# Microarthropod Community Composition Changes Along a Hedgerow–Field Gradient

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## Resume

Levende hegn kan udgøre vigtige semi-naturlige elementer i landbrugslandskaber, hvor de kan bidrage med variation, levesteder og ressourcer for mange organismer. Deres betydning for jordlevende organismer er dog mindre undersøgt end deres betydning for organismer, der lever over jorden. I dette studie blev det undersøgt, hvordan sammensætningen af jordlevende mikroarthropoder varierede med afstanden til levende hegn i et økologisk landbrugslandskab i Danmark. Derudover blev det undersøgt, om hegnets struktur og vegetation var forbundet med mikroarthropodsamfundene ved hegnskanten, samt hvilke taxa der var knyttet til henholdsvis hegnskanten og de tilstødende marker. Mikroarthropoder blev indsamlet langs transekter fra otte levende hegn ved fire afstande fra hegnskanten; 0, 2, 5 og 50 m. I alt indgik 159 jordprøver i analyserne. Artssammensætningen blev analyseret ved hjælp af PCoA, PERMANOVA, db-RDA og indikatorartsanalyse. Resultaterne viste, at artssammensætningen af mikroarthropoder adskilte sig tydeligst mellem hegnskanten og den tilstødende mark, mens forskellene mellem afstande inde i marken var mindre tydelige. Taxa rigdommen var relativt ens på tværs af afstande, hvilket tyder på, at forskellene primært var relateret til ændringer i taxonomisk sammensætning frem for en stigning i antallet af taxa. Flere taxa var knyttet til hegnskanten, herunder Oribatide og Gamaside mider samt jordlevende Collembola, mens færre taxa var knyttet til marken. Ved hegnskanten var træartsrigdom, urteartsrigdom og hegnsbredde signifikant associeret med variation i mikroarthropodernes artssammensætning.

Samlet set tyder resultaterne på, at hegnskanter og tilstødende marker understøtter forskellige mikroarthropodsamfund. Dette peger på et skift i habitatforhold snarere end en simpel kontrast mellem egnede og uegnede habitater. Levende hegn kan derfor bidrage til underjordisk habitatheterogenitet i landbrugslandskaber, særligt når de er strukturelt og botanisk varierede.

# Abstract

Hedgerows may provide important semi-natural habitats in agricultural landscapes, but their role for belowground communities remains less studied than their importance for aboveground organisms. This study investigated how soil microarthropod community composition varied with distance from hedgerow in a Danish agricultural landscape practicing organic farming. It further examined whether hedgerow structural and vegetation characteristics were associated with community composition at the hedgerow edge, and which taxa were associated with hedgerow edge and adjacent fields habitats. Microarthropods were sampled along transects from eight hedgerows at four distances from the hedgerow edge; 0, 2, 5 and 50 m. In total 159 soil samples were included in the analyses. Community composition was analysed using PCoA, PERMANOVA, db-RDA and indicator species analysis. Microarthropod community composition differed most clearly between the hedgerow edge and the agricultural field, whereas differences among distances in the field were less pronounced. Taxon richness was relatively similar across distances, suggesting that the hedgerow associations were mainly related to changes in taxonomic composition rather than an increase in richness. Several taxa were associated with the hedgerow edge, including oribatid and gamasid mites as well as soil-dwelling Collembola, while fewer taxa were associated with the agricultural field. At the hedgerow edge, tree species richness, herb species richness and hedgerow width were significantly associated with variation in the microarthropod community composition.

Overall, the results suggest that hedgerow edges and adjacent agricultural fields support distinct microarthropod communities, indicating a shift in habitat conditions rather than a simple contrast between suitable and unsuitable habitats. Hedgerows may therefore contribute to belowground habitat heterogeneity in agricultural landscapes, particularly when they are structurally and botanically diverse.

# 1. Introduction

Human land use and agricultural intensification have well-documented negative effects on terrestrial ecosystems and biodiversity loss at both local and global scales (Newbold et al., 2015). Habitat conversion, degradation and fragmentation together with harvesting and pollution, are among the major human pressures reducing species richness and abundance across ecosystems. Current rates of biodiversity loss have raised concerns that human activities are driving the sixth mass extinction event during the Earth's history (Cowie et al., 2022). Agriculture is a central part of this trend because natural and semi-natural habitats are often converted into simplified production systems where primary production is mainly redirected towards human use (Haberl et al., 2007).

Agricultural landscapes often consist of a mosaic of crop fields, semi-natural habitats, human infrastructure and remaining natural habitats, where features such as field margins, ditch banks and hedgerows form important non-crop elements (Marshall & Moonen, 2002). However, continued agricultural intensification, including field enlargement, increased mechanization and the use of pesticides and fertilizers, has simplified many rural landscapes by reducing the amount of natural and semi-natural habitats (Emmerson et al., 2016). Semi-natural habitats have declined in many European countries, particularly during periods of agricultural expansion and intensification, with substantial losses occurring between 1950 and 1980 (Ridding et al., 2020). As semi-natural habitats have declined, remaining non-crop elements such as hedgerows may play an increasingly important role in maintaining habitat heterogeneity and providing habitats and resources for organisms in agricultural landscapes.

Hedgerows are commonly defined as permanent linear landscape elements consisting of trees, shrubs and herbaceous vegetation, often situated along field boundaries in agricultural landscapes (Baudry et al., 2000; Burel, 1996). Historically, hedgerows have served several functions including marking property boundaries, producing wood, enclosing livestock and protecting crops against wind erosion (Baudry et al., 2000). Consequently, hedgerows form part of the cultural heritage of European agricultural landscapes. However, hedgerows have also been removed or degraded in many regions as fields have been enlarged and agricultural landscapes have become more homogenous (Emmerson et al., 2016). Beyond their historical and cultural value, hedgerows may provide important ecological functions in agricultural landscapes. They can offer refuges, shelter and resources for a wide range of taxa, particularly in intensively managed landscapes where resources in the surrounding fields may be limited (Burel, 1996; Kratschmer et al., 2024). By increasing structural complexity and habitat heterogeneity, hedgerows may provide food resources, nesting sites and overwintering habitats for many organisms. Hedgerows can also function as dispersal corridors, increasing connectivity for mobile organisms, and thereby mitigate some effects of habitat fragmentation (Gelling et al., 2007).

In Denmark, hedgerows have mainly been studied in relation to landscape structure and vegetation diversity. For example, plant species composition in Danish hedgerows has been shown to differ between organic and conventional farming systems, indicating that hedgerows are not isolated from the surrounding agricultural landscape, and that their ecological value may be influenced by adjacent land use and management practices (Aude et al., 2003; Burel, 1996). Hedgerows may also differ substantially in structural characteristics such as woody vegetation composition, herbaceous ground layer vegetation and size. Such heterogeneity may be important in simplified farming systems, where surrounding fields often provide more uniform vegetation and experience more frequent disturbance (Graham et al., 2018).

Although hedgerows are often considered aboveground landscape elements, their influence may extend into the soil (Holden et al., 2019). By modifying shading, litter input, soil moisture and disturbance, hedgerows can create soil conditions that differ from those in surrounding fields. However, compared with studies on hedgerow vegetation and aboveground taxa, relatively little is known about how hedgerows affect belowground biodiversity in agricultural landscapes (Graham et al., 2018; Kratschmer et al., 2024). Belowground biodiversity comprises a wide range of organisms, from microorganisms such as bacteria and fungi to nematodes, earthworms and soil arthropods. Together, these organisms form complex soil food webs that are closely linked to aboveground biodiversity and ecosystem functioning (Bardgett & Van Der Putten, 2014).

Soil invertebrates play important roles in these systems by contributing to organic matter decomposition, nutrient cycling and the formation and maintenance of soil structure (Lavelle et al., 2006). Within the soil fauna, mesofauna such as Collembola (springtails) and Acari (mites) represent important groups of microarthropods, as they are abundant and diverse components of soil food webs occurring in most terrestrial habitats worldwide (Neher & Barbercheck, 2019). Collembola are often associated with fungal grazing and consumption of organic matter, thereby contributing to decomposition processes, whereas Acari include a broad range of functional groups, including detritivores, fungivores and predators (Coleman & Crossley, 2018). Through these feeding interactions, soil microarthropods contribute to organic matter decomposition, nutrient cycling and trophic regulation within the soil food web. Because many soil microarthropods respond to changes in moisture, litter input, vegetation structure and disturbance, they may be useful for studying how hedgerows influence belowground communities in agricultural landscapes. Soil microarthropod communities may be useful indicators of soil biological quality (Menta et al., 2018).

Studies have shown major declines in insect biodiversity due to agricultural pressors (Raven & Wagner, 2021). While arthropods are frequently studied in relation to hedgerows, soil microarthropods such as springtails and mites remain underrepresented in the hedgerow literature (Kratschmer et al., 2024). This highlights a gap concerning how hedgerows influence soil microarthropod community composition, particularly in Danish agricultural landscapes. Moreover, it remains unclear whether variation in hedgerow structural characteristics and vegetation composition influences microarthropod communities at the hedgerow edge. Therefore, the aim of this study was to investigate how hedgerows affect microarthropod communities and taxon associations in agricultural landscapes. This study addresses following research questions:

1. Does microarthropod community composition differ with distance from hedgerows and among different hedgerows?
2. Are differences in hedgerow structural and vegetation characteristics associated with variation in microarthropod community composition?
3. Are specific microarthropod taxa associated with the hedgerow edge habitats and adjacent agricultural fields?

## 2. Methods

### 2.1 Study area and design

Data was collected by staff from the AfPEC project (AfPEC, n.d.) close to the Danish town of Gram in Southern Denmark (Figure 1). The eight hedgerows (ID; 9-0, 4-0, 5-0, 6-0, 143-0, 143-1, 144-0 and 535-0) belong to Gram Slot, a Danish organic farm. The hedgerows were selected based on similar soil type, composition and age as well as same crop rotation in the fields (2021-2024 was clover-grass). On the western side of each hedgerow five transects (replicates) approximately 50 meters apart from each other were sampled. Data was collected in the field at the four distances from the edge of each transect; 0, 2, 5 and 50 meters (Figure 2).

*Figure 1: Location of the study area near the town of Gram in southern Denmark. The eight hedgerows included in the study are shown in green.*

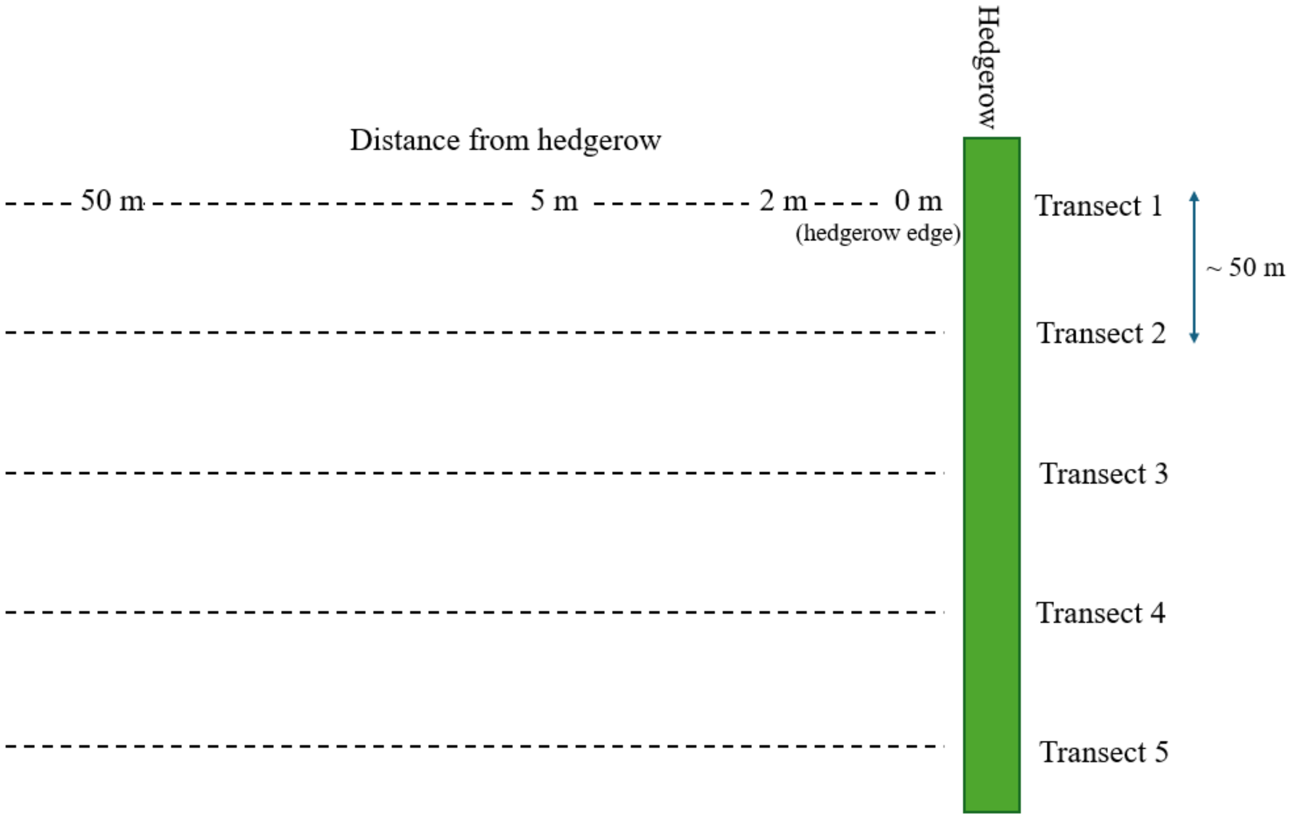

*Figure 2. Sampling design for each hedgerow.*

## 2.2 Data collection

### 2.2.1 Microarthropod sampling

Microarthropods (springtails and mites) were collected in the fall of 2024 from all transects across the eight hedgerows resulting in a total of 160 samples. Each sample was collected using a soil corer fitted with two microcosm tubes (5.5 cm height, 6 cm diameter). Soil cores were taken from the upper soil layer (0-5 cm depth) and deeper soil layer (5-10 cm), sealed with two plastic lids, and kept in the shade in the field before being stored at 5°C overnight. Microarthropods were extracted from soil with a temperature gradient extraction apparatus based on a high-gradient canister extractor (Petersen, 1978) over a period of 4-5 days. The gradual drying forced organisms to migrate downward into a collecting solution of benzoic acid. After extraction the samples were stored in glycerol until identification and counting. Microarthropods were identified and counted by specialists at Aarhus University using a stereomicroscope and a counting program. Mites were identified to order level, whereas springtails were primarily identified to species or genus level with some identified to family or order level. When samples contained a high number of individuals, they were counted using a GLP counting tray and afterwards multiplied by a correction factor of 5.37.

### 2.2.2 Hedgerow structure and vegetation sampling

Structural characteristics were recorded for each hedgerow during the summer of 2024. At each transect, hedgerow height and width were measured from the field edge. In addition, the amount of dead wood was estimated on an ordinal scale from 0 (no dead wood) to 5 (high amount of dead wood). Tree data were collected within a 20 m section along each hedgerow, with 10 m on each side of each transect. Trees were identified to species level and DBH (diameter at breast height, i.e. 130 cm above ground level) was measured for trees with a DBH greater than 5 cm. Multi-stemmed individuals were measured separately for each stem. Basal area was calculated for each stem. The species composition of the herbaceous vegetation layer was assessed using ten 1 $m^2$ quadrats with five samples placed at the hedgerow edge (0 m) and five samples in the center of the hedgerow. In each plot, all vascular plant species, including herbs and small trees below 130 cm, were identified to species level and recorded as either present or absent

## 2.3 Data preparation

All data were organized by hedgerow ID, transect and distance from hedgerow edge. For the microarthropod dataset, abundances from the upper and deeper soil layers were combined to obtain a total abundance per sampling point. Sample quality was assessed based on notes from laboratory processing. One sample was lost during extraction (hedgerow 143-0, transect 2, distance 2 m) and was therefore treated as missing data, and excluded from further analyses. Other technical issues such as dried or missing glycerol and excess organic matter were retained but noted using quality flags. For analyses combining microarthropod and hedgerow structure data, only samples present in both datasets were retained. Accounting for the one lost sample, the final datasets consisted of 159 samples.

Based on the tree data, following parameters were calculated and used for later analyses; number of stems, number of individuals, tree species richness, mean diameter, standard deviation of diameter, total basal area, mean basal area and tree Shannon diversity.

Presence/absence data for herbaceous vegetation layer was processed by pooling the ten quadrants for each hedgerow ID and transect. Species frequency was then calculated as:

$$Frequency = \frac{Number\ of\ quadrants\ with\ species\ present}{Total\ number\ of\ quadrants}$$

Based on the frequency data following herb-layer parameters were calculated; herb species richness, herb Shannon diversity and herb Simpson diversity.

## 2.4 Data analyses

### 2.4.1 Biodiversity patterns

To provide an overview of the biodiversity patterns of the microarthropod communities across distances to hedgerows and among different hedgerows, taxon richness and total abundance were calculated. Taxon richness was defined as the number of taxa with non-zero abundance values, while total abundance was calculated as the summed abundance of all taxa within each sample. Richness and abundance patterns were visualized using boxplots with jittered sample points colored according to distance from the hedgerows.

### 2.4.2 Community composition and ordination analysis

Prior to multivariate analyses, microarthropod abundance data were log-transformed using log(x + 1) to reduce the influence of highly abundant taxa. To create a low dimensional visualization of the microarthropod community data, a Principal Coordinate Analysis (PCoA) was performed based on Bray-Curtis dissimilarity matrices (Bray & Curtis, 1957). Separate PCoA plots were produced to visualize differences and potential clustering in microarthropod community composition across distances from hedgerows and among hedgerows. Group centroids and confidence ellipses were added to illustrate the central position and variation within groups.

Differences in microarthropod community composition between hedgerows and distances to hedgerows were tested using Permutational Multivariate Analysis of Variance (PERMANOVA) implemented in the vegan R package (Oksanen et al., 2026). Prior to PERMANOVA, homogeneity of multivariate dispersion was assessed using the betadisper() function (Oksanen et al., 2026) to evaluate whether group dispersions differed significantly. PERMANOVA analyses were conducted using adonis2() function with 999 permutations constrained within hedgerows (strata = hedgerow) to account for non-independence among samples collected within the same hedgerow. Separate analyses were performed for distance categories and hedgerow ID. Pairwise PERMANOVA tests were subsequently performed as post hoc analyses using the adonis2() function (Oksanen et al., 2026) to compare differences between individual distance groups (0, 2, 5 and 50 m) as well as between the eight different hedgerows. For distance comparisons permutations were restricted within hedgerows. To account for multiple pairwise comparisons, p-values were adjusted using Holm correction (Holm, 1979).

### 2.4.3 Influence of hedgerow structure on community composition

To investigate how the hedgerow structural characteristics influenced microarthropod community composition at the hedgerow edge, a distance-based redundancy analysis (db-RDA) was conducted using the dbrda() function in the vegan R package (Oksanen et al., 2026). The analysis was restricted to samples collected at 0 m from the hedgerows, as structural variables were only measured within the hedgerows and could therefore not be used for samples collected further from the hedgerows. In addition, previous ordination analyses and pairwise PERMANOVA indicated that microarthropod communities at the hedgerow edge (0 m) differed most strongly from those in the agricultural field (2, 5 and 50 m), which were more similar in species composition.

The db-RDA was conducted on Bray-Curtis dissimilarities based on log(x + 1) transformed abundance data. Prior to analysis, correlations among explanatory variables were assessed using correlation matrices and variance inflation factors (VIF's). Highly correlated variables were excluded from the final model to reduce multicollinearity. Explanatory variables included in the final model were hedgerow width, hedgerow height, amount of dead wood, number of tree stems, tree species richness, herb species richness and herb Shannon diversity. Model significance and individual variables were tested using a permutation test with 999 permutations. $R^2$ and adjusted $R^2$ values were calculated to estimate the proportion of explained variation by the model.

### 2.4.4 Taxa associated with the PCoA ordination

To further investigate taxa associated with patterns in the community composition, taxon vectors were fitted onto the PCoA ordination using the envfit() function (Oksanen et al., 2026). This was performed using the log(x + 1) transformed abundance matrix and was used to identify taxa whose abundance patterns were significantly correlated with the main ordination gradients. Vector direction indicates the association of taxa with the ordination gradients, and the vector length reflects the strength of the correlation between taxa abundances and the ordination configuration. Significance of fitted vectors were assessed using 999 permutations. For visualization, only significant taxa ($p < 0.05$) were plotted on the PCoA, and vector lengths were scaled for visual clarity.

### 2.4.5 Indicator species analysis

An indicator species analysis was performed to identify species or taxa associated with hedgerow edges (0 m) and field habitats (2, 5 and 50 m). The analysis was done by using the multipatt() function implemented in the indispecies R package (Cáceres & Legendre, 2009). For each indicator species, indicator value, specificity, fidelity and associated p-values were calculated. The indicator species analysis was performed using both abundance data and presence/absence data to assess the robustness of species associations. Only species identified as significant indicators in both analyses were retained as indicator species.

All statisctical analyses were conducted in R-version 4.5.3 (R Core Team, 2026) using R-studio version 2026.01.0.

## 3. Results

### 3.1 Patterns in taxon richness and abundance

In total, 39 microarthropod taxa were identified, including four Acari taxa and 35 Collembola taxa (Appendix 1). Taxon richness was relatively similar across distances from hedgerows and among hedgerows, although some within group variation was observed (Figure 3A, C). Median taxon richness was similar across all four distances. However, samples collected at 0 m from hedgerows included the highest richness values. Among hedgerows, taxon richness varied substantially, with hedgerow 535-0 exhibiting the highest observed richness values. Total abundances showed high variability across both distances from hedgerows and among hedgerows (Figure 3B, D). Samples collected at 0 m generally exhibited higher abundances, although the highest individual abundance values were observed at 5 m from hedgerows. Variation in total abundance was also observed among hedgerows, with hedgerow 5-0 showing consistently higher abundance values than the remaining hedgerows.

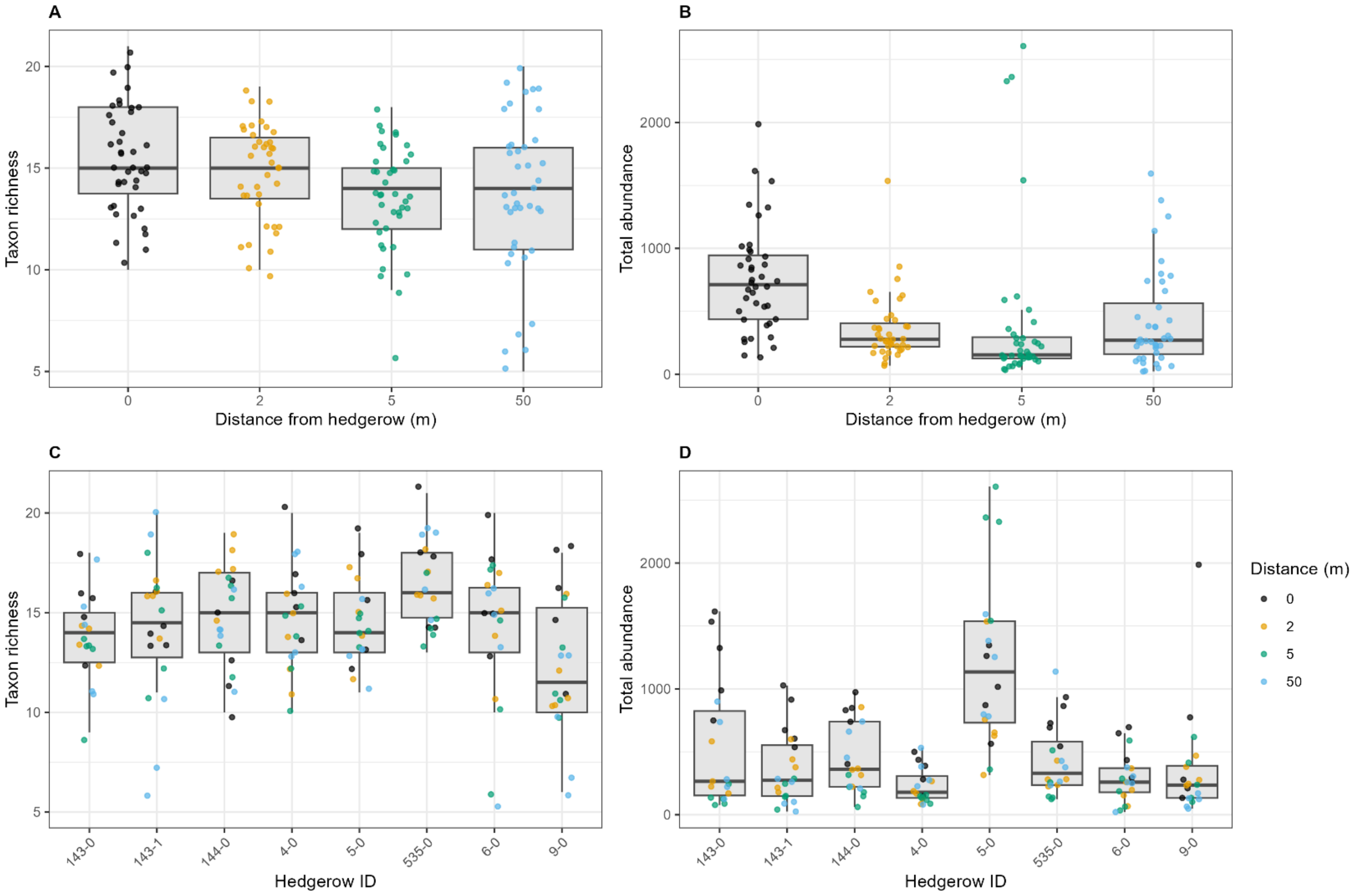

*Figure 3:* Overview of taxon richness and total abundance of microarthropods across distances from hedgerows and among hedgerows. (A) Taxon richness across distances from hedgerows. (B) Total abundances across distances from hedgerows. (C) Taxon richness among hedgerows. (D) Total

abundance among hedgerows. Points represent individual microarthropod samples colored according to distance from hedgerows.

### 3.2 Microarthropod community composition analyses

The PCoA indicated that samples collected at the hedgerow edge differed in microarthropod community composition from samples collected further into the field (Figure 4). Samples collected at 0 m from the hedgerow formed the most distinct group clustered away from the other groups, while samples collected at 2, 5 and 50 m showed grater overlap. The group centroids followed the same overall pattern with the 0 m centroid being separated from the centroids of the other distance groups along PCoA1. This suggests that the main compositional difference occurred between the hedgerow edge and the field, while differences among distance groups within the field were less clear.

When the same ordination was visualized by hedgerow identity, the samples showed substantial overlap between the eight groups (Figure 5). Variation within hedgerows is generally larger than variation between hedgerows. Most hedgerow centroids were positioned in the center of the ordination close together. However, hedgerows 5-0 and 9-0 were positioned higher along PCoA2 and separated from the remaining groups, although their ellipses overlapped.

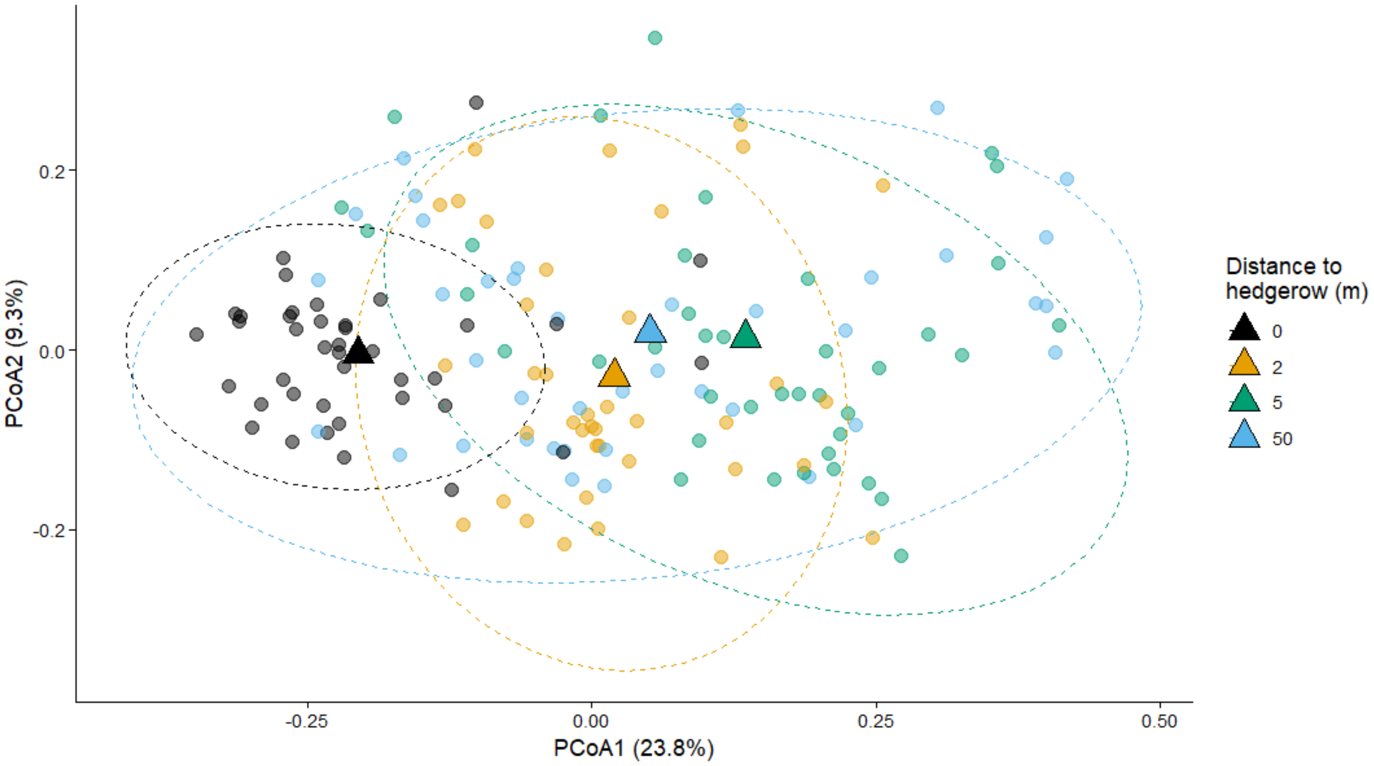

*Figure 4:* PCoA plot showing community composition of microarthropods with each point representing a sample and colored according to the distances from the hedgerow. The first two axes jointly explained 33.1% of the compositional variation, with PCoA1 and PCoA2 accounting for 23.8%

and 9.3%, respectively. Black represents 0 m, orange 2 m, green 5 m and blue 50 m from the hedgerow. Triangles represent centroids for each distance group, and each ellipse contains 95% of the samples of its group.

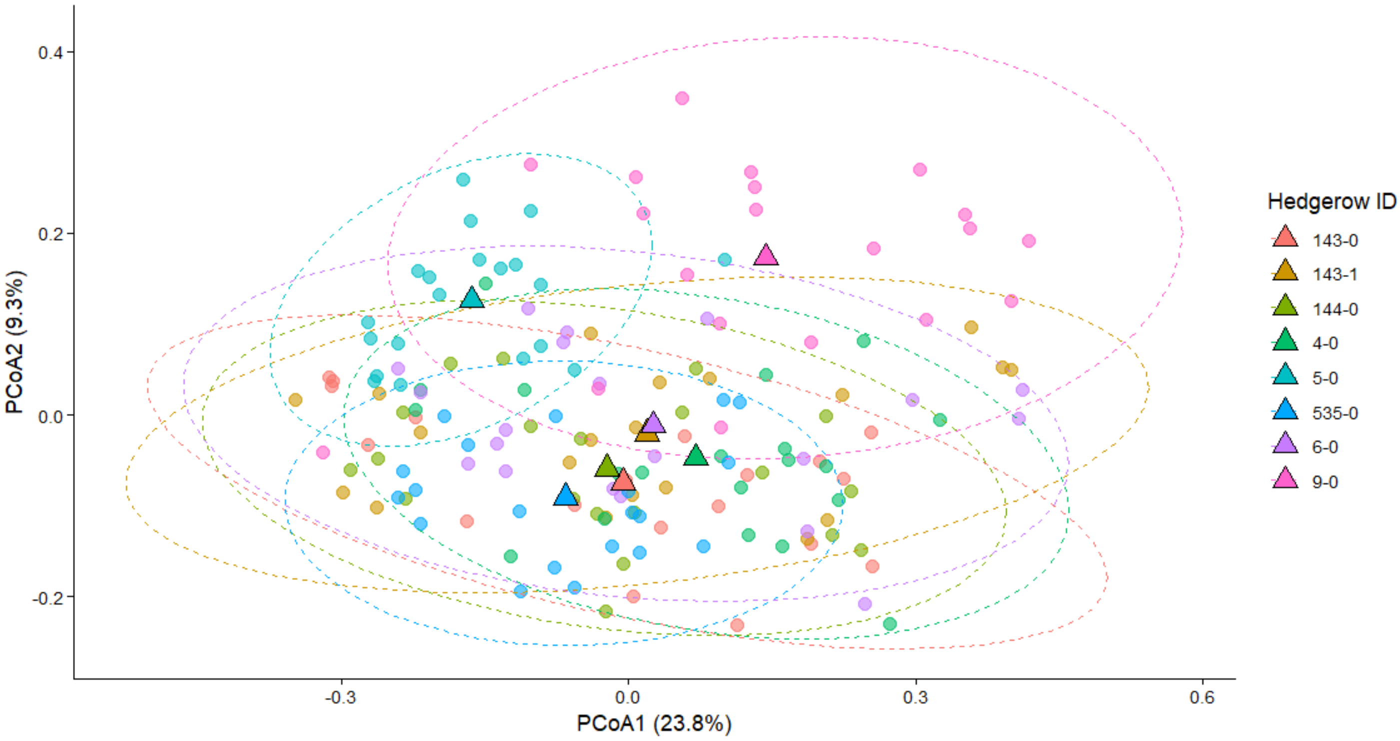

*Figure 5:* PCoA plot showing community composition of microarthropods with each point representing a sample, colored according to the hedgerow ID. The first two axes jointly explained 33.1% of the compositional variation, with PCoA1 and PCoA2 accounting for 23.8% and 9.3%, respectively. Triangles represent centroids for each hedgerow group, and each ellipse contains 95% of the samples of its group.

PERMANOVA indicated that distance from hedgerow had a significant effect on the microarthropod community composition ($R^2 = 0.187$, $F = 11.89$, $p < 0.001$). However, tests for homogeneity of multivariate dispersion (betadisper) were also significant, indicating differences in within-group variability. Therefore, the PERMANOVA results should be interpreted with caution. PERMANOVA also indicated a significant effect of hedgerow identity on microarthropod community composition ($R^2 = 0.206$, $F = 5.58$, $p < 0.001$). However, the test for homogeneity of multivariate dispersion was significant for hedgerow identity as well. The PCoA grouped by hedgerow identity showed substantial overlap and differences in dispersion among the eight hedgerows and no clear separation (Figure 5). The significant effect of hedgerow identity should therefore be interpreted cautiously as it may partly reflect differences in dispersion rather than clear differences in community composition among hedgerows.

Pairwise PERMANOVA showed significant differences in microarthropod community composition between all distance groups after Holm correction (Table 1). The comparison between distance 0 and 5 m had the highest F-value and $R^2$. The comparisons involving 0 m generally had higher F-values and $R^2$ than the comparisons between distance groups further from the hedgerows. The comparison between distance 5 and 50 m had the lowest F-value and $R^2$. Pairwise PERMANOVA between hedgerows showed that 15 out of 28 pairwise comparisons had significant differences in microarthropod community composition after Holm correction (Appendix 2). The significant comparisons were mainly associated with hedgerow 5-0 and 9-0, which each differed from other hedgerows. The largest pairwise differences were observed for 5-0 vs. 9-0, 535-0 vs. 9-0 and 4-0 vs. 5-0 with $R^2$ values of 0.294, 0.276 and 0.274, respectively. The results of the pairwise PERMANOVA are overall consistent with the substantial overlap observed in the PCoA ordination colored after hedgerow ID.

*Table 1:* Results of pairwise PERMANOVA comparing following distance groups to each other; 0, 2, 5 and 50 m. F-value, $R^2$, p-value and adjusted p-value are indicated for each comparison.

| **Comparison (m)** | **F-value** | **$R^2$** | **p-value** | **Adjusted p-value** |
|---|---:|---:|---:|---:|
| 0 vs. 2 | 17.77 | 0.187 | 0.001 | 0.006 |
| 0 vs. 5 | 32.39 | 0.293 | 0.001 | 0.006 |
| 0 vs. 50 | 18.82 | 0.194 | 0.001 | 0.006 |
| 2 vs. 5 | 4.61 | 0.056 | 0.001 | 0.006 |
| 2 vs. 50 | 2.51 | 0.032 | 0.002 | 0.006 |
| 5 vs. 50 | 2.31 | 0.029 | 0.007 | 0.007 |

### 3.3 Distance-based redundancy analysis

Distance-based redundancy analysis showed a significant association ($p < 0.001$) of hedgerow structural characteristics on the microarthropod community composition at the edge of the hedgerow (0 m). The explanatory variables hedgerow width, tree species richness and herb species richness had a significant association with the microarthropod community composition (Table 2). Amount of dead wood, number of tree stems, herb Shannon diversity and hedgerow height did not have a significant association. Thus, hedgerow height was almost significant ($p = 0.052$).

The first two db-RDA axes explained 50.7% and 21.6% of the variation represented by the constrained ordination, respectively (Figure 6). In the db-RDA ordination, the explanatory variables are shown as vectors. Herb species richness was represented by the longest vector and was oriented in a similar direction to herb Shannon diversity. Hedgerow width and dead wood were oriented in the opposite direction to the herb layer variables. Hedgerow height and tree species richness were mainly associated with the main gradient in the ordination (dbRDA1). Samples from hedgerow 9-0 were positioned apart from the remaining hedgerows.

*Table 2:* Results of a db-RDA in which seven hedgerow structural variables were used to model variation in soil microarthropod community composition in 40 samples collected within eight hedgerows. Permutation test for association between hedgerow structural variables and microarthropod community composition in samples collected at 0 m from the hedgerow. F-values and p-values are shown for each explanatory variable. The model accounted for 34.6%, or 20,3% after adjustment of the $R^2$, of the variation in the community composition.
Significant levels are indicated as: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

| **Explanatory variable** | **F-value** | **p-value** | **Significance** |
|---|---:|---:|---:|
| Hedgerow width | 2.16 | 0.035 | * |
| Hedgerow height | 1.96 | 0.052 | . |
| Amount of dead wood | 1.58 | 0.120 | |
| Number of tree stems | 0.83 | 0.594 | |
| Tree species richness | 4.65 | <0.001 | *** |
| Herb species richness | 2.00 | 0.039 | * |
| Herb Shannon diversity | 0.97 | 0.447 | |

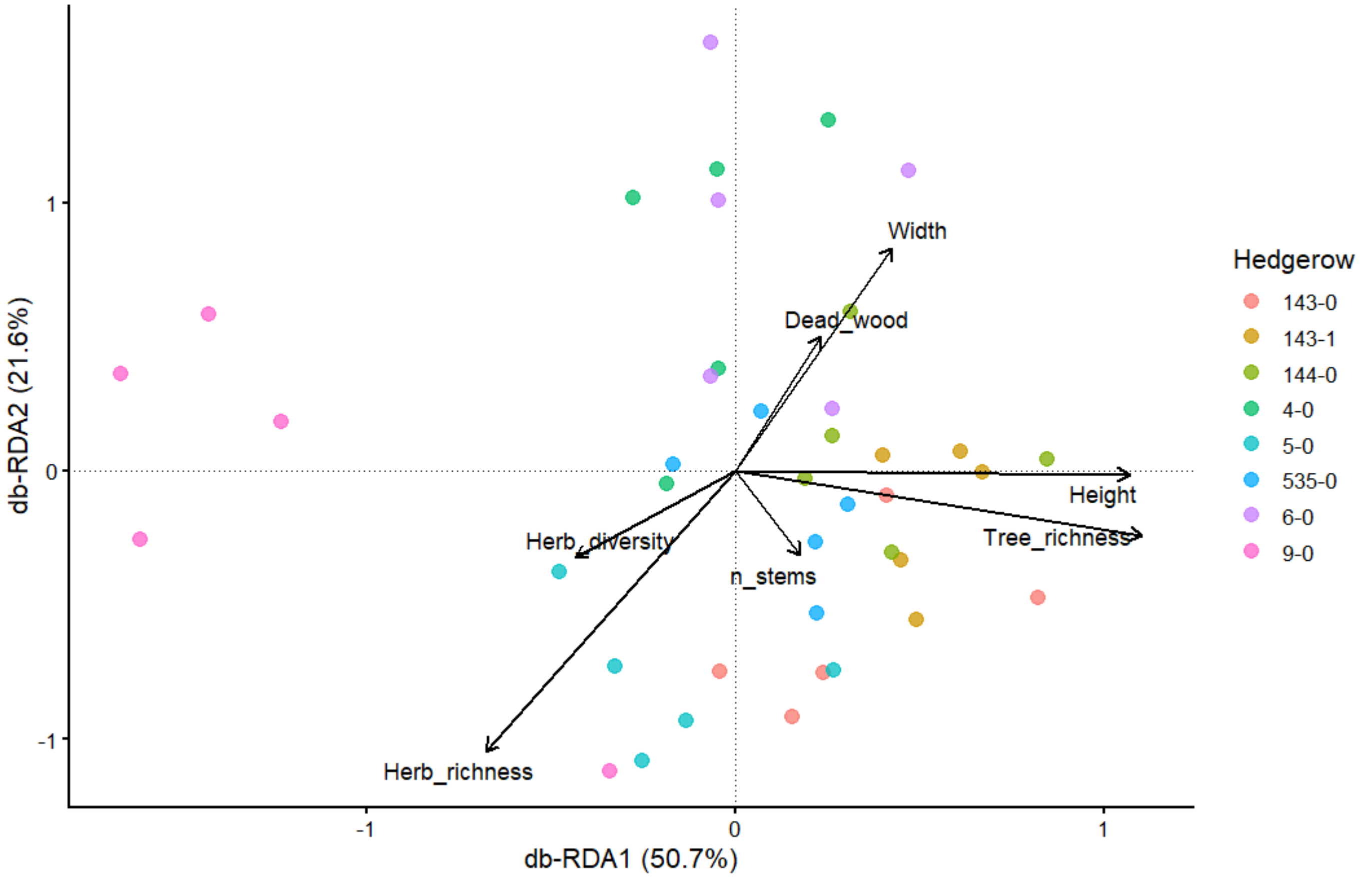

*Figure 6:* Distance-based redundancy analysis (db-RDA) ordination of microarthropod abundance data based on Bray-Curtis dissimilarity. The points represent a subset of the whole dataset, only samples at the hedgerow edge (0 m). Points are colored according to hedgerow identity. Hedgerow structural variables (explanatory variables) include hedgerow width, hedgerow height, amount of dead wood, number of tree stems, tree species richness, herb species richness and herb Shannon diversity. The variables are shown by vectors. Percentages that the depicted two axes explain of the variation in the full 7-dimensional model are given within brackets.

### 3.4 Taxa associations

Several taxa including both Collembola and mites were significantly ($p < 0.05$) associated with the main PCoA gradients (Figure 7). The majority of the significant taxa were associated with samples closer to the hedgerows (0 m). In contrast, relatively few taxa were associated with samples further from the hedgerow (2, 5 and 50 m). Hedgerow-associated taxa included taxa such as Oribatida, Gamasida, *Parisotoma notabilis* and *Megalothorax minimus*, whereas *Isotomurus* sp. was associated with samples further away from the hedgerow. Three taxa, *Folsomia sp.*, *Cryptopygus thermophilus* and *Friesea truncata*, were associated with variation along PCoA2.

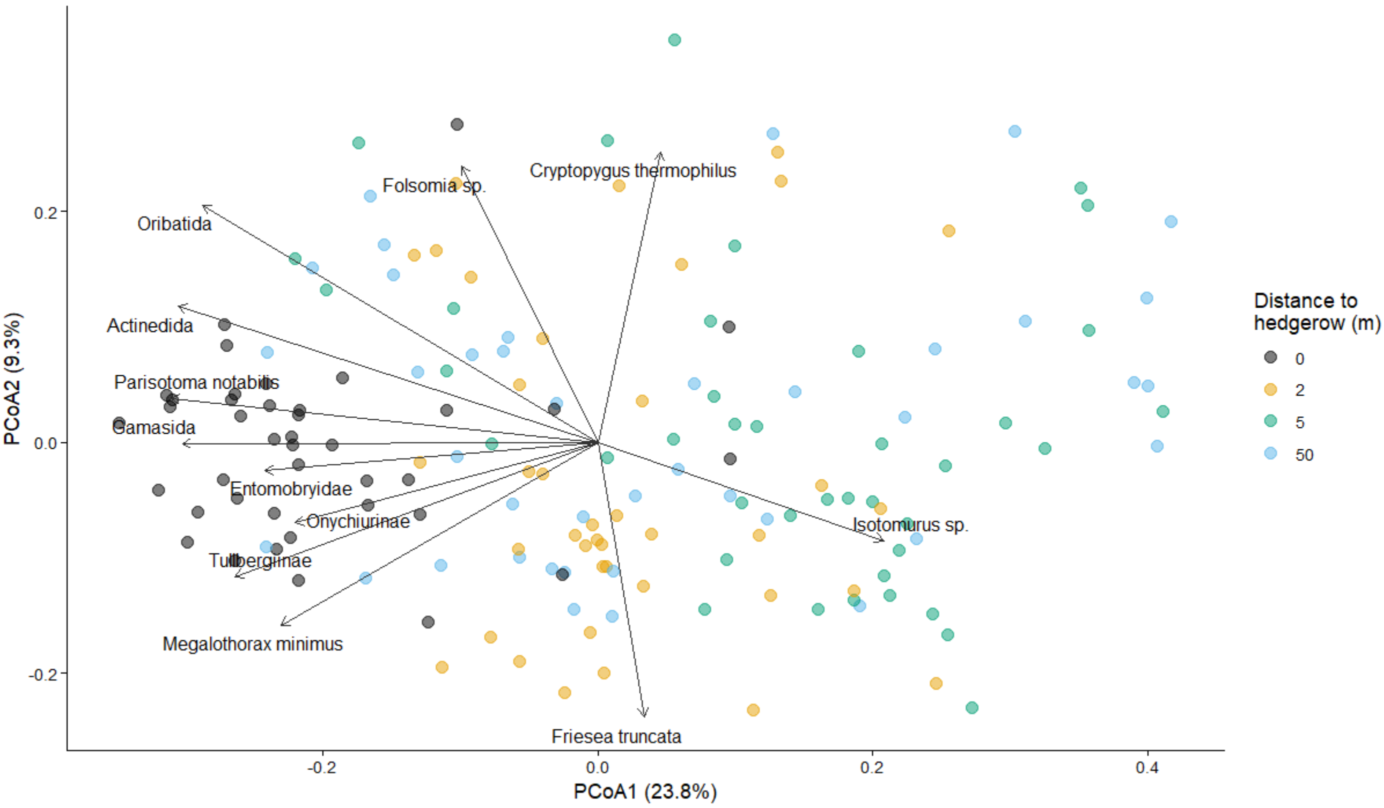

*Figure 7:* PCoA plot based on Bray-Curtis dissimilarities showing microarthropod community composition colored according to distance from hedgerow (m). Fitted taxon vectors indicate associations with the main ordination gradients. Only significant taxa with strongest correlations are visualized.

Indicator species analysis identified several taxa significantly associated with the hedgerow edge habitat and fewer taxa associated with the agricultural field (Table 3). After robustness testing, nine indicator species were associated with the hedgerow edge samples, with *Megalothorax minimus*, Onychiurinae and *Isotomiella minor* having the highest indicator values. In contrast, only two indicator species, *Cryptopygus thermophilus* and *Brachystomella parvula*, were associated with agricultural field samples. All retained indicator species belonged to Collembola. Specificity and fidelity varied among taxa, with specificity values ranging from 0.64 to 1.00 and fidelity values ranging from 0.08 to 0.90 for hedgerow edge associated taxa.

*Table 3*: Results of indicator species analysis showing taxa associated with hedgerow edge (0 m) and agricultural field (2, 5 and 50 m) samples. Indicator value, specificity and fidelity are included for each indicator species, and p-value indicates significance of each taxon and habitat association. Only taxa retained after robustness testing are shown.

| Species | Habitat | Indicator Value | Specificity | Fidelity | p-value |
|---|---|---|---|---|---|
| *Megalothorax minimus* | Hedgerow edge | 0.93 | 0.95 | 0.90 | <0.001 |
| Onychiurinae | Hedgerow edge | 0.88 | 0.97 | 0.80 | <0.001 |
| *Isotomiella minor* | Hedgerow edge | 0.82 | 0.89 | 0.75 | <0.001 |
| *Stenaphorura lubbocki* | Hedgerow edge | 0.70 | 0.90 | 0.55 | <0.001 |
| *Folsomia quadrioculata* | Hedgerow edge | 0.63 | 0.64 | 0.63 | 0.005 |
| *Micranurida pygmaea* | Hedgerow edge | 0.56 | 0.90 | 0.35 | <0.001 |
| Isotomidae | Hedgerow edge | 0.48 | 0.65 | 0.35 | 0.018 |
| *Orchesella* sp. | Hedgerow edge | 0.36 | 0.87 | 0.15 | 0.009 |
| Tomoceridae | Hedgerow edge | 0.27 | 1.00 | 0.08 | 0.024 |
| *Cryptopygus thermophilus* | Agricultural field | 0.69 | 0.80 | 0.59 | 0.002 |
| *Brachystomella parvula* | Agricultural field | 0.54 | 0.97 | 0.29 | 0.006 |

# 4. Discussion

### 4.1 Distance- and hedgerow-related variation

The strongest difference in microarthropod community composition occurred between the hedgerow edge and the agricultural field, whereas differences among samples within the field were less pronounced. This suggests that a community shift occurred locally at the transition between hedgerow edge and the agricultural field, rather than gradually across all sampled distances. This further indicates a local association between hedgerow proximity and microarthropod community composition, while field samples may have shared more similar habitat conditions. Differences among individual hedgerows were less clear than the distance-related pattern, supporting that the main compositional shift occurred between the hedgerow edge and the agricultural field, while variation among the hedgerows was more subtle.

This local hedgerow effect did not appear to be driven primarily by higher taxon richness at the hedgerow edge, as the taxon richness was relatively similar across distances. Instead, the differences among distance groups seemed to reflect changes in community composition, meaning that different taxa were associated with hedgerow edge. Total microarthropod abundance was higher close to the hedgerows, suggesting that samples near the hedgerow edge were associated with higher numbers of individuals rather than a higher number of taxa. This tendency toward higher abundance close to the hedgerow is consistent with previous studies of shelterbelt systems, where soil and litter arthropod abundance has been found to decline with increasing distance from shelterbelts (Mbuthia et al., 2012).

Similar abundance patterns have also been reported for Collembola and mites in shelterbelts and adjacent fields (Olejniczak, 2004).

### 4.2 Taxa associated with hedgerow edge and agricultural field

The interpretation that hedgerow edge and the agricultural field supported partly different microarthropod communities was supported by the taxon associations. More taxa were associated with the hedgerow edge habitat than with the field, indicating that the observed hedgerow-field pattern reflected differences in taxon composition rather than taxon richness alone. Together the taxon associations suggest that the hedgerow edge and field samples were characterized by partly different microarthropod communities.

Several hedgerow edge associated taxa indicate that the hedgerow edge may provide more stable soil and litter-based microhabitats than the adjacent fields. For example, oribatid mites are important components of decomposer food webs and can influence decomposition through grazing on fungi and fragmenting plant detritus (Coleman & Crossley, 2018). Because many oribatid mites are relatively slow-reproducing and may depend on stable, less disturbed habitats, their association with hedgerow edge samples may reflect greater litter input and lower disturbance near hedgerows (Coleman & Crossley, 2018; Maraun & Scheu, 2000; Zaitsev et al., 2006). Similarly, several of the strongest hedgerow indicators, including *Megalothorax minimus*, Onychiurinae and *Isotomiella minor* can be classified as euedaphic or soil-dwelling Collembola (Fjellberg, 1998, 2007; Petersen, 2002). These taxa were both frequent in hedgerow edge samples and mainly restricted to this habitat, indicating a strong association with the hedgerow edge. These association suggest that the hedgerow edge provided more stable soil and litter microhabitats, likely linked to greater litter input and more stable climatic conditions (Olejniczak, 2004; Petersen, 2002). This interpretation is further supported by differences in mobility and disturbance sensitivity among Collembola life forms. Epedaphic, litter- or surface-living species are generally more mobile and may be better able to escape from disturbed localities or recolonize them after the disturbance. In contrast, euedaphic species live mainly within soil pores and often have reduced eyes and jumping organs (furca), making them more closely linked to stability of the soil environment (Coleman & Crossley, 2018; Petersen, 2002). The occurrence of several euedaphic indicator taxa at the hedgerow edge may therefore further suggest that this habitat provides more stable soil conditions than the adjacent fields. However, the hedgerow associated Collembola should not be interpreted as strict hedgerow specialists, as several taxa are common and widespread across different soil or agricultural habitats. For instance, *Megalothorax minimus* occurs in a variety of soil habitats, and trait-based studies describe *Isotomiella minor* and *Parisotoma notabilis* as widespread species without strong preference for several environmental factors (Salmon et al., 2014). In addition, *Parisotoma notabilis* is common and abundant in Nordic agricultural and grass-clover systems (Fjellberg, 2007; Pommeresche & Løes, 2014). Other hedgerow associated indicator taxa also represented a mixture of habitat associations, including litter- and forest-associated taxa such as *Stenaphorura lubbocki* and *Orchesella* species (Fjellberg, 1998, 2007), as well as more generalist taxa such as *Folsomia quadrioculata* and *Micranurida pygmaea*. Thus, the hedgerow edge appeared to support a combination of soil-dwelling, litter-associated and more generalist Collembola taxa rather than a set of strict habitat specialists.

In addition to indicating differences in soil and litter microhabitats, the taxa associated with the hedgerow edge may also reflect differences in the trophic structure of the soil food web. This is supported by the association of gamasid mites with hedgerow edge samples. These are commonly described as mobile, free-living predators in soil and litter, preying on organisms such as nematodes, Collembola and insect larvae (Koehler, 1999). Their association with 0 m samples may therefore be related to the higher microarthropod abundance observed close to the hedgerow and the greater availability of potential prey. Actinedida were also associated with hedgerow-edge samples, but because this is a heterogeneous group including both predatory and fungivorous taxa, this pattern is difficult to interpret more specifically (Coleman & Crossley, 2018).

The taxa associated with the agricultural field suggest that the field represented a different land-use, rather than an unsuitable habitat for Collembola. *Isotomurus* sp. was oriented towards samples collected further into the field, which is consistent with several *Isotomurus* species being associated with humid and disturbed grassland habitats, including lawns, city parks and fields (Fjellberg, 2007). Similarly, *Cryptopygus thermophilus*, a field-associated indicator species, is commonly found in compost heaps and other disturbed habitats with high organic content (Fjellberg, 2007). These associations may reflect the grass-clover vegetation, grazing history and organic matter inputs in the field, and are consistent with studies showing that organically managed grass-clover leys can support high densities and diversity of Collembola (Pommeresche & Løes, 2014). Thus, the hedgerow-field gradient should be interpreted as a shift between habitat conditions shaped by vegetation structure, disturbance and management, rather than as a simple contrast between suitable and unsuitable habitat.

## 4.3 Hedgerow characteristics and microarthropod community composition

Hedgerow structure and vegetation appeared to be associated with the variation in microarthropod community composition at the hedgerow edge. This suggests that the local hedgerow effect was not only related to the presence of a hedgerow, but also to differences in vegetation composition and habitat heterogeneity among individual hedgerows. In particular, variation in the woody vegetation may be important because tree species can differ in their effects on shading, litter quality and quantity, root inputs and associated microbial and fungal communities (Hansen & Coleman, 1998). These factors may affect soil moisture, organic matter inputs and resource availability for soil microarthropods (Korboulewsky et al., 2016; Peng et al., 2022). Tree species-rich hedgerows may provide a greater variety of microhabitats and resources than structurally simpler hedgerows. A mixture of tree species can create variation in litter composition, canopy structure and soil conditions, potentially allowing different microarthropod taxa to occur within the same hedgerow habitat. This is supported by studies showing that tree diversity and tree species identity can influence soil fauna communities through differences in litter quality and soil properties (Hansen & Coleman, 1998; Peng et al., 2022). Common European tree species have also been shown to differ in their effects on bacterial and fungal biomass and activity, partly through differences in litter quality, soil C/N ratio and pH (Heděnec et al., 2020). Since many soil microarthropods are closely linked to microbial and fungal resources, such tree-mediated differences may contribute to variation in the microarthropod communities at hedgerow edges. The distinct community composition in the hedgerow 9-0 may be an example of this effect as this hedgerow was the only one having just a single tree species (common hawthorn, *Crataegus monogyna*). However, this interpretation should be taken cautiously, as hedgerow 9-0 also differed from other hedgerows in other characteristics, including a more open structure and higher herb species richness.

This highlights that variation in the herbaceous vegetation layer may also contribute to differences among hedgerow edge microarthropod communities. A more species-rich herb layer can reflect small-scale habitat heterogeneity, including variation in root inputs, litter resources, soil surface structure and microclimatic conditions (Kratschmer et al., 2024). Such variation may be relevant for soil microarthropods because plant species richness and plant community composition can influence Collembola and mite communities, potentially through effects on root biomass, microbial resources and soil habitat conditions (Sabais et al., 2011). This suggests that the herbaceous vegetation at the hedgerow edge may contribute to belowground community variation, rather than woody vegetation alone.

Hedgerow width may reflect both habitat size and structural complexity. Wider hedgerows may provide larger and more buffered edge habitats with greater litter accumulation, shading and more stable soil microclimates (Graham et al., 2018; Kratschmer et al., 2024). Because width was also correlated with the amount of dead wood, it may partly represent a broader gradient in structural complexity rather than physical size alone. Therefore, the association between hedgerow width and microarthropod community composition should not be interpreted purely as a size effect. The weak association with dead wood does not necessarily mean that dead wood is ecologically unimportant. Its association may have been difficult to detect because the amount of dead wood was generally low across all hedgerows. Hedgerow height may also reflect aspects of vegetation structure that are relevant for soil microarthropods, such as shading, shelter and microclimatic stability. However, this interpretation should be made cautiously, as hedgerow height was estimated in the field and may have varied along each hedgerow. Height should therefore be interpreted as a broad structural indicator rather than a precise measure of local soil or microclimatic conditions.

The association between hedgerow characteristics and microarthropod community composition should also be interpreted in the light of limited sample size of the db-RDA, which was only based on samples collected at the hedgerow edge (0 m). A large proportion of the variation remained unexplained and may be related to other environmental factors not measured, such as soil humidity, organic matter content, pH, litter depth and microbial biomass. Including such variables in future studies could provide a more direct understanding of mechanisms shaping microarthropod communities at hedgerow edges. Hedgerow and field history, management and connectivity may also influence the community composition (Burel, 1996). Overall, the associations of tree species richness, herb species richness and hedgerow width suggest that structurally and botanically diverse hedgerows provide a more heterogeneous edge habitat than the adjacent agricultural field. Although the grass-clover field should not be considered unsuitable for microarthropods, their vegetation structure is likely more homogeneous than that of the hedgerow edge. In contrast, hedgerows contain several structural layers, including woody vegetation, herbaceous ground vegetation, litter, roots and shaded soil microhabitats (Kratschmer et al., 2024). This structural complexity may provide a broader range of niches for microarthropods. Furthermore, the hedgerows are likely less disturbed than adjacent fields, which may contribute to more stable soil environments.

### 4.4 Limitations and methodological considerations

The significant PERMANOVA results should be interpreted cautiously because tests for homogeneity of multivariate dispersion were also significant. This indicates that differences in within-group variability may have contributed to the observed differences in community compositions, as PERMANOVA can be sensitive to differences in dispersion among groups (Warton et al., 2012). However, the ordination patterns suggest that the distance-related differences were not only caused by unequal dispersion but also reflected compositional differences between the microarthropod community at the hedgerow edge and the agricultural field. In addition, differences among individual hedgerows were less clear than the distance-related pattern. The apparent effect of hedgerow identity may partly reflect differences in within-group variability rather than consistent compositional separation among all hedgerows. In particular, the pattern appeared to be influenced by a few distinct hedgerows especially 9-0 and 5-0. This may reflect local vegetation differences such as dominance of common hawthorn (*Crataegus monogyna*) in hedgerow 9-0, while hedgerow 5-0 had relatively high herb species richness. Overall, this suggests that microarthropod communities varied among hedgerows, but that the pattern was mainly driven by differences in dispersion and by a few distinct hedgerows, rather than by clear compositional separation among all hedgerow groups.

It should also be considered that patterns in microarthropod community composition may not only reflect local environmental conditions, but also dispersal history and stochastic processes. This is consistent with the idea that community composition may be shaped by both niche based processes, such as environmental factors, and neutral processes related to dispersal limitation, colonization history and demographic stochasticity (Hubbell, 2001). The PCoA summarizes variation in community composition but cannot distinguish whether similarities among samples are caused by measured environmental variables, spatial arrangement, shared species pools or historical dispersal processes. Thus, two hedgerows with similar structural characteristics may still support different microarthropod communities if they differ in colonization history, connectivity or local population dynamics. Although dispersal history may contribute to variation among hedgerows, the distinct position of hedgerows 5-0 and 9-0 in the ordination is unlikely to reflect geographical isolation alone, as both were located relatively close to other sampled hedgerows. However, because dispersal history and spatial connectivity were not explicitly tested in this study, their potential influence remains a limitation when interpreting both the PCoA and the db-RDA results.

Lastly, taxonomic resolution differed between the main microarthropod groups. Mites were generally identified at higher taxonomic levels than Collembola. This broader taxonomic resolution may have obscured species- or family-level responses among mites, even though mite groups contributed to the overall community patterns. However, the absence of mites from the indicator species analysis should not be interpreted as evidence that they were unimportant.

### 4.5 Future perspectives

In a broader agricultural landscape context, hedgerows may be viewed as semi-natural woody landscape elements that contribute to structural complexity and habitat heterogeneity in otherwise simplified farming systems (Benton et al., 2003). Hedgerows are often discussed in relation to aboveground organisms and ecosystem services, but the results of this study suggest that they may also be important for belowground communities such as soil microarthropods. This places hedgerows in a broader agroecological perspective, where the integration and maintenance of semi-natural habitats may contribute to more heterogeneous and potentially more resilient habitats.

From a management perspective, the results suggest that the hedgerow structural quality may be as important as hedgerow presence. The association between microarthropod community composition and tree species richness, herb species richness and hedgerow width indicates that variation in structure and vegetation composition may provide more diverse soil and litter microhabitats. Management or establishment of hedgerows should therefore not only focus on their presence or length, but also on maintaining diverse woody vegetation and herbaceous vegetation layer. This is consistent with studies showing that hedgerow structure can influence wildlife habitat provision in farmed landscapes. In addition, recent reviews emphasize the importance of structurally diverse hedgerows for species communities and ecosystem services (Graham et al., 2018; Kratschmer et al., 2024).

However, the role of hedgerows should be interpreted in relation to the surrounding farming system and landscape history (Burel, 1996). This study was conducted in an organic system with surrounding grass-clover fields, no use of synthetic fertilizers and a specific management history. The results may therefore be most transferable to similar organically managed farming systems and should not be generalized to all Danish hedgerows. Hedgerows in conventional farming systems may be exposed to different disturbances, nutrient inputs and tillage practices, which could influence both the hedgerow vegetation and associated soil fauna. Previous studies have shown that organic and conventional hedgerows can differ in vegetation composition, with organic hedgerows often supporting more diverse vegetation (Aude et al., 2004). Future studies comparing hedgerows across organic and conventional systems would therefore be valuable for understanding how farming practice influences the role of hedgerows as habitats for soil fauna including microarthropods.

## 5. Conclusion

This study shows that hedgerow edges and adjacent agricultural fields support different microarthropod communities. The main difference was not a clear increase in taxon richness at the hedgerow edge, but a shift in taxonomic composition. This indicates that hedgerow edges do not simply represent more suitable habitats than the field, but rather distinct soil habitats supporting different parts of the microarthropod community. The association of several soil-dwelling Collembola and mites with the hedgerow edge suggests that hedgerows may provide more stable soil and litter-based microhabitats than the adjacent field. In contrast, field-associated taxa were mainly disturbance-tolerant species and generalists, indicating that the grass-clover field also supported microarthropods but under different habitat conditions. The results further suggest that the ecological value of hedgerows for soil microarthropods depends on not only their presence, but also on their structural and vegetation characteristics. Tree species richness, herb species richness and hedgerow width were associated with community composition at the hedgerow edge, indication that structurally and botanically diverse hedgerows may contribute to more heterogeneous soil habitats.

This study highlights the potential importance of hedgerows for belowground communities in agricultural landscapes. It suggests that both hedgerow presence and hedgerow characteristics may contribute to shaping soil microarthropod communities. From a management perspective, this means that maintaining hedgerows with diverse woody vegetation, a well-developed herbaceous layer and sufficient width may help increase belowground habitat heterogeneity in otherwise simplified agricultural systems.

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# Appendix

*Appendix 1:* List of identified microarthropod taxa included in the analysis (39 taxa in total). Group, identification level, total abundance across all samples and sample occurrence are shown.

| Taxon | Group | Identification level | Total abundance | Occurrence |
|---|---|---|---|---|
| Oribatida | Acari | Order | 11018 | 133 |
| Gamasida | Acari | Order | 6131 | 159 |
| Actinedida | Acari | Order | 21354 | 159 |
| Acaridida | Acari | Order | 804 | 101 |
| *Folsomia* sp. | Collembola | Genus | 3658 | 112 |
| *Isotomodes productus* | Collembola | Species | 1234 | 74 |
| *Folsomia quadrioculata* | Collembola | Species | 2575 | 59 |
| *Willemia* sp. | Collembola | Genus | 156 | 31 |
| *Orchesella cincta* | Collembola | Species | 69 | 13 |
| *Orchesella* sp. | Collembola | Genus | 23 | 9 |
| *Stenaphorura lubbocki* | Collembola | Species | 330 | 40 |
| Onychiurinae | Collembola | Subfamily | 1235 | 48 |
| *Isotomiella minor* | Collembola | Species | 1160 | 66 |
| *Isotoma* sp. | Collembola | Genus | 947 | 90 |
| *Isotomurus* sp. | Collembola | Genus | 824 | 84 |
| *Lepidocyrtus* sp. | Collembola | Genus | 1456 | 128 |
| *Friesea truncata* | Collembola | Species | 907 | 67 |
| Tullbergiinae | Collembola | Subfamily | 11701 | 148 |
| *Parisotoma notabilis* | Collembola | Species | 3631 | 126 |
| *Tomocerus minor* | Collembola | Species | 27 | 1 |
| Symphypleona | Collembola | Order | 1579 | 134 |
| *Megalothorax minimus* | Collembola | Species | 1968 | 81 |
| *Heteromurus nitidus* | Collembola | Species | 9 | 2 |
| Entomobryidae | Collembola | Family | 749 | 93 |
| *Pseudosinella alba* | Collembola | Species | 49 | 11 |
| *Cryptopygus thermophilus* | Collembola | Species | 2348 | 73 |
| *Micranurophorus musci* | Collembola | Species | 91 | 8 |
| *Desoria* sp. | Collembola | Genus | 20 | 3 |
| Tomoceridae | Collembola | Family | 10 | 3 |
| *Ceratophysella* sp. | Collembola | Genus | 70 | 19 |
| *Brachystomella parvula* | Collembola | Species | 225 | 37 |
| *Neanura muscorum* | Collembola | Species | 6 | 2 |
| Dicyrtomidae | Collembola | Family | 10 | 5 |
| Arrhopalitidae | Collembola | Family | 30 | 15 |
| *Mucrosomia garretti* | Collembola | Species | 119 | 28 |
| *Micranurida pygmaea* | Collembola | Species | 131 | 23 |
| *Sminthurinus elegans* | Collembola | Species | 204 | 62 |
| Isotomidae | Collembola | Family | 144 | 32 |
| *Hypogastrura* sp. | Collembola | Genus | 38 | 5 |

*Appendix 2:* Results of pairwise PERMANOVA for hedgerow comparison

| **Comparison (m)** | **F-value** | **$R^2$** | **p-value** | **Adjusted p-value** |
|---|---|---|---|---|
| 143-0 vs. 143-1 | 2.288 | 0.058 | 0.049 | 0.343 |
| 143-0 vs. 144-0 | 1.436 | 0.037 | 0.198 | 0.500 |
| 143-0 vs. 4-0 | 3.445 | 0.085 | 0.008 | 0.104 |
| 143-0 vs. 5-0 | 10.23 | 0.217 | 0.001 | 0.028 |
| 143-0 vs. 535-0 | 2.727 | 0.068 | 0.022 | 0.198 |
| 143-0 vs. 6-0 | 3.133 | 0.078 | 0.011 | 0.132 |
| 143-0 vs. 9-0 | 8.898 | 0.194 | 0.001 | 0.028 |
| 143-1 vs. 144-0 | 1.739 | 0.044 | 0.100 | 0.500 |
| 143-1 vs. 4-0 | 1.672 | 0.042 | 0.109 | 0.500 |
| 143-1 vs. 5-0 | 8.132 | 0.176 | 0.001 | 0.028 |
| 143-1 vs. 535-0 | 3.024 | 0.074 | 0.011 | 0.132 |
| 143-1 vs. 6-0 | 0.460 | 0.012 | 0.872 | 0.872 |
| 143-1 vs. 9-0 | 5.431 | 0.125 | 0.001 | 0.028 |
| 144-0 vs. 4-0 | 2.973 | 0.073 | 0.014 | 0.140 |
| 144-0 vs. 5-0 | 8.311 | 0.179 | 0.001 | 0.028 |
| 144-0 vs. 535-0 | 1.857 | 0.046 | 0.054 | 0.343 |
| 144-0 vs. 6-0 | 2.527 | 0.062 | 0.023 | 0.198 |
| 144-0 vs. 9-0 | 8.988 | 0.191 | 0.001 | 0.028 |
| 4-0 vs. 5-0 | 14.33 | 0.274 | 0.001 | 0.028 |
| 4-0 vs. 535-0 | 6.070 | 0.138 | 0.001 | 0.028 |
| 4-0 vs.6-0 | 1.666 | 0.042 | 0.104 | 0.500 |
| 4-0 vs. 9-0 | 7.489 | 0.165 | 0.001 | 0.028 |
| 5-0 vs. 535-0 | 12.21 | 0.243 | 0.001 | 0.028 |
| 5-0 vs. 6-0 | 9.528 | 0.200 | 0.001 | 0.028 |
| 5-0 vs. 9-0 | 15.86 | 0.294 | 0.001 | 0.028 |
| 535-0 vs. 6-0 | 4.923 | 0.115 | 0.001 | 0.028 |
| 535-0 vs. 9-0 | 14.52 | 0.276 | 0.001 | 0.028 |
| 6-0 vs. 9-0 | 6.038 | 0.137 | 0.001 | 0.028 |

## Deklaration for anvendelse af GAI-værktøjer

**X Jeg/vi har benyttet generativ kunstig intelligens til udfærdigelse af dette projekt** *(sæt kryds). Oplist, hvilke GAI-værktøjer der er benyttet (husk version):*

Chat-GPT, version GPT-5.5

**Jeg/vi har brugt GAI-værktøjer på følgende vis***) – en liste over mulige anvendelser er vedlagt til inspiration*

Til programmeringsopgaver i R:

- Ved fejlkode, når fejlen var svært at forstå eller identificere
- Feedback på samt forbedring af figurer
- Dataklargøring, fx håndtering af NA værdier
- Hvordan man skal læse R-outputs
- Mere praktiske ting i R, fx hvordan man strukturerer og overskueliggør sin kode, eller hvordan man gemmer en dataframe fra R ned på ens computer

Til brug af Zotero (referenceprogram)

- Når en reference skulle skrives manuelt ind i programmet

Til feedback på egen tekst

- Feedback i forhold til om mine tekster var grammatisk korrekte samt formuleret korrekt på engelsk. AI hjalp mig med forslag til korrekt sætningsstruktur samt gav feedback på upræcise formuleringer.
- Feedback på figur- og tabeltekster
- Feedback på struktur og opbygning af afsnit.