ARTICULATA 40 (2025): 81–94 ÖKOLOGIE

Opening and subsequent grazing of dry forests as a conservation measure for Orthoptera

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submitted: 06.07.2025; accepted: 11.08.2025 | doi.xxxxxxxxxxxxxxxxxxxxxxxxxxxx

Abstract

While closed forests generally provide poor habitats for most Central European Orthoptera, open and heterogeneous forests can offer valuable environments. We compared Orthoptera between closed forests and forests managed for biodiversity conservation by canopy opening and subsequent grazing. Orthoptera species richness was 1.5 times higher in managed forests compared to unmanaged reference sites. The total number of individuals was also higher in managed forests; however, this increase was primarily driven by the dominance of *Oedipoda caerulescens*. Forest management had a strong influence on species composition, favouring mainly xerothermic, ground-dwelling, and grass-feeding species. Opening forests by reducing canopy cover proved beneficial for many species – though not for the typical forest-dwelling *Nemobius sylvestris*. These findings suggest that through the establishment of open, grazed patches, a diversification of forest management practices can support the conservation of Orthoptera and enhance overall biodiversity in dry forest ecosystems.

Keywords: canopy cover, grazing, management, nature conservation, wood pasture

Zusammenfassung

Obwohl geschlossene Wälder im Allgemeinen schlechte Lebensräume für die meisten mitteleuropäischen Heuschrecken bieten, können offene und heterogene Wälder wertvolle Habitate darstellen. Wir untersuchten die Auswirkungen von Auflichtungen mit anschließender Beweidung in Trockenwäldern als Naturschutzmaßnahme für Heuschrecken. Der Artenreichtum war in solch lichten Wäldern 1,5 Mal höher als auf Referenzflächen ohne diese Maßnahmen. Auch die Gesamtzahl der Individuen war in bewirtschafteten Wäldern höher; dieser Anstieg war jedoch

hauptsächlich auf die Dominanz von *Oedipoda caerulescens* zurückzuführen. Die Waldbewirtschaftung hatte einen starken Einfluss auf die Artenzusammensetzung und begünstigte hauptsächlich xerotherme, bodenbewohnende und grasfressende Arten. Die Auflichtung der Wälder durch Verringerung der Kronendeckung erwies sich für viele Arten als vorteilhaft - allerdings nicht für den typischen Waldbewohner *Nemobius sylvestris*. Diese Ergebnisse unterstreichen, dass eine erhöhte Heterogenität in Trockenwäldern durch für den Naturschutz aufgelichtete Bereiche den Schutz von Heuschrecken unterstützen und die Artenvielfalt insgesamt erhöhen können.

Schlüsselwörter: Beweidung, Kronendeckung, Management, Naturschutz, Waldweide

Introduction

Most Central European Orthoptera species are confined to open habitats such as grasslands and shrublands, with relatively few species found in closed forest environments (Ingrisch & Köhler 1998, Hochkirch et al. 2016). This distribution is primarily due to the shady and humid conditions typical of dense forests, which are unsuitable for the majority of Central European species that require high levels of solar radiation and depend on well-developed grassy vegetation for food. Nonetheless, open or disturbed forest areas, early successional stages, and forest edges can provide valuable habitats for Orthoptera (Sliacka et al. 2013, Helbing et al. 2014). This is especially true for dry, warm sites on sandy soils, such as coastal and inland dunes (Schirmel et al. 2011).

Inland dunes are xerothermic habitats that often serve as important refugia for numerous xerophilous and thermophilic species (van der Ende 2008, Sonneck & Bönsel 2011). Shaped by riverine and aeolian processes, the sands of these landscapes have historically been in constant flux, resulting in the ongoing creation of new pioneer sites. However, such naturally dynamic habitats on sandy soils are increasingly rare across Europe, primarily due to succession and the loss of natural disturbance regimes (Schwabe et al. 2004).

One strategy to counteract succession and restore open forest structures is forest grazing. Historically, livestock grazing in wooded areas – commonly referred to as "wood pastures" – was widespread across Central Europe. Wood pastures are typically heterogeneous and are recognized for their high species richness and distinctive species assemblages (Bergmeier et al. 2010, Hartel et al. 2013, Rösch et al. 2019). While grazing is a well-established and effective management tool in grassland ecosystems, playing a vital role in maintaining biodiversity (Schulz 2003, Köhler et al. 2016, Tälle et al. 2016, Yuan et al. 2016, Gao & Carmel 2020), the reintroduction of grazing into forested landscapes has only recently attracted scientific and conservation interest (Van Uytvanck & Verheyen 2014, Rösch et al. 2019).

The Bienwald is an extensive forest situated along the French-German border in the southern part of Rhineland-Palatinate. It features a unique alluvial fan landscape

characterized by a mosaic of diverse habitats, including expansive dry and sandy inland dunes. From 2004 to 2021, the Bienwald was the focus of a *Naturschutz-großprojekt* (large-scale nature conservation project) – a long-term initiative aimed at preserving ecologically valuable landscapes in Germany. These projects are supported by the Federal Agency for Nature Conservation (BfN) as part of the chance.natur – Federal Funding for Nature Conservation programme. One of the management measures implemented during this project was the enhancement of habitat quality in open dry forests on inland dunes through partial clearing, i.e. targeted tree harvesting to open the forest canopy, and subsequent grazing by sheep, goats and donkeys.

We investigated the effects of this forest management measure on Orthoptera and addressed the following research questions: (i) How does opening and subsequent grazing of dry forests affect the species richness and abundance of Orthoptera? (ii) How do forest management and environmental variables influence species composition? (iii) How do individual species respond to forest canopy cover?

Material and Methods

Study area and sites

The Bienwald is located in the South of Rhineland-Palatinate at the French-German border between the lowlands of the Bruchbach and Otterbach and the Lauter valley (Landesamt für Umwelt 2016) (Fig. 1). It is the largest contiguous forest area in the Rhineland-Palatinate part of the Upper Rhine Valley (Brechtel 2004). In order to develop and preserve this unique landscape, the "Naturschutzgroßprojekt Bienwald" (large-scale nature conservation project funded by the BfN) was launched in 2004 with a project area of around 18,000 hectares (Brechtel 2004).

The deposition of sediments from the Lauter and Rhine rivers created a characteristic alluvial fan with a mosaic of different habitat types. Among these, numerous inland dunes exist, which are regionally rare habitats of outstanding importance for biodiversity (www.bienwald.eu). Due to reforestation, these once widespread habitats have been displaced in many areas and are nowadays mainly covered with pine forest (Kitt 2012).

As a conservation measure within the Naturschutzgroßprojekt Bienwald, in some inland dune areas the tree layer was thinned by removing pines and spruces in 2011-2013. This partial clearing of forest aimed at increasing light penetration to the ground and favouring light- and heat-demanding species. In the next step, low-growing shrubs and small trees were removed. In order to restore the characteristic raw sandy soil, the litter and humus-rich topsoil layer was partly removed with an excavator. To keep the areas open, they were regularly and rotationally grazed by goats, sheep, and donkeys.

We selected eleven opened forest sites with subsequent grazing (= "managed") and five reference forests without these conservation measures (= "unmanaged")

(Fig. 1). Reference forests were characterised by pine and were similar in terms of the sandy soil conditions.

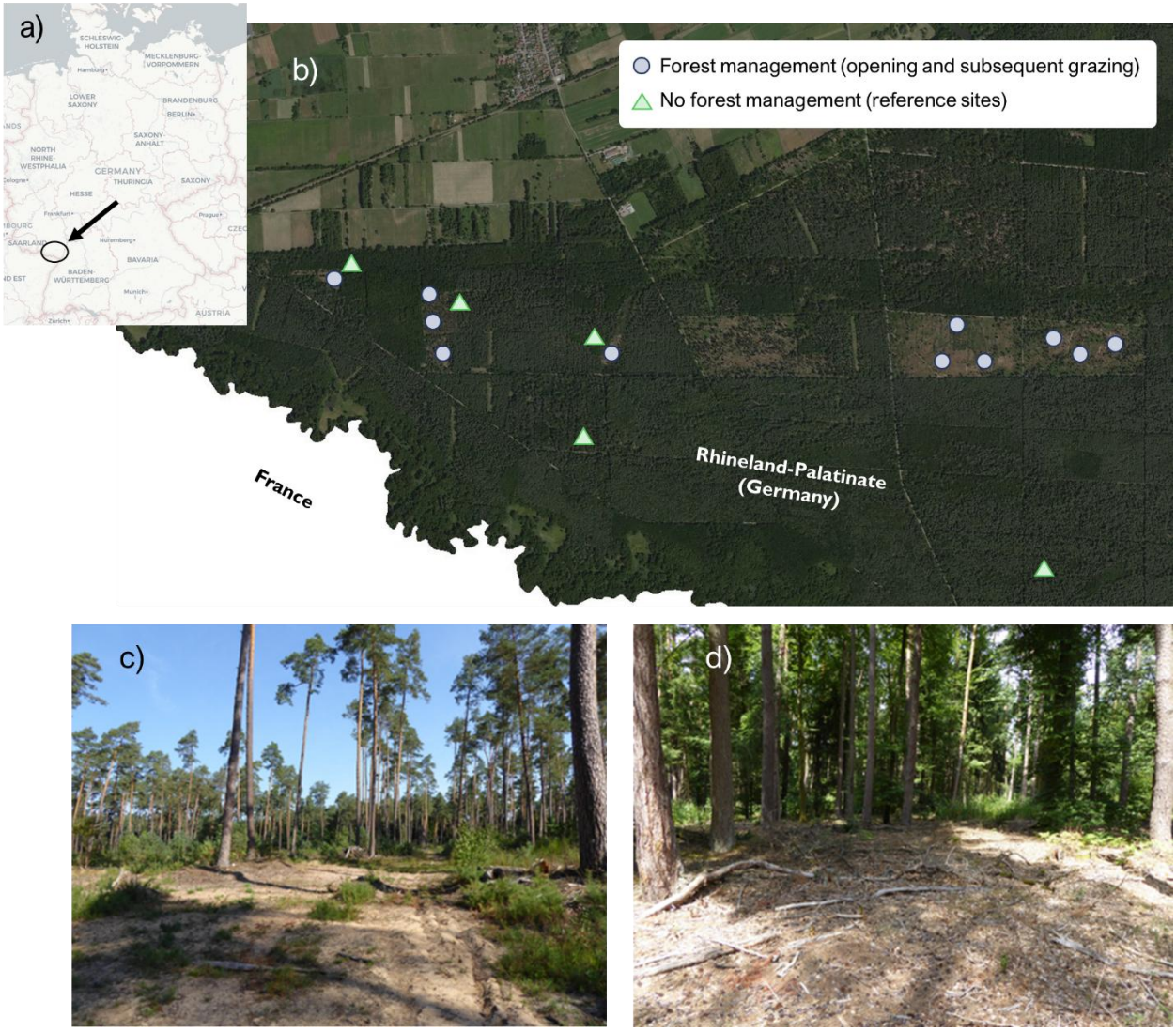

Fig. 1: Location of a) the Bienwald in Germany (source: OpenStreetMap) and b) the study sites in the western part of the Bienwald. Lower images show examples of c) an opened forest site with subsequent grazing and d) a reference forest site without conservation measures. Photos: Gina Hafner.

Sampling of Orthoptera

Orthoptera samplings were conducted in July and August 2015 using transect counts to quantitatively assess species presence. Transect counts is a commonly used method for assessing the relative abundance of Orthoptera (Gardiner et al. 2005). It is particularly well-suited for surveying heterogeneous environments with distinct micro-habitats (Bruckhaus & Detzel 1997), as was the case in the forest sites in this study. In each study site, two transects – each measuring 50 metres in length and 1 metre in width – were established. All Orthoptera observed within these transects were recorded. To enable accurate species identification, individuals were captured when necessary and temporarily placed in ventilated snap-lid

containers. This was mainly necessary for *Chorthippus*-individuals. However, in some cases individuals escaped from catching and could therefore only be determined to genus level (*Chorthippus* spec.). After completing the transect survey, the specimens were identified using Bellmann (2006) and then released back into their habitat to avoid any negative impact on local populations. Each transect was surveyed three times on different days.

In addition to the quantitative sampling, Orthoptera were also qualitatively surveyed in order to record the species spectrum as completely as possible. Therefore, each site was visited and visually and acoustically searched for species for 30 minutes after the transect counts were completed.

Vegetation and temperature

The vegetation sampling was conducted in September 2015. Within each 50-metre transect, four 1 × 1 metre quadrats were established at 12.5-metre intervals. In each quadrat, the cover (%) of grasses, herbs, cryptogams, litter, bare ground, and deadwood were recorded, along with measurements of vegetation height (field layer). The canopy cover (%) was also estimated in each quadrat.

To assess temperature, four data loggers (iButtons) were installed within each transect at 12.5-metre intervals. These loggers recorded temperature hourly over a seven-day period, from 10 to 17 September 2015.

Data analysis

Statistical analyses were done in R 4.3.2 (R Core Team 2024). For statistical analyses on Orthoptera, we only used the quantitative data from the transect counts and the number of individuals from all transects and sampling rounds were summed for each site. For vegetation data, we used the average values across the multiple quadrats and transects to obtain one data point per site. Similarly, the average temperature as well as the minimum and maximum values were calculated for each site.

Differences between managed and unmanaged dry forests were tested with general linear models (GLM). In the models where the environmental parameters were the dependent variables, GLM with Gaussian distribution were performed. In the models with count data (species richness and number of individuals of Orthoptera) as dependent variables, GLM with Poisson distribution were used. In cases of overdispersion, negative binomial models were applied. The significance of the explanatory variable forest management (‘managed’ vs. ‘unmanaged’) was subsequently tested with type II test using the R command ‘Anova’ (R package ‘car’; Fox & Weisberg 2019).

Species composition of Orthoptera was related to forest management and environmental parameters using non-metric multidimensional scaling. The Bray Curtis distance was used as distance measure. For the NMDS only species occurring in three or more sites were used.

The probability of occurrence between the individual Orthoptera species to the canopy cover was tested using multivariate generalized linear models with binomial errors to the presence-absence transformed data using the function 'manyglm' from R package mvabund (Wang et al. 2012). In 'manyglm', correlations between species are considered, which is not possible using standard GLM tools. The percentage of canopy cover was used as explanatory variable, fitting a separate GLM to each species. We considered only the eight most common species in this analysis. The function 'anova.manyglm' was used for resampling-based hypothesis testing (999 permutations). As P-value based hypothesis testing is sample size dependent (Chén et al. 2023), we considered P-values < 0.1 as significant due to our small sample size.

Results

Influence of forest management on vegetation and temperature

Canopy cover was significantly reduced in the managed forest sites (~14%) compared to the unmanaged sites (~59%) (Tab. 1). Forest management significantly reduced the amount of dead wood and cryptogams, which were about two and three times higher, respectively, in unmanaged than in managed sites (Tab.1). In contrast, bare ground cover was almost absent in unmanaged sites (~1%) and significantly higher in managed sites (~43%). Finally, mean temperature was significantly higher in managed sites than in unmanaged sites. All other vegetation parameters were not significantly affected by forest management (Tab. 1).

Table 1: Differences in environmental parameters and vegetation structure between managed (cleared and grazed) and unmanaged dry forests. Significant results in bold.

Environmental parameter	Forest management		F	P
	Managed (N=11)	Unmanaged (N=5)		
Canopy cover (%)	14.3 ± 3.8	59.0 ± 9.4	28.4	**< 0.001**
Dead wood (%)	6.4 ± 1.6	15.0 ± 4.0	6.0	**0.028**
Vegetation height (cm)	22.0 ± 5.1	16.7 ± 4.5	0.4	0.528
Grasses (%)	17.2 ± 5.5	18.3 ± 8.7	0.0	0.915
Herbs (%)	5.7 ± 1.0	5.5 ± 2.0	0.0	0.911
Cryptogams (%)	9.0 ± 4.0	27.0 ± 6.2	6.2	**0.026**
Litter (%)	19.8 ± 5.0	33.3 ± 6.6	2.4	0.144
Bare ground (%)	42.5 ± 7.8	1 ± 1	12.5	**0.003**
Mean temperature (°C)	16.0 ± 0.1	14.8 ± 0.2	23.9	**< 0.001**
Soil moisture (%)	4.8 ± 1.1	4.8 ± 1.3	0.0	0.994

General results of Orthoptera

In total, we recorded 17 species including the Mantodea *Mantis religiosa*. Three species (*Aiolopus thalassinus*, *M. religiosa* and *Pseudochorthippus parallelus*) were detected only during the qualitative surveys of the sites. Quantitative sampling yielded a total of 975 Orthoptera individuals. Of these, 52 individuals could only be determined to the genus *Chorthippus* (most likely *C. biguttulus* or *C. brunneus*). *Oedipoda caerulescens* was the dominant species and made up about 53% of all sampled individuals. Three species are of conservation concern and on the German Red List (Poniatowski et al. 2024) (Table 2).

Table 2: Number of individuals of recorded Orthoptera species (mean and SE) in forest sites managed by opening and subsequent grazing (N=11) and unmanaged reference forest sites (N=5). [1]detected only in qualitative surveys (number in brackets = number of sites). V = near threatened („Vorwarnliste“) in German Red List (Poniatowski et al. 2024).

Species	**Forest management**	
	Managed (N=11)	**Unmanaged (N=5)**
Aiolopus thalassinus[1] [V]	present (1)	absent
Chortippus biguttulus	5.5 ± 1.9	0.6 ± 0.4
Chortippus brunneus	0.5 ± 0.2	0.6 ± 0.6
Chortippus spec.	4.3 ± 2.0	0.4 ± 0.4
Conocephalus fuscus	0.3 ± 0.3	0
Gomphocerippus rufus	1.3 ± 0.7	2.4 ± 1.0
Gryllus campestris	0.1 ± 0.1	0
Leptophyes punctatissima	0.1 ± 0.1	0
Mantis religiosa[1]	present (3)	absent
Myrmeleotettix maculatus [V]	16.0 ± 8.8	1.2 ± 0.8
Nemobius sylvestris	0.1 ± 0.1	17.4 ± 7.7
Oedipoda caerulescens	46.7 ± 6.6	0.6 ± 0.4
Phaneroptera falcata	1.4 ± 0.5	1.0 ± 0.8
Pholidoptera griseoaptera	0	0.6 ± 0.2
Pseudochorthippus parallelus[1]	present (2)	absent
Sphingonotus caerulans	0.3 ± 0.3	0
Tetrix undulata	0.9 ± 0.4	0
Average number of individuals	77.5 ± 13.3	23.9 ± 3.9
Total number of species	16	9
Average number of species	6.7	4.4

Influence of forest management on Orthoptera

Forest management significantly affected species richness of Orthoptera, which was on average about 1.5 times higher in managed than in unmanaged sites (Chi^2 = 3.29, P = 0.070; Fig. 2a). In total, 16 species were detected in managed and only 9 species in unmanaged forest sites (Table 2). The total number of individuals was significantly and about three times higher in managed forest sites compared to unmanaged sites (Chi^2 = 15.99, P < 0.001; Fig. 2b). This effect was, however, mainly driven by the dominant species *O. caerulescens*, which almost exclusively occurred in managed forest sites (Chi^2 = 80.56, P < 0.001; Fig. 2d). Analyses without this species showed no significant difference in the number of individuals between managed and unmanaged forest sites (Chi^2 = 0.23, P = 0.632; Fig. 2c).

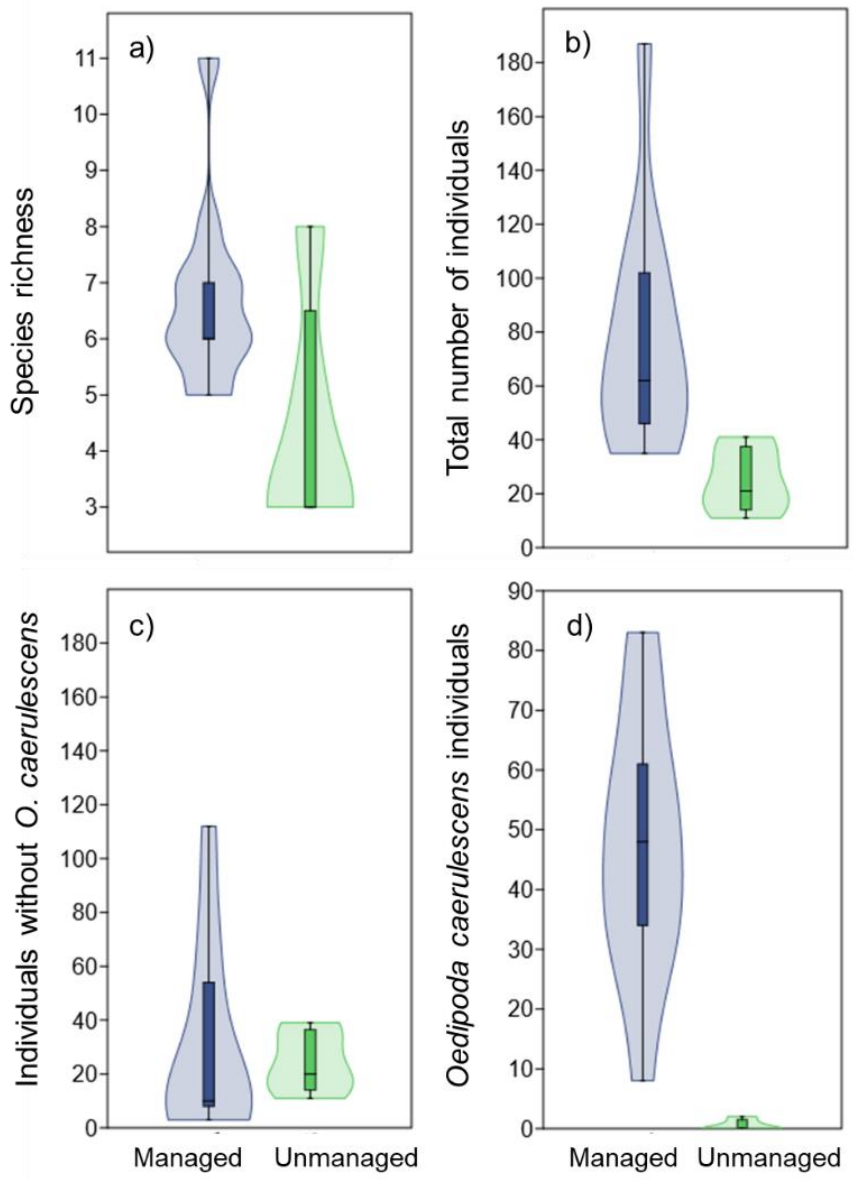

Fig. 1: Comparison of a) species richness, b) total number of individuals, c) total number of individuals without the dominant species *Oedipoda caerulescens*, and d) number of individuals of *Oedipoda caerulescens* between managed and unmanaged forests.

Influence of forest management and environmental parameters on species composition

The species composition of Orthoptera differed significantly between managed and unmanaged forest sites (Table 3, Fig. 3). Environmental parameters associated with the forest management also showed significant influences on species composition, namely canopy cover and dead wood cover (associated with unmanaged sites) as well as bare ground cover and the mean temperature (associated with managed forests) (Table 3, Fig. 3).

Most species, especially the geophilic species *O. caerulescens* and *Tetrix undulata*, were related to managed and open forest sites, which contained more bare ground and higher temperatures (Fig. 3). Only two species, *Nemobius sylvestris* and *Pholidoptera griseoaptera*, were associated to unmanaged forests with its closer canopies and higher cover of litter and dead wood (Fig. 3).

Table 3: Relation of Orthoptera species composition to environmental parameters (non-metric multidimensional scaling).

Environmental parameter	R^2	P
Forest management	0.54	**< 0.001**
Canopy cover	0.69	**0.002**
Dead wood	0.43	**0.025**
Vegetation height	0.19	0.265
Grasses	0.41	**0.038**
Herbs	0.05	0.708
Cryptogams	0.22	0.187
Litter	0.31	**0.094**
Bare ground	0.70	**0.003**
Mean temperature	0.72	**< 0.001**
Soil moisture	0.00	0.994

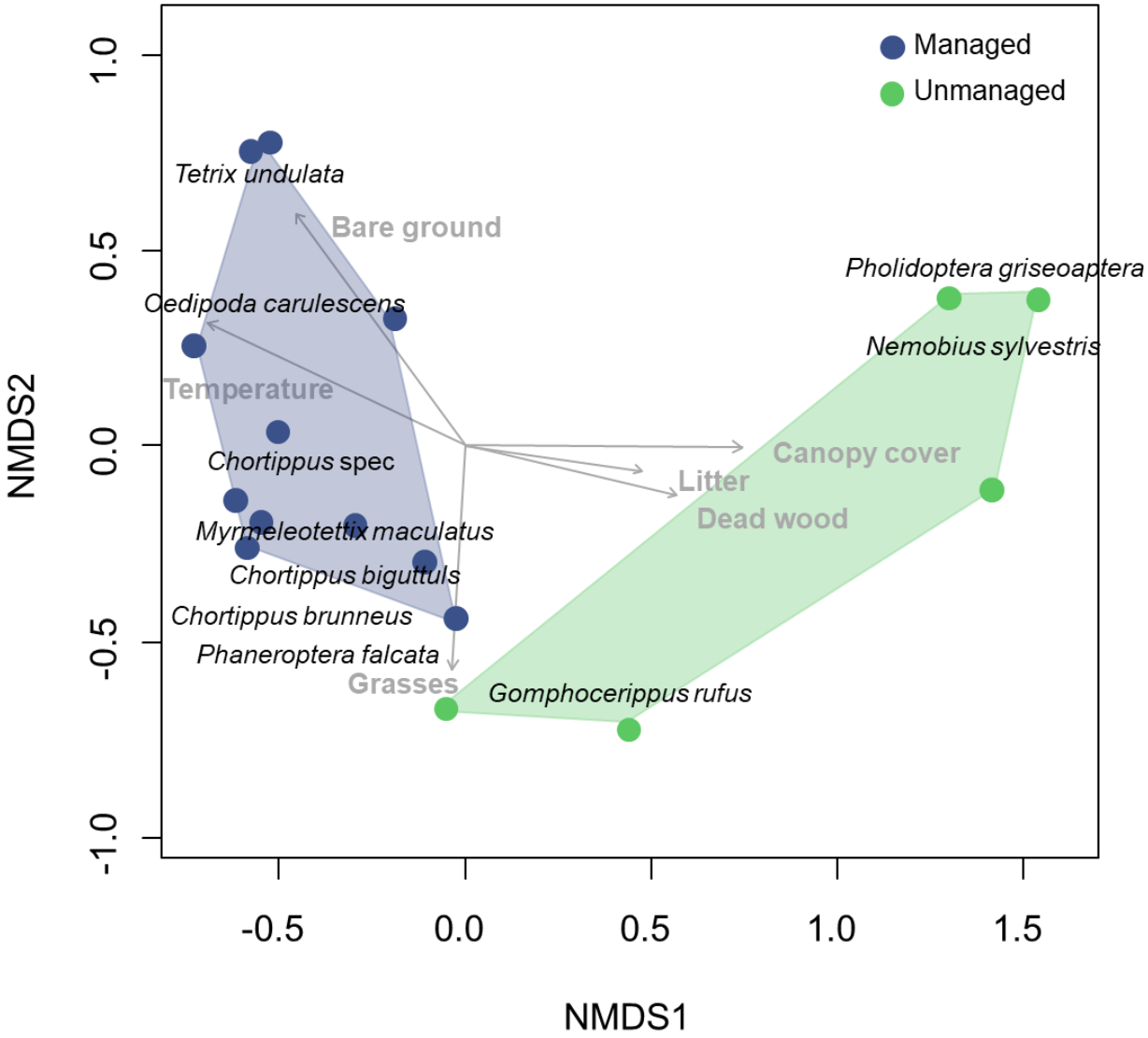

Fig. 3: Species composition of Orthoptera in managed (cleared with subsequent grazing) and unmanaged dry forests. Species composition was significantly related to forest management, canopy cover, the cover of bare ground, dead wood, grasses and litter, and temperature. Only species occurring in > 3 sites have been included in the analyses. For test statistics see Table 2.

Probability of occurrence of Orthoptera in relation to canopy cover

The canopy cover significantly affected the probability of occurrence of the multiple Orthoptera species (Dev = 32.76, P = 0.014). Five out of the eight considered species showed a significant decrease in the probability of occurrence with increasing canopy cover and only *N. sylvestris* showed a significant positive relation (Fig. 3). Two species (*Gomphocerippus rufus* and *Phaneroptera falcata*) were not significantly affected by canopy cover (Fig. 3).

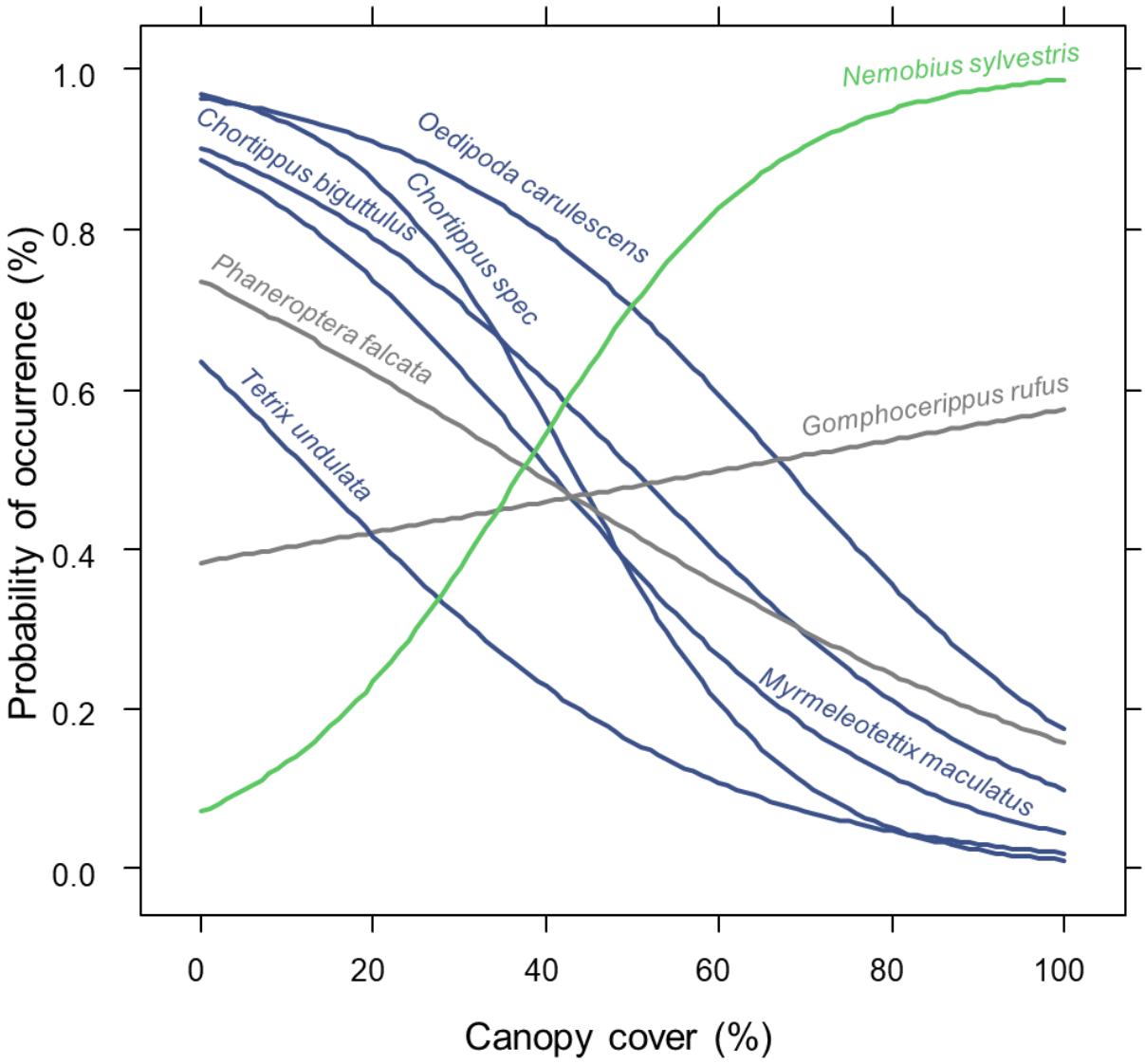

Fig. 4: Probability of occurrence of the eight most common Orthoptera species in relation to canopy cover in dry forests. blue = significant negative relation, green = significant positive relation, grey = no significant relation.

Discussion

We studied Orthoptera in dry forests of the Bienwald, a large forest located along the French border in southern Rhineland-Palatinate, Germany. Specifically, we investigated the effects of forest opening followed by grazing – implemented as a conservation measure – and compared these managed forests with unmanaged reference pine forests. Managed forests were characterized by an open canopy, a high proportion of bare ground, and a correspondingly warmer microclimate. In contrast, unmanaged forests exhibited greater coverage of dead wood and cryptogams.

We found that Orthoptera species richness and abundance were higher in managed forests compared to unmanaged ones. However, the increased total abundance was largely driven by the dominance of *O. caerulescens*. These findings suggest that forest opening followed by grazing enhances Orthoptera diversity in

dry forests and can therefore serve as an effective conservation tool. Our results support the findings of Rösch et al. (2019), who also observed that canopy opening combined with grazing promotes grasshopper populations. Similarly, Kati et al. (2003) emphasized the importance of maintaining forest openings, structural heterogeneity, and grazing for Orthoptera conservation in a forest nature reserve in Greece. The ecological value of open habitats within forested landscapes is further supported by Sliacka et al. (2013), who demonstrated that clear-cuts benefit Orthoptera, and Helbing et al. (2014), who highlighted the significance of early successional forest stages for Orthoptera diversity.

As expected, the Orthoptera species that benefited from forest management were primarily ground-dwelling and xerophilic. These species clearly profited from the more favorable vegetation structure and microclimatic conditions found in managed forests. In our study, this group included not only widespread generalist species such as *O. caerulescens* and *C. biguttulus*, but also regionally rare species like *Sphingonotus caerulans* and *Myrmeleotettix maculatus*. In contrast, only *N. sylvestris* and *P. griseoaptera* – both typical forest dwellers or shade-tolerant species – were characteristic of the unmanaged dry reference forests (Detzel 1998, Rösch et al. 2019). Canopy cover emerged as the key driver influencing both local vegetation and forest microclimate. In the dry forests of the Bienwald, most Orthoptera species exhibited sharp declines when canopy cover exceeded 50%, with the exception of the forest specialist *N. sylvestris*. From a conservation perspective, this suggests that creating open forest habitats with canopy cover below 50% is a highly effective strategy to promote Orthoptera diversity.

Over the past decade, several student excursions under the guidance of the first author have been conducted to some of the managed forest sites included in this study. During these excursions, additional Orthoptera species – absent from our current survey but observed regularly – were recorded. These include *C. mollis*, *Stenobothrus lineatus*, and *Platycleis albopunctata*, which also appeared to be largely restricted to managed forest areas. Furthermore, species such as *Oecanthus pellucens*, *Ruspolia nitidula*, *Tettigonia viridissima*, and *T. cantans* were commonly associated with open forests (including managed sites), ecotones, and shrub-dominated habitats. In moist grasslands bordering the forest and along the river Lauter, *C. dorsatus* and *Stetophyma grossum* are consistently found as part of the local Orthoptera fauna.

To conclude, our findings demonstrate that opening dry forests followed by grazing is a highly effective management strategy for enhancing Orthoptera diversity. This approach creates habitat conditions that particularly benefit ground-dwelling and xerothermic species, supporting both common generalists and regionally rare taxa. By promoting structurally open environments and warmer microclimates, such management measures may contribute to the conservation of threatened Orthoptera species and the overall biodiversity of dry forest ecosystems. These results underscore the ecological value of targeted habitat restoration practices in forest conservation planning.

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