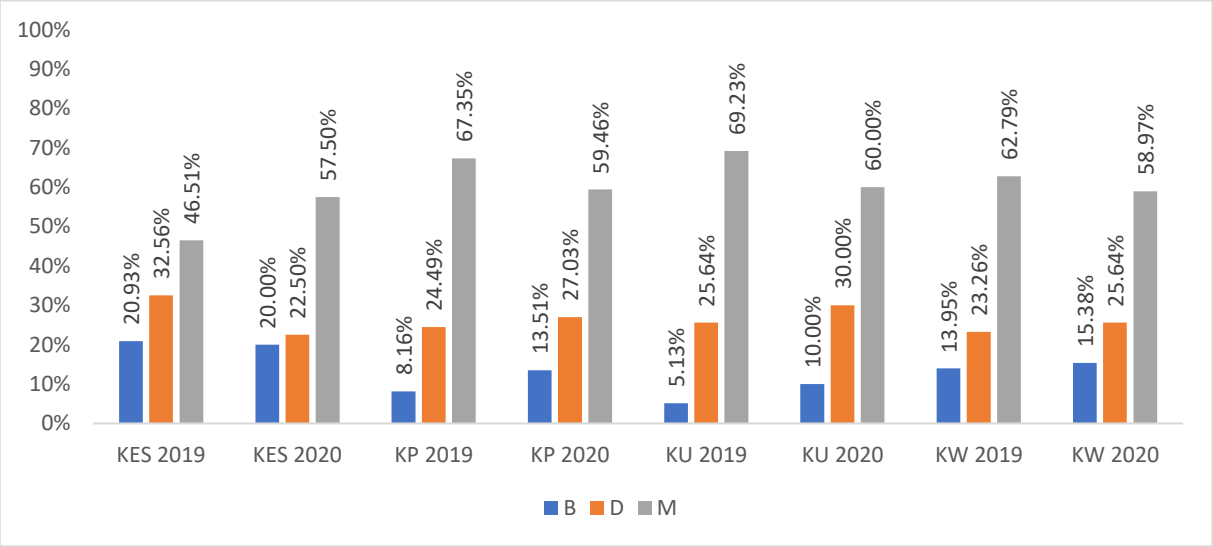


Figure137. Percentage of Carabidae species with different dispersion capacities (B - brachypterous, D – dipterous, M – macropterous). The abbreviations used on the graph mean respectively: KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow

Brachypterous ground beetles were more numerous on the SRC willow plantation (KW) than in arable crop (KP) and fallow land (KU). On this plant (KW) 43 individuals were noticed, constituting 2.98% of the assemblage in 2019. In 2020 it was 48 individuals, constituting 8.25% of the assemblage (**Tab. 134-135**). In both study seasons, 6 brachypterous species were indicated on this plant, constituting 13.95% and 15.38% of the assemblage in years 2019 and 2020, respectively (**Tab. 136-137**). In both study seasons, *C. granulatus* was the most numerous brachypterous species on the SRC willow plantation (KW) (**Tab. 12. Tab. 14)**.

In arable crop (KP) 14 brachypterous individuals were captured in 2019 (1.14% of the assemblage). In 2020 it was 7 individuals (0.50% of the assemblage) (**Tab. 134-135**). In qualitative terms, it was 4 species in the first study year, and 5 species, recorded in the second study season. They constituted 8.16% and 13.51% of the assemblage in the years 2019 and 2020, respectively (**Tab. 136-137**). All brachypterous species were represented in low numbers on this plot (**Tab. 136-137**).

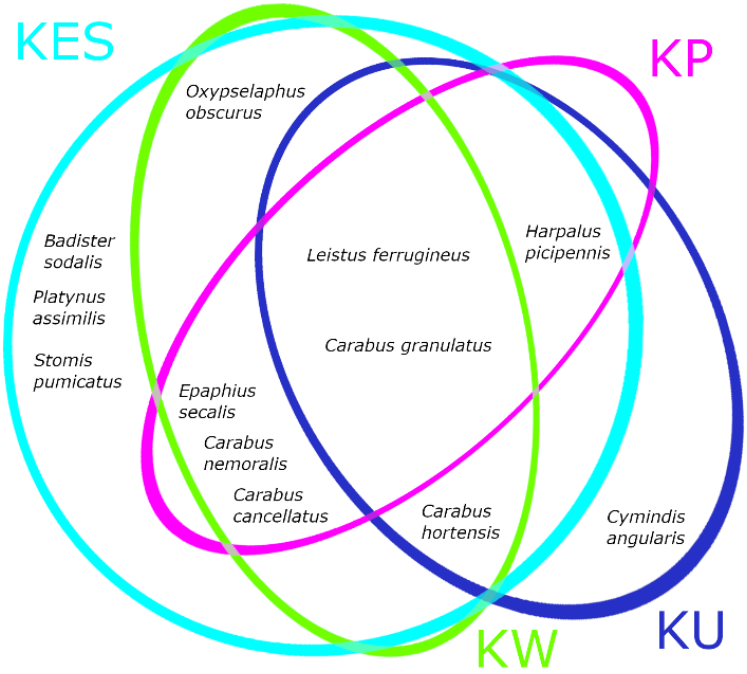


Figure 138. Presence of the brachypterous species on the particular plots in the study site: ”Kocibórz”. The abbreviations used on the graph mean respectively: KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow

Dimorphic species

Dimorphic species were the most numerous among all dispersion groups. There were 19 species (3,488 individuals) and 16 species (2,321 individuals) of dimorphic species in the years 2019 and 2020, respectively (**Tab. 15-16**). Statistical analysis indicated significant differences in the number of beetles representing this group between studied plots (*p-value*=1.675E-08) (**Tab. 21**). They were indicated for: a) Eco-Salix crop (KES) and SRC willow plantation (KW); b) Eco-Salix crop (KES) and the arable crop (KP); c) arable crop (KP) and fallow land (KU); d) fallow land (KU) and SRC willow plantation (KW) (**Fig. 139**).

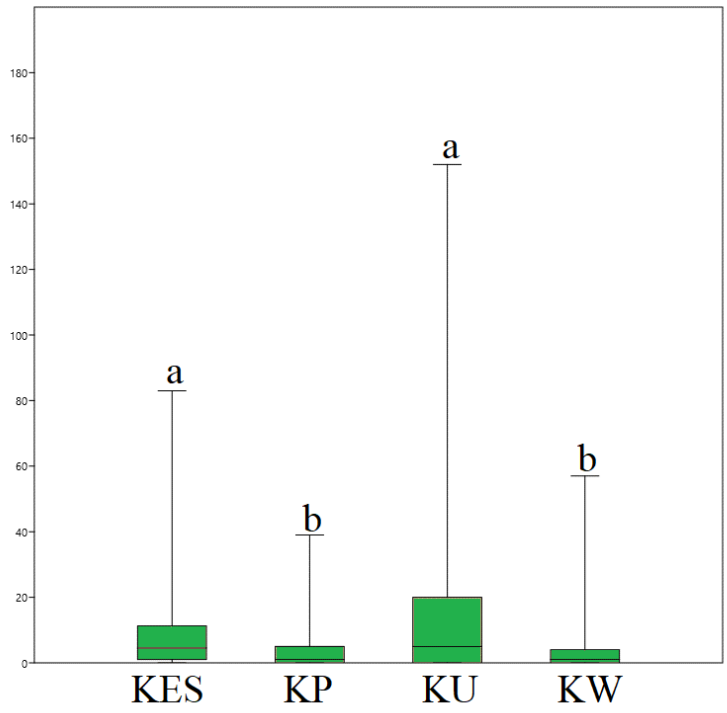


Figure 139. Rarefied dimorphic Carabidae individuals abundance for different plots (Dunn's post hoc; p-value with Bonferroni correction). Mean values per trap are shown for the particular plots (KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow;) in the study site "Kocibórz". Different letters above the boxplots indicate significant differences between the habitats ($p < 0.05$)

In both, quantitative and qualitative terms dimorphic species were the most numerous in the fallow land (KU). There were 1,862 individuals (constituting 78.80% of the assemblage) in 2019 and 982 individuals (constituting 75.83% of the assemblage) in 2020 (**Tab. 134-135**). In qualitative terms, there were 10 species (constituting 25.64% of the assemblage) in 2019 and 9 species (constituting 30.00% of the assemblage) in 2020 (**Tab. 136-137**). Arable field (KP) and SRC willow crop (KW), differed significantly from the fallow land (KU), especially in quantitative terms.

The second most abundant in dimorphic ground beetles was the Eco-Salix crop (KES). In this plot, 648 individuals of dimorphic ground beetles (constituting 46.45% of the assemblage) were collected in 2019 and 759 individuals (constituting 49.38% of the assemblage) were collected in 2020 (**Tab. 134-135**). They belonged to 14 species (constituting 32.56% of the assemblage) in 2019 and 9 species (constituting 22.50% of the assemblage) in 2020 (**Tab. 136-137**). During a 2-years study, the most numerous dimorphic species were: *P. melanarius* and *P. niger*. The most numerous dimorphic species, outnumbering 100 individuals, were in 2019: *C. erratus, C. fuscipes* and *P. lepidus.* In 2020 there were *C. erratus* and *C. fuscipes* (**Tab. 12. Tab. 14)**.

On arable crop (KP) 450 individuals of dimorphic ground beetles (constituting 36.50% of the assemblage) were collected in 2019 and 339 individuals (constituting 24.21% of the assemblage) were collected in 2020 (**Tab. 134-135**). They belonged to 12 species (constituting 24.49% of the assemblage) in 2019 and 10 species (constituting 27.03% of the assemblage) in 2020 (**Tab. 136-137**). The most numerous dimorphic species, recorded on the arable crop (KP), were in 2019: *C. fuscipes, P. lepidus, C.erratus* and *C. melanocephalus.* In 2020 *C. fuscipes* significantly outnumbered all other species. (**Tab. 12. Tab. 14)**.

On the SRC willow plantation (KW) 528 individuals of dimorphic ground beetles (constituting 36.59% of the assemblage) were collected in 2019 and 241 individuals (constituting 41.41% of the assemblage) were collected in 2020 (**Tab. 134-135**). In both study seasons, 10 species were indicated, constituting respectively 23.26% and 25.64% of the assemblage (**Tab. 136-137**). The most numerous dimorphic species, recorded on the SRC willow crop (KW), were in 2019: *C. fuscipes* and *P. melanarius* and *P. niger.* In 2020 there were *P. melanarius* and *P. niger* and *C. melanocephalus* (**Tab. 12. Tab. 14)**.

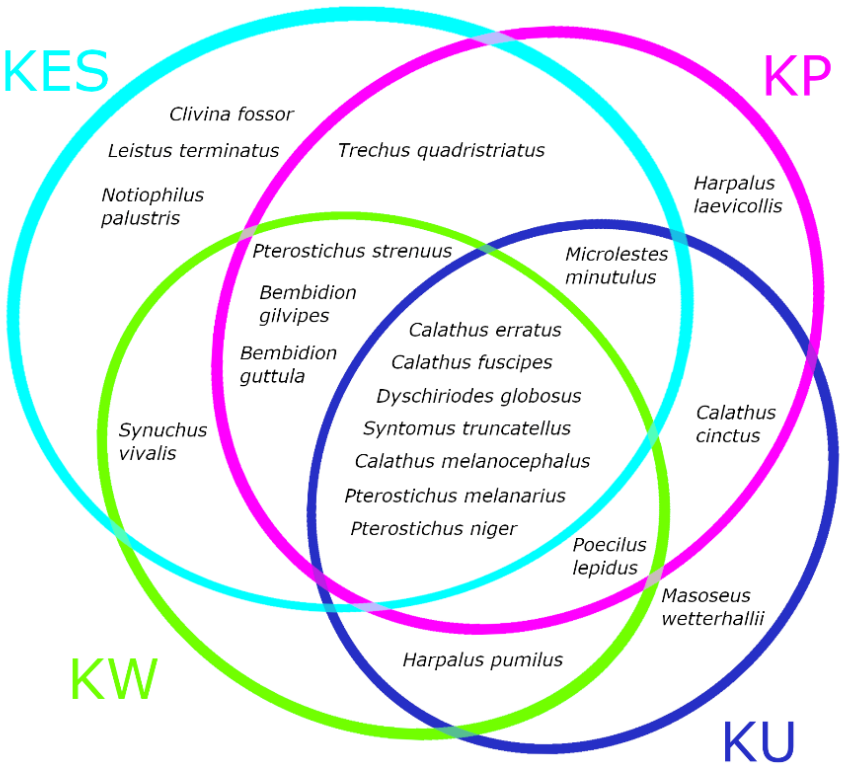


Figure 140. Presence of the dimorphic species on the particular plots in the study site: ”Kocibórz”. The abbreviations used on the graph mean respectively: KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow

Macropterous species

Macropterous species were the most numerous among all habitat preference groups. There were 46 species (2,379 individuals) and 37 species (1,904 individuals) in the years 2019 and 2020, respectively (**Tab. 15-16)**. Statistical analysis indicated, that there were significant differences in the number of beetles representing this group (*p-value*=5.957E-16) (**Tab. 21**). Differences were indicated for all study plots, except, there was no difference between the SRC willow plantation (KW) and the fallow land (KU) (**Fig. 141**).

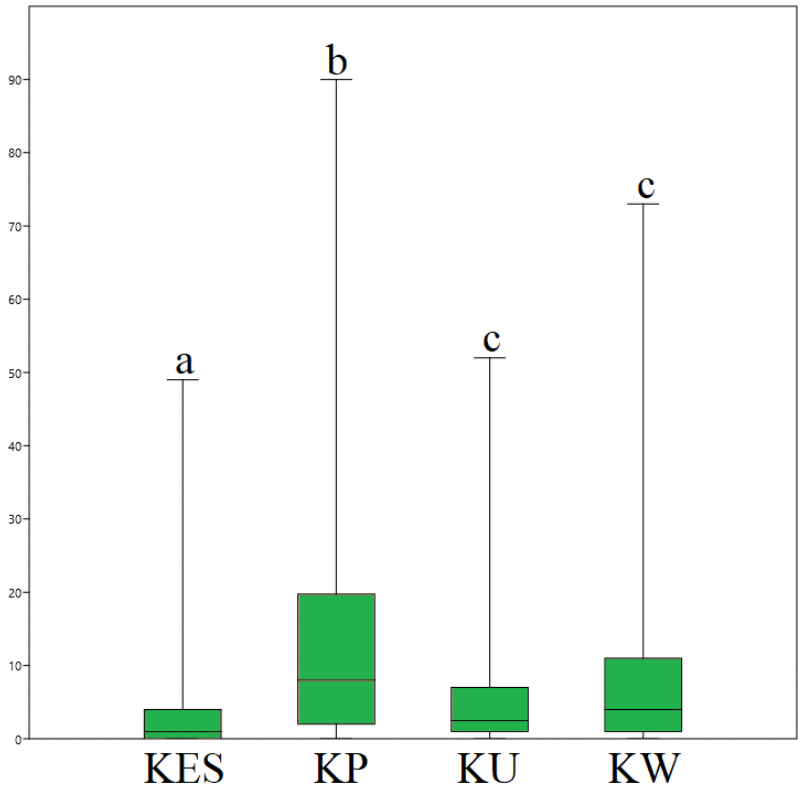


Figure 141. Rarefied macropterous Carabidae individuals abundance for different plots (Dunn's post hoc; p-value with Bonferroni correction). Mean values per trap are shown for the particular plots (KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow;) in the study site "Kocibórz". Different letters above the boxplots indicate significant differences between the habitats (p <0.05)

In quantitive terms, macropterous species were the most numerous in the arable crop (KP). There were 769 individuals (constituting 62.37% of the assemblage) in 2019 and 1,054 individuals (constituting 75.29% of the assemblage) in 2020 (**Tab. 134-135**). They were also the most numerous in qualitative terms – there were 33 species (constituting 67.35% of the assemblage) in 2019 and 22 species (constituting 59.46% of the assemblage) in 2020 (**Tab. 136-137**). During a 2-years study, the most numerous macropterous species noticed on the arable crop (KP) were: *H.rufipes, P. cupreus,* and *P. versicolor* (**Tab. 12. Tab. 14)**.

There were significant differences in the number of macropterous species in study years 2019 and 2020 in SRC willow plantation (KW). In the first study season, there were 872 individuals (constituting 60.43% of the assemblage) and there were 293 individuals (constituting 50.34% of the assemblage) in the second study year (**Tab. 134-135**). In qualitative terms, it was, respectively 27 species (constituting 62.79% of the assemblage) in 2019 and 23 species (constituting 58.97% of the assemblage) in 2020 (**Tab. 136-137**). The most numerous macropterous species, indicated in 2019 were: *P. versicolor,* and *H. rufipes.* Only those species outnumbered 200 individuals. Also, *P. cupreus* was numerous. In 2020 none of the macropterous species outnumbered 200 individuals on the SRC willow crop (KW). The most numerous were *P. versicolor* and *H. rufipes* (**Tab. 12. Tab. 14)**.

In the fallow land (KU) 493 macropterous individuals (constituting 20.86% of the assemblage) were indicated in 2019. In 2020 there were 310 individuals (constituting 23.94% of the assemblage) (**Tab. 134-135**). In qualitative terms, it was, respectively 27 species (constituting 69.23% of the assemblage) in 2019 and 18 species (constituting 60.00% of the assemblage) in 2020 (**Tab. 136-137**). The most numerous species, indicated in 2019 were: *H. smaragdinus*, *H. rubripes* and *A. aenae*. Only those species outnumbered 50 individuals. Also, *H. tardus*, *H. calceatus* and *P. versicolor* were numerous (> 30 individuals) this year. In 2020 species that outnumbered 50 individuals were: *H. smaragdinus,* and *A. bifrons* (**Tab. 12. Tab. 14)**.

In both, quantitative and qualitative terms, macropterous species were the last numerous in the Eco-Salix crop (KES). There were 245 individuals (constituting 17.56% of the assemblage) in 2019 and 247 individuals (constituting 16.07% of the assemblage) in 2020. (**Tab. 134-135**). They were also the last numerous in the number of species – there were 20 of them, (constituting 46.51% of the assemblage) in 2019 and 23 of them (constituting 57.50% of the assemblage) in 2020 (**Tab. 136-137)**. The most numerous macropterous species, exceeding 30 individuals in 2019 were: *P. versicolor* and *H. rufipes*. In 2020 there were *P. versicolor* and *B. lampros* (**Tab. 12. Tab. 14)**. Macropterous species distribution among all study plots was visualised in **Figure 131.**

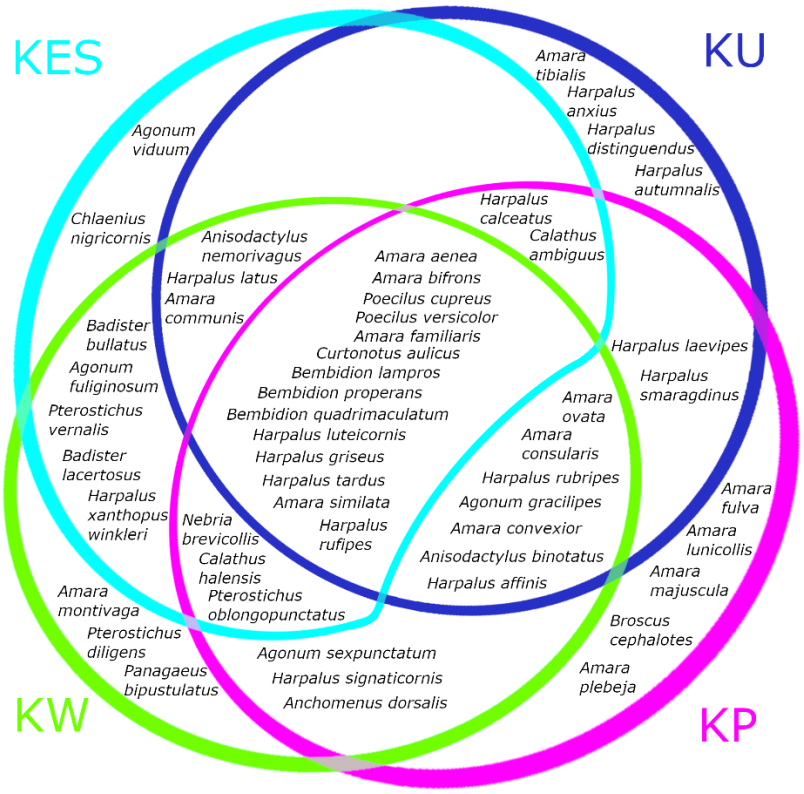


Figure 142. Presence of the macropterous species on the particular plots in the study site: ”Kocibórz”. The abbreviations used on the graph mean respectively: KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow.

Compared to the other plots, fallow land (KU) was characterised by the highest number of dimorphic Carabidae individuals. In this plot, dimorphic species were the most numerously represented group. Similarly, dimorphic species were the most numerously represented on the Eco-Salix crop (KES). However, on this plantation, also a large number of brachypterous species was observed. In general, brachypterous Carabidae species were represented more numerously in both willow plantations (KW&KES), compared to fallow land (KU) and row crops (KP), but it was particularly apparent in Eco-Salix plantation (KES), in which it was the second most numerous group. It confirms hypothesis **H1**, and partially hypothesis **H2**.

In the PCA based on the species assemblages, the first and the second ordination axes explained 41.7% and 21.4% of the variation in the dataset, respectively in the first year of the study. In the second year of the study, it was 43.1% and 17.8% of the variation in the dataset, respectively (**Fig. 143, Fig. 144**). In the ordination diagram, the Eco-Salix plantation (KES) was shifted along the first ordination axis far from the fallow land (KU) and the agricultural crop (KP), which was observed in both years of the study (**Fig. 143, Fig. 144**). In the first year of the study, the SRC willow plantation (KW) was slightly shifted towards an arable crop (KP)

(**Fig. 143)**. In the second year of the study, it was shifted towards the Eco-Salix plantation (KES), which proves the change in the composition of the assemblage on this plantation(**Fig. 144)**. Some species were located close to the Eco-Salix plantation in the ordination diagram throughout two years of study. There were large carnivores: forest *P. niger* and *C. hortensis*, eurytopic *P. melanarius* and wetland *C. granulatus* (**Fig. 143, Fig. 144)**. Similarly, the presence of *C. erratus* was correlated with fallow land (KU) (**Fig. 143, Fig. 144)**. *H. rufipes*, *P. versicolor* and *P. cupreus*, correlated with the SRC willow (KW) and arable crop (KP) on the second ordination axis in 2019 were shifted in different directions in 2020 – *P. versicolor* were located close to a willow (KW), whereas *H. rufipes* and *P. cupreus* were shifted towards the arable crop (KP) (**Fig. 143, Fig. 144)**.

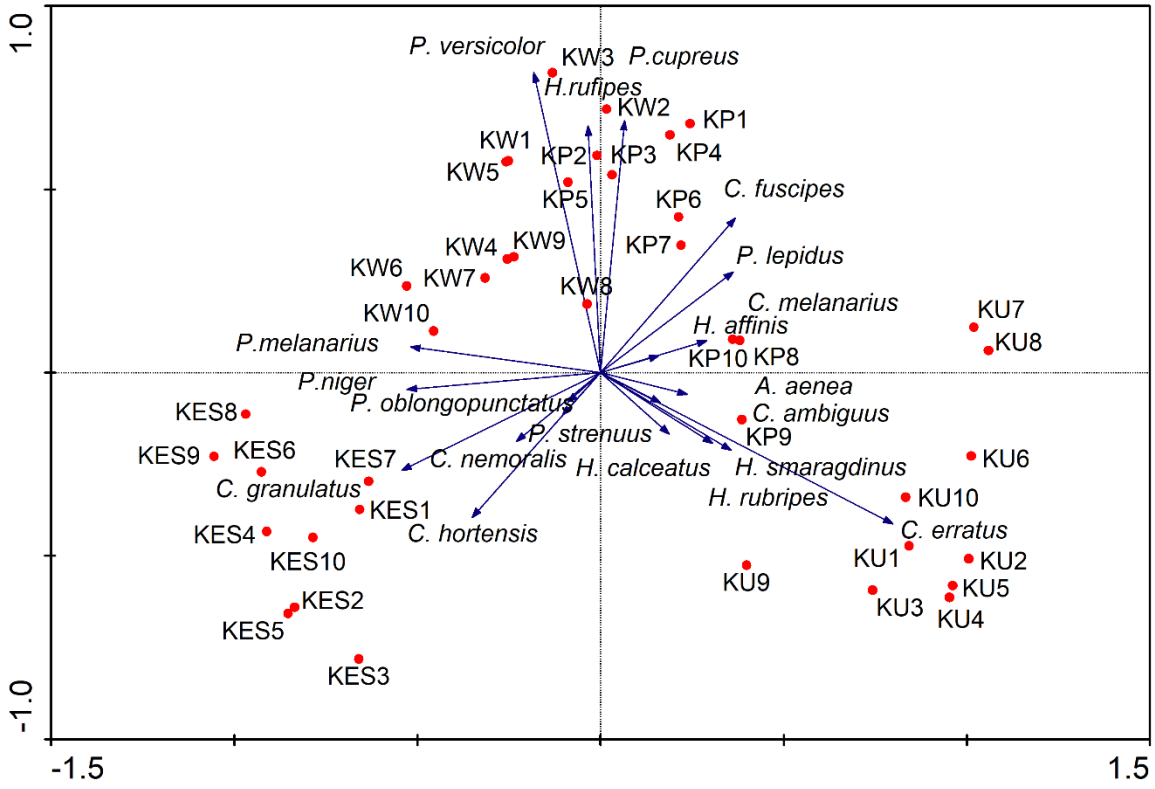


Figure 143. Ordination plot based on Principal Component Analysis (PCA) of the Carabidae assemblages (species information) inhabiting investigated study plots (KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow) in the study site "Kocibórz" in the year 2019

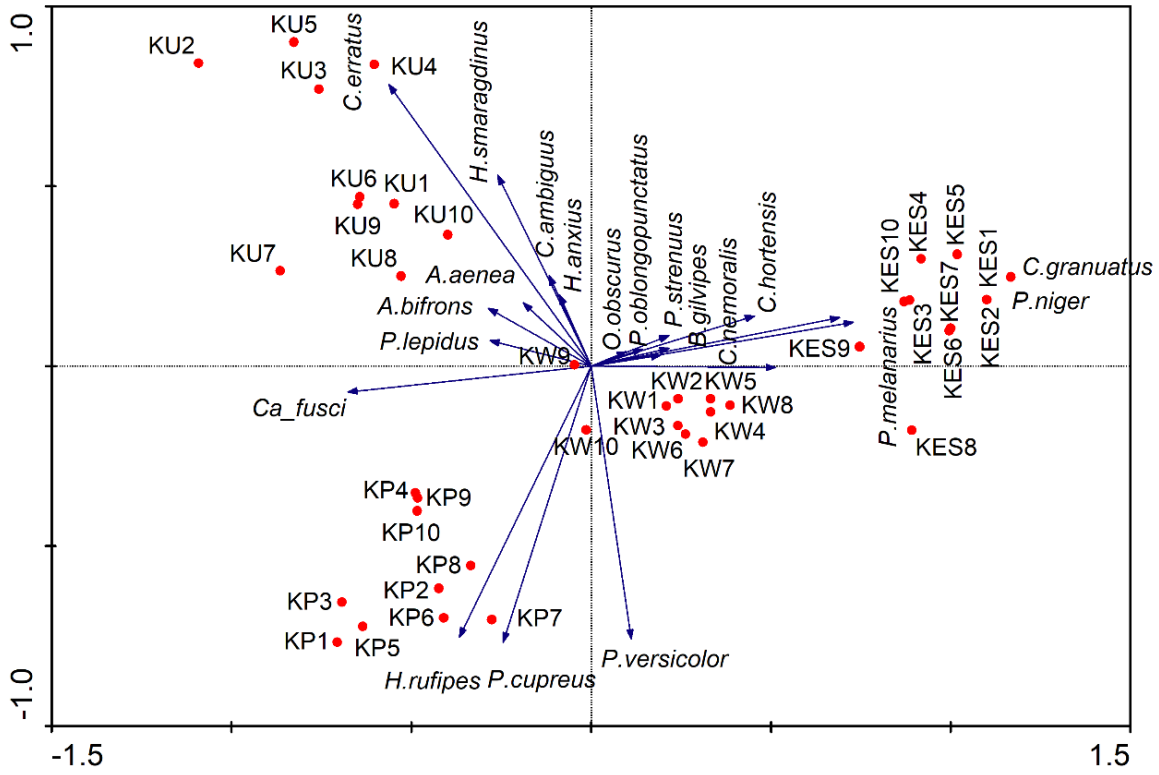


Figure 144. Ordination plot based on Principal Component Analysis (PCA) of the Carabidae assemblages (species information) inhabiting investigated study plots (KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow) in the study site "Kocibórz" in the year 2020

In the PCA based on the functional traits, the first and the second ordination axes explained 58.3% and 16.3% of the variation in the dataset, respectively, in the first year of study. In the second year of the study, it was 59.3% and 18.7% of the variation in the dataset (**Fig. 145, Fig. 146)**. Species located at the first ordination axis, close to Eco-Salix plantation (KES) were characteristic to wetlands as well as they were hygrophilous and brachypterous. Also, large carnivores were shifted toward this plantation. Xerophilous species were located on the opposite side of the diagram, close to the fallow land (KU). Also, medium carnivores, hemizoophages, species preferring open areas and macropterous ones were shifted towards this crop in the second year of the study (**Fig. 145, Fig. 146)**. In the first year, they were located closer to the SRC willow plantation (KW). Surprisingly, in 2019 forest species were shifted towards fallow land (KU), possibly as a result of numerous *C. erratus* prevalence. Eurytopic species were shifted towards willow plantations (KES, KW). (**Fig. 145**).

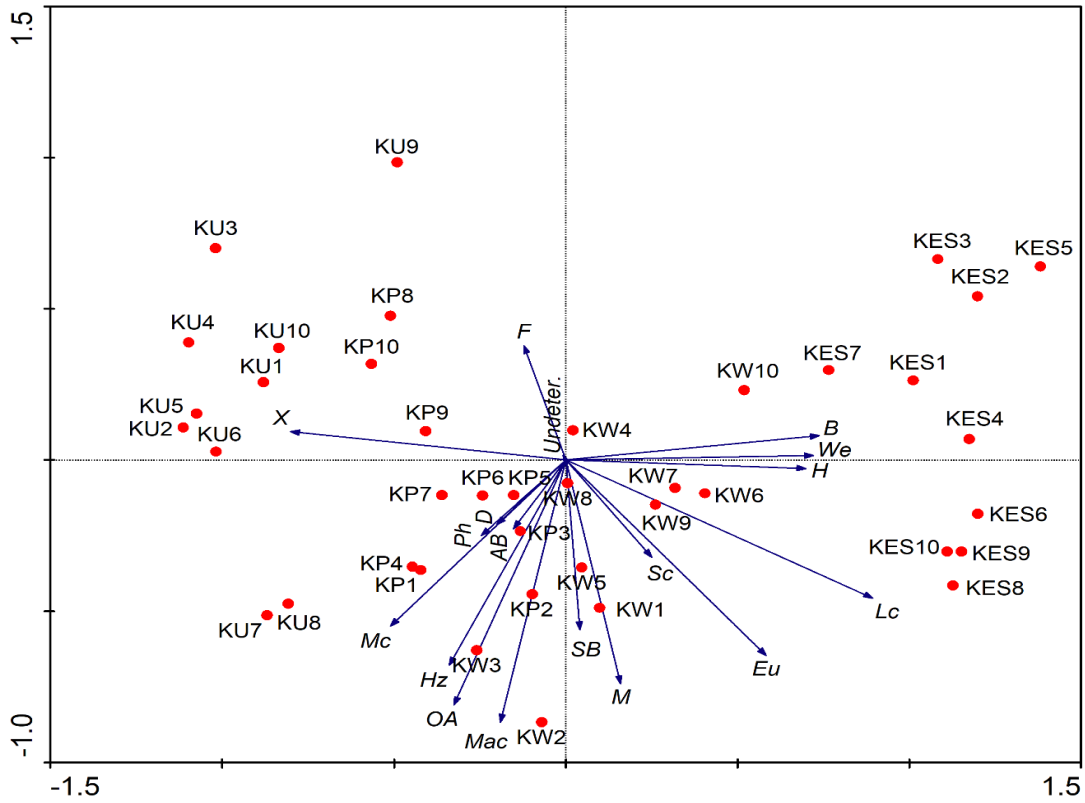


Figure 145. Ordination plot based on Principal Component Analysis (PCA) of the functional traits of Carabidae assemblages inhabiting investigated study plots (KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow) in the study site "Kocibórz" in the year 2019

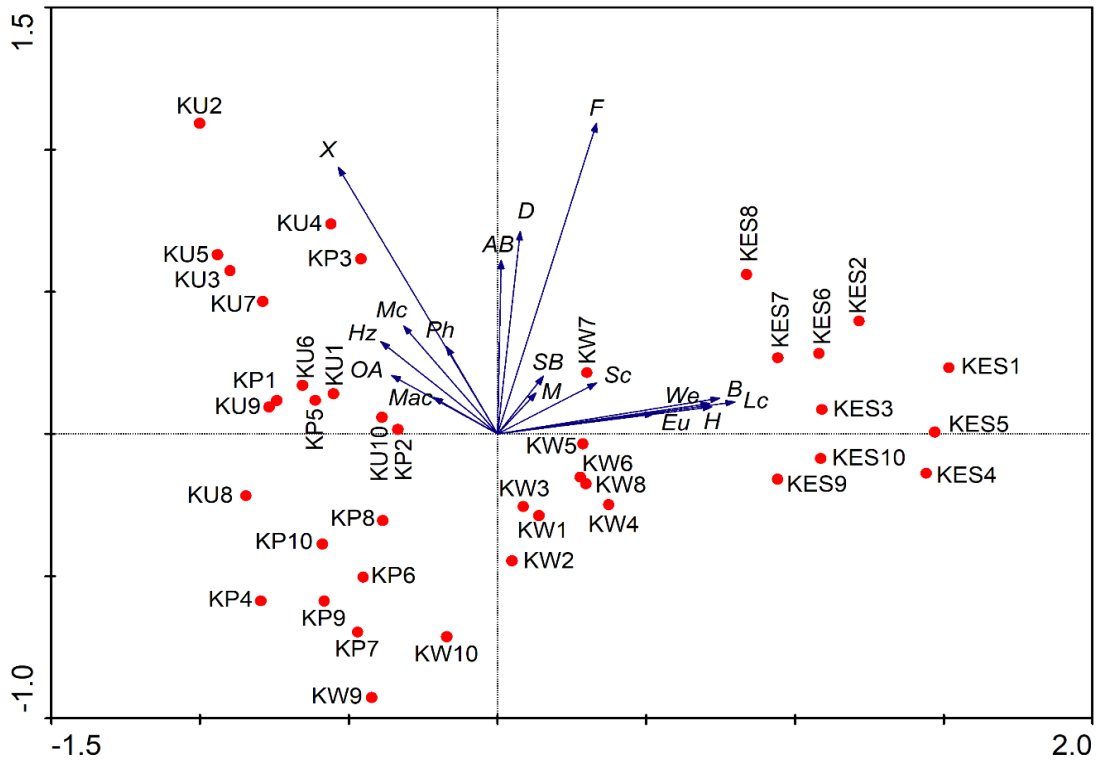


Figure 146. Ordination plot based on Principal Component Analysis (PCA) of the functional traits of Carabidae assemblages inhabiting investigated study plots (KES - Eco-Salix, KP – row crops, KU – fallow land, KW – SRC willow) in the study site "Kocibórz" in the year 202

For better visualisation of the assemblages functional traits distribution in the studied plots, two-year PCA analyses were also done (**Fig. 147, Fig. 148).** In this approach, data for the years 2019 – 2020 were presented in one plot, which enabled observation of shifts in the distribution of the functional traits on particular plots between the investigation years 2019 and 2020. In the PCA based on the species assemblages, the first and the second ordination axes explained 40.3% and 19.6% of the variation in the dataset (**Fig. 147).** In this plot, it was visualised, that there was a distinct shift between the assemblages inhabiting the SRC willow plantation (KW) in the years 2019 and 2020. There was no common part between the years 2019, and 2020. Additionally, willow crop (KW) was shifted towards row crop (KP) in the year 2019 (**Fig. 147).** A similar tendency was observed for PCA based on the functional traits. In this plot, the first and the second ordination axes explained 46.5% and 19.8% of the variation in the dataset (**Fig. 148).** Also in this analysis SRC willow (KW) was more similar to row crops (KP). However, there was no common part for SRC willow (KW) and row crops (KP) in the year 2019, as well as 2020. Instead of that, there was a common part for row crops (KP) and fallow land (KU), large especially in 2020. Moreover, significant distinctiveness of Eco-Salix willow plantation (KES) was evident (**Fig. 148)**. It was the final confirmation distinctiveness of willow plantations, especially those grown in the more extensive Eco-Salix system (KES).

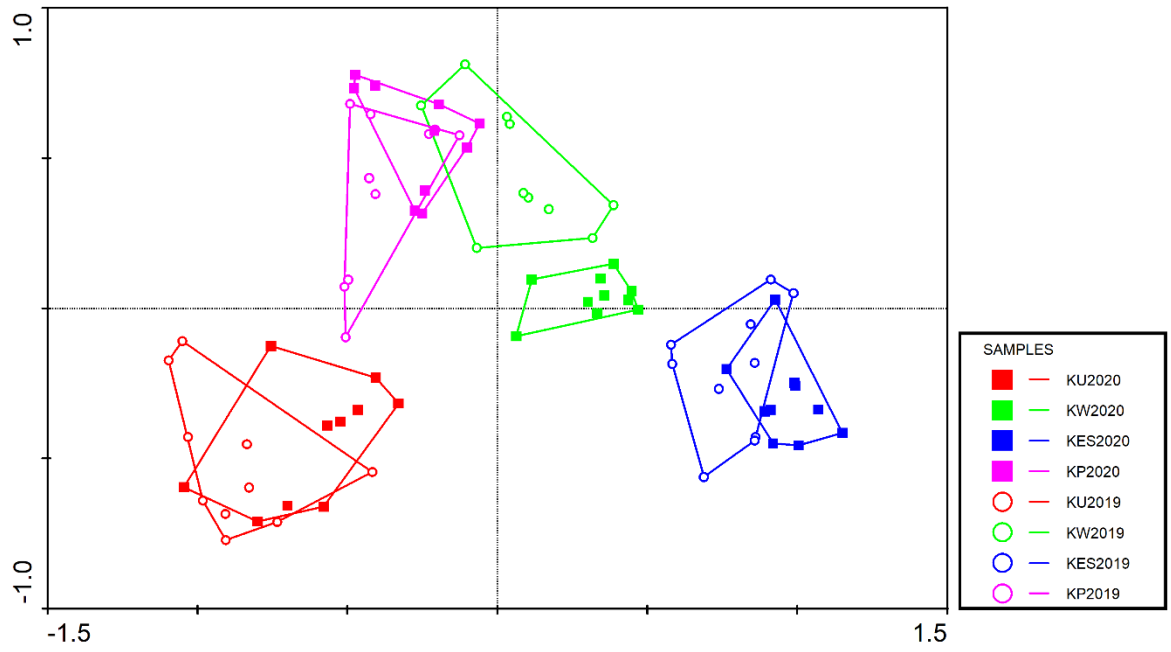


Figure 147. Ordination plot based on Principal Component Analysis (PCA) of the Carabidae assemblages (species information) inhabiting investigated study plots (KES - Eco-Salix (dark blue), KP – row crops (red), KU – fallow land (magenta), KW – SRC willow (green) in the study site "Kocibórz" in the years 2019 and 2020. Samples from 2019 and 2020 are assigned by empty circles and solid squares, respectively

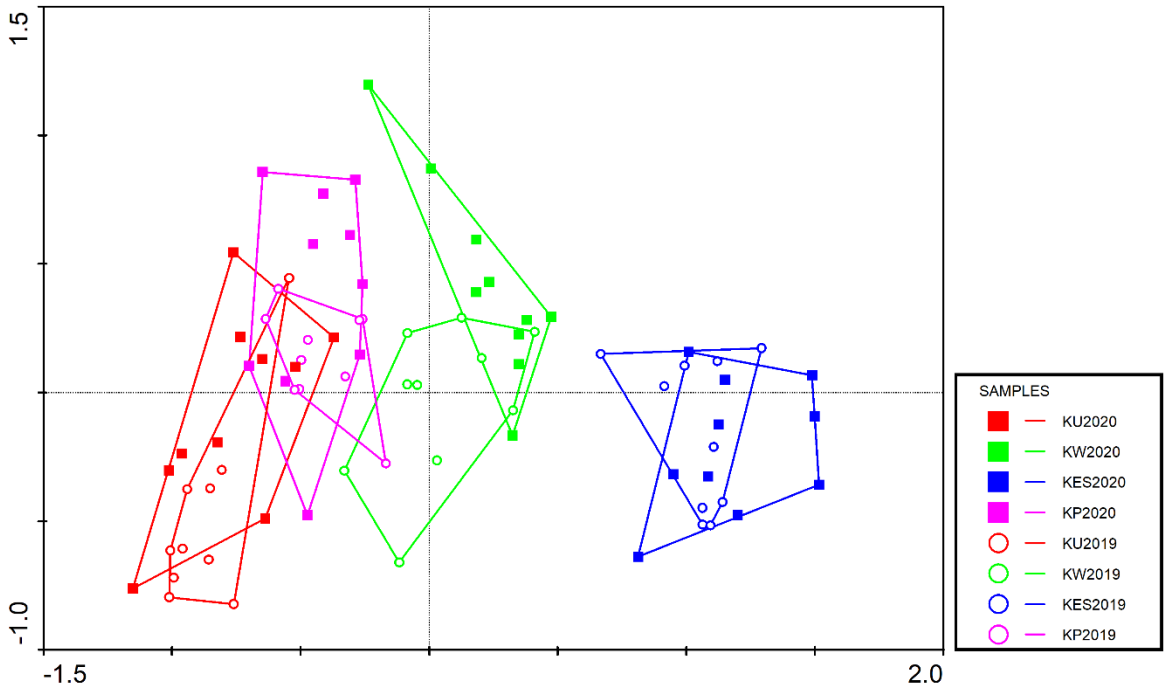


Figure 148. Ordination plot based on Principal Component Analysis (PCA) of the functional traits of Carabidae assemblages inhabiting investigated study plots (KES - Eco-Salix (dark blue), KP – row crops (red), KU – fallow land (magenta), KW – SRC willow (green) in the study site "Kocibórz" in the years 2019 and 2020. Samples from 2019 and 2020 are assigned by empty circles and solid squares, respectively

5. DISCUSSION

During the 2-year study, a total of 13,425 beetles from the Carabidae family, belonging to 90 species, were caught. It accounts for almost 20% of Carabidae species listed for Poland and over 30% of Carabidae species present in the Masurian Lake District (Aleksandrowicz, 2020; Aleksandrowicz et al., 2003; Burakowski et al., 1974, 1973; Pacuk and Regulska, 2014). This number consisted of Carabidae caught on energy crops in Leginy in 2019 (2,177 individuals belonging to 45 species) (Tab. 4), as well as Carabidae caught on energy willow plantations, managed in two different coppicing systems: Eco-Salix (KES) and short rotation coppice SRC (KW), fallow land (KU) and arable fields (KP) in Kocibórz in years 2019-2020 (11,248 individuals belonging to 86 species) (Table 13). In total, on all examined willow plantations (SV, KES, KW), 73 species were found, which is a high value compared to the number shown in most willow cultivations located in Central Europe (Boháč et al., 2007; Brauner and Schulz, 2011; Konieczna et al., 2013; Kosewska et al., 2010; Walerys et al., 2008; Weger et al., 2013; Zitzmann et al., 2022).

In the part of the experiment carried out on plantations in Leginy where perennial herbaceous plants (giant miscanthus (MG), cup plant (SP), virginia mallow (SH)), and woody plants (willow in the SRC system (SV)) grew for energy purposes, the 2,177 beetles caught comprised 10.27 beetles per trap. The most significant number of Carabidae per trap was caught in the cup plant crop (SP), but the number of collected beetles did not differ significantly for particular plantations (Table 4). In the part of the experiment carried out in the study site "Kocibórz", where the ground beetle communities inhabiting willow plantations in two cultivation systems (KES and KW) were compared with arable fields (KP) and fallow land (KU), 11,248 beetles comprised 19.63 individuals per trap. The most significant number of ground beetles per trap was found in the fallow land (KU) (Table 13). Similarly, a higher number of Carabidae in fallow land compared to plantations of energy crops was indicated by Radzikowski et al. (2020). Moreover, Rischen et al. (2022) emphasized higher numbers of Carabidae captured on fallow land compared to arable fields. Many other authors point to agricultural environments as places of high abundance and activity of Carabidae (Aleksandrowicz et al., 2008; Kosewska et al., 2008, 2009; Kotze et al., 2011; Kromp, 1999; Thiele, 1977). Research conducted by Rowe et al. (2013) showed a greater capture rate of ground beetles when food sources were scarce, and beetles may have been more mobile, searching for food in larger areas. Also, other factors, such as temperature, light exposure, and humidity, may change the activity

of the ground beetles and thus affect their capture rate (Fricke et al., 2022; Honek, 1997; Lövei and Sunderland, 1996; Růžičková et al., 2021).

One of the essential elements of habitat assessment is the analysis of biodiversity indicators (Desrochers and Anand, 2004; Fedor and Zvaríková, 2018; Keylock, 2005; Urbisz, 2010). Together with the data on the size of the population and the number of species, these indicators allow a better comparison of the assemblages inhabiting different areas (Trojan, 1997, 1992). They are also widely used in research on Carabidae communities inhabiting agrocenoses (Hummel et al., 2012; Ivanič Porhajašová and Babošová, 2022; Kosewska, 2016; Massaloux et al., 2020), and despite some controversy, are still valid (Chiarucci et al., 2011; Konopiński, 2020; Magurran, 2013).

Part of this research, aiming at assessing biodiversity indices in willow plantations, showed that the value of those indices was not significantly different for the willow and comparative plots. The comparison of both willow plantations (KES, KW) with arable crops (KP) showed no significant differences in the values of biodiversity indices (Table 13). However, a difference was observed for fallow land (KU), which showed a high prevalence of *C. erratus.* The strong dominance of one, most numerous species on the fallow land was also indicated by Feng et al. (2021). Nevertheless, it was shown for fallow lands relatively younger than the one being the subject of this research.

Similarly, no significant differences in the biodiversity indices for a short rotation woody crop (SV) and perennial herbaceous energy plants (MG, SH, SP) were indicated (Tab. 4). They were slightly different only for the giant miscanthus crop (MG). This plantation showed the lowest value of the Shannon-Weiner index, which achieves higher values in less numerous assemblages with a well-balanced structure (Kosewska et al., 2008).
For miscanthus (MG), the Pielou index (J ') defining community evenness was also the lowest. Also, Simpson's Diversity Index (D), which gives the most significant importance to common species, indicated a strong dominance of some of the most numerous species in this assemblage. Low biodiversity in miscanthus plantations was also shown by (Williams and Feest, 2019), which may indicate that, compared to willow, this plant contributes less to the enrichment of entomofauna communities in the agricultural landscape.

Along with biodiversity indices, the dominance structure is an essential element in Carabidae communities assessment. It can serve as one of the determinants of the habitat conditions (Allegro and Sciaky, 2003; Thiele, 1977 Leśniak, 1997; Leśniak et al., 2003; Szyszko, 1997). The occurrence of unfavourable environmental factors, such as increased anthropopression,

may result in disturbances in the dominance class structure. On the other hand, the equal share of each dominance class in the assemblage indicates habitat stability and is a sign of the low influence of destructive factors on the community (D. Riddell-Black, 1994; Teofilova, 2015; Huruk, 2006). The results of the assessment of biodiversity indices have a reflection in the dominance structure, in which strong disturbances were observed in areas with a high Simpson dominance index (D) and a low Pielou index (J'), such as miscanthus (MG) or fallow land (KU). Disturbances in the distribution of dominance classes were visible in all the studied areas. It was mainly due to the predominance of the species from the eudominant class, which is characteristic of agricultural areas subjected to strong anthropopression (Aleksandrowicz et al., 2009; Teofilova, 2022). Compared to other studied plots, willow plantations (SV, KES, KW) and cup plant plantation (SP) were characterized by the highest evenness of dominance classes distribution (Fig. 25, Fig. 80-83). Since, compared to other investigated agricultural areas, including fallow land (KU), willow plantations were characterized by the evenest distribution of dominance classes, it can be assumed that they have the lowest level of destructive factors impact. On the other hand, even in willow plantations, the distribution of dominance classes was far from that observed in natural habitats, which was also confirmed by data from other willow plantations (Piotrowska et al., 2020). According to Kosewska et al., (2010), the distribution of dominance classes indicates that willow plantations have traits of a transitional environment, and the communities inhabiting them are characterized by high variability.

For better visualization and statistical evaluation of ground beetles communities on the studied plots, non-metric multidimensional scaling (NMDS) was used, which enabled to point out differences not indicated by the comparison of biodiversity indices or dominance structure. In both cases - when comparing willow plantation (SV) with other perennial energy crops and when comparing willow plantations (KES, KW) with fallow land (KU) and an arable field (KP), large disparities in the structure of assemblages, inhabiting particular plots were recorded, which was confirmed by the results of NMDS analyses (Fig. 26, Fig. 84-85). Therefore, hypothesis H1 was confirmed: Carabidae assemblages inhabiting the willow plantations differ significantly from assemblages inhabiting other perennial bioenergy crops, as well as row crops and fallow land. Additionally, the high distinctiveness of the studied plots in the NMDS analysis, despite the lack of apparent differences in the Carabidae abundance or biodiversity indicators values, proves that the correct assessment of the ground beetles assemblages requires the use of a greater number of diversified statistical methods. According to Mueller-Kroehling et al. (2020) and Schulz et al. (2009), a better reflection of the actual diversity of ground beetles than the individuals or species number is the assessment of the functional traits in the

assemblages. The description of the communities functional traits provides valuable information about Carabidae ecological features. It thus enables the evaluation of their ecological niche and the potential ecosystem services. Indirectly it also gives substantial data about the features of the ecosystem (Díaz et al., 2013; Gobbi et al., 2015; Gobbi and Fontaneto, 2008; Schwerk et al., 2021). Functional traits, such as development type, average body weight, wing morphology or trophic preferences reflect the response of ground beetles communities to environmental factors, including destructive ones (Gobbi et al., 2015; Gobbi and Fontaneto, 2008; Kotze and O'Hara, 2003; Ribera et al., 2001; Schwerk and Szyszko, 2007; Szyszko, 1997). Their analysis allows us to evaluate and compare the features of various habitats.

In this research, differences were observed not only in the number of individuals caught or in species composition but also in the distribution of functional traits in the assemblages inhabiting particular plots, confirmed by the results of the canonical PCA analysis (Fig. 76, Fig. 146).

The developmental type was the parameter for which the differences observed between particular plots were the most weakly expressed. The comparison of particular energy crops, including willow (SV), carried out in Leginy showed no significant differences in the domination of spring or autumn breeders. In all crops located there, the predominance of ground beetles with the autumn type of development was observed. Also, on the plots located in the study site " Kocibórz", apart from the SRC willow plantation (KW), the predominance of the autumn breeders in terms of quantity and spring breeders in terms of quality was observed (Tab. 6-7, Tab. 15-16). Carabidae from the autumn breeders group are reported for open areas (Huruk, 2006; Kromp, 1999; Thiele, 1977) as well as well-balanced environments, e.g. old forests (Nietupski et al., 2008; Thiele, 1977). According to Górny (1971), the domination of species of this development type is typical for fields. Moreover, Huruk (2007) demonstrated for the fields a phenomenon he described as "asymmetric dominance", which means the dominance of autumn breeders in quantitative terms and the dominance of spring breeders in qualitative terms. Similar results were obtained by Kosewska (2010, 2004; Kosewska et al., 2006), examining the woodlots and shelterbelts in the agricultural landscape. Those habitats performed ecological functions similar to energy willow plantations. In addition, species with the autumn type of development are also considered to be more "energy-efficient" than spring species and thus may have a higher reproductive potential (Grüm, 1978, 1976), so their populations may be more numerous. It seems, therefore, that the significant quantitative dominance of species with autumn development type in the studied assemblages may indicate a large inflow and colonization of plantations by the populations of Carabidae from the surrounding open areas.

On the other hand, a study conducted by (Kujawa et al., 2006) assessing the migration of H. rufipes between the cereal fields and shelterbelts indicated the opposite direction of Carabidae movement, which migrated from the woodlots to adjacent arable plots. Literature data, as well as conducted research, allows assuming that "asymmetric dominance" with a quantitative predominance of autumn breeders is probably a natural state also for energy crops. This also indicates another function of these plantations. Permanently inhabited by populations shared with the adjacent arable fields, plantations may serve as a refuge for Carabidae in the agricultural landscape, being subjected to strong anthropopressure and contributing to ground beetles dispersion to the adjacent arable fields (Fusser et al., 2018; Purtauf et al., 2005; Rischen et al., 2022). Since Carabidae provide valuable ecosystem services, introducing energy crops into the agricultural landscape appears advantageous from the perspective of sustainable agriculture.

Only in the short rotation coppice willow crop (KW) the distribution of Carabidae with those two breeding strategies was different (Fig. 89-92). In the first year after the harvest, spring breeders predominated in qualitative and quantitative terms. In the second year of the production cycle - the number of specimens from both development types was equal. Spring breeders have been classified by Flis and Skłodowski (1998) as typical for disturbed environments, as well as for crops and young forests. The presence of many specimens belonging to the spring development type group reflected the dynamic changes in the structure of communities that took place on this crop in the first year after the harvest. Coppicing changes the nature of the habitat on SRC plantations, resulting in the large influx of species preferring open areas (Koivula and Niemelä, 2002; Mueller-Kroehling et al., 2020; Nakamura et al., 2006; Piotrowska et al., 2020; Zitzmann et al., 2022). Such dynamic changes were not observed in any other investigated plot. However, it is worth noticing that a similar proportion of autumn and spring breeders was indicated in the farmland (KP) and willow plantation maintained in the Eco-Salix system (KES). The percentage difference between both breeding types was slight, indicating more dynamic changes taking place in those environments compared to the fallow land (KU).

Compared with other crops of perennial energy plants, willow plantation (SV) was characterised by the lowest number of species preferring open areas. They were sparse, both in quantitative and qualitative terms (Tab. 6-7), which was also observed for the willow plantations maintained in the Eco-Salix (KES) system in Kociborz during the entire study (Tab. 15-16). In the willow plantation in Leginy (SV), the ground beetles preferring open areas accounted for slightly more than 50% of the population (Fig. 47). The remaining part of the community investigated on this plantation was forest and eurytopic Carabidae. Similar results were

obtained by Konieczna et al. (2013) in studies carried out on unexploited common osier (*Salix viminalis*) plantations in southeastern Poland. Based on the analysis of data from publications describing European plantations, performed by Piotrowska et al. (2020), as well as the results obtained on all willow plantations (KES, KW, SV) during this experiment, it was expected to be a value characteristic for willow plantations located in the agricultural areas, during the later stages of the production cycle.

This kind of distribution of habitat preferences in Carabidae communities is characteristic of plantations with dense canopy, whereas the harvest changes the population structure. During this study, it was observed on the SRC willow plantation (KW) in Kocibórz. On this plantation, established in 2014, the harvest was carried out in the year preceding conducted research, and therefore the study started in the first year of the coppicing cycle. Both NMDS analysis and PCA analysis showed that the ground beetle communities inhabiting this plantation had different compositions and characteristics in two consecutive years (Figs. 84-85, Figs. 147-148). There was a significant decrease in the number of ground beetles captured - from 1,443 individuals caught in 2019 to 582 individuals caught in 2020 (Tab. 13). It may have been related to the renewal of a habitat function for open-area species taking place in the initial SRC establishment phase. After the harvest, the plantations were also quickly colonised by herbaceous plants, creating favourable, "fallow-like" conditions for Carabidae species preferring open areas. Segetal flora overgrew this plantation through better insolation until the canopy became denser (Allegro and Sciaky, 2003; Baum, 2012; Mueller-Kroehling et al., 2020). This phenomenon is more pronounced for older plantations, in which stem regeneration time is longer (Weger et al., 2013). Open-area species can utilise a temporary habitat, characteristic of the plantation in the initial growth phase. Therefore, after the harvest, a large influx of open-area species with high dispersion capabilities is observed (Koivula and Niemelä, 2002; Mueller-Kroehling et al., 2020; Nakamura et al., 2006; Zitzmann et al., 2022). Also, in this study colonisation of willow crop (KW) after the harvest by Carabidae from adjacent agricultural areas can be observed. The PCA species analysis showed a more remarkable similarity of the assemblages inhabiting the willow plantation (KW) in the first year after harvesting to those inhabiting the adjacent arable fields (KP). In 2019, in both studied plots (KW & KP), *P. versicolor, C. fuscipes* and *H. rufipes* belonged to the eudominant group (Tab. 14). According to Aleksandrowicz et al. (2008), those species are a typical component of this dominance class in agricultural crops of northern Poland. Additionally, the group of dominants in the willow plantation (KW) included *P. cupreus*, which was also a eudominant species in the arable field (KP). *P. cupreus*, as well as the previously mentioned *P. versicolor, C. fuscipes* and *H. rufipes* are typical of open

areas and have a high dispersion capacity. Furthermore, the PCA analyse of ecological features showed a high similarity of the willow plantation in the first year after the harvesting to the arable fields (KP). In the following year, both PCA analyses showed that the communities of ground beetles inhabiting the SRC willow crop (KW) changed their structure and became more similar to those indicated for Eco-Salix (KES) plantations. In the second year of the production cycle, two species were represented in the group of eudominants - forest *P. niger*, belonging to the dominant class a year earlier, and *P. versicolor*. While the subdominant class included eurytopic *P. melanarius* and wetland *C. granulatus*. It is worth noting that the number of individuals belonging to forest species in 2019 did not differ significantly from the number indicated in 2020. In contrast, their percentage in the assemblage varied between the first and the second year of the coppicing cycle. In 2019, after the harvest, the share of forest species in the assemblage was lower, which was caused by a high influx of open area species, four times more numerous in 2019 than in 2020. Forest species were also less numerous on the SRC (KW) willow plantation, established in 2014, than on the older Eco-Salix (KES) plantation, established in 2010. This confirms the results obtained by Mueller-Kroehling et al. (2020) that the abundance of forest species depends more strongly on the age of the plantation than on the rotation phase (Figs. 110-113).

Also, species preferring wetlands, if they occurred, were present only in plantations of willow (SV, KES, KW) or virginia mallow (SH) (Tab. 6-7, Tab. 15-16). It was, for example, hygrophilous *C. granulatus*, present in all willow plantations (KES, KW, SV). It was very numerous, especially on the Eco-Salix (KES) plantation, where it belonged to the group of eudominants (Tab. 14). This species was observed on willow plantations also by other researchers (Boháč et al., 2007; Czerniakowski and Olbrycht, 2009; Konieczna et al., 2013; Weger et al., 2013). The study carried out indicated that the Eco-Salix (KES) plantation differed significantly from all other plots, being characterised by the highest number of wetland-preferring species and hygrophilous Carabidae. Those species were also numerously represented in the SRC willow plantation in Kocibórz (KW) but were still less numerous than in the Eco-Salix crop (KES). Most likely, it was caused by the age of the stand, higher on the Eco-Salix (KES) plantation, established in 2010. Nine-year-old trees provided much more shade, contributing to a significant increase in humidity, forming the litter with a specific microclimate. Also, in the SRC willow (SV) plantation located in Leginy, the ground beetles of this group were more numerous than in the cup plant (SP) and miscanthus (MG) plantations, although they were caught in low numbers. This may indicate an influence of other factors, such as the proximity to wetlands from which such species, often brachypterous, could migrate and the type of soil. Factors

influencing the presence of this ground beetle group require further research, but it seems that the age of the stand, as well as the age of the plantation itself, may be of great importance for their occurrence. Older plantations provided well-established, balanced soil conditions and specific microclimate, depending on various factors, including the presence of segetal weeds cover on the plantation (Baum et al., 2009; Briones et al., 2019; Kahle and Janssen, 2020). The willow crop directly protects the soil surface from exposure to solar radiation. In addition, shedding leaves every year provides large amounts of detritus, which shapes the microclimate effects of high litter accumulation, enabling the development of beetle larvae with higher hygropreferences. It also improves water availability in shallower soil layers (Kahle and Janssen, 2020). Long-established plantations provide better soil conditions, including moisture and soil particle distribution, which is of great importance, especially for the development of larval forms (Allegro and Sciaky, 2003; Kromp, 1999; Sotherton, 1985). It was visible in the willow plantations investigated during this study.

The difference in moisture preferences was particularly noticeable between Eco-Salix (KES) willow plantation and fallow land (KU), which was dominated by xerophilous species during all study courses (Figs. 123-126). The dominance of xerophilous species in fallow land is also described by other authors (Skłodowski and Sławski, 2003) and is associated with the lack of well-developed plant cover. It has been shown that xerophilous species prevalence decreases in the following stages of succession, especially when young trees appear. In contrast, mesophilic species with a wide moisture tolerance were the most numerous in all tested crops. The predominance of species of this type is also confirmed by the metastudy conducted by Piotrowska et al. (2020). Therefore it should be considered that willow plantations, especially those maintained in the SRC system, constitute a habitat favourable mainly for ground beetles with wide moisture tolerance.

Compared to other areas, all willow plantations (KES, KW, SV) were characterized by a greater number of forest Carabidae species (Tab. 6-7, Tab. 15-16). Their number was the highest for Eco-Salix (KES) plantations. Interestingly, the number of individuals from this group was not the highest for the willow plantation. It was due to the abundance of *C. erratus*, a forest xerophilous species in the fallow land (KU). This species prefers light and even sandy soils, and some authors consider it a eurytopic (Burakowski et al., 1973) and even a pioneering species, appearing in large numbers in open areas in the first stages of succession (Güth, 2008; Güth et al., 2006; Zdzioch, 2003). This species has been found in various habitats, including post-agricultural areas (Kędzior et al., 2017; Schwerk, 2014) and fallow land (Sivcev et al., 2018). In forests, it is indicated rather on low humidity stands (Lakotko and Sushko, 2021;

Rizun, 2020). During this study, it was not found in the large numbers in willow plantations (KES, KW) in Kocibórz, but it was present in dominants class in the willow stands in Leginy (SV). In the Eco-Salix willow plantation in Kociborz (KES), where *C. erratus* was the least abundant, numerous hydrophilic Carabidae were noticed. It proves that the presence of *C. erratus* in fallow land (KU) was related somewhat to hygropreferences.

The H3 hypothesis, which was: Plantations maintained in the Eco-Salix system are inhabited by the largest number of ground beetles preferring the forest environment, turned out to be partially false due to the vast number of *C. erratus* specimens recorded on fallow land (KU). However, according to the questionable classification of this species and the fact that it was the only forest Carabidae inhabiting fallow land (KU) in large numbers, it will be proven that the Eco-Salix (KES) plantation was the most abundant in forest ground beetles. It was apparent when the presence of ecologically valuable species was considered.

Many forest species are also brachypterous, with low dispersibility powers. In the Eco-Salix (KES) willow plantation, this kind of species was numerously represented by a large carnivore, *C. hortensis*. According to Müeller-Kroehling et al. (2020), for such species, the limiting factor is the distance from the nearest forest. Similar results were obtained in studies by Boháč et al. (2007) carried out on poplar plantations maintained in the SRC system. It was shown there that large beetles of the genera *Carabus* and *Pterostichus* were more numerous in plantations adjacent to the forest or surrounded by a varied landscape. It is also known that the increase in landscape heterogeneity generally positively contributes to the diversity of Carabidae inhabiting agricultural lands (Frank and Reichhart, 2004; Fusser et al., 2016; Hoffmann et al., 2021; Pfiffner and Luka, 2000).

According to research by Mueller-Kroehling et al. (2020), the size of plantations is also important for the occurrence of forest species. It has been shown that for plantations with an area of less than 10 ha, the number of forest species does not exceed 6; meanwhile, for larger plantations, up to 15 ha, it sometimes reaches even more than ten species. This research also observed a similar relationship - the larger plantation in Kocibórz was richer in forest species than the less extensive plantation in Leginy. It is consistent with the concept of MacArthur, in which larger environmental islands can provide habitats for more species (Fletcher et al., 2018; Losos et al., 2010; MacArthur and Wilson, 2001; Rogan and Lacher, 2018). It is worth noting that the number of species observed in this research was higher than that of Müeller-Kroehling et al.. However, some forest species were represented not numerously, such as *P. strenuus* or *P. oblongopunctatus*, belonging to the group of recedents on the Eco-Salix (KES) plantation; further some species were represented even only by single individuals.

According to Trojan (1997), apart from the larger dominant group, containing species less sensitive to environmental changes, the community also includes a group of species more sensitive to them. They are less numerous and form the so-called "distribution tail" consisting of only a few or even single specimens. In the event of adverse environmental factors, species from this group disappear first. Therefore the reduction in the number of subdominants should be associated with increasing environmental pressure (Trojan, 1997). Referring to the assemblage should be concluded that even single individuals of rare species give positive evidence of the conditions existing in willow plantations for species of conservation value.

It also indicated that for forest ground beetles introducing larger plantations would be more beneficial. However, in the absence of such a possibility, even increasing the mosaic of the landscape can help maintain habitat continuity - if not by providing a habitat where multiple species can coexist without strong competition, then by creating environmental corridors.
This research, as well as literature data (Boháč et al., 2007; Brauner and Schulz, 2011; Mueller-Kroehling et al., 2020; Schulz et al., 2009), show that willow plantations have a great potential to create environmental corridors and refugia for these species in the highly modified agricultural landscape. It confirms hypothesis H2: Energy willow, as a woody plant, is a valuable habitat for forest Carabidae species, creating corridors that allow brachypterous ground beetles to disperse in an agricultural landscape dominated by large monocultures.

Bérces et al. (2022) claim that the presence of large ground beetles of the genus *Carabus* can serve as an indicator of good environmental status. In this study, four species from this group were indicated on the Eco-Salix plantation (KES): eudominant *C. granulatus*, dominant *C. hortensis, C. nemoralis* and *C. cancellatus*. These species were also present on the SRC plantation in Kocibórz (KW). Sporadically they appeared on fallow land (KU) and arable crops (KP), as well as, noticeably less abundant, on crops of other energy plants. Five species from this group were indicated in the study site “Leginy”: *C. cancellatus, C. marginalis, C. granulatus, C. nemoralis,* and *C. coriaceus*. Other authors also reported species from this group on willow plantations, such as *Carabus ulrichii, Carabus violaceus* or *Carabus convexus* (Czerniakowski and Olbrycht, 2009; Konieczna et al., 2013; Weger et al., 2013). On a plantation of poplar, related to willow, also *Carabus scheidleri* was indicated (Boháč et al., 2007). Species belonging to this group are primarily brachypterous. Having low dispersal powers, they were endangered in a highly fragmented agricultural landscape (Eyre et al., 2016). Due to the long coppicing cycle and the production technology not requiring soil ploughing, willow plantations seem to affect the presence of beetles from this group positively. It was also confirmed by the results of this research, which showed that species from this group were significantly more

abundant in willow plantations (KES, KW, SV) in comparison with other plots. It was apparent, especially in the Eco-Salix crops (KES), where those species were the most numerously represented.

It also confirmed the H2 hypothesis: Energy willow, as a woody plant, is a valuable habitat for Carabidae preferring a forest environment, creating corridors that allow brachypterous species to disperse in an agricultural landscape dominated by large monocultures. Moreover, compared to other plots, there were much fewer macropterous ground beetles in the willow cultivation. A similar result was obtained by Gobbi and Fontaneto (2008), comparing wooded and agricultural areas and Havlickova et al. studying SRC willow plantations (Havlickova after Weger et al., 2013).

According to (Mueller-Kroehling et al., 2020), the presence of brachypterous species in willow plantations is more strongly related to the plantation age than to the stage of the production cycle. In quantitative terms, it was visible also in this research, which showed a significant difference between the oldest Eco-Salix plantation (KES), established in 2010 and the younger short rotation coppice willow crops: SV plantation located in the study site "Leginy", established in 2013, and KW, located in the study site "Kocibórz", established in 2014. The number of brachypterous beetles found per trap was lowest on the youngest stand. It is worth noting that their number did not change significantly on this plantation in the subsequent years of the study, which proves that the harvests and following habitat type change do not contribute to the elimination of this species from cultivation. It is probably related to the low dispersion powers of those species and, consequently, their low abilities to colonize new areas.

Regarding trophic preferences, the willow plantation (SV) differed from other crops by a lower number of hemizoophages, which increases in disturbed environments (Czechowski, 1981; Huruk, 1993, 2006;). Compared to miscanthus (MG) and cup plant (SP), willow crops were connected to a more significant number of large carnivorous species, which was similar to the virginia mallow plantation (SH). However, the most numerous Carabidae group recorded on this plantation were medium zoophages. It made the willow plantation (SV) similar to the second investigated willow plantation maintained in the SRC system, located in the study site "Kocibórz". Regarding trophic preferences, the observed Carabidae communities in the SV willow plantation showed the most remarkable similarity to the communities inhabiting the KW plantation in the second year after harvest. After the medium zoophages, the large carnivores were the most abundant group represented in the second year after the coppicing in the KW plantation and the SV plantation. The third most abundant group were hemizoophages. It shows that the trophic arrangement of the ground beetle communities in SRC willow plantations in

which canopy closure has already occurred is constant, regardless of the year of the study (SV - 2019 vs KW - 2020), as well as the study site location (SV - Leginy vs KW - Kocibórz, 3 km apart in a straight line). However, shares in trophic preferences in the assemblages inhabiting the KW plantation in the first year after the harvests differ significantly from the following year. In the first year of the production cycle, an increased influx of hemizoophages and medium carnivores from open areas was observed. Therefore the most numerous groups were consecutively: medium carnivores, hemizoophages, and large carnivores. It is confirmed by the results obtained by Walerys et al. (2008) in the years 2004-2005 at the plantation in Tomaszkowo, placed 60 km from the present study site. The following arrangement of trophic groups was also observed on these plantations in the first year after coppicing: medium carnivores, hemizoophages and large carnivores, which changed in the subsequent year and was as follows: medium carnivores, large carnivores, and hemizoophages. This trophic traits composition (medium carnivores, hemizoophages, large carnivores) was also observed by Kosewska et al. (2010) in the willow plantation in the first growth stage. Similarly, in this plantation, the proportion of large carnivores increased in the following year of the production cycle. On the other hand, the second plantation studied by this author Kosewska et al. (2010), investigated in the second and the third year of growth, was characterized by the dominance of large zoophages. This result was similar to those obtained in research conducted in the Eco-Salix plantation (KES) in Kocibórz, where large zoophages were the dominant group throughout the entire study period. A better understanding of the trophic group arrangement of Carabidae in energy crop plantations is, therefore, a matter for further consideration. However, analysis of the data obtained in this study and literature data indicates that the number of hemizoophages as well as medium carnivores increases in the first year after coppicing.

As already mentioned, in the conducted research, the Eco-Salix plantation (KES) was characterized by the highest percentage of large carnivores, significantly differentiating from all other study plots. According to many authors, a large share of this Carabidae group confirms the good condition of the studied environment (Bérces et al., 2022; Hanson et al., 2016; Huruk, 2007; Pfiffner and Niggli, 1996; Szyszko, 1997). Species from this group are considered to be very sensitive to anthropopressure - their percentage decrease on crops where a large number of agro-technical operations are carried out. The most significant differences in the trophic groups composition were observed between the willow maintained in the Eco-Salix system (KES) and the fallow land (KU), in which medium zoophages constituted the most significant part of the assemblage, and hemizoophages were the second most numerous group. Such a large number of hemizoophages is typically observed in disturbed environments (Huruk, 1993).

In contrast, the number of species from this group noticed on the Eko-Salix plantation (KES) was significantly lower than in other studied plots.

In general, it is considered that Carabidae with high mean individual biomass (MIB), including large predatory species, are a good indicator of the maturity of the forest environment, whilst habitat disturbance results in the inflow of small species with high dispersal powers (Schwerk and Szyszko, 2007). These results can also be extrapolated to the short-rotation woody energy crops, like a willow. The most numerously represented large carnivorous species indicated on the Eco-Salix plantation (KES) in the following years were the eurytopic *P. melanarius* and the similar, slightly larger, forest *P. niger*. Both of these species are numerous and commonly distributed throughout the country. They are also dimorphic species, and their macropterous forms are highly dispersible in the environment. As mesophiles, they have a wide humidity tolerance range. Considered a forest species, *P. niger*, in the absence of its typical preferred habitat, may move to most similar sited, for example, shelterbelts or woodlots. According to Skłodowski (2002), this species often crosses stand boundaries, being able to migrate into environments that appear more characteristic than *P. melanarius*. Furthermore, conversely, *P. melanarius*, classified as an open area species, may inhabit woodlots and less dense woodlands (Kosewska, 2004; Kosewska et al., 2006). However, it avoids nutrient-poor, dense forest stands occupying large acreages. Both species can therefore be considered highly adaptable and widespread in agricultural landscapes. Energy willow crops, which are generally more abundant than forests, are considered suitable habitats for their development. *P. melanarius* and *P. niger* were shown on SRC willow and poplar plantations as the component of the eudominants or dominants class also by many other authors (Boháč et al., 2007; Konieczna et al., 2013; Kosewska et al., 2010; Weger et al., 2013). Therefore, these species may be a characteristic element of the ground beetle communities in the energy willow plantations (Konieczna et al., 2013) and probably, also other perennial energy plant crops.

Except for the virginia mallow crop (SH), which was characterised by Carabidae communities highly similar to the willow plantations (SV), forest species and large carnivores were indicated on perennial herbaceous energy crops only sporadically. It was significant, especially for the cup plant crop (SP), the least similar to the willow plantation (SV), where both those groups were the least abundant. Similarly, these plantations were distinguished from willow plantations (SV, KW, KES) by a significantly higher abundance of macropterous and hemizoophagous species, characteristic of environments subjected to the strong impact of the destructive factors (Czechowski, 1981; Huruk, 2006). Additionally, a high proportion of xerophilous species was observed on cup plant (SP) and miscanthus (MG) crops.

Studies describing the diversity of entomofauna in virginia mallow and cup plant crops are still relatively scarce. In particular, there is a lack of works that comprehensively describe the Carabidae assemblages inhabiting these plantations. However, the available literature (Burmeister, 2021; Platen et al., 2017; Radzikowski et al., 2020) indicates that they are unlikely to negatively impact the biodiversity of ground beetles inhabiting them. Also, the effects on other insect groups, e.g. pollinators, seem to be favourable compared to conventional field crops (Chmelikova and Wolfrum, 2019; Schorpp et al., 2016). In the study conducted, the presence of a large predatory species, *C. halensis* was indicated on the cup plant crop (SP). This species prefers open-area habitats, such as arable fields or wastelands. It is not very abundant in central Europe and usually occurs locally (Kapla and Vrezec, 2007). As this species overwinters in the soil in larval form, ploughing crops may have a negative impact on its population (Yamazaki et al., 2003). Therefore, the plantations of the cup plant, as well as other perennial energy crops, may provide breeding sites for it in an intensively managed agricultural landscape. They can play a similar role for all Carabidae (Kramer Jacobsen et al., 2022; Twardowski, 2006), especially for species with an autumn development type, more sensitive to ploughing as well as species preferring woodlands as an overwintering shelter (Kosewska, 2016; Lövei and Sunderland, 1996).

The results obtained during this research, as well as abovementioned literature data indicate that the cup plant and virginia mallow can provide foraging sites but also a reservoir, enabling xerophilous species, as well as open area species, to survive in highly disturbed agricultural areas. Hence, cup plant and virginia mallow plantations are valuable as refugia for Carabidae in agricultural landscapes. However, they promote species with different functional characteristics than older willow stands, especially cup plant crops. They are also unlikely to contribute significantly to creating environmental corridors for species that prefer forested areas. Miscanthus seems to be the least useful in terms of increasing biodiversity in the agricultural landscape. Although research by Semere and Slater (2007) found the abundant occurrence of species widespread in agricultural areas, like *Harpalus rufipes, Amara* spp. and *Pterostichus* spp. on its plantations, it should be taken into account that the age of miscanthus plantations studied by those authors did not exceed 3 years. Thus, the density of these crops was much lower than in mature crops, and thus they can provide better conditions for the development of weeds (Christian et al., 1998). Differences between young and older plantations have been demonstrated in the Williams & Feest study (2019). It was found there that the biomass, species diversity and abundance of epigeic beetles were much smaller in miscanthus plantations than in cultivated fields and meadows. It was related to the decrease in the number of weeds in a

mature plantation (Radzikowski et al., 2020) and the absence of pests feeding on the miscanthus itself. The number of ground beetles recorded by Radzikowski et al. (2020) was greater in the cup plant crops than in the willow plantation. Therefore, information about the condition of Carabidae communities inhabiting the miscanthus plantation was incomplete without additional analyses based on the species composition and functional traits.

For Carabidae, especially for the phytophagous and hemizoophagous species, the segetal flora has a great importance, providing ground beetles space for development and foraging (Kromp, 1999). Due to the rapid growth and dense canopy, miscanthus practically displaces weeds from crops. Except for the cases when part of the crop is damaged, i.e. by frost, vell-developed miscanthus plantations create a uniform, dense monocultures, where, due to the natural competition for resources, only very few noncrop plants can survive. While this is economically desirable, it significantly reduces structural biodiversity (Radzikowski et al., 2020). In such case, in this type of cultivation, the only areas characterized by a high diversity of segetal flora become openings, technological paths and headlands.

At the study site "Kocibórz", it was shown that in terms of assemblage functional traits as well as Carabidae species composition, willow plantations differed significantly from the fallow land (KU) and the agricultural field (KP). Also, the research carried out in Leginy showed differences between the willow plantation (SV) and other energy crops. Due to features such as: no soil cultivation, little or no fertilisation as well as herbicide application and relatively rare harvesting, willow plantations create a habitat characterised by a low degree of anthropopressure. This enables the survival and connectivity of the population of species preferring forests and wooded areas. They also promote species with higher hygropreferences, especially in comparison with the surrounding open areas. It applies in particular to older willow plantations cultivated in a certain location for many years, and perhaps also crops maintained in the Eco-Salix system. Plantations maintained in this system, due to the long production cycle, can create environments similar to young forests and mid-field woodlots (Flis and Skłodowski, 1998). Unfortunately, there is still a lack of comprehensive studies investigating the biodiversity of this type of willow plantation. Therefore is hard to determine whether the high abundance of forest and hygrophilous Carabidae is connected with the age of the stand (coppicing phase), the age of the plantation itself, or perhaps other yet unexplored factors.

Increasing the landscape continuity is essential, especially for brachypterous ground beetles with low dispersibility, the most significant number of which, compared to other studied plots, was found on all willow plantations. This study showed that energy willow plantations can serve as ecological corridors in agricultural areas, which was also described by other

authors (Burel, 1989; Londo et al., 2004; Mueller-Kroehling et al., 2020; Piotrowska et al. ., 2020). Additionally, these plantations can potentially increase landscape mosaicism, which positively affects the diversity of ground beetles in neighbouring field crops (Boutaud et al., 2022; Putchkov, 2019). They also provide a habitat from which beneficial ground beetles can spread to the surrounding arable crops and where they contribute to biological pests and weed control. Thanks to this, willows can play an essential role in the model of sustainable agriculture, reducing the use of plant protection products. Establishing them in areas with poor soil conditions, especially on marginal lands, allows for the diversified use of agricultural land and for obtaining income for local farmers, including farmers managing poor-quality lands (Shortall, 2013; Stolarski et al., 2011). Thanks to this, willow plantations can also be important from a socio-economic perspective, significantly contributing to the development of rural areas.

6. SUMMARY WITH CONCLUSIONS

1. A total of 13,425 Carabid beetles were caught during the experiment. These numbers consisted of Carabidae caught in energy crop plantations in Leginy in 2019 (2,177), and Carabidae caught in Eco-Salix (KES) and SRC (KW) energy willow plantations, fallow land (KU) and agricultural fields (KP) in Kocibórz in 2019-2020 (11,248).

2. A total of 45 Carabidae species were found in the study plots in Leginy and 86 Carabidae species in the study plots in Kocibórz. In total, 90 species of Carabidae were caught throughout the experiment.

3. The distinctness of the ground beetle communities inhabiting particular energy crop plantations in the study site "Leginy" was demonstrated. It mainly concerned the distribution of functional traits in the assemblages. The energetic willow plantation (SV) differed the most from the cup plant crop (SP) and was the most similar to the virginia mallow crop (SV). The cup plant (SP) and miscanthus (MG) plantations shared the largest number of common traits.

4. Compared to other energy crops: miscanthus (MG), virginia mallow (SH) and cup plant (SP), willow plantation (SV) was characterised by a significantly lower share of open-area species in the assemblage (slightly more than 50% of the assemblage). Willow plantation (SV) was also characterised by the highest percentage of woodland-preferring Carabidae (32.97%). It suggested that it provided the best habitat conditions for this species group among all the plantations studied.

5. In comparison with other energy crops, the willow (SV) plantation was characterised by the highest share of large carnivores (38.62%) and the lowest share of hemizoophages in the assemblage (9.38%). Combined with the highest share of brachypterous Carabidae (11.52%) and the lowest share of macropterous ones (16.55%) in the assemblage, recorded on this plantation, as well as the best-balanced dominance structure, this indicates that the willow plantation was probably subjected to the lowest anthropopressure level of all energy crops.

6. The willow plantation managed in the short rotation coppice (SRC) system (KW) in the first year of the production cycle had the "fallow-like" character of an open area, which resulted in a large influx of ground beetles preferring open habitats. It made the composition of the assemblages observed on this plantation similar to the composition characteristic of the arable field (KP). In the second year of the study, canopy closure resulted in a change in the habitat type

and, thus, an outflow of species preferring open areas. In the older growth cycle stage, the SRC willow crop was more similar to the Eco-Salix plantation (KES).

7. Despite the change in the nature of the habitat in the SRC willow plantation, which occurred as a result of the harvest (2019), no significant decrease was observed in the number of forest Carabidae individuals inhabiting this plantation. In the first year after coppicing, 115 individuals from this group were found, while in the following year, 141 individuals were found. However, their proportion in the assemblage in consecutive years has changed (7.97% in 2019 and 24.23% in 2020). The most abundant species represented was the common *P. niger*.

8. In the Eco-Salix willow plantation (KES) the highest percentage of medium and large zoophages, forest species, dipterous and brachypterous species, as well as wetlands preferring species was recorded. Moreover, the forest species found on this plantation were the most diverse. Environmentally valuable species of the genus *Carabus* were also observed on this plantation. It suggests that the Eco-Salix (KES) willow plantation provided good environmental conditions for the development of ground beetle communities.

9. *C. erratus*, classified as a forest species, was the most abundant on fallow land (KU), making forest species the most abundant in this plantation. However, this species is more strongly associated with dry environments and less with woodland and is classified as a eurytopic by some researchers. Apart from this species, no forest ground beetles were abundant on the fallow land (KU).

10. The older plantation (established in 2010), maintained in the Eco-salix system, appeared to be more abundant in environmentally-valuable species, especially forest and brachypterous species, than the plantation maintained in the SRC system, established in 2014. However, it is difficult to determine whether this was related to the age of the trees or the plantation itself. Therefore, this issue requires further research conducted on older plantations.

11. Most likely, "asymmetric dominance", the phenomenon of the quantitative predominance of autumn forms and qualitative predominance of spring forms, is a natural state for energy crop plantations. It was demonstrated in this study in all investigated plantations except the SRC plantation in the first year after harvesting. It indicates a disturbance of the environment in this plantation, correlated with the influx of spring species, characteristic of habitats undergoing change.

12. Compared to the other energy crops studied, willow plantations seem to have the highest potential for creating habitats for ground beetles in disturbed agrocenoses. It is most likely due to a longer production cycle, a less dense canopy that does not block herbaceous plants' access to light and the annual supply of detritus in the form of fallen leaves, which shapes a specific, more humid litter microclimate enabling the development of beetle larvae with higher hygro-preference.

13. Energy willow (*Salix viminalis*) plantations can significantly contribute to biodiversity in agricultural landscapes by increasing land mosaicism and creating new habitats for Carabidae and providing environmental corridors that promote migration between different habitat patches in the landscape.

14. Energy willow plantations can be considered as a refugium of Carabidae in an agricultural landscape subjected to strong anthropopressure. The Carabidae that inhabit them can also provide valuable ecosystem services in adjacent plantations, contributing to the control of pest and weed populations. Therefore, these crops are valuable plantings that should be considered in a sustainable agriculture model, especially in areas of low agricultural value, such as marginal lands.

7. LITERATURE

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Summary

Energy willow plantations as a refuge for ground beetle assemblages (Coleoptera, Carabidae) in agricultural lands

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Key words: ground beetles, Carabidae, energy crops, willow, *Salix viminalis*;

The study of the epigeic carabid beetles fauna (Coleoptera, Carabidae) inhabiting energy crops has been conducted in north-eastern Poland, in the Masurian Lake District. The research sites were energy crop plantations, supervised by the Department of Genetics, Plant Breeding and Bioresource Engineering. They were located in Kocibórz and Leginy, about 60 km from Olsztyn. In the study site "Kocibórz", observations were carried out on two plantations of energy willow (*Salix viminalis* L.). First, maintained in the short-rotation coppice (SRC) system and the second, maintained in the more extensive Eco-Salix system. Reference plots were fallow land and arable crops. Research at this location was carried out in two seasons, in 2019-2020. At the study site "Leginy", where observations were carried out on SRC willow plantations and perennial herbaceous energy crops: cup plant (*Silphium perfoliatum* L.), virginia mallow (*Sida hermaphrodita* Rusby L.) and giant miscanthus (*Miscanthus* × *giganteus* J.M.Greef & M.Deuter) observations were carried out in 2019.

The main goal of this study was to clarify the impact of willow (*Salix* spp.) plantations on the Carabidae assemblages in areas intensively used for agricultural purposes. The research problem was formulated in the form of a question: "Can willow plantations be a refuge for ground beetles from the Carabidae family in the agricultural landscape, and thus contribute to increasing biodiversity in the model of sustainable agriculture?". In order to answer this question, the ground beetles assemblages inhabiting different plots were investigated, taking into account their ecology and role in determining the state of the natural environment. Among the detailed objectives was also the comparison of two willow crops, planted in different systems, as well as willow comparison with herbaceous perennial energy crops.

During the experiment, a total of 13,425 Carabid beetles were caught. These numbers consisted of Carabidae collected in energy crop plantations in Leginy (2,177), and Carabidae collected in Eco-Salix (KES) and SRC (KW) energy willow plantations, fallow land (KU) and agricultural fields (KP) in Kocibórz (11,248). Finally, 45 Carabidae species were found in the study plots in Leginy and 86 Carabidae species in the study plots in Kocibórz. In total, 90 species of Carabidae were caught throughout the experiment. The distinctness of the ground beetle communities inhabiting willow plantations was demonstrated. Compared to other plots they were characterised by a significantly lower share of open-area species in the assemblage as well as the highest percentage of woodland-preferring Carabidae. Also large carnivorous species including those from the *Carabus* family were numerously represented on willow crops. Combined with the highest share of brachypterous carabids and the lowest share of macropterous ones in the assemblages, recorded on these plantations, as well as the best-balanced dominance structure, it suggests that willow crops provide beneficial habitat for Carabidae in highly disturbed agricultural areas.

Streszczenie

Plantacje wierzby energetycznej jako refugium dla zgrupowań biegaczowatych (Coleoptera, Carabidae) na terenach użytkowanych rolniczo

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Słowa kluczowe: biegaczowate, Carabidae, uprawy roślin energetycznych, wierzba, *Salix viminalis*;

Badania dotyczące epigeicznej fauny biegaczowatych (Coleoptera, Carabidae) zasiedlającej plantacje roślin energetycznych przeprowadzone zostały w północno-wschodniej Polsce, na terenie pojezierza Mazurskiego. Teren badań stanowiły plantacje roślin energetycznych, nadzorowane przez Katedrę Genetyki, Hodowli i Inżynierii Biosurowców, zlokalizowane w Kociborzu i Leginach, około 60 km od Olsztyna. W Kociborzu obserwacje prowadzone były na plantacji wierzby energetycznej (*Salix viminalis* L.) utrzymywanej w systemie zagajników o krótkiej rotacji (SRC) oraz drugiej, utrzymywanej w bardziej ekstensywnym systemie Eco-Salix. Powierzchnie porównawcze stanowiły grunty ugorowane oraz uprawy polowe. Badania w tej lokalizacji przeprowadzone były w dwóch sezonach, w latach 2019-2020. Na powierzchni badawczej w Leginach, gdzie obserwacje prowadzone były na plantacjach wierzby SRC oraz wieloletnich zielnych roślin energetycznych: rożnika przerośnietego (*Silphium perfoliatum* L.), ślazowca pensylwańskiego (*Sida hermaphrodita* Rusby L.) i miskanta olbrzymiego (*Miscanthus* × *giganteus* J.M.Greef & M.Deuter) obserwacje prowadzono w roku 2019.

Głównym celem pracy było wyjaśnienie wpływu plantacji wierzby na zgrupowania Carabidae na terenach intensywnie użytkowanych rolniczo. Problem badawczy został sformułowany w postaci pytania: "Czy plantacje wierzby mogą stanowić ostoję dla chrząszczy naziemnych z rodziny Carabidae w krajobrazie rolniczym, a tym samym przyczynić się do zwiększenia różnorodności biologicznej w modelu zrównoważonego rolnictwa?". Aby odpowiedzieć na to pytanie, zbadano zespoły chrząszczy epigeicznych zasiedlających różne powierzchnie, uwzględniając ich ekologię i rolę w określaniu stanu środowiska przyrodniczego. Wśród celów szczegółowych znalazło się również porównanie dwóch upraw wierzby, utrzymywanych w różnych systemach produkcyjnych, a także porównanie wierzby z zielnymi wieloletnimi roślinami energetycznymi.

W trakcie doświadczenia odłowiono łącznie 13 425 chrząszczy Carabidae. Na te liczby składały się Carabidae zebrane na plantacjach roślin energetycznych w Leginach (2 177) oraz Carabidae zebrane na plantacjach wierzby energetycznej Eco-Salix (KES) i SRC (KW), ugorach (KU) i polach uprawnych (KP) w Kociborzu (11 248). Ostatecznie na powierzchniach badawczych w Leginach stwierdzono 45 gatunków Carabidae, a na powierzchniach badawczych w Kociborzu 86 gatunków Carabidae. Łącznie w całym doświadczeniu odłowiono 90 gatunki Carabidae. Wykazano odrębność zbiorowisk chrząszczy naziemnych zasiedlających plantacje wierzby. W porównaniu z innymi powierzchniami charakteryzowały się one istotnie mniejszym udziałem w gatunków terenów otwartych oraz najwyższym udziałem Carabidae preferujących tereny leśne. Również duże gatunki drapieżne, w tym z rodziny *Carabus*, były licznie reprezentowane na uprawach wierzby. W połączeniu z najwyższym udziałem biegaczowatych brachypterycznych i najniższym udziałem biegaczowatych makropterycznych, odnotowanym na tych plantacjach, oraz najlepiej zbalansowaną strukturą dominacji, sugeruje to, że uprawy wierzby stanowią korzystne siedlisko dla Carabidae w silnie zaburzonych obszarach rolnych.

Appendix

Table contains functional traits of species captured during the study (abbreviations mean respectively: sb-spring breeders, ab-autumn breeders; eu–eurytopic, o-open area, we-wetland, f-forest; h-hygrophilous, m-mesophilous, x-xerophilous; mc-medium carnivores, ph-phytophages, hz-hemizoophages, sc- small carnivores, lc – large carnivores, ud.-undetermined; M-macropterous, D-dipterous, B-brachypterous)

	Breeding time	Environment	Hygropreference	Trophic type	Dispersion
Agonum fuliginosum (Panzer, 1809)	**sb**	**eu**	**h**	**mc**	**M**
Agonum gracilipes (Duftschmid, 1812)	**sb**	**eu**	**m**	**mc**	**M**
Agonum sexpunctatum (Linnaeus, 1758)	**sb**	**o**	**h**	**mc**	**M**
Agonum viduum (Panzer, 1796)	**sb**	**we**	**h**	**mc**	**M**
Amara aenea (Degeer,1774)	**sb**	**o**	**x**	**ph**	**M**
Amara bifrons (Gyllenhal, 1810)	**ab**	**o**	**x**	**hz**	**M**
Amara communis (Panzer, 1797)	**sb**	**o**	**m**	**hz**	**M**
Amara consularis (Duftschmid, 1812)	**ab**	**o**	**m**	**hz**	**M**
Amara convexior (J.F. Stephens, 1828)	**sb**	**o**	**m**	**hz**	**M**
Amara familiaris (Duftschmid, 1812)	**ab**	**eu**	**m**	**hz**	**M**
Amara fulva (Degeer, 1774)	**ab**	**o**	**m**	**hz**	**M**
Amara lunicollis (Schiødte, 1837)	**sb**	**eu**	**m**	**hz**	**M**
Amara majuscula (Chaudoir, 1850)	**ab**	**o**	**m**	**hz**	**M**
Amara montivaga (Sturm, 1825)	**sb**	**o**	**x**	**hz**	**M**
Amara ovata (Fabricius, 1792)	**sb**	**f**	**m**	**hz**	**M**
Amara plebeja (Gyllenhal, 1810)	**sb**	**o**	**m**	**ph**	**M**
Amara similata (Gyllenhal, 1810)	**sb**	**o**	**m**	**ph**	**M**
Amara tibialis (Paykull, 1798)	**sb**	**o**	**m**	**hz**	**M**
Anchomenus dorsalis (Pontoppidan, 1763)	**sb**	**o**	**h**	**mc**	**M**
Anisodactylus binotatus (Fabricius, 1787)	**sb**	**o**	**m**	**hz**	**M**
Anisodactylus nemorivagus (Duftschmid, 1812)	**sb**	**f**	**m**	**mc**	**M**
Badister bullatus (Schrank, 1798)	**sb**	**eu**	**h**	**hz**	**M**
Badister lacertosus (Sturm, 1815)	**sb**	**f**	**m**	**mc**	**M**
Badister sodalist (Duftschmid, 1812)	**sb**	**we**	**h**	**sc**	**B**
Bembidion gilvipes (Sturm, 1825)	**sb**	**we**	**h**	**sc**	**D**
Bembidion guttula (Fabricius, 1792)	**sb**	**o**	**h**	**sc**	**D**

Bembidion lampros (Herbst, 1784)	**sb**	**o**	**m**	**sc**	**M**
Bembidion properans (Stephens, 1828)	**sb**	**o**	**m**	**sc**	**M**
Bembidion pygmaeum (Fabricius, 1792)	**sb**	**o**	**x**	**sc**	**D**
Bembidion quadrimaculatum (Linnaeus, 1761)	**sb**	**o**	**m**	**sc**	**M**
Broscus cephalotes (Linnaeus, 1758)	**ab**	**o**	**x**	**lc**	**M**
Calathus ambiguus (Paykull, 1790)	**ab**	**o**	**x**	**mc**	**M**
Calathus cinctus (Motschulsky, 1850)	**ab**	**o**	**m**	**mc**	**D**
Calathus erratus (Sahlberg, 1827)	**ab**	**f**	**x**	**mc**	**D**
Calathus fuscipes (Goeze, 1777)	**ab**	**o**	**m**	**mc**	**D**
Calathus halensis (Schaller, 1783)	**ab**	**o**	**m**	**lc**	**M**
Calathus melanocephalus (Linnaeus, 1758)	**ab**	**o**	**m**	**mc**	**D**
Carabus cancellatus (Illiger, 1798)	**sb**	**eu**	**m**	**lc**	**B**
Carabus coriaceus (Linnaeus,1758)	**ab**	**f**	**m**	**lc**	**B**
Carabus granulatus (Linnaeus, 1758)	**sb**	**we**	**h**	**lc**	**B**
Carabus hortensis (Linnaeus, 1758)	**ab**	**f**	**m**	**lc**	**B**
Carabus marginalis (Fabricius,1794)	**sb**	**f**	**m**	**lc**	**B**
Carabus nemoralis (Muller, 1764)	**sb**	**eu**	**m**	**lc**	**B**
Chlaenius nigricornis (Fabricius, 1787)	**sb**	**we**	**h**	**mc**	**M**
Cicindela campestris (Linnaeus, 1758)	**sb**	**o**	**x**	**mc**	**M**
Clivina fossor (Linnaeus, 1758)	**sb**	**o**	**m**	**mc**	**D**
Curtonotus aulicus (Panzer, 1797)	**ab**	**o**	**m**	**hz**	**M**
Cymindis angularis (Gyllenhal, 1810)	**ab**	**o**	**x**	**mc**	**B**
Dyschiriodes globosus (Herbst, 1784)	**sb**	**o**	**h**	**mc**	**D**
Epaphius secalis (Paykull, 1790)	**ab**	**eu**	**m**	**sc**	**B**
Harpalus affinis (Schrank, 1781)	**sb**	**o**	**x**	**hz**	**M**
Harpalus anxius (Duftschmid, 1812)	**sb**	**o**	**x**	**hz**	**M**
Harpalus autumnalis (Duftschmid, 1812)	**sb**	**o**	**x**	**hz**	**M**
Harpalus calceatus (Duftschmid, 1812)	**ab**	**o**	**x**	**hz**	**M**
Harpalus distinguendus (Duftschmid, 1812)	**sb**	**o**	**x**	**hz**	**M**
Harpalus griseus (Duftschmid, 1812)	**ab**	**o**	**x**	**hz**	**M**
Harpalus laevicollis (Duftschmid, 1812)	**sb**	**f**	**m**	**un.**	**D**
Harpalus laevipes (Zetterstedt, 1828)	**ab**	**eu**	**m**	**hz**	**M**
Harpalus latus (Linnaeus, 1758)	**ab**	**eu**	**m**	**hz**	**M**
Harpalus luteicornis (Duftschmid, 1812)	**sb**	**o**	**m**	**hz**	**M**
Harpalus picipennis (Duftschmid, 1812)	**sb**	**o**	**x**	**hz**	**B**
Harpalus pumilus (Sturm, 1818)	**sb**	**o**	**x**	**hz**	**D**
Harpalus rubripes (Duftschmid, 1812)	**sb**	**o**	**x**	**hz**	**M**

Harpalus rufipes (Degeer, 1774)	**ab**	**o**	**m**	**hz**	**M**
Harpalus signaticornis (Duftschmid, 1812)	**sb**	**o**	**x**	**hz**	**M**
Harpalus smaragdinus (Duftschmid, 1812)	**sb**	**o**	**x**	**hz**	**M**
Harpalus tardus (Panzer, 1797)	**sb**	**o**	**x**	**hz**	**M**
Harpalus xanthopus winkleri (Schauberger, 1923)	**sb**	**f**	**m**	**hz**	**M**
Leistus ferrugineus (Linnaeus, 1758)	**ab**	**f**	**m**	**mc**	**B**
Leistus terminatus (Panzer, 1793)	**ab**	**we**	**h**	**mc**	**D**
Masoseus wetterhallii (Gyllenhal, 1813)	**ab**	**o**	**x**	**mc**	**D**
Microlestes minutulus (Goeze, 1777)	**sb**	**eu**	**x**	**sc**	**D**
Nebria brevicollis (Fabricius, 1792)	**ab**	**eu**	**m**	**mc**	**M**
Notiophilus palustris (Duftschmid, 1812)	**sb**	**o**	**m**	**sc**	**D**
Oxypselaphus obscurus (Herbst, 1784)	**sb**	**f**	**h**	**sc**	**B**
Panagaeus bipustulatus (Fabricius, 1775)	**sb**	**o**	**x**	**mc**	**M**
Platynus assimilis (Paykull, 1790)	**sb**	**eu**	**h**	**mc**	**B**
Poecilus cupreus (Linnaeus, 1758)	**sb**	**o**	**m**	**mc**	**M**
Poecilus lepidus (Leske, 1785)	**sb**	**o**	**x**	**mc**	**D**
Poecilus versicolor (Sturm, 1824)	**sb**	**o**	**m**	**mc**	**M**
Pterostichus diligens (Sturm, 1824)	**sb**	**we**	**h**	**sc**	**M**
Pterostichus melanarius (Illiger, 1798)	**ab**	**eu**	**m**	**lc**	**D**
Pterostichus niger (Schaller, 1783)	**ab**	**f**	**m**	**lc**	**D**
Pterostichus oblongopunctatus (Fabricius, 1787)	**sb**	**f**	**m**	**mc**	**M**
Pterostichus strenuus (Panzer, 1796)	**sb**	**f**	**h**	**mc**	**D**
Pterostichus vernalis (Panzer, 1796)	**sb**	**o**	**h**	**mc**	**M**
Stomis pumicatus (Panzer, 1796)	**ab**	**f**	**m**	**mc**	**B**
Syntomus truncatellus (Linnaeus, 1761)	**sb**	**o**	**x**	**sc**	**D**
Synuchus vivalis (Illiger, 1798)	**ab**	**o**	**m**	**mc**	**D**
Trechus quadristriatus (Schrank von Paula, 1781)	**ab**	**o**	**m**	**sc**	**D**

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