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A box quadrat for standardised sampling of Orthoptera in open habitats: Design, handling, applications and baseline data

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ABSTRACT

Globally, insects are declining at an alarming rate. Therefore, there is an urgent need for standardised monitoring methods to detect changes in insect populations at an early stage. Box quadrat sampling enables highly precise assessments of Orthoptera community composition within a specific area. However, a detailed design of a box quadrat that guarantees an easy workflow, precise descriptions of its handling and a compilation of baseline data for future comparisons have yet been lacking. Based on thirty years of our own experience in box quadrat sampling, we present here: (i) the detailed design of a box quadrat, (ii) its standardised handling in the field (including a video as a supplement), (iii) its applications and (iv) Orthoptera species richness and abundance baseline data for open habitats. The low construction costs (~300 €) and simple design allow for a wide distribution of this type of box quadrat in future. Moreover, due to the plug system and the light aluminium construction, the quadrat can easily be transported, assembled, handled and dismantled by one person. For comparisons of Orthoptera species richness, abundance and community composition between habitats, we recommend using a quadrat of 2 m^2 size and 0.8 m height and a minimum sampling area of 20 m^2 per plot (10 touchdowns per plot). For long-term monitoring or when species are sampled that generally occur in low density, a sampling area of 30 m^2 (15 replicates) is suggested. By contrast, for the surveys of tiny species (e.g., groundhoppers) and developmental stages (nymphs), smaller box quadrats can also be used and the sampled area per plot can be below 20 m^2. Box quadrat sampling is less dependent on favourable weather conditions and vegetation structure than many other insect survey techniques. Overall, it allows rapid and highly precise assessments of Orthoptera community composition.

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1. Introduction

Globally, insects are the most species-rich branch of the tree of life (Stork, 2018). However, they are declining rapidly (Seibold et al., 2019; van Klink et al., 2020) and their loss rates are much higher than those of many other taxa (Thomas, 2005; Cardoso et al., 2020; Wagner, 2020). Insects provide a large variety of key ecosystem services (Ripple et al., 2017; IPBES, 2019; Cardoso et al., 2020). Therefore, their decrease has cascading effects on a wide range of other species and threatens human well-being on our planet. Consequently, to conduct suitable countermeasures timely, there is an urgent need for systematic long-term monitoring that uses standardised methods to detect changes in insect populations and their drivers at an early stage (Streitberger et al., 2024). Indeed, the development of monitoring schemes and funding of monitoring has gained much more attention in recent years (Streitberger et al., 2024; van Klink et al., 2024)

Orthoptera play a pivotal role in grassland ecosystems. They are often the major arthropod consumers (Samways, 2005) and a vital food resource for insectivorous vertebrates, particularly birds (Ingrisch and Köhler, 1998; González del Portillo et al., 2021). Moreover, they are highly sensitive to environmental change, such as alterations in land use or climate (Bazelet and Samways, 2011; Uchida and Ushimaru, 2014; Kenyeres et al., 2020; Theron et al., 2021). Thus far, the long-term effects of environmental alterations on Orthoptera have mainly been assessed by modelling approaches using opportunistic distribution data (Poniatowski et al., 2020; Engelhardt et al., 2022; Neff et al., 2022) or re-surveys that compared historical and recent distributions (Schuch et al., 2011; Löffler et al., 2019; Fartmann et al., 2022a; Thorn et al., 2022).

For assessments of Orthoptera species richness, abundance and community composition in grasslands, different sampling techniques are regularly applied (Ingrisch and Köhler, 1998; Gardiner et al., 2005). Particularly, sweep netting but also transect counts are very popular (Gardiner et al., 2005). However, popularity does not necessarily mean that the applied method is always the most suitable one (Samways et al., 2010). For example, Orthoptera data obtained by sweep netting and acoustic or visual counts along transects strongly vary depending on weather conditions and vegetation structure (e.g., Gardiner et al., 2005). By contrast, box quadrat sampling is less impacted by both and enables highly precise assessments of Orthoptera species richness, abundance and community composition within a specific area (Fartmann, 1997; Ingrisch and Köhler, 1998; Gardiner et al., 2005; Gardiner and Hill, 2006; Badenhausser et al., 2009). Consequently, it has been proposed as the standard method for systematic long-term monitoring of Orthoptera communities in grasslands as part of the recently established German insect monitoring scheme (Streitberger et al., 2024).

However, yet, a detailed design of a box quadrat that guarantees an easy workflow and precise descriptions of its handling in the field have not been available. Based on thirty years of own experience in box quadrat sampling, we present here: (i) the detailed design of a box quadrat, (ii) its standardised handling in the field and (iii) Orthoptera species richness and abundance baseline data for open habitats in Germany. The first version of the box quadrat introduced here was used in 1994 for assessing Orthoptera community composition in dry and wet grasslands (Fartmann, 1997). Since then, it has been refined to allow a quick and simple assembly and disassembly as well as easy handling in the field. As a supplement to the guideline for the handling in the field, we provide a video that shows the precise workflow.

Published data on Orthoptera species richness and abundance are often hardly comparable due to different survey techniques or differences in the standardisation of sampling (e.g., Ingrisch and Köhler, 1998). Consequently, our assessment of Orthoptera species richness and abundance baselines in open habitats rests upon data that were gathered by standardised box quadrat sampling. These baseline data can serve as a first basis for comparisons with surveys in the future.

So far, the basics on the applications of box quadrat sampling for assessing Orthoptera species richness, abundance and community composition were scattered over several publications (Fartmann, 1997; Ingrisch and Köhler, 1998; Gardiner et al., 2005; Gardiner and Hill, 2006; Badenhausser et al., 2009). Accordingly, we here discuss (i) the main findings of these publications, including the advantages but also the limitations of the survey method, (ii) the most suitable size of the quadrat and (iii) the favourable size of the sampling area depending on the aim of the study. Moreover, we evaluate the presented baseline data on the basis of the current knowledge on Orthoptera species richness and abundance in open habitats across Central Europe.

2. Material and methods

2.1. Design of the box quadrat and its handling in the field

Based on own long-term experience in constructing the box quadrat and its handling in the field, we here provide detailed instructions on the design and dimensions of the box quadrat (see Section 3.1.). Moreover, we explain the workflow in the field (see Section 3.2.). As a supplement, a detailed video on the setup of the box quadrat and its handling is made available.

2.2. Orthoptera species richness and abundance baselines in open habitats across Germany

Overall, we analysed data from 2478 sampled plots that had been surveyed between 1994 and 2022 across the five biogeographical regions in Germany (for data sources see Appendix 1). All data had been sampled: (i) by using the box quadrat proposed here (see Section 3.1.), (ii) in accordance with the handling guidelines described in this paper (see Section 3.2.), (iii) on an area of 20 m^2 and 30 m^2 per plot, respectively, (see also Section 4.1.) and (iv) during July or August, which is the phenology peak of the vast majority of Central European Orthoptera species (Ingrisch and Köhler, 1998; Schlumprecht and Waeber, 2003). To avoid any area effects on species richness, only data that had been assessed on 20 m^2 per plot were considered. Mean species richness and abundance were analysed for the eight most intensively sampled open habitat types ($n > 70$ plots per type; five types of grasslands [acidic, calcareous, mesic, tussock and wet grasslands], heathlands, mires and light woodlands). Acidic grasslands included semi-dry grasslands on sandy soils and acidic bedrock, tussock grasslands comprised dry, sparsely vegetated grasslands on sandy soils, where tussock grasses (*Corynephorus canescens*, *Festuca polesia*, *Festuca psammophila*, *Koeleria glauca* or *Stipa capillata*) dominated, and mires covered transition mires and raised bogs.

2.3. Statistical analysis

All statistical analyses were performed using R 4.3.1 (R Development Core Team, 2024). Differences in species richness (species/10 m^2) and abundance (individuals/10 m^2) between habitat types or species were analysed by using generalised linear mixed-effects models (GLMM) with gamma error structure (R package 'lme4'; Bates et al., 2015). 'Habitat type' and 'species', respectively, served as a categorical predictor, 'year' and 'biogeographical region' as random factors. For the analysis of abundance data, we included 'sampling effort' (20 m^2 vs. 30 m^2 of sampled area) as a further random factor. Pairwise comparisons between habitat types were conducted using Tukey's contrasts (R package 'multcomp'; Hothorn et al., 2008). Differences in Ensifera and Caelifera abundance were analysed by using the Mann-Whitney *U* test.

3. Results

3.1. Design of the box quadrat

To guarantee a quick and simple assembly, disassembly and easy handling in the field, the quadrat is based on a plug system. The rods and connector blocks consist of light aluminium (Figs. 1 and 2). Depending on the aim of the study, we regularly use box quadrates of three different sizes: 0.71 m × 0.71 m (0.5 m^2), 1 m × 1 m (1 m^2) and 1.41 m × 1.41 m (2 m^2) (see Section 4.1.). All these quadrates have a height of 0.8 m and differ only in the length of the horizontal rods (see below). Here, we present the design for the 2 m^2 box quadrat since it is recommended for most cases of sampling of Orthoptera species richness, abundance and community composition (see Section 4.1.).

The box quadrat consists of five components: (i) fabric sheet, (ii) corner rods, (iii) connector blocks, (iv) horizontal rods and (v) bungee cords (Fig. 2). The fabric sheet for the cover of the sidewalls of the box quadrat is sewn from a fabric of 6 m × 1 m size and a thickness of ~ 320 g/m^2 (Fig. 3a). The upper and lower 10 centimetres of the fabric sheet are sewn into a loop, so that the sheet can later be fixed between the horizontal rods. Where the connector blocks are to be placed, small notches 8 cm in length and 5 cm in height are cut out of the fabric. The distance from notch to notch is 1.37 m, and the fabric sheet for the cover of the sidewalls is sewn as a loop with a 5.80 m circumference.

All rods and connector blocks consist of aluminium. Each of the four corner rods has a height of 0.8 m, a diameter of 1.7 cm and a material thickness of 1.5 mm (Fig. 3b). The length and width of each of the four connector blocks is 4 cm, and their height is 3.2 cm (Fig. 3c). On two adjacent lateral sides of the block, there are boreholes, one on each side, 1.5 cm in depth and 1.7 cm in diameter. The centre of the boreholes is situated 1.45 cm from the outer and 1.15 cm from the upper edge of the block. Moreover, a continuous borehole 1.7 cm in diameter is bored from the bottom to the top of the two adjacent sides. Its centre is located 1.2 cm from the lateral sides without boreholes. At the top and bottom of the box quadrat, a corner rod is inserted into the continuous borehole of a connector block; corner rod and block are then welded or bolted together. In total, eight horizontal rods are needed, two for each side of the quadrat (Fig. 3d). Each rod has a length of 1.42 m and the same diameter and material thickness as the corner rods. To plug the horizontal rods into the connector blocks, the rods have to be narrowed to a diameter of 1.6 cm over a length of 1.5 cm at both ends of the rod. The bungee cords for stabilising the sidewalls are 1 m long (Fig. 3e).

The complete box quadrat has a weight of ~6 kg. Hence, it can easily be transported and handled by one person (see Section 3.2.).

Fig. 1. Box quadrat in a semi-dry calcareous grassland. Photo credit: Dominik Poniatowski.

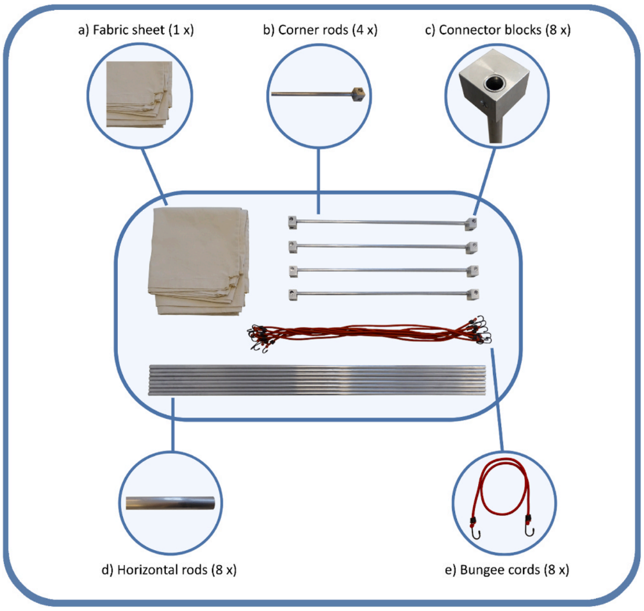

Fig. 2. The five components of the box quadrat.

The total costs for the construction amount to ~300 €. Aluminium for the rods and connector blocks cost ~50 €, the fabric sheet for the sidewalls ~36 € (6 €/m) and the bungee cords ~12 €. For aluminium processing and sewing, further costs of ~200 € arise.

3.2. Handling of the box quadrat in the field

For the assembly of the box quadrat, the horizontal rods have to be inserted into the hems of the fabric (Video 1). Afterwards, the fabric sheet has to be unfolded and spread out on the ground. For quick assembly, we recommend placing all remaining components in the centre of the quadrat. To set up the sidewalls, the corner rods have to be raised on the inside of the fabric loop and the horizontal rods must be inserted into the connector blocks. To prevent the rods from slipping out of the connector blocks while sampling, each sidewall has to be stabilised with a bungee cord at the top and bottom. Overall, the assembly and disassembly (see below) of the box quadrat, respectively, takes less than five minutes.

For sampling Orthoptera in the field, the box quadrat has to be thrown forward and down with momentum on the soil surface (Video 1). To avoid chasing Orthoptera away with the shadow of the researcher on sunny days, the movement has to be towards the sun during this procedure. To prevent it from bouncing off the ground, the touchdown has to be executed in a controlled movement without letting go of the quadrat (Video 1). In case of dense swards, the vegetation below the sidewalls has to be pressed down with the box quadrat. By ensuring the full contact between the sidewalls and the ground surface, any escape of individuals from the area inside the quadrat is avoided. After each touchdown, the Orthoptera usually jump on the sidewalls, where they can easily be collected by hand or with a collecting jar. For the remaining individuals, a thorough search in the vegetation is necessary. Adults of all Central European species can be identified in the field, some with assistance of a loupe or calliper (Fischer et al., 2020). This is also true for the vast majority of older nymphs (Thommen, 2021). Once identified, the individuals can be released directly outside the quadrat.

Disassembling the box quadrat is as simple as its assembly (Video 1). First, all bungee cords have to be removed and the horizontal rods must be detached from the connector blocks without pulling them out of the fabric hems. Then, the fabric is folded and the four corner rods and six of the eight bungee cords are wrapped in it. Tightening of both ends of the rolled-up fabric loop with the two remaining bungee cords allows for easy transportation and storage.

3.3. Orthoptera species richness and abundance baselines in open habitats across Germany

The number of plots per biogeographical region varied from 235 to 698 (Fig. 4). Overall species richness decreased in the following order: calcareous grasslands (mean ± SE: 2.8 ± 0.1 species/10 m^2), acidic grasslands (2.5 ± 0.1 species/10 m^2), wet grasslands (2.2 ± 0.1 species/10 m^2), heathlands (2.1 ± 0.1 species/10 m^2), tussock grasslands (2.0 ± 0.1 species/10 m^2), light woodlands (1.8 ± 0.1 species/10 m^2), mires (1.4 ± 0.1 species/10 m^2) and mesic grasslands (1.3 ± 0.1 species/10 m^2) (Fig. 5a). Calcareous grasslands differed significantly from all other habitat types except acidic grasslands. Moreover, mires and mesic grasslands were significantly different from most of the habitat types except heathlands, tussock grasslands and light woodlands. Species richness of Ensifera peaked in calcareous grasslands (0.9 ± 0.0 species/10 m^2) and wet grasslands (0.8 ± 0.0 species/10 m^2), and decreased over tussock grasslands, heathlands, mires, acidic grasslands and light woodlands (0.6 ± 0.1 to 0.3 ± 0.0 species/10 m^2) to mesic grasslands (0.2 ± 0.0 species/10 m^2) (Fig. 5c). The pattern for Caelifera was similar to those for the overall number of species: species richness was

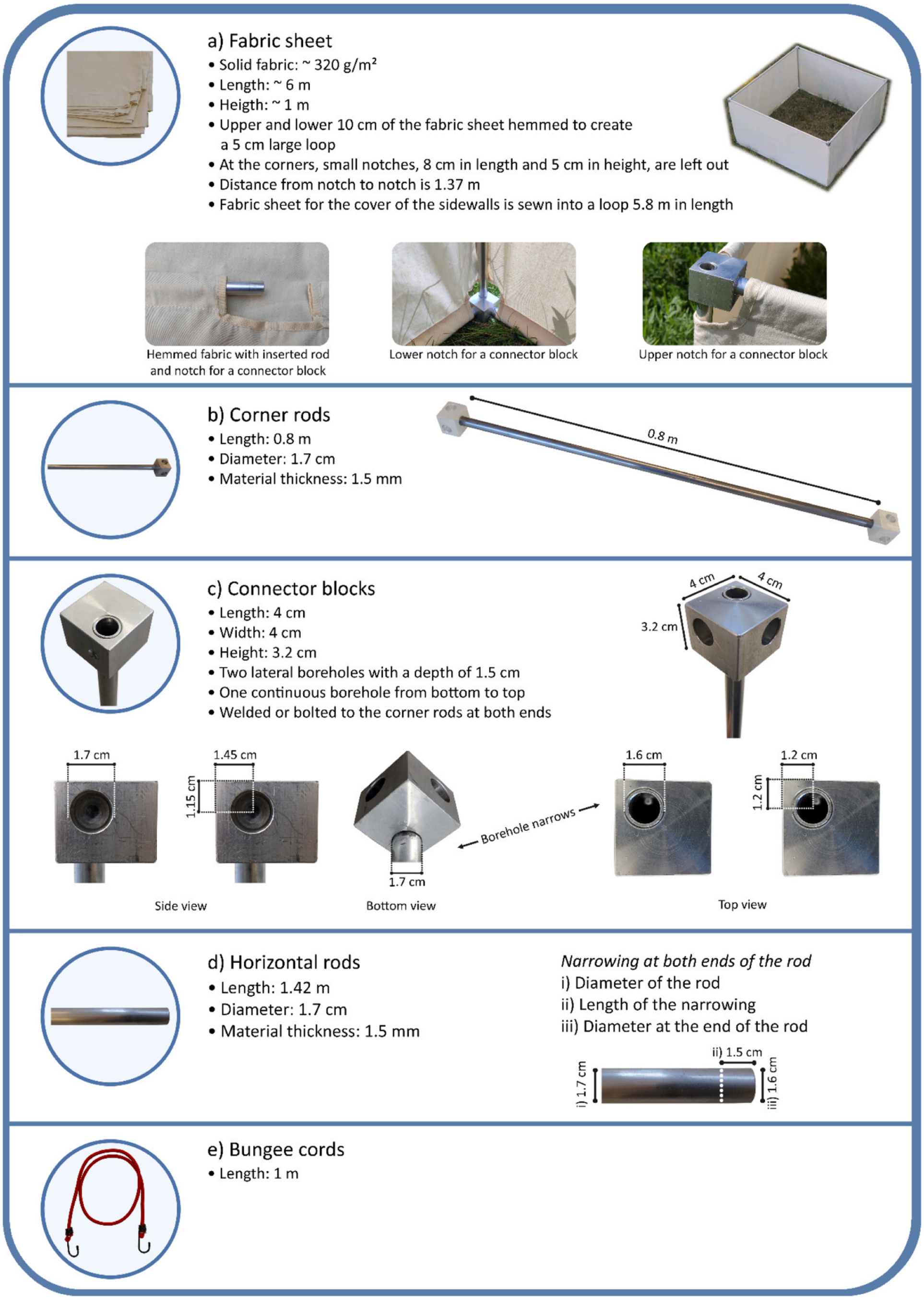

Fig. 3. Design of the box quadrat and dimensions of each of its five components.

highest in acidic and calcareous grasslands (2.0 ± 0.1 and 1.8 ± 0.0 species/10 m^2, respectively) and decreased over heathlands, light woodlands, wet grasslands and tussock grasslands (1.5 ± 0.1 to 1.4 ± 0.1 species/10 m^2) to mesic grasslands and mires (1.0 ± 0.1 and 0.9 ± 0.1 species/10 m^2, respectively) (Fig. 5e).

Overall abundance of Orthoptera decreased in the following order: wet grasslands (mean ± SE: 25.8 ± 2.2 individuals [ind.]/10 m^2), acidic grasslands (22.3 ± 1.3 ind./10 m^2), calcareous grasslands (21.3 ± 1.2 ind./10 m^2), mesic grasslands (20.3 ± 1.0 ind./10 m^2), tussock grasslands (12.1 ± 1.3 ind./10 m^2), heathlands (8.5 ± 0.6 ind./10 m^2), mires (6.5 ± 0.6 ind./10 m^2) and light woodlands (5.2 ± 0.3 ind./10 m^2) (Fig. 5b). However, acidic grasslands did not differ significantly from wet and calcareous grasslands, mesic grasslands not from calcareous ones and mires not from heathlands and woodlands. Abundance of Ensifera peaked also in wet grasslands (7.1 ± 2.2 ind./10 m^2) and decreased over calcareous grasslands (2.7 ± 0.2 ind./10 m^2), mesic grasslands, heathlands and

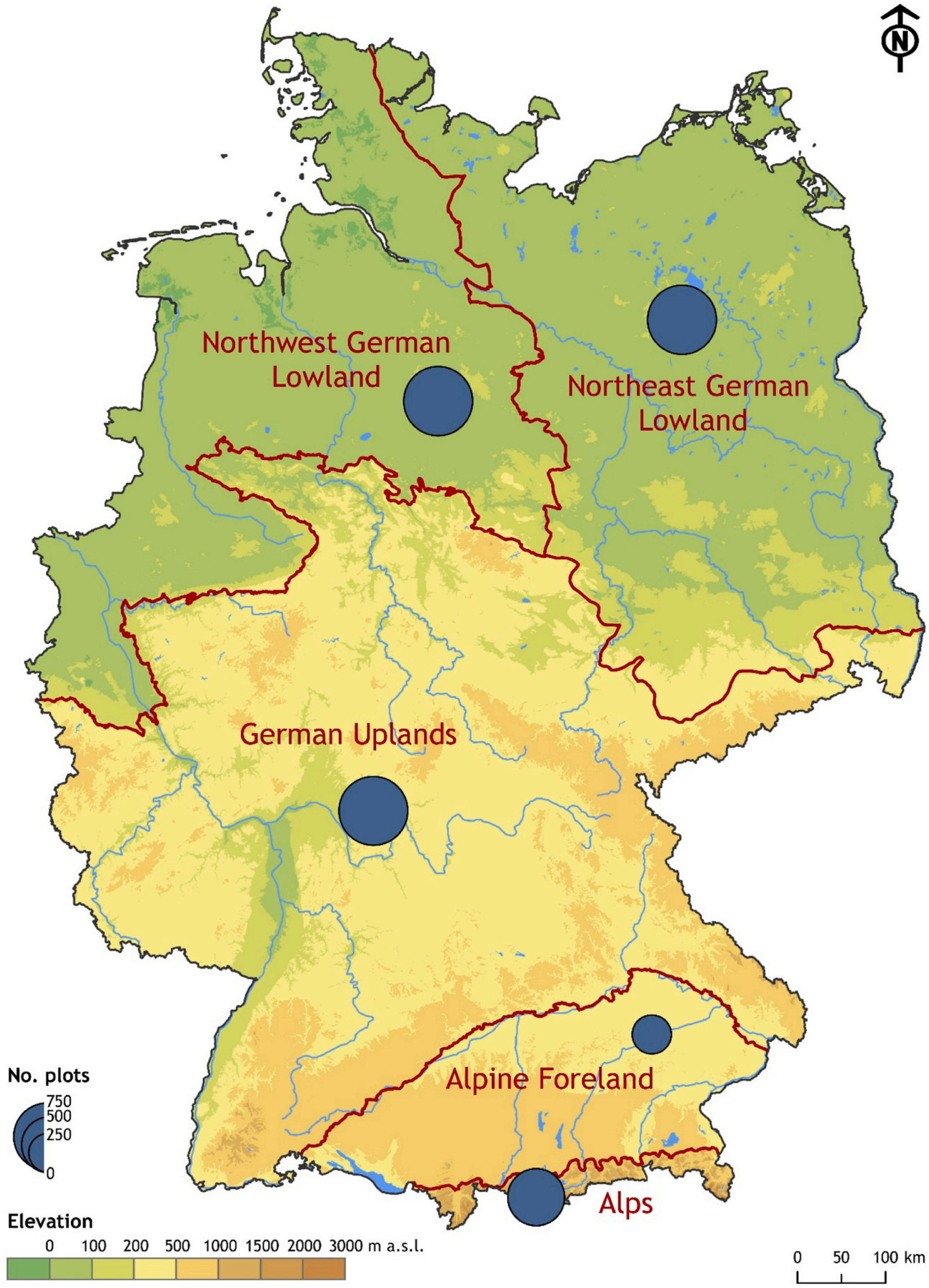

Fig. 4. Number of sampled plots ($N = 2478$) between 1994 and 2022 in July/August within each of the five biogeographical regions in Germany. Data sources: see Appendix 1.

mires (1.4 ± 0.1 to 1.2 ± 0.1 ind./10 m^2) to acidic grasslands, tussock grasslands and woodlands (0.9 ± 0.1 to 0.7 ± 0.1 ind./10 m^2) (Fig. 5d). The abundance pattern for the Caelifera was very similar to those of overall Orthoptera abundance (Fig. 5f): Abundance decreased from the four types of more or less closed grasslands (acidic, wet, calcareous and mesic grasslands; 21.3 ± 1.3 to 18.3 ± 1.1 ind./10 m^2) over sparsely vegetated tussock grasslands (11.4 ± 1.3 ind./10 m^2) to heathlands, mires and light woodlands (7.3 ± 0.5 to 4.5 ± 0.3 ind./10 m^2).

Mean abundance of the ten most common Caelifera species was 2.9 times higher (5.2 ± 1.2 vs. 1.8 ± 0.6 ind./10 m^2) and maximum abundance even 4.8 times higher (83.8 ± 23.3 vs. 17.3 ± 5.6 ind./10 m^2) than those of the ten most common Ensifera species (Fig. 6). Abundance of the ten most common Ensifera species decreased in the following order: *Conocephalus dorsalis* (6.5 ± 0.8 ind./10 m^2), *Conocephalus fuscus*, *Roeseliana roeselii* and *Metrioptera brachyptera* (2.2 ± 0.2–1.7 ± 0.1 ind./10 m^2), *Pholidoptera griseoaptera*,

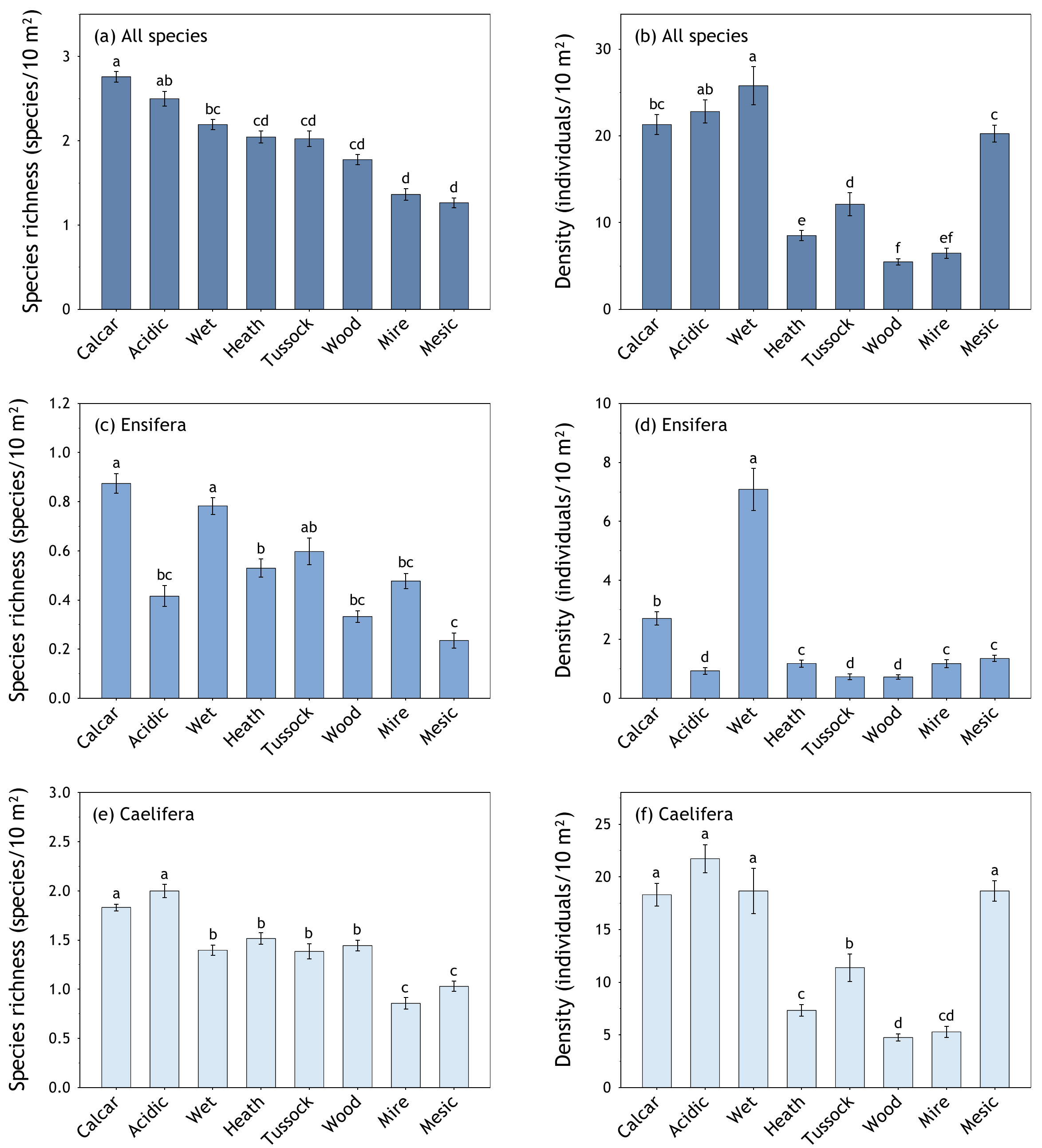

Fig. 5. Mean species richness and abundance (± SE), respectively, of all species (a, b), Ensifera (c, d) and Caelifera (e, f) in July/August in the eight most intensively sampled open habitat types ($n > 70$ plots per type) across Germany. Acidic grassland (acidic): $n = 101$ (species richness), $n = 366$ (abundance); calcareous grassland (calcar): $n = 330$, $n = 348$; wet grassland (wet): $n = 212$, $n = 230$; heathland (heath): $n = 220$, $n = 220$; tussock grassland (tussock): $n = 82$, $n = 134$; light woodland (wood): $n = 215$, $n = 215$; mire: $n = 70$, $n = 82$; mesic grassland (mesic): $n = 85$, $n = 805$. Acidic grasslands included semi-dry grasslands on sandy soils and acidic bedrock; tussock grasslands included dry, sparsely vegetated grasslands on sandy soils, where tussock grasses (*Corynephorus canescens*, *Festuca polesia*, *Festuca psammophila, Koeleria glauca* or *Stipa capillata*) dominated; mires included transition mires and raised bogs. Differences between habitat types were analysed by using generalised linear mixed-effects models (GLMM) (R package 'lme4'; Bates et al#, 2015). 'Habitat type' served as a categorical predictor, 'year', 'biogeographical region' and 'sampling effort' (only abundance data) as random factors. Pairwise comparisons between habitat types were conducted using Tukey's contrasts (R package 'multcomp'; Hothorn et al#, 2008). Different symbols indicate significant differences ($P > 0.05$). Data source: see Fig. 4.

Tettigonia cantans, *Phaneroptera falcata*, *Bicolorana bicolor* and *Decticus verrucivorus* (1.1 ± 0.1–0.9 ± 0.1 ind./10 m^2) and *Tettigonia viridissima* (0.4 ± 0.0 ind./10 m^2) (Fig. 7a). Abundance of the ten most common Caelifera species decreased in the following order: *Chorthippus mollis* (12.3 ± 0.8 ind./10 m^2), *Chorthippus bigittulus*, *Pseudochorthippus montanus*, *Pseudochorthippus parallelus* and

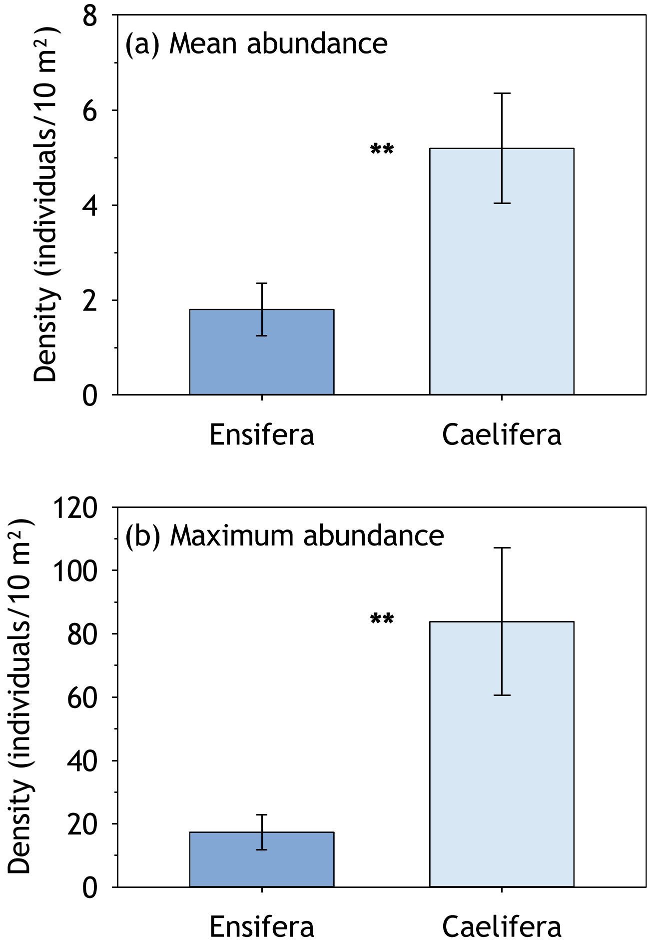

Fig. 6. Mean (± SE) (a) and maximum abundance (b) of the ten most common Ensifera ($N = 10$) and Caelifera ($N = 10$) species, respectively, in the sampled plots in July/August. For considered species see Fig. 7. Differences between Ensifera and Caelifera were analysed by using the Mann-Whitney U test. Maximum abundance: $U = 11.5$, ** $P \leq 0.01$; mean abundance: $U = 14.0$, ** $P \leq 0.01$. Data source: see Fig. 7.

Chorthippus albomarginatus (7.4 ± 0.4–7.1 ± 0.7 ind./10 m^2), *Chorthippus dorsatus* (3.8 ± 0.2 ind./10 m^2), *Omocestus viridulus* and *Stenobothrus lineatus* (2.1 ± 0.2–2.0 ± 0.1 ind./10 m^2) and *Euthystira brachyptera* and *Chorthippus brunneus* (1.3 ± 0.1 ind./10 m^2) (Fig. 7b).

4. Discussion

4.1. Application of box quadrat sampling

The box quadrat has widely been used to assess species richness, abundance and composition of Orthoptera communities in open habitats, including sparsely vegetated ones and those that exhibit closed, taller swards. The studied habitats comprise riverine gravel bars (Lemke et al., 2010; Münsch et al., 2013), coastal dunes (Fartmann et al., 2008), grasslands (Dorda, 1995; Gardiner et al., 2005; Gardiner and Hill, 2006; Poniatowski and Fartmann, 2008; Badenhausser et al.; 2009; Fartmann et al., 2012), heathlands (Borchard et al., 2013), fallow arable fields (Fartmann et al., 2008; Badenhausser et al., 2009), mires (Fartmann et al., 2008; Schwarz and Fartmann, 2022) and light woodlands (Helbing et al., 2014). In these habitats, the box quadrat provides accurate data on species richness and abundance of all Orthoptera species that occur as nymphs or adults on the soil surface or within the herb and dwarf-shrub layer (Schulte, 2003; Gardiner et al., 2005; Gardiner and Hill, 2006; Badenhausser et al., 2009; Fartmann et al., 2022b). By contrast, it is not suitable to assess abundance of crickets that live mostly hidden below the soil surface (e.g., *Gryllus campestris*) or arbusticolous and arboricolous bush-crickets (Fartmann, 1997; Löffler and Fartmann, 2017). Among the 78 native Orthoptera species that are still present in Germany, the vast majority (63 species [81 %]) occur in the mentioned strata of open habitats and can precisely be sampled by using a box quadrat (Fischer et al., 2020; Poniatowski et al., 2024a).

When sampling of Orthoptera is conducted as described in Section 3.2., an escape of unidentified individuals can almost completely be excluded (Fartmann, 1997; Gardiner et al., 2005; Gardiner and Hill, 2006; Badenhausser et al., 2009). Since the lower edges of the

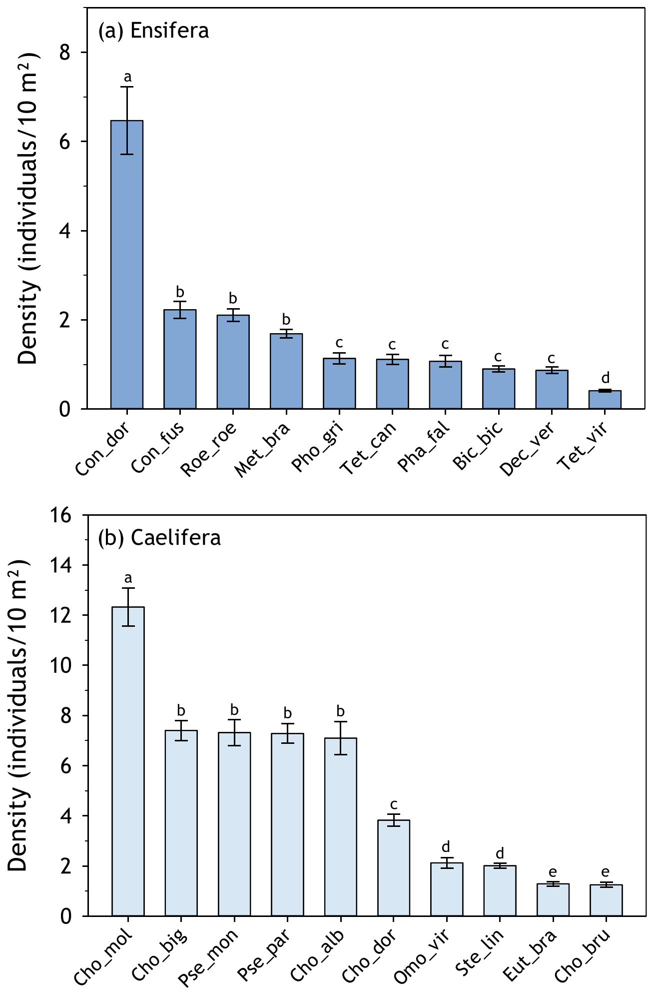

Fig. 7. Mean abundance (± SE) of the ten most common Ensifera and Caelifera species ($n > 100$ plots per species), respectively, in the sampled plots in July/August. Ensifera – *Conocephalus dorsalis* (Con_dor): $n = 190$; *Conocephalus fuscus* (Con_fus): $n = 177$; *Roeseliana roeselii* (Roe_roe): $n = 882$; *Metrioptera brachyptera* (Met_bra): $n = 486$; *Pholidoptera griseoaptera* (Pho_gri): $n = 150$; *Tettigonia cantans* (Tet_can): $n = 115$; *Phaneroptera falcata* (Pha_fal): n = 127; *Bicolorana bicolor* (Bic_bic): $n = 128$; *Decticus verrucivorus* (Dec_ver): $n = 144$; *Tettigonia viridissima* (Tet_vir): $n = 232$. Caelifera – *Chorthippus mollis* (Cho_mol): $n = 612$; *Chorthippus biguttulus* (Cho_big): $n = 1073$; *Pseudochorthippus montanus* (Pse_mon): $n = 229$; *Pseudochorthippus parallelus* (Pse_par): $n = 1366$; *Chorthippus albomarginatus* (Cho_alb): $n = 418$; *Chorthippus dorsatus* (Cho_dor): $n = 578$; *Omocestus viridulus* (Omo_vir): $n = 432$; *Stenobothrus lineatus* (Ste_lin): $n = 509$; *Euthistyra brachyptera* (Eut_bra): $n = 210$; *Chorthippus brunneus* (Cho_bru): $n = 210$. Differences between species were analysed by using generalised linear mixed-effects models (GLMM) (R package 'lme4'; Bates et al#, 2015). 'Species' served as a categorical predictor, 'year', 'biogeographical region' and 'sampling effort' as random factors. Pairwise comparisons between species were conducted using Tukey's contrasts (R package 'multcomp'; Hothorn et al#, 2008). Different symbols indicate significant differences ($P > 0.05$). Data source: see Fig. 4.

sidewalls sit flush with the soil surface, an emigration of individuals below the sidewalls is rather unlikely, even for tiny species (e.g., groundhoppers) or developmental stages (nymphs) (Fartmann, 1997). Another potential way of escape from the area encircled by the box quadrat might be flying or jumping over the sidewalls. However, mobility in Orthoptera is generally a function of temperature and intensive flight activity is, hence, restricted to periods of very high ambient temperatures (Ingrisch and Köhler, 1998). Moreover, those Central European species that have a high capability of flight are among the rarer ones in the wider countryside and usually exhibit only a low abundance (Ingrisch and Köhler, 1998). In line with this, individuals flying out of the quadrat during hot summer days are rarely observed (Fartmann, 1997). The two species where this is sometimes the case are *Chorthippus brunneus* and *Oedipoda caerulescens*. However, both are among the less common species in Central European landscapes (Streitberger et al., 2024; see also Section 3.3.), occur generally in low abundance (Ingrisch and Köhler, 1998, see also Section 3.3.) and can easily be determined visually when flying (Fartmann, 1997). Even the sex can be assessed in flight due to the strong sexual dimorphism (Fischer et al., 2020). Since even in tall grassland and dwarf-shrub vegetation the average vegetation height (cf. Fartmann et al., 2012; Poniatowski and Fartmann, 2008; Schwarz et al., 2023) is usually clearly lower than the box quadrat sidewalls, an escape of individuals by jumping over the sidewalls also rarely occurs (Fartmann, 1997). By contrast, in eastern and southern Europe, where some species that are highly capable of flight may reach higher densities (e.g., *Calliptamus* ssp. or *Sphingonotus* spp.), we recommend separate transect counts of these species under favourable weather conditions (e.g., Fartmann et al., 2001).

In many insect survey techniques (e.g., acoustic counts or sweep netting of Orthoptera), species richness and especially density data strongly vary depending on weather conditions and vegetation structure (Gardiner et al., 2005; Samways et al., 2010). By contrast, sampling of Orthoptera by using a box quadrat is less impacted by both of these factors (Fartmann, 1997; Gardiner et al., 2005; Gardiner and Hill, 2006). For counting all Orthoptera species and individuals inside the quadrat precisely, the only demands are that they have to be active and the vegetation is not sticky. Otherwise, some individuals may get lost through trampling by the surveyors inside the quadrat or remain undetected under the vegetation. Accordingly, box quadrat sampling only requires dry conditions and temperatures of 15 °C or more (Schwarz et al., 2023; Streitberger et al., 2024). Daytime also has no effect on count results (Badenhausser et al., 2009).

For the exclusive sampling of tiny species (e.g., groundhoppers) and developmental stages (nymphs), which are often restricted to small microhabitats, box quadrats of smaller size are used (0.5 m^2 or 1 m^2) (e.g., Cherrill, 2002; Schulte, 2003; Fartmann et al., 2008; Poniatowski and Fartmann, 2010; Münsch et al., 2013). By contrast, larger quadrats having a size of 2 m^2 are applied much more frequently, especially for the sampling of Orthoptera communities (e.g., Oppermann et al., 1987; Fartmann et al., 2012, 2022b; Helbing et al., 2014, 2023; Schwarz and Fartmann, 2022). A quadrat of this size can still easily be transported, assembled, handled and disassembled by one person (see Section 3.2. and Fartmann, 1997). Moreover, due to the size of the quadrat, the number of replicates that is necessary to reach the required minimum sampling area for accurate species richness and abundance estimations decreases, which results in an overall lower sampling time (Ingrisch and Köhler, 1998; see also below).

Ingrisch and Köhler (1998) reviewed Central European box quadrat studies for different types of grasslands regarding the minimum sampling area size that is needed to produce reliable data on species richness and abundance of Orthoptera communities. They showed that a saturation of species richness is reached between a sampled area of 9 and 15 m^2 and that abundance did not vary when increasing the sampling area further. Consequently, for comparisons of Orthoptera species richness, abundance and community composition between habitats, 20 m^2 are usually considered as the minimum sampling area per plot (e.g., Löffler and Fartmann, 2017; Fartmann et al., 2022b; Schwarz and Fartmann, 2022). Therefore, the 2 m^2 quadrat has to be touched down at 10 different, previously undisturbed points per plot. By contrast, monitoring schemes aim to detect even small changes at a very early stage. Therefore, in the newly established German insect monitoring scheme, Orthoptera are sampled on 30 m^2 per grassland plot (15 touchdowns per plot) (Streitberger et al., 2024). Moreover, a specific monitoring for single species that usually occur in low abundance may also require larger sampling areas. In line with this, the Federal State of Lower Saxony has founded a monitoring of the large bush-cricket *Gampsocleis glabra*, which usually exhibits low population densities, on a sampled area of 30 m^2 per heathland plot (own observation). By contrast, for tiny species, the sampling area per plot can be much smaller than 20 m^2 to produce reliable data (e.g.; *Tetrix* spp. or *Xya* spp.; see Schulte, 2003; Münsch et al., 2013).

If besides the species also the sex of each individual is to be determined, biomass assessments are possible. Fartmann and Poniatowski (2025) provide sex-specific live weights for 37 common Central European Orthoptera species. These data have for example already been used to assess biomass loss of Orthoptera through mowing in hay meadows (Schwarz et al., 2023) or to compare Orthoptera biomass inside and outside nature reserves (Poniatowski et al., 2024b).

To identify the drivers of Orthoptera species community composition and its changes, it is also important to record a set of suitable environmental parameters. Since assemblage composition strongly depends on vegetation structure and the interrelated microclimate (Gardiner and Dover, 2008; Ingrisch and Köhler, 1998), we recommend to gather at least the cover of relevant layers (e.g., gravel/stones, bare ground, grasses/herbs and shrubs), vegetation height and type of land use (Fartmann et al., 2012; Löffler and Fartmann, 2017; Streitberger et al., 2024). To compare assemblage composition and to analyse changes, species traits, such as mobility (low vs. high), habitat specificity (generalist vs. specialist), and indicator values such as the species farmland or species temperature index have been proven as very useful (Poniatowski et al., 2020; Fartmann and Poniatowski, 2025).

4.2. Orthoptera species richness and abundance baselines in open habitats

Thus far, a compilation of Orthoptera species richness and abundance data that had been gathered by standardised box quadrat sampling was missing. Our analysis revealed that particularly calcareous and acidic grasslands exhibited a high number of species, whereas especially mires and mesic grasslands had a low species richness. By contrast, abundance was highest in wet, acidic, calcareous and mesic grasslands, and lowest in tussock grasslands, heathlands, mires and woodlands. Mean abundance of the ten most common Caelifera species was nearly three times and maximum abundance even almost five times higher than those of the ten most common Ensifera species. Among the most common Caelifera species, particularly *Chorthippus mollis*, but also *Chorthippus biguttulus*, *Pseudochorthippus montanus*, *Pseudochorthippus parallelus* and *Chorthippus albomarginatus* had a high mean abundance. Among the most common Ensifera species, however, *Conocephalus dorsalis* was the only one that had on average a relatively high abundance.

At the habitat level, the heterogeneity of a habitat is known to have the strongest impact on species richness of Orthoptera (Löffler and Fartmann, 2017; Fartmann, 2024). A high habitat heterogeneity fosters species richness in three different ways:

(i) For many Orthoptera species, structurally diverse habitats are mandatory, since they undergo microhabitat shifts during their ontogenetic development. A typical example is *Decticus verrucivorus* (Cherrill and Brown, 1992; Schirmel et al., 2010; Wünsch et al., 2012): The species requires bare soil for egg-laying and the young nymphs also stay there due to the warm microclimate. Larger, older nymphs and later especially adults, however, also depend on taller vegetation that provides shelter against predators and too high temperatures.

(ii) Heterogeneous habitats exhibit a higher variety of microhabitats and therefore enable the coexistence of many grasshopper species with sometimes very different habitat requirements (Joern, 2005; Jerrentrup et al., 2014; Löffler and Fartmann, 2017).
(iii) Moreover, heterogeneous habitats are significantly more resistant and resilient against the impacts of climate change and generally against strong environmental variation than homogeneous ones (Fartmann, 2024). This is also true for grasshopper populations (Kindvall, 1996; Fartmann et al., 2022b). Overall, habitat heterogeneity decisively contributes to the long-term viability of grasshopper populations, even under strongly fluctuating environmental conditions.

In line with this, calcareous and acidic grasslands exhibited the highest species richness. Both habitat types are well-known for their high habitat heterogeneity (Diacon-Bolli et al., 2012; Ellenberg and Leuschner, 2010; Fumy et al., 2021; Fumy and Fartmann, 2023). Usually, they consist of heterogeneous mosaics of bare ground, short turf and taller vegetation. By contrast, those habitat types that had the lowest species richness, especially mesic grasslands but also mires, are usually characterised by a homogeneous habitat structure (Fumy et al., 2021; Fumy and Fartmann, 2023).

High Orthoptera abundance, however, is often a trade-off between sufficient food and an ample warm microclimate (Gardiner and Dover, 2008; Schirmel et al., 2011; Helbing et al., 2014; Kenyeres et al., 2024). In fact, all four habitat types that were characterised by high Orthoptera densities (wet, acidic, calcareous and mesic grasslands) are normally characterised by a well-established grass/-herbaceous layer, which provides sufficient plant and insect food resources (Fartmann, 2024), as well as sunlit conditions that result in a warm microclimate (Ellenberg and Leuschner, 2010). By contrast, in sparsely vegetated tussock grasslands, heathlands and mires, the low cover of the grass/herbaceous layer and hence, a limited amount of food for grass-feeding species (most Caelifera species; Ingrisch and Köhler, 1998; Schlumprecht & Waeber, 2003), but also for insectivorous or omnivorous ones, was very likely responsible for the low abundance. However, in woodlands, which had the lowest abundance, shade is known to limit Orthoptera densities (Helbing et al., 2014).

Overall, Caelifera are known to be the dominant group of Orthoptera in open Central European habitats and usually only a few of them, such as *C. mollis*, *C. biguttulus*, *P. montanus*, *P. parallelus* and *C. albomarginatus*, account for most of the total abundance of the Orthoptera community (Ingrisch and Köhler, 1998; Schlumprecht and Waeber, 2003). This is also confirmed by our analysis. Both mean abundance and maximum abundance of the most common Caelifera species were much higher than those of the most common Ensifera species.

5. Conclusions and outlook

Here, we presented the design and handling of a box quadrat for standardised assessments of Orthoptera species richness, abundance, biomass and community composition in open habitats. The low construction costs (~300 €) and simple design allow for a wide application of this type of box quadrat in future. Moreover, due to the plug system and the light aluminium construction, the quadrat can easily be transported, assembled, handled and disassembled by one person. For comparisons of Orthoptera communities between habitats and to work efficiently, we recommend using the largest version of the quadrat (size: 2 m^2, height: 0.8 m) and a minimum sampling area of 20 m^2 per plot. The specific handling of the quadrat during sampling should follow the guidelines in this paper. For long-term monitoring or when species are sampled that generally occur in low density, we suggest a sampling area of 30 m^2 (15 replicates). For the sampling of tiny species (e.g., groundhoppers) and developmental stages (nymphs), smaller box quadrats can also be used (size: 0.5 m^2 or 1 m^2) and the sampled area per plot can be much smaller than 20 m^2. If besides the species also the sex of each individual within the quadrat is to be determined, biomass assessments are possible by using available sex-specific live weights. Overall, box quadrat sampling allows rapid and highly precise assessments of Orthoptera community composition, since it is less dependent on favourable weather conditions and vegetation structure than many other insect survey techniques.

Moreover, this paper presents Orthoptera species richness and abundance baseline data in the most frequently studied open habitats and for the most common species within these habitats across Germany. These data are an important basis for comparisons with further box quadrat data from open habitats in Central Europe, for example those that will be generated by the German insect monitoring scheme (Streitberger et al., 2024).

Besides Orthoptera, the described box quadrat sampling can also be applied to assess the species richness and abundance of Mantodea (cf. Streitberger et al., 2024) or, in combination with a suction sampler, other smaller arthropods of the grass/herbaceous layer (e.g., Auchenorrhyncha or Heteroptera) (Cherrill, 2015; Helbing et al., 2023). When using suction samplers, it is difficult to define a concrete sampling area since not only individuals directly below but also in the vicinity of the suction tube are soaked in. Therefore, Cherrill (2015) recommended using suction samplers to sample the complete area within small enclosures. To do so, small box quadrats (size: 0.5 m^2) seem to be as good as the cylindrical enclosures (size: 0.17 m^2) that were used by Cherrill (2015). Chisté et al. (2018) even sampled plant- and leafhopper communities of grasslands within box quadrats of 1 m^2 size.

Ethical statement

Hereby, I, Thomas Fartmann, consciously assure that for the manuscript, A box quadrat for standardised sampling of Orthoptera in open habitats: design, handling, applications and baseline data, the following is fulfilled:

This material is the authors' own original work, which has not been previously published elsewhere.
The paper is not currently being considered for publication elsewhere.
The paper reflects the authors' own research and analysis in a truthful and complete manner.

The paper properly credits the meaningful contributions of co-authors and co-researchers.
The results are appropriately placed in the context of prior and existing research.
All sources used are properly disclosed (correct citation). Literally copying of text must be indicated as such by using quotation marks and giving proper reference.
All authors have been personally and actively involved in substantial work leading to the paper, and will take public responsibility for its content.

The violation of the Ethical Statement rules may result in severe consequences.
To verify originality, your article may be checked by the originality detection software iThenticate. See also http://www.elsevier.com/editors/plagdetect.

CRediT authorship contribution statement

Thomas Fartmann: Conceptualisation, Data curation, Formal analysis, Writing – original draft. Felix Maximilian Freienstein: Video preparation, Writing – review & editing. Felix Helbing: Video preparation, Writing – review & editing. Gwydion Scherer: Data curation, Writing – review & editing. Dominik Poniatowski: Data curation, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

The authors do not have permission to share data.

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Appendix 1

Data sources: Behrens and Fartmann (2004a,b), Fartmann et al. (2022b), Fleischer (2011), Graser (2016), Helbing et al. (2014), (2023), Kämpf (2011), Lemke et al. (2010), Löffler and Fartmann (2017), Ludwig (2015), own unpublished data, Poniatowski and Fartmann (2005, 2007, 2008), Poniatowski et al. (2024b), Poschmann (2011), Poschmann et al. (2009), Schwarz and Fartmann (2022), Schwarz et al. (2023).

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