



Effects of diversified cropping on arthropod communities

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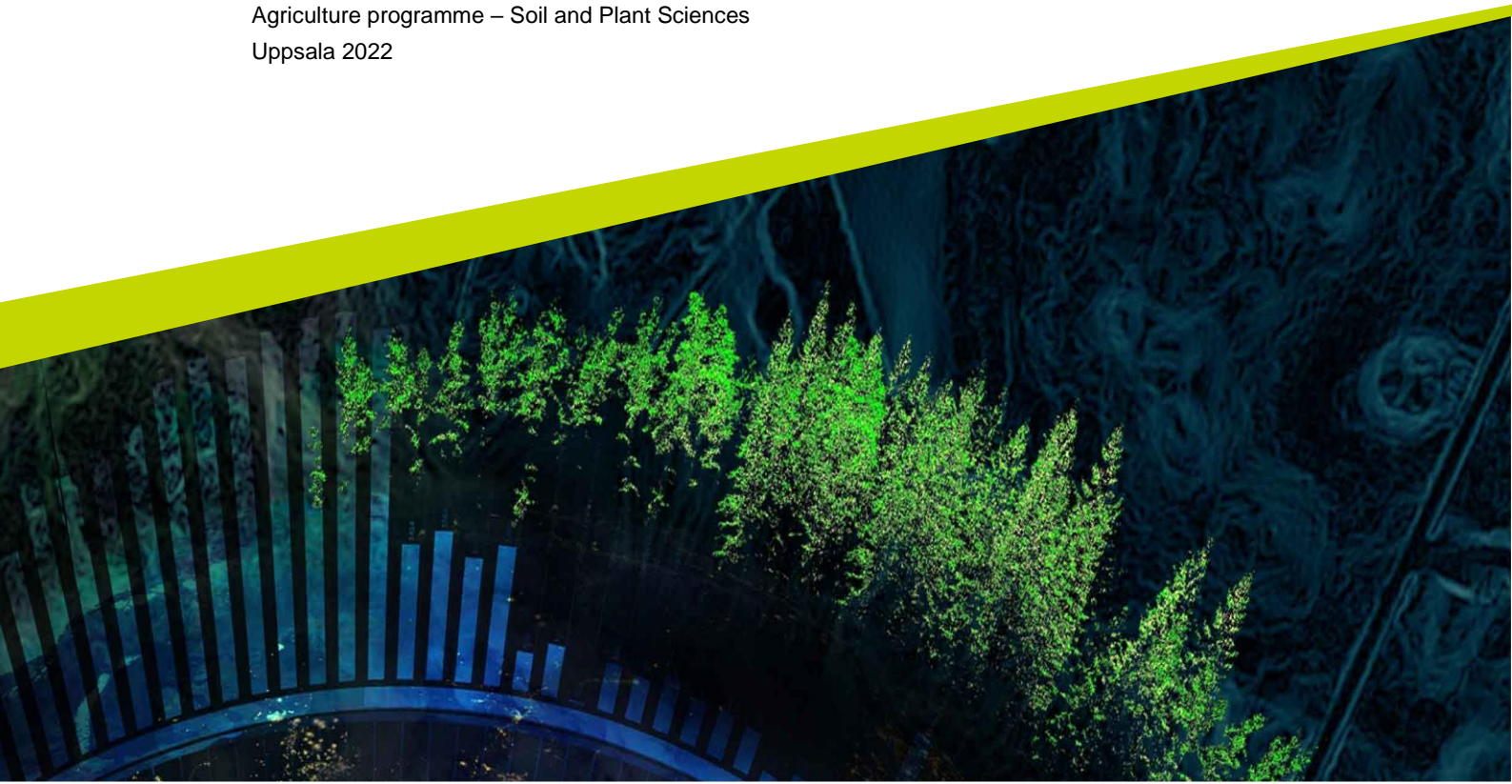
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Effects of diversified cropping on arthropod communities.

Effekter av diversifierad odling på leddjurssamhällen.

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Sammanfattning

Även intensiva moderna jordbruk är beroende av ekosystemtjänster som organismer bidrar med såsom biologisk bekämpning av skadedjur. Effekten av biodiversitet på ekosystemprocesser förklaras inte i tillräcklig grad av taxonomisk mångfald, utan beror snarare på mångfalden av funktionella egenskaper bland arterna. I den här studien undersöks effekten av diversifierad odling i form av tillförsel av organiskt gödselmedel och införandet av vall i växtföljden, samt olika tidpunkter för provtagning under säsongen, på proportionerna av jordlöpare (*Carabidae*) och spindlars (*Araneae*) funktionella egenskaper på fältnivå. Jordlöpare och spindlar samlades in från tre behandlingar, mineralgödsel med en annuell växtföljd, organisk gödsel med en annuell växtföljd och organisk gödsel med vall i växtföljden, över 19 fält i Halland samt tre tidpunkter för provtagning, maj, juni och juli. De funktionella egenskaper hos jordlöpare som undersöktes var jordlöparens diet, uppdelat i köttätare, allätare och växtätare (i huvudsak fröätare), vingmorfologi, uppdelat i vingade och dimorfa, d.v.s. kan både ha vingar och vara vinglösa, samt community weighted mean (CWM) kroppsstorlek. De funktionella egenskaper hos spindlar som undersöktes var jaktmetod, uppdelat i aktivt jagande och mattvävsspindlar, samt CWM kroppsstorlek. Proportionerna av köttätande och dimorfa jordlöpare ökade i behandlingen med vall i växtföljden, medan växtätande och vingade jordlöpare minskade i behandlingen med vall i växtföljden. Proportionerna av spindlars jaktmetoder samt CWM kroppsstorlek av spindlar och jordlöpare påverkades inte av behandlingarna. Proportionen av växtätare och CWM kroppsstorleken av jordlöpare ökade över säsongen. Proportionen av köttätande och dimorfa jordlöpare samt mattvävsspindlar var lägre under juni jämfört med maj och juli, medan proportionerna av allätande och vingade jordlöpare samt aktivt jagande spindlar samt spindlars CWM kroppsstorlek minskade under juni. En högre proportion av köttätare till följd av införandet av vall i växtföljden och organisk gödsel, kan leda till starkare biologisk bekämpning av skadeinsekter. En hög proportion av köttätare samt en högre CWM kroppsstorlek kan dock även innebära en ökad risk för predation av jordlöpare på spindlar. Vad som avgör sammansättningen av egenskaper samt hur dessa påverkar ekosystemtjänster är komplext och mer forskning i ämnet behövs.

Nyckelord: Jordlöpare, Spindlar, Funktionella egenskaper, Organiskt gödselmedel, Kvarvarande effekter av vall

Abstract

Highly intensified modern agriculture remains dependent on species-mediated ecosystem services such as pest control. Taxonomic diversity does not sufficiently explain biodiversity effects on ecosystem processes but rather depend on the diversity of functional traits among species. In this study the effect of cropping diversification, such as added organic amendments in the form of manure and incorporation of ley in the crop rotation, as well as the effect of time of sampling during the season on the proportions of carabid (*Carabidae*) and spider (*Araneae*) functional traits was investigated. Carabids and spiders were sampled across 19 fields in Halland county, Sweden, with three different diversification treatments, mineral fertilizer with an annual crop rotation, manure with an annual crop rotation, and manure with ley incorporated in the crop rotation, as well as three sampling sessions, early, mid, and late cropping season. The carabid functional traits diet, divided into carnivores, omnivores and phytophagous (mainly seed eaters) carabids, wing morphology divided into macropterous and dimorphic, and community weighted mean (CWM) body size were studied. The spider functional traits studied were hunting mode divided into ground runners and sheet-web weavers, and CWM body size. The proportion of carnivorous and dimorphic carabids increased with ley in the crop rotation whereas phytophagous and macropterous carabids decreased. No treatment effect was found on spiders hunting mode or on CWM body size of carabids or spiders. Phytophagous and CWM body size of carabids increased during the season. Carnivores and dimorphic carabids, as well as sheet-web weaving spiders were lower in June compared with May and July. In contrast, the proportion of omnivorous carabids, macropterous carabids, ground runners and spiders CWM body size was higher in June compared with May and July. Adding organic amendments such as manure and ley in the crop rotation, and thereby increasing the proportion of carnivores could lead to a stronger biological pest control. A higher proportion of predators and a higher CWM body size of carabids could however also increase the risk of intraguild predation. What determines the composition of traits and how that in turn affects ecosystem services is complex and more research is needed.

Keywords: Carabids, Spiders, Traits, Organic amendments, Ley legacy effects

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1. Introduction

Intensive agriculture threatens biodiversity and biodiversity-related ecosystem services worldwide (Foley et al. 2005). Yet highly intensified modern agriculture remains dependent on several species-mediated ecosystem services such as pollination, nutrient retention, waterflows and biological control, and the conservation and promotion of biodiversity in agricultural landscapes is therefore essential (Östman et al. 2003; Letourneau et al. 2009; Tscharntke et al. 2012; Bommarco et al. 2013). Although these ecosystem services are mediated by the communities of beneficial organisms, it is yet not well understood what consequences changes in these communities could have for ecosystem functioning and the delivery of ecosystem services (Rusch et al. 2015).

1.1 Organic amendments and crop rotations

Ley is a temporary grassland composed of grasses and/or legumes integrated in a crop rotation and is used for forage production through haying or grazing (Allen et al. 2011; Martin et al. 2020). Including perennial ley in a crop rotation adds a period with habitat continuity and low disturbance (Heggenstaller et al. 2006). Agricultural intensification negatively affect the soil biodiversity and changes the composition of functional groups, and integrating ley in an annual crop rotation in order to extensify the production can increase the abundance and diversity of soil organisms (Postma-Blaauw et al. 2010; Tsiafouli et al. 2015; Hoeffner et al. 2021b). Ley also provides a different plant composition, plant species richness and vegetational structure which can affect abundances of arthropods (Perner et al. 2005; Ebeling et al. 2018). Incorporating ley into the crop rotation can also have a positive effect on the soil structure (Hoeffner et al. 2021a), increase the soil organic carbon as well as the level of nitrogen in the soil and its water holding capacity (Albizua et al. 2015).

Having ley in the crop rotation not only has an effect on soil properties and soil organisms while the ley is there, but there are also legacy effects continuing after the conversion to annual crops. There are positive legacy effects of ley in the crop rotation on both the soil structure and microbial biomass (Hoeffner et al. 2021a). Larger soil organisms, such as earthworms and nematodes, appear to be more negatively affected by agricultural intensification compared to soil microorganisms (Postma-Blaauw et al. 2010). There is a longer positive legacy effect of ley in the crop rotation for soil microorganisms with a significant reduction in protozoans and bacterial biomass first after three to four years after conversion from grassland to annual crops. Soil microorganisms appear to be affected primarily by long term consequences of a conversion from grass ley to annual crops, most likely the loss

of soil organic matter (SOM) (Postma-Blaauw et al. 2010). Depending on management and duration, ley can have long-lasting effect on the SOM (Crème et al. 2018). It appears, in contrast, to be less of a legacy effect for larger-sized soil organisms since these taxonomic groups seem to be more affected by short-term consequences such as soil disturbance (Postma-Blaauw et al. 2010).

Including organic amendments such as manure also increases SOM and promotes microbial biomass and soil mesofauna (Birkhofer et al. 2008). Higher SOM improves a number of different food and habitat characteristics (Garratt et al. 2011; Rowen et al. 2019) such as microclimate, soil tilth and the structural complexity of the soil environment (Bulluck et al. 2002), which in turn could increase spatial niches for arthropod predators at the soil surface (Snyder 2019). Promoting arthropod predators with additional food resources, such as detrital soil fauna, to improve the variety and abundance of prey as well as alternative prey during parts of the season where herbivorous pests are scarce, can benefit the predator communities and subsequently their potential biological control on pests (Rowen et al. 2019).

Mineral fertilizers and manure have been shown to affect the food webs differently. Using manure fertilizer, and thereby subsidizing the detrital soil fauna compartment in food webs, results in a top-down trophic cascade of arthropod predators, such as spiders and carabids, on plant biomass (Riggi & Bommarco 2019). Mineral fertilizers do instead increase the plant productivity resulting in a positive bottom-up effect on aphid densities. Compared to using mineral fertilizers, adding organic matter by using manure increases the soil fauna and coleopteran abundances which leads to stronger top-down control on primary production by predators (Riggi & Bommarco 2019). The increase in SOM can enhance both the soil mesofauna and provide beneficial microclimates and refugia benefiting generalist arthropod predators (Chen & Wise 1999; Halaj & Wise 2002; Rowen et al. 2019). Adding organic amendments such as manure therefore has the potential to increase arthropod predators' top-down control in the food web and its effects on yield (Riggi & Bommarco 2019; Rowen et al. 2019). Changing the within-field environment affects the food resources and habitat, which in turn affects the organisms in the field and the interactions between them. By carefully choosing agricultural practices, such as crop rotations and fertilizer use, we therefore have the potential to promote beneficial organisms and the ecosystem services they provide.

1.2 Traits

It has become clear in recent years that taxonomic diversity does not sufficiently explain biodiversity effects on ecosystem processes but rather depend on the diversity of functional traits among species (McGill et al. 2006; Cadotte et al. 2011; Gagic et al. 2015). The main limitation of taxonomic diversity is that it assesses only the number of species and their relative abundances but neglects the assessment of potential ecological functions in the field, derived from specific traits. How different species respond to agricultural landscape structure and management is determined by species-specific traits (Ekroos et al. 2013). The functional traits of different species such as life history, dispersal ability and habitat

preferences influence ecosystem functioning by mediating changes in trophic interactions, and through responses to changes in the local environment (Wood et al. 2015). The functional traits of species influence ecosystem functioning both directly and indirectly. Ecosystem functioning can be influenced directly by the functional traits mediating changes in biotic control, such as predation or competition, and indirectly via responses to changes in local environment, e.g., microclimates or disturbance (Chapin III et al. 2000). There is evidence that the composition of traits and the functional trait diversity rather than species or taxonomic diversity, drives the delivery of ecosystem services of arthropods (Cadotte et al. 2011; Wood et al. 2015; Finney & Kaye 2017; Perović et al. 2018), and ecological studies are therefore increasingly moving towards trait-based approaches (Maas et al. 2021).

Looking at trait values across environmental conditions and different agricultural management regimes will help predict how ecosystem services vary with agricultural practices and environment. Such knowledge could be used to develop specific trait-based management strategies in order to increase ecosystem services as well as to manage trade-offs among ecosystem services in agriculture (Wood et al. 2015).

This study focuses on the ecosystem services of biological pest and weed control. Herbivorous pests and weeds globally stands for potential yield losses of 18 and 34% respectively (Oerke 2006) and the pesticides used for pest and weed control threatens the biodiversity both in and around arable land (Wivstad 2005). Today there is also a growing problem with resistant weeds and insects (Wivstad 2005) and promoting biological pest control is therefore an important sustainable mitigation measure. Spiders and carabids are arthropod predators that play an important role in biological control of both herbivorous pests and weeds (Sunderland et al. 1987; Kromp 1999; Marc et al. 1999; Westerman et al. 2003) and their trait composition could affect the level of potential pest control in the field.

1.3 Chosen carabid and spider traits

1.3.1 Traits affecting predator-prey feeding interactions

All spiders and many carabid species are polyphagous predators, i.e., feeds on several types of prey, that are commonly found in agricultural landscapes (Lövei & Sunderland 1996; Gallé et al. 2019) and are therefore important for biological control of pests (Sunderland et al. 1987; Kromp 1999; Marc et al. 1999). There are however carabid species that are both omnivorous, i.e., feeds on both arthropods and plant material, and those that are phytophagous, i.e., feeds on plant material mainly seeds, as well (Lövei & Sunderland 1996; Sunderland & Samu 2000), and carabids therefore also play a role in the control of weeds through weed seed predation (Westerman et al. 2003). The diet traits can affect the pest control of carabids differently and tend to react differently to agricultural management and land use intensity (Gobbi & Fontaneto 2008; Hanson et al. 2016; Gallé et al. 2019).

Spiders hunting mode can have important effects on predator-prey interactions and has the potential to predict top-down control of crop pests (Schmitz 2009). The hunting mode of predators such as spiders also affects the pests in different ways (Schmitz 2007). Roaming, actively hunting predators exert highly variable predation risk cues, and are therefore unlikely to cause any persistent behavioral responses in their prey. In contrast, ambush predators can apart from reducing the prey density, cause largely evasive behavioral responses in their prey since prey species respond to persistent, point-source cues of predator presence (Schmitz 2007). There is also a possibility for web-building spiders to have an additional accidental effect on pest control by small pests being caught and dying in the webs regardless of if the spider consumes them or not (Sunderland & Samu 2000).

Another important life-history trait in determining the strength and type of interactions between species within food webs is body size (Woodward et al. 2005; Schneider et al. 2012). Body size is also an important predictor for pest consumption since large species consume higher amounts of larger pests (Williams et al. 2010; Rusch et al. 2015). There is a hump-shaped relationship between predator-prey body mass ratios and predation rates with the highest predation rates at optimal body mass ratios and decreasing feeding rates towards larger and smaller predator-prey body mass ratios (Brose 2010). How efficient a predator exploits a prey of a certain size is therefore related to the size of the predator (Brose 2010; Schneider et al. 2012).

Negative relationships have been found between predation rates of pests and the community average body size of carabids and spiders (Rusch et al. 2015). One possible explanation for this is an increase in intraguild predation where predators feed on other predators. When the average body size of predator communities increases while the prey remains the same size, the larger predator species are expected to exploit smaller predators or larger alternative prey. The motifs within the food web might therefore change from exploitative competition to intraguild predation (Schneider et al. 2012) which would reduce the interaction strengths with basal prey (Rusch et al. 2015). There can be high levels of intraguild predation in arable fields between carabids and spiders. *Pterostichus melanarius*, a relatively large carabid, have for example been found to consume a high amount of the relatively small linyphiid spiders (Davey et al. 2013).

1.3.2 Traits affecting predator dispersal ability

Carabids can be both macropterous, i.e., have fully formed wings, brachypterous, i.e., have very reduced wings resulting in a lack of flight ability, or be dimorphic, i.e., having either fully formed wings or very reduced wings (Lövei & Sunderland 1996). Wing dimorphism in carabids appears to be inherited through a dominant gene for brachyptery and seems to be influenced by environmental conditions (Aukema 1990). The proportion of flightless individuals in dimorphic carabid species increases with increasing habitat persistency and time since colonization (den Boer et al. see Lövei & Sunderland 1996). Being able to fly highly impacts the dispersal ability of the carabid species and affects how it will respond to disturbance (Hanson et al. 2016). Brachypterous carabids tend to be larger than macropterous species. There also seems to be a positive relationship between traveling distances

and body size, especially for brachypterous species, meaning that larger wingless carabids would have a higher dispersal ability compared to smaller sized wingless carabids (Gutiérrez & Menéndez 1997).

1.4 Aim and hypothesis

The aim of this master thesis is to provide an insight in how organic amendments, such as manure and incorporation of perennial crops, such as ley, into a crop rotation, affects the proportion of traits associated with the delivery of ecosystem services within spider and carabid communities. This study focuses on the traits diet, body size and wing morphology of carabid species, as well as hunting mode and body size of spider species. Additionally, the variation in proportion of traits during the season is examined. The aim is further to contribute to the understanding of how changes in trait composition can affect ecosystem services, provided by carabids and spiders, necessary for sustainable agriculture.

I hypothesize that (1) more diet specialized species will benefit from diversification, carnivorous carabids due to a subsidized detrital soil fauna by organic amendments and phytophagous carabids due to a legacy effect of an increased availability and variety of plant-derived food resources during periods with ley. The proportion of carnivorous and phytophagous carabids is therefore expected to increase in the diversified treatments, i.e., fields with manure and ley in the crop rotation, compared with omnivorous carabids. The (2) proportions of cursorial and web-weaving spiders are however not expected to differ significantly between treatments as they are both expected to benefit from added organic amendments. I further hypothesize that (3) the proportion of macropterous carabids is higher in less diverse treatments due to a higher need to disperse to find suitable habitats. I expect there to be a legacy effect of low disturbance in ley on the arthropod community with a higher proportion of brachypterous carabids in fields with ley in the crop rotation.

Carnivorous and phytophagous carabids, as well as both ground runners and sheet-web weaving spiders, are hypothesized to (4) increase later in the season as there is an increase in plant-derived food resources and herbivorous pests. The proportion of omnivores are therefore expected to decrease late in the season as the proportions of carnivorous and phytophagous carabids increases. The proportions of hunting mode traits are expected to remain approximately the same across sampling sessions. The wing morphology and CWM body size is also expected to be unaffected by sampling session.

2. Materials and method

2.1 Study site and design

The study took place in Halland County, Sweden in 2020. Sampling was conducted across three diversification treatments over 19 conventionally farmed fields. The diversification treatments consisted of seven fields with annual crop rotations receiving only mineral fertilizer (MIN), six fields with annual crop rotations treated with organic fertilizer (OnL), and six fields receiving organic fertilizers with three years of consecutive ley in the crop rotation (OL). The organic fertilizers used were manure and liquid manure in both treatments. All three treatments were implemented by the farmers for at least six years. The fields with ley in the crop rotation had been without ley for at least two years at the time of the sampling. This was done in order to study the potential legacy effects of the ley rather than immediate pre-crop effects. The specific plant species present in the ley was not controlled for. Information on specific crop rotations and the locations of study sites can be found in table 4 and figure 1 in the appendix. The percentage of arable land and forest in a 500 m radius around the study sites was calculated and the difference in landscape across treatments was balanced in order to control for the effect of surrounding landscape. Crop data were obtained from the Integrated Administration and Control System (IACS), administered by the Swedish board of Agriculture. Forest cover was estimated using digitalized maps (Lantmäteriet 2018) in ArcMap software version 10.4.1 (ESRI, 2015).

Sampling was conducted at three occasions, 4-10th of May (sampling session 1), 1-8th of June (sampling session 2) and 1-7th of July (sampling session 3), using pitfall traps. The sampling sessions corresponded to the crop stages of tillering, heading, and ripening (Large 1954). An unsprayed area of 25x50 m in which no insecticides were applied, was set up at each study site. Fungicides and herbicides were still applied within the areas in line with conventional farming. The sampling areas were placed either at the field border or inside of the field depending on farmer's needs. Each unsprayed area had two transects containing four pitfall traps each. The transects were placed 4 and 12 meters from the border of the unsprayed areas to avoid the effect of spray drift-off into the sampling area. Placement of transects at the border or inside of the fields was balanced within treatments.

The pitfall traps in the transects were placed approximately 3.5 meters apart giving eight pitfalls per field. The pitfall traps consisted of plastic cups, with 12 cm in diameter and 15 cm in height, containing 200 ml of water containing an odorless

detergent. The pitfalls were operated for four consecutive days during each sampling session. The collected specimen was then stored in 70% ethanol and identified in the lab. Both carabids and spiders were identified to species level.

2.2 Traits

In this study the traits diet, body size and wing morphology of carabids, as well as the hunting mode, body size and ballooning ability of spiders were examined. The carabid traits for diet and wing morphology are divided into three levels each, carnivorous, omnivorous, and phytophagous for diet and brachypterous, dimorphic and macropterous for the wing morphology. The trait hunting mode for spiders are here divided into six levels, ground runners, sheet-web weavers, space-web weavers, orb-web weavers, ground-web ambushers, and ambushers. The body size for spiders are divided into male and female because of the common difference in size between spider sexes (Kuntner & Coddington 2020).

Due to a lack of data by reason of low sampled abundances, a total of seven trait levels were excluded from further analyses. This was the case for brachypterous wings, space-web weavers, ground-web ambushers, orb-web weavers, ambushers and both ballooning ability and no ballooning ability (Appendix, Figure 2-5). This means that the ballooning trait for spiders were excluded altogether, and that the traits wing morphology and hunting mode were both reduced to two trait levels each: dimorphic and macropterous, and ground runner and sheet-web weaving respectively. Additionally, five carabid species and five spider species were excluded because of lack of information regarding the studied traits for the species in question (Appendix, Table 2 & 3). All of the excluded species were considered to have a total abundance low enough to not make a significant change in the results.

Trait data, compiled from several studies and databases (Appendix, Table 1), was provided by Laura Riggi, Guillermo Aguilera Nuñez, Eirini Lamprini Daouti and Fabian Bötzel, and complemented using the World Spider Trait database (Pekár et al. 2021).

2.3 Statistical analyses

Linear mixed models were used to assess the effects of treatment and sampling session on the proportion of traits for both carabids and spiders. The trait levels assessed was carnivore, omnivore, phytophagous, dimorphic, macropterous and community weighted mean (CWM) body size for carabids, and ground runner, sheet-web weaver, and CWM body size for spiders. Diet, hunting mode and wing morphology trait levels were assessed as proportions in each field. The proportion of each trait was calculated by dividing the number of carabids or spiders with a certain trait with the total abundance of carabids or spiders in each field. The CWM body size was calculated by adding the products of the species body size and the corresponding species abundance and then dividing the sum of the products by the total carabid or spider abundance. Models were run for each trait level using gaussian distribution with treatment and sampling session as fixed factors and field

ID included as a random factor (Appendix, Table 5). The model assumptions for all models were checked and validated by testing for under- and overdispersion and inspecting the residual distribution and homogeneity. Parameter significance was tested using Type II Wald chi-square tests. Model summary outputs and estimates were used to check for differences between treatments and sampling sessions. All data were analyzed using R version 4.1.2. (R core Team 2022) and the packages “glmmTMB” (Brooks et al. 2017), “DHARMA” (Hartig 2020) and “car” (Fox and Weisenberg 2019).

3. Results

3.1 Carabids

3.1.1 Diet

In total 31 carnivorous, 3 omnivorous and 13 phytophagous species were found with a total abundance of carnivores of 3379 across treatments (MIN: 1049, OnL: 714, OL: 1616) and sampling sessions (sampling session1: 986, sampling session 2: 800, sampling session 3: 1593). The total abundance of omnivores across treatments (MIN: 574, OnL: 251, OL: 557) and sampling sessions (sampling session1: 286, sampling session 2: 805, sampling session 3: 291) was 1382, and the phytophagous total abundance across treatments (MIN: 419, OnL: 249, OL: 198) and sampling sessions (sampling session1: 113, sampling session 2: 247, sampling session 3: 506) was 866 (Appendix, Table 8).

Treatment had a significant effect on the proportion of carnivorous (chisq = 11.199, df = 2, p = 0.004) and phytophagous carabids (chisq = 11.932, df = 2, p <0.005), but not on the proportion of omnivorous carabids (chisq = 2.816, df = 2, p = 0.245) (Appendix, Table 9). The proportion of carnivorous carabids was higher in the OL compared with the MIN treatment. In contrast, the proportion of phytophagous carabids decreased in the OL treatment in comparison with the MIN treatment. There was no significant difference in proportion of carnivorous and phytophagous carabids between the MIN treatment and the OnL treatment (Table 1).

Sampling session had a significant effect on the proportion of carnivorous (chisq = 61.666, df = 2, p <0.005), omnivorous (chisq = 38.229, df = 2, p <0.005) and phytophagous (chisq = 19.326, df = 2, p <0.005) carabids (Appendix, Table 9). The proportion of carnivorous carabids was the highest during the first sampling session and then decreased during sampling session 2. Between sampling session 2 and 3 the proportion increased, the proportion of carnivores was however still lower in sampling session 3 than in sampling session 1. The proportion of omnivores increased between sampling session 1 and 2, and there was no difference between sampling session 1 and 3. The proportion of phytophagous carabids increased over the season with higher proportions in sampling session 2 and sampling session 3 compared with sampling session 1 (Table 1).

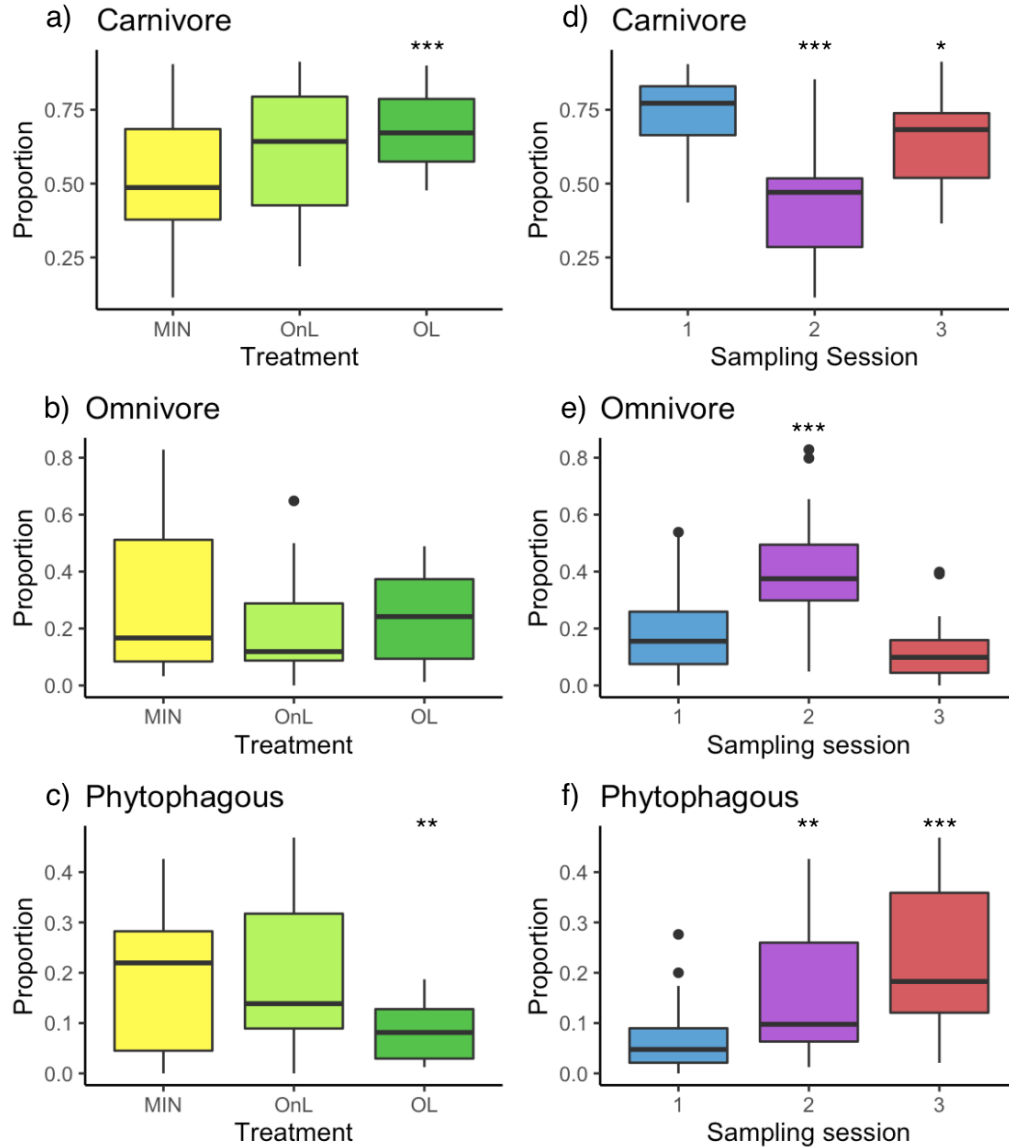


Figure 1. Difference in proportion of the carabid diet trait levels carnivore (a), omnivore (b) and phytophagous (c) across treatments: annual crops and mineral fertilizer (MIN), annual crops and organic fertilizer (OnL), ley in the crop rotation and organic fertilizer (OL), as well as the proportion of carnivores (d), omnivores (e) and phytophagous carabids (f) across sampling sessions: sampling session 1 in May (1), sampling session 2 in June (2), and sampling session 3 in July (3). The boxplots show medians (horizontal line) and 1st and 3rd quartile (upper and lower box limits). The whiskers show either the minimum and maximum values or 1.5 times the difference between the 1st and 3rd quartile and observations outside of the whiskers range are plotted individually. Significance is shown using * ($p < 0.05$), ** ($p < 0.01$) or *** ($p < 0.001$).

3.1.2 Wing morphology

13 species of dimorphic carabids with the total abundance of 2431 across treatments (MIN: 778, OnL: 448, OL: 1205) and sampling sessions (sampling session 1: 861, sampling session 2: 452, sampling session 3: 1118), and 26 macropterous species with a total abundance of 3088 across treatments (MIN: 1243, OnL: 711, OL: 1134) and sampling sessions (sampling session 1: 519, sampling session 2: 1372, sampling session 3: 1197) were found.

Treatment had an effect on the proportion of dimorphic ($\text{chisq} = 10.534$, $\text{df} = 2$, $p = 0.005$) and macropterous ($\text{chisq} = 10.534$, $\text{df} = 2$, $p = 0.025$) carabids (Appendix, Table 9). The OL treatment had a higher proportion of carabids with dimorphic wings compared with the MIN treatment. In contrast, the proportion of carabids with macropterous wings was lower in the OL treatment compared with the MIN treatment. There was no difference in proportion of wing morphology traits between the MIN treatment and the OnL treatment (Table 1).

The proportion of dimorphic ($\text{chisq} = 64.040$, $\text{df} = 2$, $p < 0.005$) and macropterous ($\text{chisq} = 64.836$, $\text{df} = 2$, $p < 0.005$) carabids changed over the season (Appendix, Table 9). The proportion of dimorphic carabids was the highest during sampling session 1 and decreased during sampling session 2. Sampling session 3 had a higher proportion of dimorphic carabids than sampling session 2 but still decreased compared with sampling session 1. The macropterous trait level had the opposite pattern with an increase in proportion for sampling session 2 and sampling session 3 compared to sampling session 1 (Table 1).

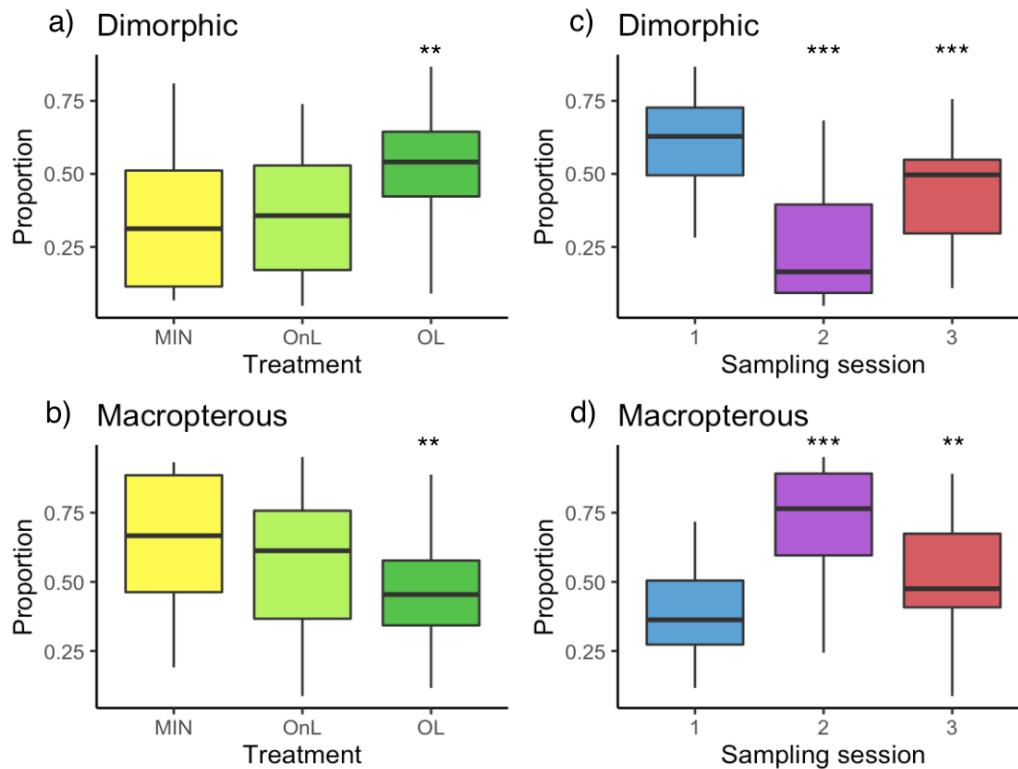


Figure 2. Difference in proportion of the carabid wing morphology trait levels dimorphic (a) and macropterous (b) across treatments: annual crops and mineral fertilizer (MIN), annual crops and organic fertilizer (OnL), ley in the crop rotation and organic fertilizer (OL), as well as the proportion of dimorphic (c) and macropterous carabids (d) across sampling sessions: sampling session 1 in May (1), sampling session 2 in June (2), and sampling session 3 in July (3). The boxplots show medians (horizontal line) and 1st and 3rd quartile (upper and lower box limits). The whiskers show either the minimum and maximum values or 1.5 times the difference between the 1st and 3rd quartile and observations outside of the whiskers range are plotted individually. Significance is shown using * ($p < 0.05$), ** ($p < 0.01$) or *** ($p < 0.001$).

3.1.3 CWM body size

There was no significant effect of treatment on the CWM body size (chisq = 0.718, df = 2, $p = 0.698$) however, sampling session did have an effect (chisq = 127.259, df = 2, $p < 0.005$) (Appendix, Table 9). The CWM body size increased between the first sampling session and sampling session 2 and 3 (Table 1).

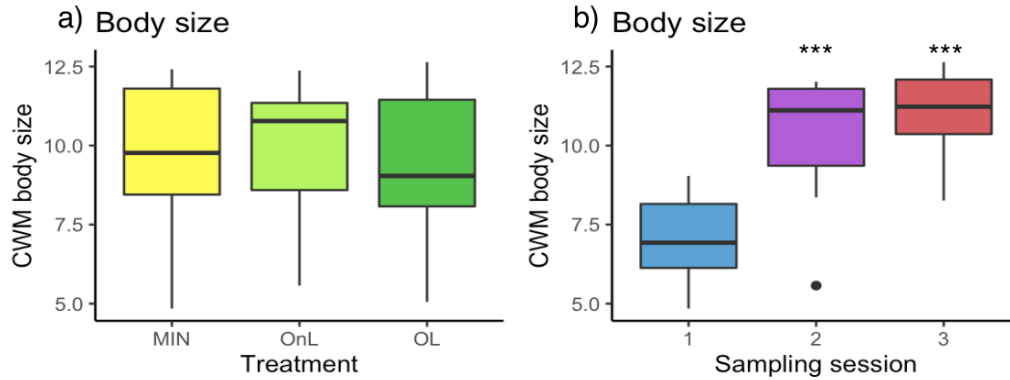


Figure 3. Difference in carabid CWM body size across treatments (a): annual crops and mineral fertilizer (MIN), annual crops and organic fertilizer (OnL), ley in the crop rotation and organic fertilizer (OL), and sampling sessions (b): sampling session 1 in May (1), sampling session 2 in June (2), and sampling session 3 in July (3). The boxplots show medians (horizontal line) and 1st and 3rd quartile (upper and lower box limits). The whiskers show either the minimum and maximum values or 1.5 times the difference between the 1st and 3rd quartile and observations outside of the whiskers range are plotted individually. Significance is shown using * ($p < 0.05$), ** ($p < 0.01$) or *** ($p < 0.001$).

Table 1. Summary table showing the model estimates and *p* values for the carabid trait levels as well as the marginal and conditional r^2 values for each model. Significant *p* values are bold and marginally significant ($0.05 < p < 0.1$) in italic.

<i>Predictors</i>	Carnivore		Omnivore		Phytophagous		Dimorphic		Macropterous		CWM body size	
	<i>Estimates</i>	<i>p</i>	<i>Estimates</i>	<i>p</i>	<i>Estimates</i>	<i>p</i>	<i>Estimates</i>	<i>p</i>	<i>Estimates</i>	<i>p</i>	<i>Estimates</i>	<i>p</i>
(Intercept)	0.64	<0.001	0.25	<0.001	0.11	0.002	0.54	<0.001	0.47	<0.001	7.27	<0.001
Treatment [OL]	0.20	0.001	-0.08	0.243	-0.12	0.002	0.21	0.002	-0.21	0.006	-0.52	0.433
Treatment [OnL]	0.11	<i>0.052</i>	-0.11	0.103	-0.01	0.837	0.04	0.552	-0.08	0.290	-0.10	0.871
Sampling Session [2]	-0.31	<0.001	0.22	<0.001	0.10	0.007	-0.37	<0.001	0.36	<0.001	3.37	<0.001
Sampling Session [3]	-0.10	0.020	-0.06	0.216	0.16	<0.001	-0.19	<0.001	0.14	0.002	3.89	<0.001
Observations	53		53		53		53		53		53	
Marginal R ² / Conditional R ²	0.532 / 0.666		0.387 / 0.533		0.367 / 0.394		0.537 / 0.685		0.491 / 0.709		0.577 / 0.773	

3.2 Spiders

3.2.1 Hunting mode

18 ground running spider species and 16 species of sheet-web weaving species were found in total. Ground runners had a total abundance of 1768 across treatments (MIN: 708, OnL: 486, OL: 574) and sampling sessions (sampling session 1: 432, sampling session 2: 520, sampling session 3: 816), and the total abundance of sheet-web weavers found across treatments (MIN: 254, OnL: 162, OL: 198) and sampling sessions (sampling session 1: 212, sampling session 2: 94, sampling session 3: 308) was 614.

Treatment had no significant effect on the proportion of ground runners ($\text{chisq} = 0.049$, $\text{df} = 2$, $p = 0.975$) or sheet-web weavers ($\text{chisq} = 0.049$, $\text{df} = 2$, $p = 0.976$). Sampling session did however have a significant effect on both ground runners ($\text{chisq} = 12.458$, $\text{df} = 2$, $p = 0.002$) and sheet-web weavers ($\text{chisq} = 12.268$, $\text{df} = 2$, $p = 0.002$) proportion (Appendix, Table 9). The proportion of ground runners was the lowest during sampling session 1 and increased in sampling session 2 and sampling session 3 compared with sampling session 1. The result was consequently the opposite for sheet-web weaving spiders with the proportion being lower in sampling session 2 and 3 compared with sampling session 1 (Table 2).

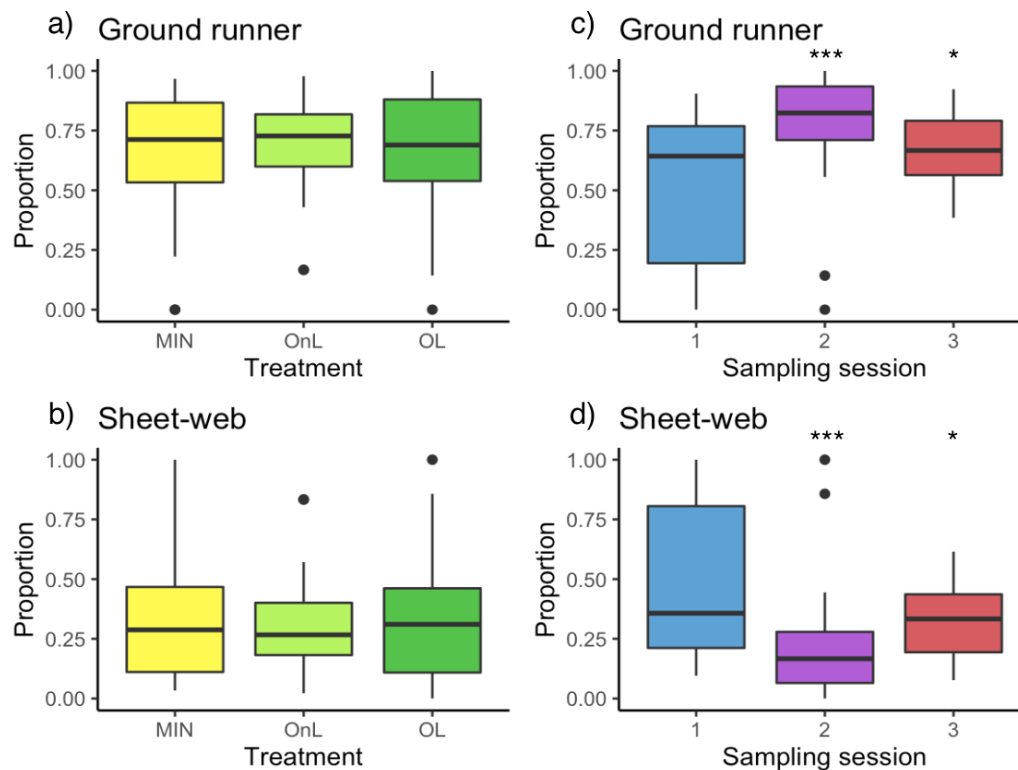


Figure 4. Difference in proportion of the spider hunting mode trait levels ground runner (a) and sheet-web (b) across treatments: annual crops and mineral fertilizer (MIN), annual crops and

organic fertilizer (OnL), ley in the crop rotation and organic fertilizer (OL), as well as the proportion of ground runners (c) and sheet-web weavers (d) across sampling sessions: sampling session 1 in May (1), sampling session 2 in June (2), and sampling session 3 in July (3). The boxplots show medians (horizontal line) and 1st and 3rd quartile (upper and lower box limits). The whiskers show either the minimum and maximum values or 1.5 times the difference between the 1st and 3rd quartile and observations outside of the whiskers range are plotted individually. Significance is shown using * ($p < 0.05$), ** ($p < 0.01$) or *** ($p < 0.001$).

3.2.2 CWM body size

The CWM body size for female spiders was slightly higher than male spiders for both all treatments and sampling sessions. There was no significant difference in CWM body size for male (chisq = 3.851, df = 2, $p = 0.1456$) or female spiders (chisq = 2.174, df = 2, $p = 0.337$) between treatments. Sampling session explained both male CWM body size (chisq = 61.614, df = 2, $p < 0.005$) and female CWM body size (chisq = 57.122, df = 2, $p < 0.005$) (Appendix, Table 9). The CWM body size for both male and female spiders was higher during sampling session 2 compared with sampling session 1. There was no difference in CWM body size for either male or female spiders between sampling session 1 and 3 (Table 2).

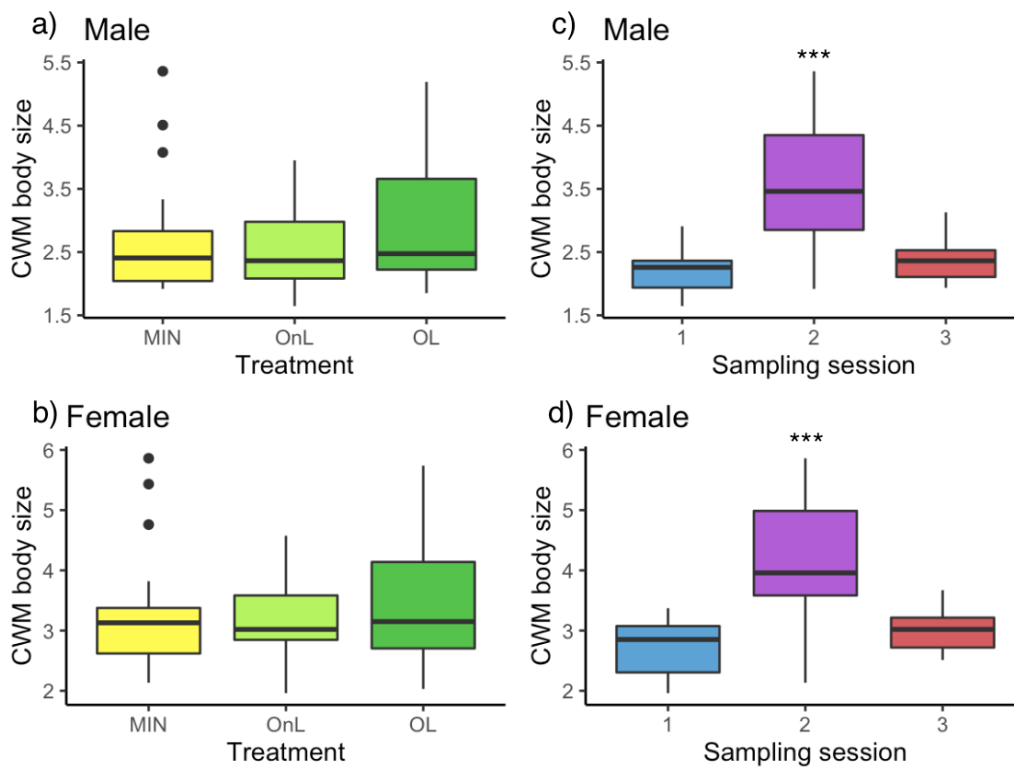


Figure 5. Difference in spider CWM body size for male (a) and female (b) spiders across treatments: annual crops and mineral fertilizer (MIN), annual crops and organic fertilizer (OnL), ley in the crop rotation and organic fertilizer (OL), as well as male (c) and female (d) spiders across sampling sessions: sampling session 1 in May (1), sampling session 2 in June (2), and sampling session 3 in July (3). The boxplots show medians (horizontal line) and 1st and 3rd quartile (upper and lower box limits). The whiskers show either the minimum and maximum values or 1.5 times the difference between the 1st and 3rd quartile and observations outside of the whiskers range are plotted individually. Significance is shown using * ($p < 0.05$), ** ($p < 0.01$) or *** ($p < 0.001$).

Table 2. Summary table showing the model estimates and *p* values for each spider trait level as well as the marginal and conditional r^2 values for each model. Significant *p* values are bold.

	Ground runner		Sheet-web		CWM body size M		CWM body size F	
<i>Predictors</i>	<i>Estimates</i>	<i>p</i>	<i>Estimates</i>	<i>p</i>	<i>Estimates</i>	<i>p</i>	<i>Estimates</i>	<i>p</i>
(Intercept)	0.52	<0.001	0.47	<0.001	2.22	<0.001	2.75	<0.001
Treatment [OL]	0.00	0.983	0.00	0.969	0.20	0.391	0.14	0.605
Treatment [OnL]	0.02	0.840	-0.02	0.867	-0.25	0.271	-0.24	0.350
Sampling Session [2]	0.22	<0.001	-0.23	<0.001	1.39	<0.001	1.46	<0.001
Sampling Session [3]	0.13	0.040	-0.13	0.046	0.17	0.398	0.30	0.147
Observations	53		53		53		53	
Marginal R^2 / Conditional R^2	0.119 / 0.535		0.120 / 0.518		0.532 / 0.590		0.492 / 0.582	

4. Discussion

4.1 Treatment

4.1.1 Carabids

Diet

The proportion of carnivorous carabids was higher in the OL treatment compared with the MIN treatment, which is likely explained by the promotion of detrital soil fauna by the added organic amendment and consequently higher SOM, which can provide a higher variety and abundance of prey (Chen & Wise 1999; Halaj & Wise 2002; Riggi & Bommarco 2019; Rowen et al. 2019). The detrital soil fauna can act as a supplemental food resource during periods where other prey such as pests are scarce and therefore enhance the predator community.

The increase in proportion of carnivores in the OnL treatment was marginally significant. The OnL treatment not having as strong of an effect on the carnivorous diet trait as the OL treatment could be due to a difference in quality of the added organic matter (Riggi & Bommarco 2019). The carbon and nitrogen levels of the soil as well as soil pH affects microorganisms and soil mesofauna differently, and how types of fertilizer affect organisms depends on taxa. It is therefore not just the amount of SOM that determines the effect of organic amendments on the detrital soil fauna but also the properties of different organic amendments (Viketoft et al. 2021). The organic matter produced by the ley in combination with the organic fertilizer used, might both result in an organic matter of higher quality for detrital soil fauna and higher SOM compared with the SOM in the OnL treatment, and therefore be more beneficial for the detrital community and subsequently the carnivorous carabids. The composition of grass and legumes in the ley can also affect the quality of the SOM (Elgersma & Hassink 1997). The plant species and composition in the ley was however not controlled for in this study.

In contrast to my hypothesis the proportion of phytophagous carabids did not increase with added organic amendments. Ley have a higher diversity of plant species and a higher availability of plant-derived food resources than crop fields, which benefits phytophagous carabids (Hanson et al. 2016). The expectation was that there would be a legacy effect of these benefits on the proportion of phytophagous carabids in the OL treatment. Ley is however used to suppress weeds

by competition (Döring et al. 2017) and consequently reducing the amount of weed seeds produced. There could be a legacy effect of the reduction in weeds and therefore less available seeds for the phytophagous carabids in the OL treatment compared with the other treatments. Regarding a higher variety of seeds potentially being produced during the ley, seeds stop being available to carabids after burial, by for example tillage, or germination (Westerman et al. 2003), and it is likely that the seeds produced during the ley therefore stopped being available to the carabids at the conversion to annual crops and therefore not having an effect on the food availability two years later. Additionally, herbicides were used in all treatments and could limit the weeds available regardless of treatment.

There was no effect of treatment on the proportion of omnivorous carabids. Treatment not having an effect on the proportion of omnivores could simply be because of omnivorous carabids having a niche broad enough to find suitable habitat and food regardless of treatment. The fact that phytophagous carabids were inhibited by added organic amendments also meant that the proportion of omnivores did not necessarily have to decrease as the proportion of carnivores increased. Carabids with more specialized diets such as carnivores and phytophagous carabids appear to be more affected by treatment compared with omnivorous carabids and spiders.

The diet trait levels are dominated by just one or two species each and the results are therefore expected to be driven by the preferences and traits of these species. The carnivorous carabids are dominated by the species *Bembidion lampros* and *Pterostichus melanarius*. The omnivorous trait level almost completely consists of the species *Poecilus cupreus* and the phytophagous carabids consist mainly of *Harpalus rufipes* (Appendix, Figure 2).

Wing morphology

Since the brachypterous wing morphology trait was excluded from the study due to a lack of data, it is difficult to draw any conclusions on the effect of treatment and sampling session on the dispersal ability of carabids. The proportion of dimorphic carabids was higher in the OL treatment, but because the presence of wings is not known no conclusion can be drawn on the carabid dispersal ability at the time of the study. Since the dominating dimorphic species are *B. lampros* and *P. melanarius*, the dominant carnivorous species, one possibility is that the apparent effect of treatment on carabids with dimorphic wings is in actuality because of the diet trait or vice versa. The macropterous trait is however made up of species from different trait levels to a greater degree with the three species of highest abundance being *P. cupreus* (omnivore), *H. rufipes* (phytophagous) and *Nebria brevicollis* (carnivore) (Appendix, Figure 3).

The legacy effect of the lower disturbance in ley and subsequent effect on dispersal ability is most likely low considering the level of disturbance returns to a disturbance level common in a crop rotation with annual crops immediately after the conversion back to annual crops. Brachypterous species might have been more abundant in the ley compared to the annual crops and had higher initial abundance at the conversion back to annual crops. Thus, even if management became more

intensive again, initial high abundances would lead to survival of a greater net amount of brachypterous species after disturbance. This legacy might however diminish after two years.

The surrounding environment could also impact the result. Ground beetle species with good flight ability tend to increase with increasing distances to semi-natural habitats (Hendrickx et al. 2009) and dispersal ability is expected to affect the chance of survival in fragmented habitats (Henle et al. 2004; Ewers & Didham 2005). A lack of semi-natural habitats with lower disturbance near by the fields might therefore be an explanation for the low amount of brachypterous carabids. The surrounding landscape was controlled for in the study design, but the quality of nearby habitats was not assessed.

CWM body size

As hypothesized, there was no difference in CWM body size across treatments. Carnivorous carabids tend to be larger than phytophagous carabids (Gobbi & Fontaneto 2008), in this study however most of the dominant species regardless of trait level are of similar size (Appendix, Table 6). Additionally, since the brachypterous trait was excluded from the study one aspect that could have affected the CWM body size was also excluded. The changes in proportions of the other trait levels would therefore not affect the result of the CWM body size.

Because of the few dominant species and them being similar in size, CWM that is weighted by abundance might not give the most representative result. One option to reduce the impact of dominant species could have been to divide the body sizes into classes and calculate proportions similar to the other traits in this study, or to remove the most abundant species, assess the remaining species pool and compare the results.

4.1.2 Spiders

Hunting mode

The ground runner trait level consists mainly of the species *Oedothorax apicatus*. The sheet-web weaving spiders are, in contrast to the other traits, not as strongly dominated by one or two species but instead have several species of a more similar abundance (Appendix, Figure 4).

The non-significant effect of treatment on hunting mode could be explained by spiders' tendency to colonize the field from the surroundings and field edges (Sunderland & Samu 2000) and the conditions in the field might therefore be less important compared with arthropods overwintering within the field. Since the vast majority of the spiders found were ballooning spiders (Appendix, Figure 5), they all have the ability to disperse into the field through ballooning. Similarly to the omnivorous carabids, both ground runners and sheet web weavers might have a niche broad enough to find suitable habitats and prey regardless of the treatments. Sheet-web weavers build their webs close to the ground (Sanders et al. 2015) and might therefore benefit from an increase in detrital soil fauna similarly to ground

runners, whereas spiders building their webs higher up in the vegetation might not be affected by the available prey on the soil surface. There is the possibility that spiders living predominantly in the foliar would benefit from mineral fertilizers as they increase plant productivity resulting in an increase of herbivorous pests (Aguilera et al. 2021).

The very low abundance of space-web and orb-web weaving spiders found in the study could be because of the use of pitfall traps. Space-web weaving spiders and orb-web weaving spiders spend a majority of their time higher up in the vegetation (Sanders et al. 2015) and might therefore evade being caught in pitfall traps. For a potentially better representation of the spider community in the field additional sampling methods could be considered.

CWM body size

There was no significant difference in CWM body size for spiders across treatments. Even if the sheet-web weaving spiders found in this study tend to be smaller than the ground runners (Appendix, Table 7), there being no difference in proportion of hunting mode, reflects the lack of significant difference in CWM body size across treatments. Spider species with a larger body size increases in abundance in habitats with lower disturbance (Plath et al. 2021). The lack of significant difference between the treatments could be due to a similar reason to the lack of brachypterous carabids. There might have been a higher abundance of larger spider species in the ley, but the legacy of a higher initial abundance of larger species, and a higher CWM body size, at the conversion to annual crops, could have diminished after two years.

4.2 Sampling session

4.2.1 Carabids

Because of the few dominating species, it is likely that the different proportions of traits over the season is because of the life cycles of the dominating species. *H. rufipes*, as an example, start emerging during spring and then increase in activity during the summer season until august (Ribera et al. 2001), which is consistent with the results. Regardless of the life cycle of the dominant phytophagous species, a higher proportion of seed eating carabids later on in the season could be because of the higher food availability in July compared with May. Compared with May, more plant species have shed their seeds in July (Westerman et al. 2003).

There is an unexpected drop in the proportion of carnivores during sampling session 2. Phytophagous and especially omnivorous carabids do increase during sampling session 2, which affects the proportion of carnivores, however the total abundance of carnivores in sampling session 2 is lower as well. The expectation was rather that the carnivore proportion would follow a similar pattern to the proportion of phytophagous carabids and increase during the season as both diet trait levels would benefit from additional food resources later in the season. The change in

proportions of dimorphic and macropterous carabids could reflect the results for the diet traits.

The increase in carabid CWM body size later on in the season seem to be because of *H. rufipes*, *P. melanarius* and *P. cupreus* all having a mean size of 12 mm or more, and omnivores and phytophagous carabids higher proportion in sampling session 2 or 3.

4.2.2 Spiders

The change in hunting mode proportion during sampling session 2 seems to be driven by the change in the abundance of sheet-web weavers. In contrast to the carabids the change in proportion of traits across sampling sessions does not seem to be explainable by the life cycle of the most abundant species. Among the most abundant sheet-web weaving spider species (Appendix, Figure 4), all are active as adults during the period May-July, with several of them peaking during June (British Archanological Society 2022) and a drop in proportion and total abundance is therefore unexpected. I hypothesized that both ground runners and sheet web weavers would benefit later in the season with more available food resources, and the proportions consequently remaining approximately the same across sampling sessions.

The lower proportion of sheet-web weavers during sampling session 2 does however appear to explain the change in spider CWM body size. The ten spider species found with the lowest average body size are all sheet-web weavers, whereas 9 of the 10 largest species found are ground runners (Appendix, Table 7). The increase in CWM body size during sampling session 2 could therefore be because of the lower proportion of sheet-web weavers and subsequent higher proportion of larger ground runners.

4.3 Implication for crop protection services

A higher proportion of carnivores could mean that there is a stronger top-down control on pests. There is also the possibility of the level of pest control remaining unchanged due to an overabundance of alternative prey (Sunderland & Samu 2000) in the form of detrital soil fauna or intraguild predation on other predators. Roubinet et al. (2017) however, found that DNA of herbivorous pests such as aphids were more frequently detected as prey in carabids and spiders compared with detrital soil fauna and intraguild predation prey, and that aphids became more important prey later in the season when the abundance was higher. Aphids were also detected as prey in carabids and spiders early in the season when the abundance of aphids was low even with a high abundance of detrital soil fauna.

An increase in carnivorous carabids might also influence the intra guild predation since one of the dominant carnivorous species, *P. melanarius*, is known to prey on spiders. There is therefore potentially a higher degree of intraguild predation in the OnL and OL treatments compared to the MIN treatment. The other dominant

carnivorous carabid species, *B. lampros*, is much smaller (Appendix, Table 6) and is therefore not expected to influence the rate of intraguild predation. Intraguild predation between carabids and spiders is unidirectional as the spiders in question are smaller than carabids as well as spiders having difficulties penetrating carabids chitinous exoskeleton (Roubinet et al. 2017).

Due to the negative relationships between predation rates of pests and the community average body size of carabids and spiders as a result of potential intraguild predation (Schneider et al. 2012; Rusch et al. 2015), there is potentially an increased risk of intraguild predation during sampling session 2 and 3 due to the higher CWM body size of carabids. An increase in intraguild predation would reduce the interaction strength with basal prey and inhibit pest control. The higher CWM body size of spiders during sampling session 2 might also affect the intraguild predation of carabids on spiders as the body size ratio between the two changes.

Some sheet web weavers build their webs high up enough in the vegetation to evade predating carabids (Davey et al. 2013), and a higher proportion of ground runners might therefore mean that there is a higher proportion of the spider community exposed to intraguild predation. The high proportion of ground runners both across treatments and over the season could also mean that pests are less likely to have evasive behavioral responses to spiders compared with a high proportion of more stationary web-weaving spiders.

Weed seed predation likely increases during sampling session 2 and 3 as phytophagous carabids increase. The weed seed availability is however also higher during these sampling sessions and the potential for weed seed predation earlier in the season is likely lower as well. The high proportion of dimorphic carabids and low proportion of macropterous carabids in the OL treatment could mean that there is a lower proportion of carabids in that treatment that are able to disperse if needed during instances of disturbance. The carabid community might therefore be more sensitive to disturbance in fields with ley in the crop rotation. Similarly, a higher proportion of macropterous carabids during sampling session 2 could mean that there is a higher proportion of carabids during that sampling session that have the ability to disperse if needed during instances of disturbance. The carabid community might therefore be more sensitive to disturbance in May and July compared with June.

The composition of traits in carabid and spider communities vary over the cropping season and what agricultural practices are done and when during the season, could affect arthropod communities differently depending on the proportion of traits. Having a better understanding of the seasonal variations of arthropod communities can thus be beneficial in determining when to perform agricultural practices and what consequences that has on arthropod communities and the ecosystem services they provide.

There are both uncertainties regarding the actual effect of changed trait proportions on the level of pest control as well as trade-offs between traits. However, Roubinet et al. (2017) study indicates that herbivorous pests continue to be an important part

of carabids and spiders' diet regardless of abundance of detrital soil fauna and potential intraguild predation. Diversified cropping through added organic amendments and incorporating ley in the crop rotation, therefore appears to have the potential to promote arthropod predators and subsequently the level of pest control in the fields. Even if the proportion of phytophagous carabids decreased in the OL treatments, incorporating ley in the crop rotation is by itself a management strategy to reduce the level of weeds without using herbicides. Diversified cropping through added organic amendments and including ley in the crop rotation could, in addition to improving soil health and structure, be valuable measures to promote biological control of insects and weeds, reduce the need of pesticides and support agricultural biodiversity.

4.4 Future research

The interactions within the arthropod food webs, how organic amendments and diversification affects predator communities and their potential control of pest populations are complex. Additional traits, such as overwintering life stages and habitat preferences, as well as the relations between different traits should be examined to get a further understanding of how cropping diversification affects the arthropod communities. Other arthropods such as rove beetles also play a role in pest control (Riggi & Bommarco 2019) but are not as commonly studied as spiders and carabids. Compiling traits for rove beetles and examining how they are affected by cropping diversification would be beneficial to get a better understanding of the arthropod predator community in arable land.

4.5 Conclusion

Carabids with more specialized diets such as carnivores and phytophagous carabids appear to be more affected by treatment compared with omnivorous carabids and spiders. The change in proportion of carabid traits over the season seems to be at least partially due to the life cycles of dominant species. For spiders however, the reason is more unclear. With there being several important traits, as well as trade-offs between them, determining the pest control potential and them reacting differently to agricultural management, determining the result on pest control is difficult. Diversified cropping through organic amendments and including ley in the crop rotation does however have the potential to be valuable measures to promote biological control of insects and weeds, reduce the need of pesticides and support agricultural biodiversity. More research into additional traits, as well as how they are related, is needed to better understand arthropod functional trait's role in providing ecosystem services in different cropping systems. Since the ecosystem services provided by arthropod communities is necessary for sustainable agriculture, it is also essential to do so.

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Popular science summary

Arthropod predators such as carabids and spiders provide agriculture with ecosystem services such as biological pest control. Both carabids and spiders do however, have different traits such as diet preferences, way of hunting, body size, and flight ability that make them react to changes in the field differently. For example, carabids with wings can easily avoid agricultural machines or move out of the field if it is not suitable to their needs anymore. Carabids without wings can't do that as easily. Carabids and spiders that feed on pests, i.e., carnivores, would benefit from a higher amount and variety of prey whereas seed eating carabids would benefit from more available weed seeds. How farmers manage their fields, which changes the conditions in the fields, can therefore affect which carabid and spider traits that are benefitted and consequently the level of pest control. The aim of this study was therefore to examine how cropping diversification in the form of fertilizer choice and adding ley to the crop rotation affects the composition of traits in carabid and spider communities.

Using manure and adding ley to the crop rotation is beneficial to decomposers, and an increase in decomposers in the field provides carnivores with both more prey and a higher variety of prey during the season. Having ley in the crop rotation also adds a period of low disturbance and a higher variety of crops to the crop rotation. Fields with annual crop rotation treated with mineral fertilizer were in this study compared with fields with annual crop rotations treated with manure, and fields with ley in the crop rotation treated with manure. This was done in order to see how adding manure and ley to the crop rotation affects the composition of carabids and spiders with different traits. How the trait proportions changed over the season was also studied and carabids and spiders were sampled in early, mid and late season. The traits examined were diet, wing morphology and body size of carabids as well as hunting mode and body size of spiders.

The results showed that using manure and adding ley to the crop rotation affected traits differently. Carnivores benefitted from manure and ley whereas seed eating carabids and carabids able to fly were disadvantaged. The composition of traits also changed over the season with the average body size of carabids and seed eating carabids increasing later in the season. Carnivores and web-building spiders were lower in the middle of the season compared with early and late season whereas omnivores, flying carabids and actively hunting spiders were higher in the middle of the season. An increase in carnivores and decrease in seed eating carabids could mean that there is a stronger control of pests but a weaker weed control in the fields. A higher average body size of carabids could however weaken the pest control as large carabids tend to feed on smaller spiders. With there being several traits

determining the level of pest control, and there being trade-offs between them, more research on how traits are affected by agricultural management, how they are related to each other, and what effects that has on ecosystem services is needed.

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Appendix

Table 1. Sources used to compile trait data.

Trait	Source
Diet	Homburg et al. 2014; Fournier et al. 2015; Purtauf et al. 2005; Saska et al. 2008, 2019; Honek et al. 2003, 2007; Koprodova et al. 2008; Ribera 2001; Lindroth 1985;
Wing morphology	Ribera 2001; Lindroth 1985; Hendricks et al. 2009
Carabid body size	Ribera 2001; Lindroth 1985; Homburg et al. 2014
Hunting mode	Pekár et al. 2021; Keys
Ballooning	Bell et al. 2005
Spider body size (m & f)	Nentwig et al. 2022; Pekár et al. 2021

Table 2. Excluded carabid species.

Species	Missing trait	Total abundance
Badister bullatus	Wing morphology	2
Broscus cephalotes	Wing morphology	8
Dolichus halensis	Wing morphology	2
Dyschirius globosus	Wing morphology	1
Harpalus signaticornis	Wing morphology	1

Table 3. Excluded spider species.

Species	Missing trait	Total abundance
Halorates reprobis	Ballooning	2
Hilaria excisa	Ballooning	4
Lessertia denticelis	Hunting mode	4
Eratigena atrica	Ballooning	2
Textrix denticulata	Ballooning	2

Table 4. Additional information on field sites 1 to 19. Table contains information on previous crop rotations, type of fertilizers, soil composition (clay, silt, sand), chemical soil parameters (pH) and the proportion of arable land and forest within the respective buffer zones.

Treatment	Field ID	Type of crop	Crop 2019	Crop 2018	Crop 2017	Crop 2016	Crop 2015	Type of fertilizer	pH	SOM	Clay%	Silt%	Sand%	% Forest 500m	% Arable 500m
MIN	2	barley	barley	barley	barley	oat	oat	mineral	6,3	3	20	30	47	19	68
	9	barley	winter wheat	oil seed rape	barley	winter wheat	oat	mineral	6,3	3,5	10	22	64	0	96
	13	barley	sugar beet	winter wheat	winter wheat	oat	barley	mineral	7,1	5,1	6	30	58	8	88
	16	barley	barley	oats	barley	oats	raps	mineral	6,5	5,8	18	44	32	10	83
	17	oat	barley	barley	barley	winter wheat	barley	mineral	6	4,2	< 4	16	78	0	83
	19	oat	winter wheat	winter wheat	winter wheat	fava bean	winter wheat	mineral	6,9	2,7	16	32	49	0	69
OnL	6	barley	winter wheat	potato	winter wheat	oil seed rape	pea	liquid manure	6,1	4,5	10	30	55	14	63
	7	barley	barley	barley	winter wheat	oil seed rape	pea	liquid manure	6,2	3,5	12	30	54	0	93
	8	barley	barley	winter wheat	winter wheat	oil seed rape	winter barley	manure	5,8	4,3	16	47	33	3	85
	10	barley	winter wheat	fava bean	barley	winter wheat	oat	liquid manure	6,3	5,9	< 4	31	60	19	73
	12	barley	barley	kale	winter wheat	potato	barley	manure	5,9	4,9	6	17	72	0	91
	15	barley	rye	barley	triticale	oil seed rape	pea	manure	6,4	4,7	7	20	69	0	77
	18	barley	rye	barley	winter wheat	potato	winter wheat	manure	5,3	6,2	< 4	18	75	3	76
OL	1	barley	oil seed rape	spring wheat	spring wheat	ley	ley	manure	5,5	4,9	7	47	42	30	52
	3	oat	barley	rape	ley	ley	ley	manure	5,4	6,2	< 4	14	79	1	88
	4	barley	spring wheat	ley	ley	ley	spring wheat	liquid manure	5,6	6,8	11	31	52	0	97
	5	barley	spring wheat	ley	ley	ley	spring wheat	liquid manure	5,6	8	< 4	22	69	1	86
	11	barley	barley	winter wheat	oil seed rape	ley	ley	liquid manure	5,9	11,2	< 4	24	63	2	90
	14	barley	winter wheat	winter wheat	ley	ley	ley	liquid manure	6,3	7,9	6	30	56	0	95

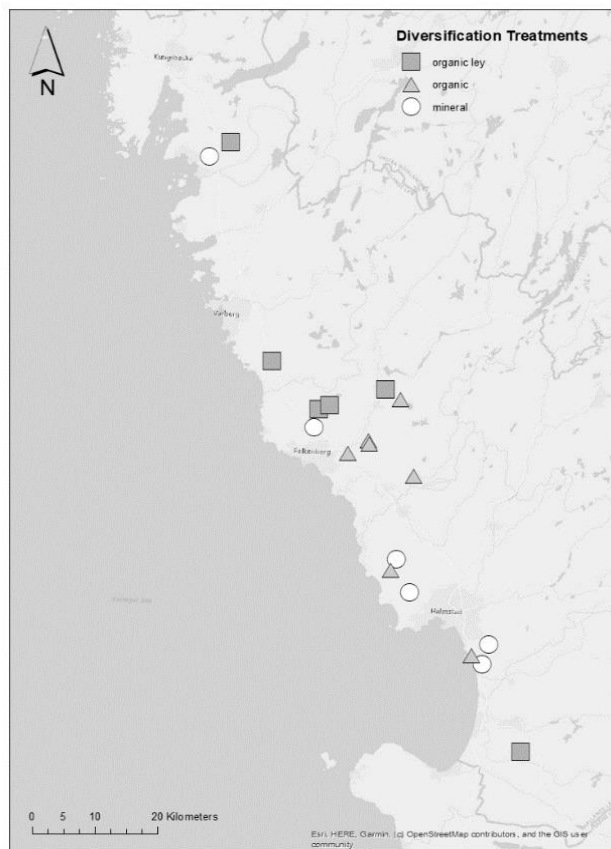


Figure 1. Locations of 19 spring cereal fields in 2020 in Halland, Sweden. Circular Icon represents fields treated with mineral fertilizer rotated with annual crops (MIN), triangular icon represents fields treated only with organic fertilizer being rotated with annual crops (OnL) and rectangular icon represents fields treated with organic fertilizer and being rotated with ley (OL).

Table 5. Example code used in R for the models used to assess carabid and spider trait levels.

	R-code
Carabid traits	<code>C_trait_level<-glmmTMB(proportion_trait_level~ Treatment + Sampling.Session + (1 Field), data=Carabid_Trait, family = gaussian())</code>
Spider traits	<code>S_trait_level<-glmmTMB(proportion_trait_level~ Treatment + Sampling.Session + (1 Field), data= Spider_Trait, family = gaussian())</code>

Figure 2. Total abundance of each carabid species divided into the diet trait levels carnivorous (A), omnivorous (B) and phytophagous (C).

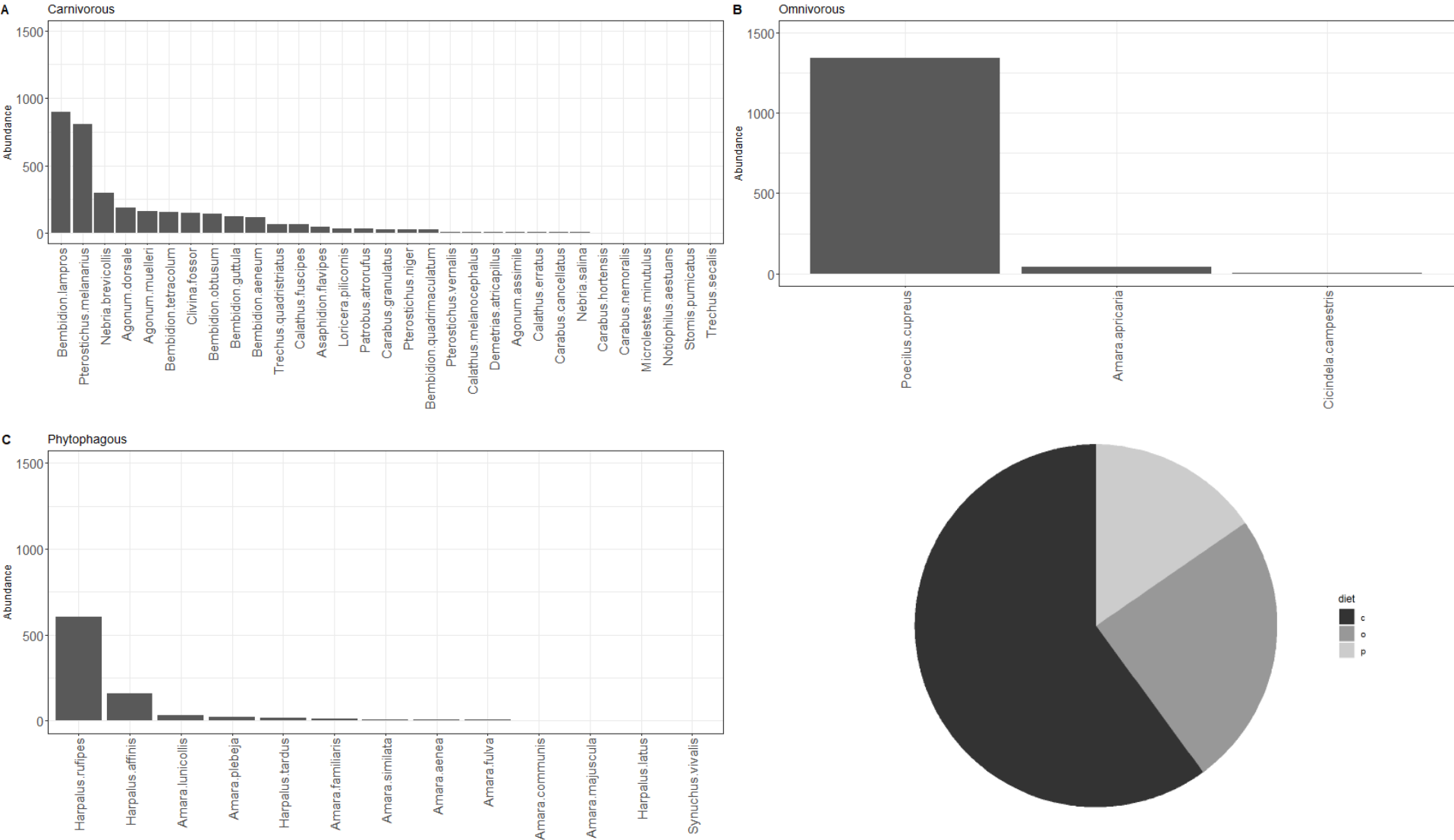


Figure 3. Total abundance of each carabid species divided into the wing morphology trait levels dimorphic (A), brachypterous (B) and macropterous (C).

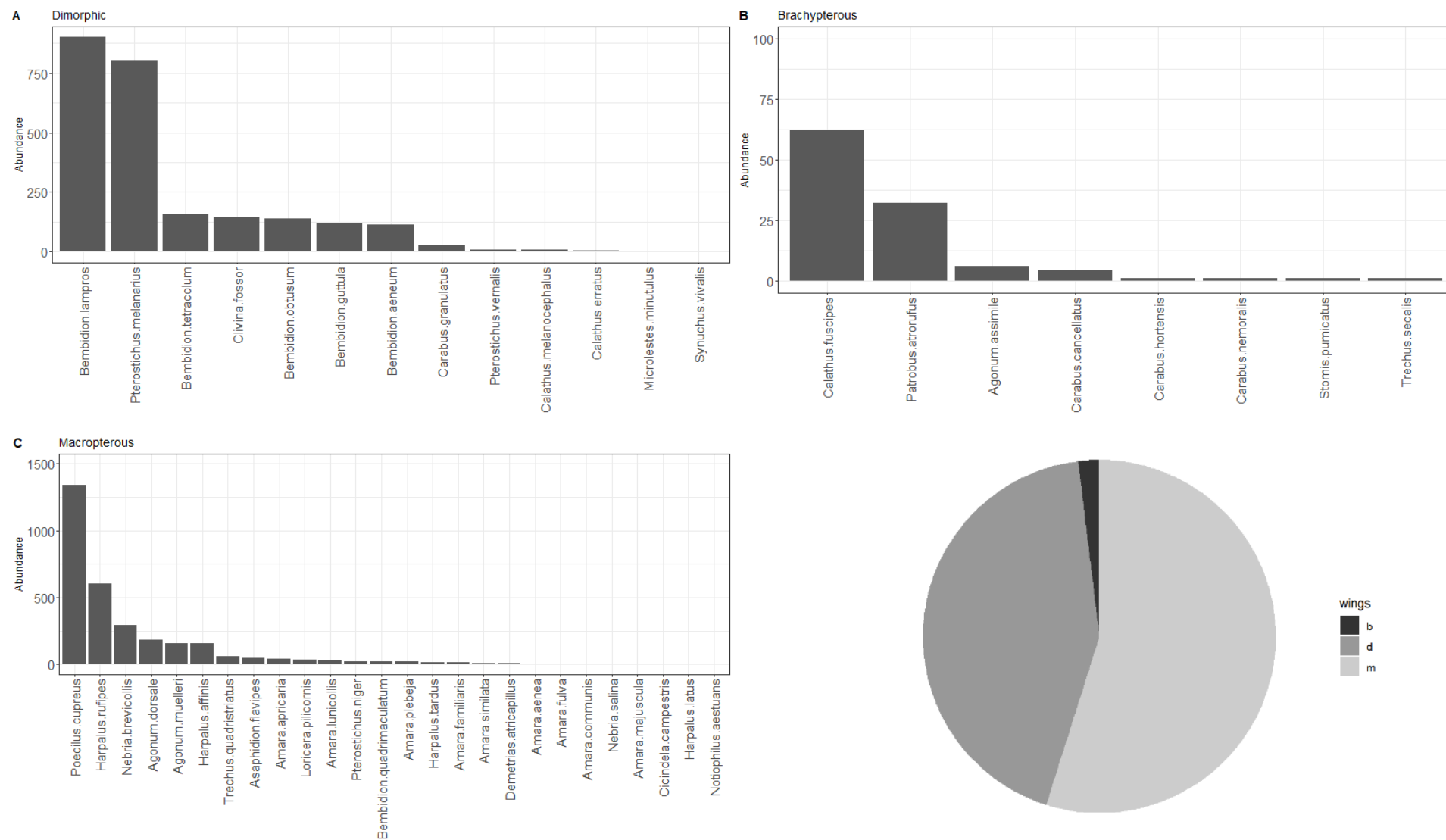


Figure 4. Total abundance of each spider species divided into the hunting mode trait levels space-web (A), sheet-web (B), ground runner (C) and ground-web runner (D). No orb-web weaving or ambusher spiders were found.

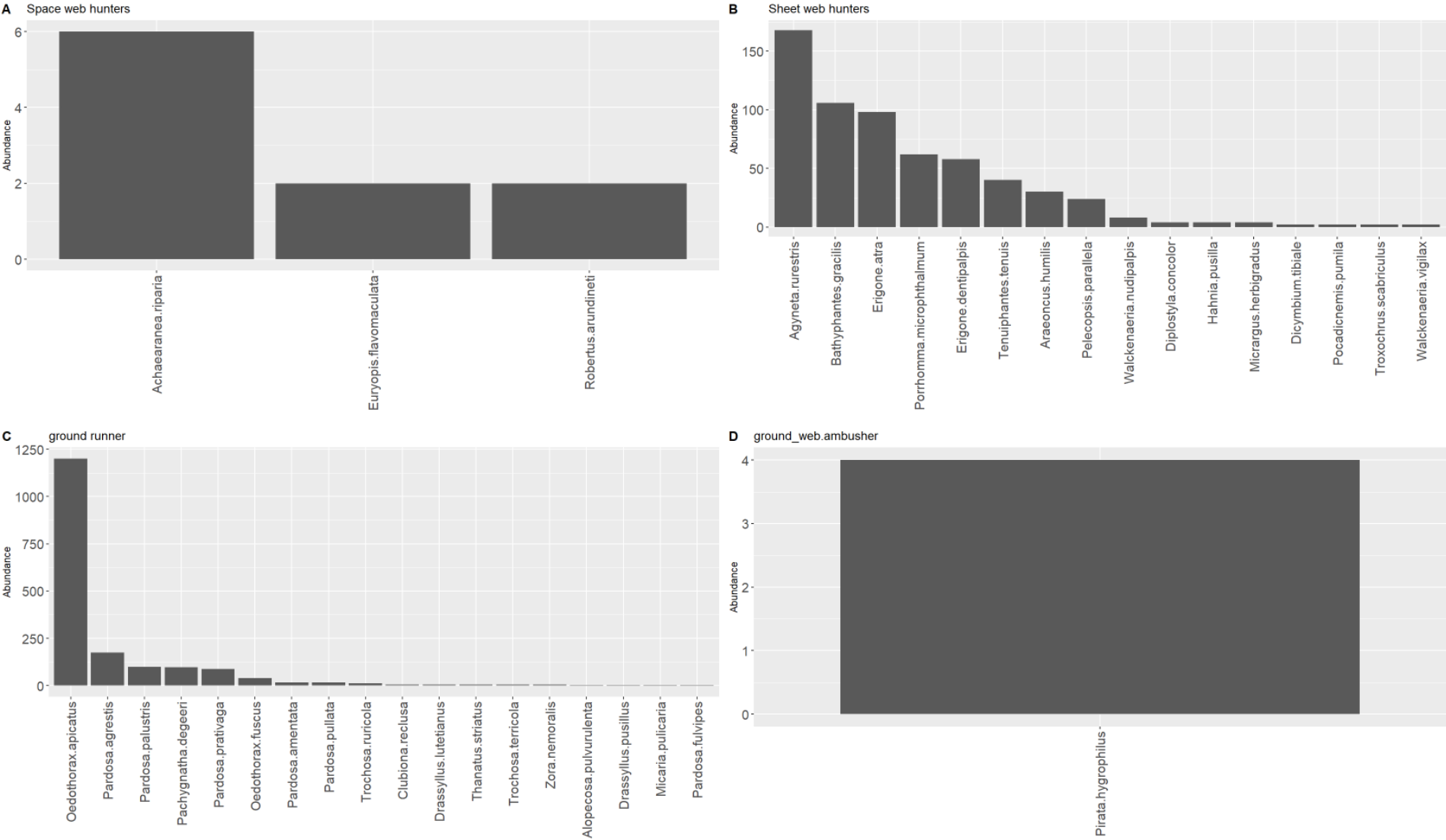


Figure 4. Continuation.

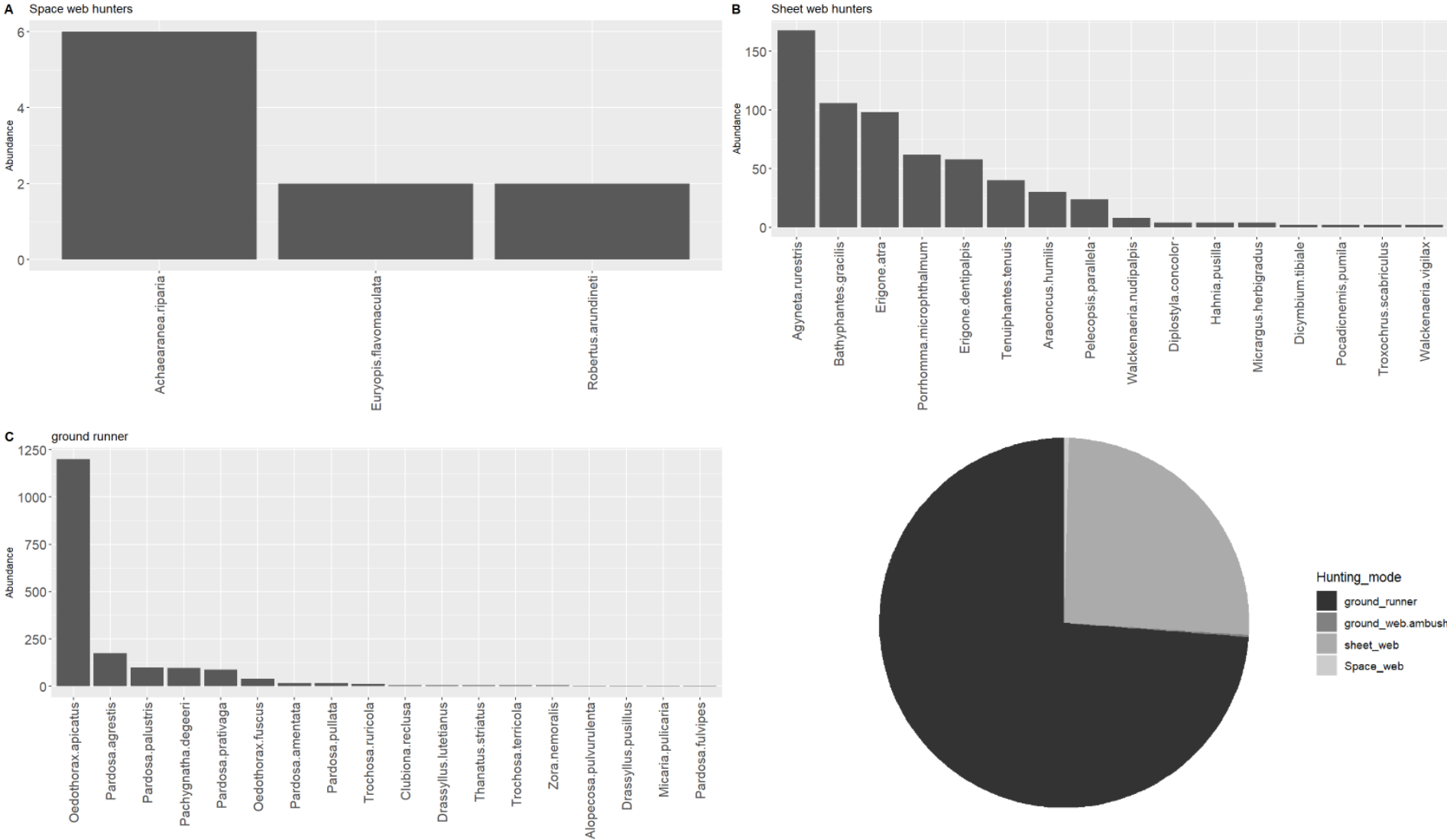


Figure 5. Total abundance of each spider species divided into the ballooning ability trait levels non-ballooning (A) and ballooning (B).

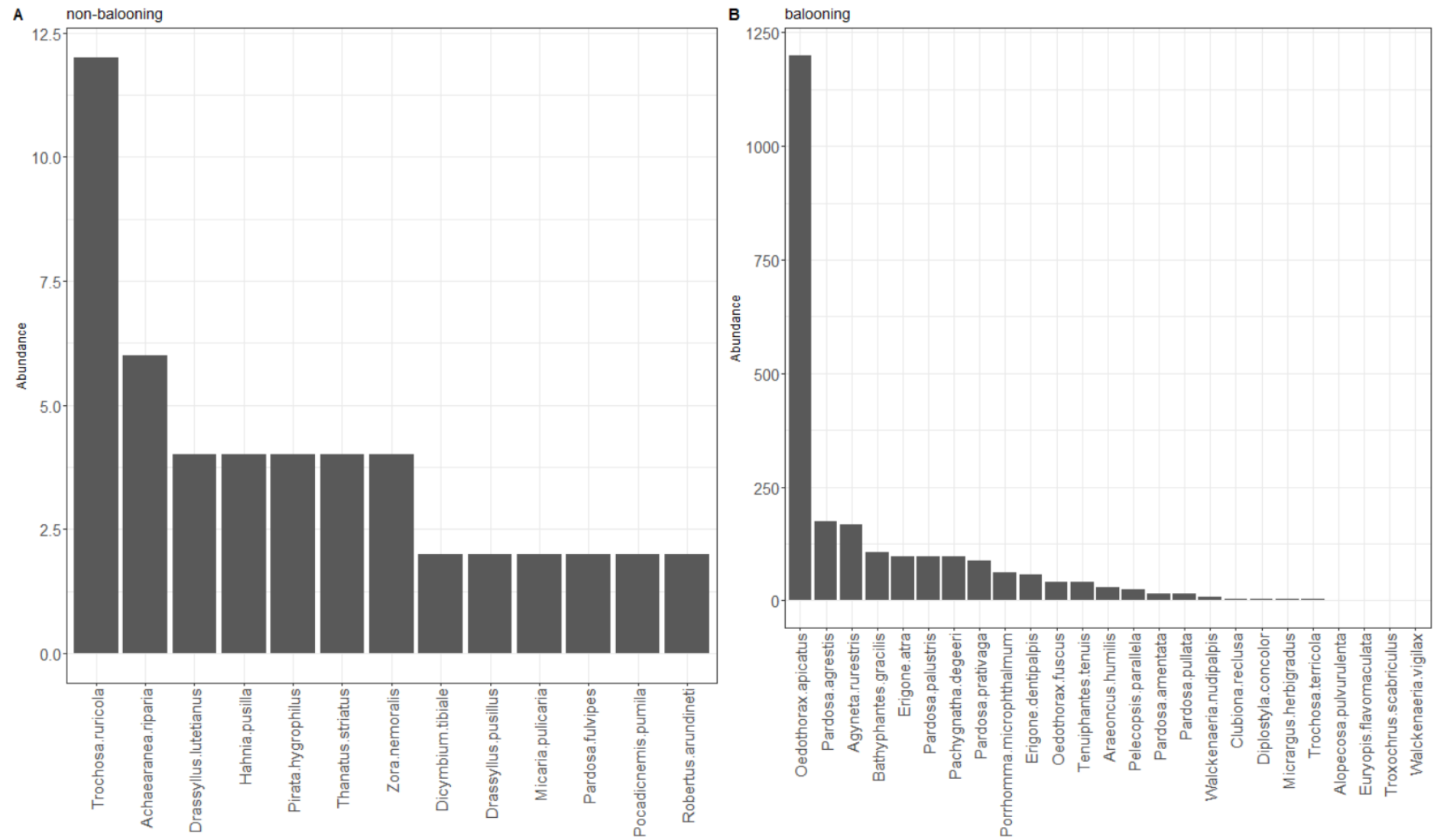


Table 6. *Carabid species mean size (mm).*

Species	Mean size	Species	Mean size
Agonum assimile	11.50	Carabus hortensis	25.00
Agonum dorsale	7.10	Carabus nemoralis	24.00
Agonum muelleri	8.35	Cicindela campestris	14.00
Amara aenea	7.50	Clivina fossor	6.00
Amara apricaria	7.75	Demetrias atricapillus	5.05
Amara communis	6.40	Harpalus affinis	10.25
Amara familiaris	6.40	Harpalus latus	9.60
Amara fulva	9.00	Harpalus rufipes	13.35
Amara lunicollis	8.15	Harpalus tardus	9.70
Amara plebeja	7.05	Loricera pilicornis	7.25
Amara similata	8.90	Microlestes minutulus	3.20
Asphidion flavipes	5.50	Nebria brevicollis	12.00
Bembidion aeneum	3.95	Nebria salina	11.50
Bembidion guttula	3.15	Notiophilus aestuans	4.50
Bembidion lampros	3.17	Patrobus astrorufus	8.70
Bembidion obtusum	3.15	Poecilus cupreus	12.20
Bembidion quadrimaculatum	3.15	Pterostichus melanarius	15.00
Bembidion tetracolum	5.50	Pterostichus niger	17.75
Calathus erratus	10.00	Pterostichus vernalis	6.75
Calathus fuscipes	12.20	Stomis pumicatus	7.55
Calathus melanocephalus	7.40	Synchus vivalis	7.00
Carabus cancellatus	26.00	Trechus quadristriatus	3.75
Carabus granulatus	19.50	Trechus scalis	3.75

Table 7. *Spider species mean size (mm).*

Species	Mean size M	Mean size F	Species	Mean size M	Mean size F
Archaeearanea riparia	3.13	3.35	Pardosa agrestis	4.75	5.00
Agyreta rurestris	1.85	2.09	Pardosa amentata	6.00	6.50
Alopecosa pulvurenta	7.00	9.25	Pardosa fulvipes	4.75	5.50
Araeoncus humilis	1.50	1.70	Pardosa palustris	5.50	6.50
Bathypantes gracilis	1.75	2.20	Pardosa prativaga	5.85	6.35
Clubiona reclusa	5.00	6.50	Pardosa pullata	4.50	5.00
Dicymbium tibiale	2.25	2.35	Pelecopsis. parallela	1.25	1.65
Diplostyla concolor	2.75	2.75	Pirata hygrophilus	5.85	5.85
Drassyllus lutetianus	5.10	6.25	Pocadicnemis pumila	1.90	2.05
			Porrhomma		
Drassyllus pusillus	4.05	4.75	microphthalmum	1.85	1.85
Erigone atra	2.20	2.30	Robertus arundineti	2.13	2.38
Erigone dentipalpis	2.35	2.30	Tenuiphantes tenuis	2.60	3.15
Euryopis flavomaculata	3.05	3.40	Thanatus striatus	3.60	5.35
Hahnia pusilla	1.40	1.40	Trochosa ruricola	8.25	11.00
Micaria pulicaria	3.50	3.60	Trochosa terricola	8.00	10.50
Micrargus herbigradus	2.00	2.15	Troxochrus nudipalpis	2.68	3.20
			Walckenaeria		
Oedothorax apicatus	2.10	3.00	nudipalpis	2.68	3.20
Oedothorax fuscus	2.15	2.55	Walckenaeria vigilax	2.10	2.48
Pachygnatha degeeri	3.25	3.85	Zora nemoralis	3.50	4.70

Table 8. Abundance of trait levels for each treatment and sampling session.

Trait	Trait level	Variable	Abundance
Diet	Carnivore	MIN	1049
		OnL	714
		OL	1616
		Sampling session 1	986
		Sampling session 2	800
		Sampling session 3	1593
	Omnivore	MIN	574
		OnL	251
		OL	557
		Sampling session 1	286
		Sampling session 2	805
		Sampling session 3	291
	Phytophagous	MIN	419
		OnL	249
		OL	198
		Sampling session 1	113
		Sampling session 2	247
		Sampling session 3	506
Wing morphology	Dimorphic	MIN	778
		OnL	448
		OL	1205
		Sampling session 1	861
		Sampling session 2	452
		Sampling session 3	1118
	Macropterous	MIN	1243
		OnL	711
		OL	1134
		Sampling session 1	519
		Sampling session 2	1372
		Sampling session 3	1197
Hunting mode	Ground runner	MIN	708
		OnL	486
		OL	574
		Sampling session 1	432
		Sampling session 2	520
		Sampling session 3	816
	Sheet-web	MIN	254
		OnL	162
		OL	198
		Sampling session 1	212
		Sampling session 2	94
		Sampling session 3	308

Table 9. Analysis of Deviance Table (Type II Wald chisquare tests) for treatment and sampling sessions effect on carabid and spider traits.

Trait	Trait level	Variable	Chisq	Df	Pr(>Chisq)
Diet	Carnivore	Treatment	11.199	2	0.0037**
		Sampling session	61.666	2	4.068e-14***
	Omnivore	Treatment	2.8159	2	0.2446
		Sampling session	38.2289	2	4.997e-09***
	Phytophagous	Treatment	11.932	2	0.002565**
		Sampling session	19.326	2	6.361e-05***
Wing morphology	Dimorphic	Treatment	10.534	2	0.005159**
		Sampling session	64.040	2	1.241e-14***
	Macropterous	Treatment	7.3984	2	0.02474*
		Sampling session	64.8362	2	8.337e-15***
CWM size - Carabid	CWM size	Treatment	0.7179	2	0.6984
		Sampling session	127.2588	2	<2e-16***
Hunting mode	Ground runner	Treatment	0.0498	2	0.975394
		Sampling session	12.4583	2	0.001971**
	Sheet web	Treatment	0.0488	2	0.975913
		Sampling session	12.2683	2	0.002168**
CWM size - Spider	CWM size M	Treatment	3.8506	2	0.1458
		Sampling session	61.6135	2	4.176e-14***
	CWM size F	Treatment	2.1738	2	0.3373
		Sampling session	57.1223	2	3.945e-13***

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