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The invasion of *Bromus erectus* alters species diversity of vascular plants and leafhoppers in calcareous grasslands

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Abstract. 1. The most common mechanism of biological invasions is an increase in competition, which usually results in the loss of biodiversity. The invasion of *Bromus erectus* (Syn. *Bromopsis erecta*) in calcareous grasslands of western and central Europe is well-documented. Although, it is largely unknown to what extent this development affects biodiversity.

2. In this study, we analysed the effects of *B. erectus* invasion on vascular plant and leafhopper assemblages of calcareous grasslands. At each of the 15 randomly selected sites, we compared one plot with stands of *Bromus* (presence) and one without (absence) (paired sampling design).

3. The invasion of *B. erectus* affected vegetation structure as well as vascular plant and leafhopper assemblages. Despite similar abiotic site characteristics, *Bromus* plots had a higher turf height, vegetation density, and litter cover. Additionally, we recorded a much lower species richness in *Bromus* plots than in absence plots in all analysed groups of vascular plants. A similar pattern was found for leafhoppers. Absence plots exhibited a higher species richness of habitat and diet specialists than *Bromus* plots. The overall abundance of all leafhopper species was highest in presence plots, whereas that of diet specialists peaked in absence plots.

4. We conclude that the ongoing invasion of *B. erectus* will lead to a strong structural homogenisation with negative effects on plant and insect diversity. One possible management tool might be a goal-driven rough grazing with sheep – especially in spring when *B. erectus* is much more palatable than in summer and autumn.

Key words. Alien plant, Auchenorrhyncha, *Bromopsis erecta*, climate change, insect, range shift, semi-dry grassland, species richness, structural homogenisation, vegetation structure.

Introduction

Biological invasions by alien plants may have diverse ecological impacts on the invaded ecosystem (Ricciardi *et al.*, 2013; Kumschick *et al.*, 2015). The most common mechanism is an increase in competition (Rumlerová *et al.*, 2016), which usually results in changes in primary

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production and the loss of biodiversity (Gaertner *et al.*, 2009; Vilà *et al.*, 2011; Pyšek *et al.*, 2012). Perennial invasive plants are often very competitive and able to suppress low-growing (annual) native plant species (Isermann *et al.*, 2007; Brewer, 2008; Thiele *et al.*, 2010). Rumlerová *et al.* (2016) attributed this to the long-term impact exerted by long-lived invaders. Such changes in plant-species compositions are often followed by alterations in the diversity and abundance of arthropod communities (Spafford *et al.*, 2013). Consequently, ecosystem services and the trophic structure of food webs may be negatively affected (McCary *et al.*, 2016; Mitchell & Litt, 2016).

Such processes are particularly acute when alien plants penetrate into ecosystems with high biodiversity. Calcareous grasslands rank among the most species-rich habitats throughout Europe (Poschlod & WallisDeVries, 2002; van Swaay, 2002); however, as a result of land-use intensification, abandonment and afforestation, calcareous grasslands have lost much of their original extent and have become increasingly fragmented. Today, they are often situated in a matrix of intensively used farmland (Steffan-Dewenter & Tscharntke, 2002; Poniatowski *et al.*, 2016), which makes them a refuge for many specialised species (Poniatowski & Fartmann, 2008; Krämer *et al.*, 2012; Zulka *et al.*, 2014). Due to their role as biodiversity hotspots, and the great threats they face, they are priority habitats of the EU Habitats Directive (Ssymank *et al.*, 1998).

The perennial tussock grass *Bromus erectus* W. Hudson 1762 (Syn. *Bromopsis erecta*) is characteristic of subatlantic and submediterranean calcareous grasslands in western and southwestern Europe (Royer, 1991; Sutkowska *et al.*, 2013). In central Europe, however, it was absent until the modern age (Poschlod & WallisDeVries, 2002). Although *B. erectus* has been established in southern Germany for many centuries, it has only been known since the mid 19th century in northern Germany (e.g. Noeldeke, 1886; Beckhaus, 1893; Brandes, 1897). The strong expansion of the species in northern Germany, however, only began in the course of the 20th century (Bornkamm, 2006, 2008). In the calcareous grasslands of our study area, the Diemel Valley (eastern Westphalia, northern Hesse), *B. erectus* was still very rare at the end of the 1990s. At this time, *B. erectus* was present in only 6% of 110 plant relevés representative of the calcareous grasslands of the study area (Fartmann, 2004). Currently, the species occurs in most calcareous grasslands, and regularly forms patches of dominance stands (T. Fartmann, D. Poniatowski, unpublished observation).

Some authors explain the recent expansion of *B. erectus* in central Europe with the cessation of the former low-intensity grazing regimes (e.g. Bornkamm, 2008; Ellenberg & Leuschner, 2010). In the calcareous grasslands of the Diemel Valley, however, no such changes in grassland management took place between the 1990s and today (Fartmann, 2004; T. Fartmann, D. Poniatowski, unpublished observation). In contrast, the effects of climate change were clearly visible during that period. Temperatures significantly increased and relative humidity significantly decreased (Poniatowski & Fartmann, 2011; Stuhldreher & Fartmann, 2014, 2018). Indeed, global warming is known to promote the invasion of *B. erectus* in calcareous grasslands (Moser *et al.*, 2011). *Bromus erectus* is well-adapted to drought (Grime *et al.*, 2007); and consequently, it currently germinates earlier in the season due to higher temperatures in spring and can produce more biomass during the year, favouring the expansion of the species (Moser *et al.*, 2011). In the Diemel Valley, the patches dominated by *B. erectus* are, therefore, restricted to the driest and warmest parts of the study area (T. Fartmann, D. Poniatowski, unpublished observation).

Although, the invasion of *B. erectus* in western and central Europe is well-documented, it is widely unknown to what extent this development affects biodiversity. We therefore aimed to analyse if the invasion of *B. erectus* alters vascular plant and insect assemblages within central European calcareous grasslands. Furthermore, we wanted to know if the magnitude of the response differs among the considered groups. For this purpose a paired sampling design was conducted on 15 randomly selected sites to compare the community composition in plots with monospecific stands of *B. erectus* (presence) and without (absence). As a representative insect group for the study, we chose Auchenorrhyncha (hereafter referred to as leafhoppers) because they are important primary consumers and, in contrast to other insect herbivores (such as grasshoppers or butterflies), have a higher species richness and level of philopatry (Nickel & Hildebrandt, 2003; Achtziger *et al.*, 2014). To disentangle the effects of the invasion of *B. erectus* on the diversity of our model organisms, we considered not only the overall species richness, but also the number of threatened species and habitat specialists. Due to a high degree of host plant specificity in leafhoppers (Nickel & Remane, 2002), we additionally analysed the effects on leafhopper diet specialists and their host plants.

Materials and methods

Study area

The study area is located at the northern edge of the German uplands. More specifically, it comprises the middle and lower part of the Diemel Valley along the border between the federal states of North Rhine-Westphalia and Hesse (51°32′N/9°00′E and 51°36′N/9°24′E) at an elevation of 160–280 m a.s.l. (Fig. 1). The climate is suboceanic (Müller-Wille, 1981) with mean annual temperatures of 7.5–9°C and a mean annual precipitation of 650–800 mm (MURL NRW, 1989). Typical elements of the study area are calcareous grasslands (~400 ha), which lie isolated in an intensively used agricultural and forested landscape. As a part of the Diemel Valley, the study area belongs to the largest area of semi-dry calcareous grasslands in the northern half of Germany (Fartmann, 2004). Because of its European relevance for biodiversity conservation, the study area

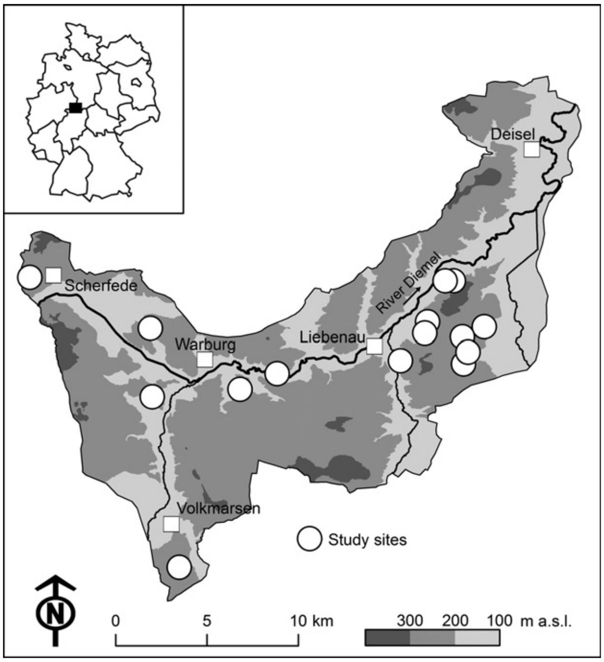


Fig. 1. The study area, the middle and lower Diemel Valley in central Germany (inlay), and the 15 study sites.

Table 1. Mean values (±SE) of the abiotic parameters of the plots with (presence) and without (absence) *Bromus erectus*. Wilcoxon signed-rank test (*W*) or paired *t* test (*t*) for significance (α = 0.05): n.s. = not significant.

Parameter	*Bromus erectus* Presence	*Bromus erectus* Absence	Statistics	*P*
Climate				
Sunshine (hours)*	12.2 ± 0.4	11.9 ± 0.4	*t* = –0.5	n.s.
Northness[†]	–0.6 ± 0.1	–0.5 ± 0.2	*t* = 1.5	n.s.
Eastness[†]	–0.4 ± 0.1	–0.2 ± 0.2	*t* = 1.2	n.s.
Slope (°)	15.7 ± 1.9	16.3 ± 1.6	*t* = 0.4	n.s.
Ellenberg indicator value				
Light	7.2 ± 0.0	7.3 ± 0.0	*t* = –0.3	n.s.
Moisture	3.8 ± 0.1	3.8 ± 0.0	*W* = –8.0	n.s.
Nitrogen	2.9 ± 0.1	2.9 ± 0.1	*t* = –0.5	n.s.
Soil reaction	7.4 ± 0.1	7.4 ± 0.1	*t* = 0.4	n.s.

*Potential daily sunshine duration measured using a horizontoscope (Tonne, 1954) for August, accuracy: 0.5 hour (for details see Section Materials and methods).

[†] Conversion of aspect by sine and cosine into "eastness" and "northness" (eastness = 0 and northness = 1 meaning 360°, eastness = 1 and northness = 0 meaning 90°).

has the status of a 'Prime Butterfly Area' (van Swaay & Warren, 2003) and most of the calcareous grasslands are protected as Natura 2000 sites.

Study sites and plots

Within the study area, we randomly selected 15 calcareous grasslands with monospecific stands of *B. erectus* as study sites. At each study site, we randomly chose one plot with occurrence of *B. erectus* (presence) and one without (absence) (paired design). To avoid edge effects, we placed the presence plots (hereafter also referred to as *Bromus* plots) in the centre of the stands dominated by *B. erectus*. The minimum size of each chosen *B. erectus* stand was 500 m^2. Even though these stands had a mean *B. erectus* cover of at least 50%, the *B. erectus* cover within our presence plots varied between 20 and 62.5% (mean: 40.7%). In contrast, absence plots were defined as sites with a *B. erectus* cover of <5%. Although, in the majority of cases, the species was completely absent. The absence plots were at least 10 m apart from the respective *B. erectus* stand. Both plots had an area of 10 m × 10 m and similar abiotic site characteristics (Table 1). For plant sampling alone, plots were smaller (3 m × 3 m).

Habitat characteristics

Several parameters of horizontal habitat structure were recorded: cover of total vegetation, cryptogams, litter, bare soil, and gravel and stones. In addition, vertical vegetation structure was ascertained by measuring vegetation height and vegetation density. We used a wire-framed box (50 cm × 30 cm × 30 cm), which was open on all sides except the back, to estimate vegetation density (Poniatowski & Fartmann, 2008). The front of the box was horizontally divided into six height layers of 5 cm each to estimate the vegetation density between 0 and 30 cm above ground. The cover of each layer was viewed horizontally against the bright back of the box. For further analysis, the cover of the six layers was summarised. Among abiotic site characteristics, we ascertained aspect, slope and potential daily sunshine duration. The latter was measured with a horizontoscope according to Tonne (1954) (cf. Mühlenberg, 1993). We also calculated Ellenberg's indicator values for vascular plants (Ellenberg *et al.*, 2001) to characterise the plots in more detail (mean values for light, moisture, nitrogen, and soil reaction).

Plant sampling

Plant species richness and cover of each plant species was sampled once between the end of May and the beginning of June 2011. Plant species were defined as habitat specialists when they were typical calcareous grassland species according to the regional classification scheme of Schmidt (2000) and Fartmann (2004). The threat status of the species was taken from Hemm *et al.* (2008) and Raabe *et al.* (2010). Plants were identified to species level using Jäger (2011). The nomenclature followed Buttler and Thieme (2017).

Leafhopper sampling

Leafhoppers (Auchenorrhyncha: Cicadomorpha and Fulgomorpha, that is, including plant- and froghoppers) were sampled three times, in mid-spring, and early and late summer 2011. The insects were caught by standardised sweep-net samples. In each plot, we made 60 sweeps with a round net of 30 cm diameter covering the entire plot. Afterwards, we directly searched for epigeic leafhopper species for 10 minutes. We utilised these additional catches only for analyses that included species richness. All individuals were transferred to vials, killed, and determined to species level in the laboratory using Biedermann and Niedringhaus (2004). The nomenclature followed Nickel *et al.* (2016).

For each species, we checked whether it is threatened in Germany (Nickel *et al.*, 2016), and whether it is a habitat and/or diet specialist. Habitat specificity was derived from Poniatowski and Hertenstein (2013). Species that exclusively occur in (semi)-dry grasslands were classified as habitat specialists. Evaluation of diet preferences was based on Nickel and Remane (2002) and Nickel (2003). We defined diet specialists as species that depend on a single host plant species within the calcareous grasslands of the study area (1st degree monophagy *sensu* Nickel, 2003).

Statistical analysis

Differences of environmental and species data between presence and absence plots were analysed using a paired *t* test. If data were not normally distributed or had no homogeneous variance (Kolmogorov-Smirnov and Levene test, respectively), we performed Wilcoxon signed-rank test. Indicator species analyses (ISA) were carried out for vascular plant and leafhopper samples in order to identify the indicator species for each plot type (Dufrêne & Legendre, 1997).

For the pairwise comparison of the samples we used SigmaPlot 13 statistical packages. ISA was carried out using PC-ORD 5.0 (MjM Software Design, Gleneden Beach, OR, USA).

Results

Environmental conditions

Abiotic site conditions did not differ between presence and absence plots (Table 1). In contrast, some vegetation characteristics differed significantly (Table 2): *Bromus* plots had higher turf height, vegetation density, and litter cover.

Plant assemblages

In total, we found 88 vascular plant species. More than 20% of these species were classified as threatened species ($n = 21$) and habitat specialists ($n = 21$) (Table S1). The number of plant species differed strongly between plots with and without *B. erectus* (Fig. 2a): total species richness, as well as the number of threatened, habitat specialist and host plant species, were significantly higher in absence plots. Altogether, the most frequent species were *Sanguisorba minor* and *Lotus corniculatus*, both occurred in ≥80% of all plots (Table S1). The ISA identified only one significant indicator species for the presence plots: *B. erectus* (Table 3). In contrast, absence plots were rich in indicator species: four grass species (*Brachypodium pinnatum*, *Briza media*, *Festuca ovina* agg., and *Helictotrichon pratense*) and one rosette herb (*Hieracium pilosella*).

Leafhopper assemblages

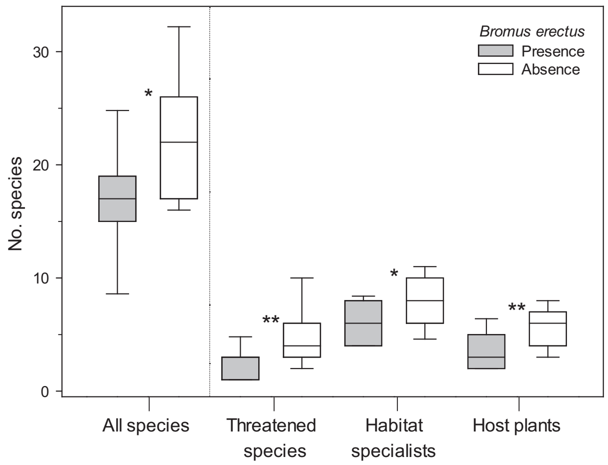
In total, we caught 62 leafhopper species (comprising 1659 individuals); 15 of which were threatened (Table S2), nine of these species were habitat specialists and 16 were diet specialists. The number of habitat and diet specialists was significantly higher in absence than in presence plots (Fig. 2b). In contrast, the number of all and threatened species did not differ between the two plot types. The occurrence of *B. erectus* affected the overall abundance of all species and of diet specialists significantly, but not that of threatened species and habitat specialists (Fig. 3). The abundance of all leafhopper species was highest in presence plots, whereas that of diet specialists peaked in absence plots. *Turrutus socialis* and *Psammotettix helvolus* were the most widespread and abundant species, both

Table 2. Mean values (±SE) of the habitat-structure parameters of the plots with (presence) and without (absence) *Bromus erectus*. Wilcoxon signed-rank test (*W*) or paired *t* test (*t*) for significance ($\alpha = 0.05$): ***$P < 0.001$, **$P < 0.01$, n.s. = not significant.

	Bromus erectus			
Parameter	Presence	Absence	Statistics	*P*
Cover (%)				
Total vegetation	91.7 ± 2.2	91.6 ± 2.8	$W = -13.0$	n.s.
Cryptogam layer	57.0 ± 7.5	60.0 ± 6.5	$t = 0.3$	n.s.
Litter layer	41.0 ± 5.2	22.3 ± 4.4	$t = -3.5$	**
Bare soil	9.9 ± 3.7	8.3 ± 2.6	$W = 14.0$	n.s.
Gravel and stones	0.3 ± 0.2	1.2 ± 0.6	$W = -12.0$	n.s.
Vegetation height (cm)	24.4 ± 2.7	12.7 ± 1.9	$t = -3.2$	**
Vegetation density (%)*	179.0 ± 15.3	80.2 ± 13.1	$t = -4.7$	***

*Measured for different layers with a 50-cm wide and 30-cm deep wire-framed box (for details see Section Materials and methods); the sum of all layers is used in the analysis.

(a) Vascular plants



(b) Leafhoppers

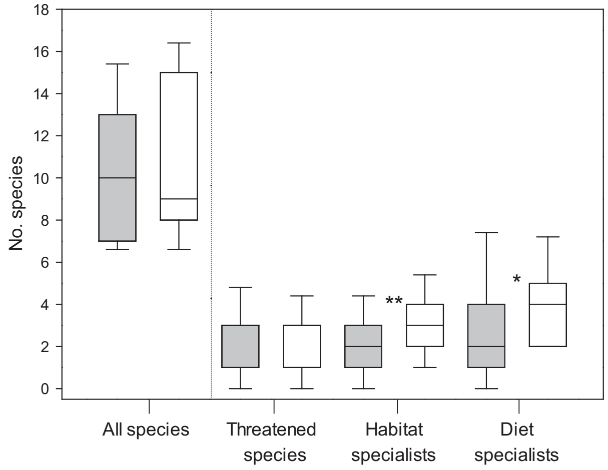


Fig. 2. Number of vascular plant (a) and leafhopper species (b) per plot of all species, threatened species, and habitat specialists as well as host plants and diet specialists, respectively (for details see Table S1 and S2). Box plots show 10th and 90th percentiles (whiskers), 25th and 75th percentiles (boundary of the box) and median (line). Wilcoxon signed-rank test or paired t test for significance ($\alpha = 0.05$): $*P < 0.05$, $**P < 0.01$. Statistics: (a) all species: $t = 2.7$, $P = 0.018$; threatened species: $W = -62$, $P = 0.003$; habitat specialists: $t = 2.2$, $P = 0.04$; host plants: $t = -3.5$, $P = 0.004$; (b) all species: $t = 0.2$, $P = 0.8$; threatened species: $t = -0.3$, $P = 0.8$; habitat specialists: $t = 3.1$, $P = 0.008$; diet specialists: $t = 2.2$, $P = 0.045$.

occurred in ≥70% of all plots (Table S2), with 375 and 225 individuals, respectively. The ISA identified three leafhopper indicator species for each plot type (Table 3, Table S2): the unspecialised grass feeders, *T. socialis*, *P. helvolus,* and *Arocephalus longiceps*, were characteristic of *Bromus* plots. In contrast, the indicator species of absence plots, *Adarrus multinotatus*, *Ribautodelphax pungens,* and *Psammotettix cephalotes*, are diet specialists. While the first two species feed on *Brachypodium pinnatum*, the latter is specialised on *Briza media*.

Table 3. Indicator species of (a) vascular plants and (b) leafhoppers for plots with (presence) and without (absence) *Bromus erectus* (results of ISA, Dufrêne & Legendre, 1997). IV = indicator value, ab = relative abundance comparing both plot types, % = frequency. Grey shaded values: Species are indicator species for this plot type. $***P < 0.001$, $**P < 0.01$, $*P < 0.05$.

		Presence			Absence		
Species	*P*	IV	ab	%	IV	ab	%
(a) Vascular plants							
Bromus erectus	***	**93**	93	100	.	7	40
Brachypodium pinnatum	**	.	11	60	**71**	89	80
Briza media	**	.	21	27	**64**	79	80
Festuca ovina agg.	*	.	29	53	**61**	71	87
Hieracium pilosella	*	.	11	20	**53**	89	60
Helictotrichon pratense	*	.	0	0	**40**	100	40
(b) Leafhoppers							
Turrutus socialis	**	**72**	77	93	.	23	60
Arocephalus longiceps	**	**62**	93	67	.	7	13
Psammotettix helvolus	*	**61**	76	80	.	24	60
Adarrus multinotatus	**	.	23	33	**72**	77	93
Ribautodelphax pungens	*	.	13	13	**53**	88	60
Psammotettix cephalotes	**	.	4	13	**51**	96	53

Bold indicates both plot types.

Discussion

The invasion of *Bromus erectus* in calcareous grasslands of the study area affected vegetation structure as well as vascular plant and leafhopper assemblages. Despite similar abiotic site characteristics, *Bromus* plots had a higher turf height, vegetation density and litter cover. Additionally, we recorded a much lower species richness in *Bromus* plots than in absence plots in all analysed groups of vascular plants. A similar pattern was found for leafhoppers. Absence plots exhibited higher species richness of habitat and diet specialists than *Bromus* plots. The overall abundance of all leafhopper species was highest in presence plots, whereas that of diet specialists peaked in absence plots.

As abiotic site conditions were similar in presence and absence plots, the taller, denser, and more litter-rich vegetation with lower vascular plant species diversity in the *Bromus* plots is very likely a genuine effect of the *B. erectus* dominance. Indeed, *B. erectus* is known to be a tall-growing grass that produces dense litter layers when abundant (Grime *et al.*, 2007; Steinger *et al.*, 2007; Möllenbeck *et al.*, 2009). In particular, less-competitive plant species depending on high light availability suffer from such shady conditions (Fleischer *et al.*, 2013; Streitberger *et al.*, 2017; Vítová *et al.*, 2017) resulting in species-poor swards (Steinger *et al.*, 2007; Moser *et al.*, 2011).

Leafhoppers are herbivorous insects with a high proportion of highly specialised species, that is, habitat and diet specialists. Consequently, the strong changes in vegetation structure and plant species composition due to the

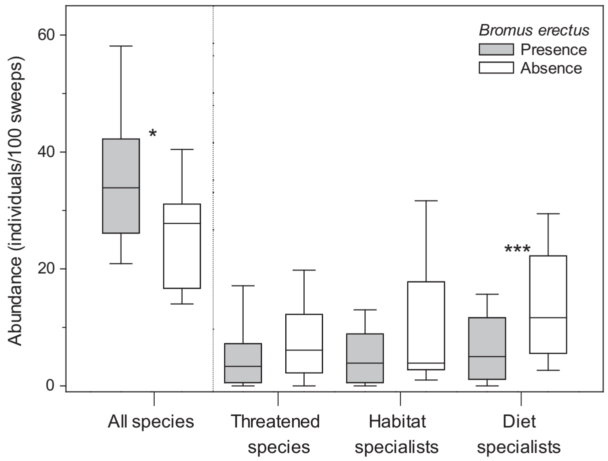


Fig. 3. Abundance of leafhoppers in plots with (presence) and without (absence) *Bromus erectus*. Box plots show 10th and 90th percentiles (whiskers), 25th and 75th percentiles (boundary of the box) and median (line). Wilcoxon signed rank test or paired *t*-test for significance ($\alpha = 0.05$): $*P < 0.05$, $***P < 0.001$. Statistics: all species: $t = -2.5$, $P = 0.03$; threatened species: $W = -49$, $P = 0.09$; habitat specialists: $W = -56$, $P = 0.08$; diet specialists: $W = -113$, $P < 0.001$.

invasion of *B. erectus* should result in altered leafhopper assemblages. The number of host plants of monophagous leafhopper species was higher in absence plots, and four of the host plant species were identified as indicator species of these plots (*Brachypodium pinnatum*, *Briza media*, *Festuca ovina* agg., and *Helictotrichon pratense*). In contrast, *B. erectus* was the only indicator species for presence plots. Consequently, the number of associated diet specialist leafhopper species was also lower in *Bromus* plots. This pattern might be valid for most or even all calcareous grassland regions in central Europe. All over Germany for instance, the number of leafhopper species that exclusively feed on the four indicator grass species of the absence plots is at least 24, whereas the figure for *Bromus erectus* is only two (Nickel, 2003; Nickel *et al*., 2017). The low importance of the *Bromus* plots for diet specialists underlies the indicator species analysis, whereas all indicator species of *Bromus* plots (*Arocephalus longiceps*, *Psammotettix helvolus,* and *Turrutus socialis*) are unspecialised grass feeders, all indicator species of the absence plots (*Adarrus multinotatus*, *Psammotettix cephalotes,* and *Ribautodelphax pungens*) were diet specialists (Nickel & Remane, 2002; Nickel, 2003; Table S2).

We also observed lower species richness of habitat specialist leafhopper species in plots with *B. erectus* presence, although not all of them were diet specialists (Table S2). Besides the presence of the host plants, several other environmental factors may explain the occurrence of leafhopper species. Therefore, the vegetation structure and the interlinked microclimate are of prime importance (Biedermann *et al*., 2005; Helbing *et al*., 2017). Many dry grassland habitat specialists, such as *Goniagnathus brevis* and *Hephatus nanus*, are xerothermophilous and avoid grasslands with tall and dense vegetation (cf. Tropek *et al*., 2010; Zulka *et al*., 2014), as found in the *Bromus* plots. Litter accumulation leads to cooler microclimatic conditions (Stoutjesdijk & Barkman, 1992) with negative effects on xerothermophilous organisms (Fartmann *et al*., 2012; Helbing *et al*., 2014).

Although, not all studied leafhopper groups were negatively affected by the invasion of *B. erectus* in the calcareous grasslands: the species richness of all and threatened leafhopper species, as well as the abundance of threatened leafhopper species and habitat specialists, did not differ between presence and absence plots. Additionally, the overall abundance of all leafhoppers was even higher in *Bromus* plots. Consequently, the *Bromus* plots seem to provide suitable conditions for species-rich assemblages of unspecialised and even some threatened leafhopper species.

The abundance of insects is usually related to the amount of food available (Speight *et al*., 2008). Several leafhopper species are unspecialised grass feeders, such as *Turrutus socialis* and *Psammotettix helvolus*, the two most abundant species and indicator species of *Bromus* plots (Nickel & Remane, 2002; Nickel, 2003). Indeed, the tall and dense stands of *B. erectus* provide sufficient grass biomass for such species, probably explaining their high abundance and the observed abundance patterns.

The stands of *B. erectus* within the calcareous grassland patches currently contribute to a higher habitat heterogeneity and, consequently, to a higher leafhopper diversity. As has been shown in our study, some leafhopper species are strongly associated with the *Bromus* stands and occurred in high densities at these sites. In the long run, however, it is very likely that the negative effects – the decline in diet and habitat specialists – will predominate. Current climate change is known to favour the invasion of *B. erectus* (Moser *et al*., 2011). Hence, without any conservation management, a further expansion of the grass within the calcareous grasslands can be expected, leading to a strong structural homogenisation. This development will not only result in a loss of plant species, but also contribute to the decline in the biodiversity of primary consumers such as leafhoppers and other arthropods (cf. Pryke *et al*., 2013; Helbing *et al*., 2017; Löffler & Fartmann, 2017). Due to the strong impact of land use on plant and insect diversity (Marini *et al*., 2008; Bazelet & Samways, 2011; Littlewood *et al*., 2012; van Klink *et al*., 2015), the management of the *Bromus* stands should be carefully handled. It is widely known that mowing and mulching favours *B. erectus* (Dierschke & Engels, 1991; Moog *et al*., 2002). In contrast, although unpalatable, the species is sensitive to heavy grazing (Grime *et al*., 2007). Taking this into account, one possible management tool might be a goal-driven rough grazing with sheep. Meaning sheep should only locally graze with a high intensity – especially in spring when *B. erectus* is much more palatable than in summer and autumn. Additionally, prescribed burning should be tested as another possibility to suppress the stands dominated by *B. erectus*, because the species hardly tolerates burning (Moog *et al.*, 2002; Grime *et al.*, 2007; Möllenbeck *et al.*, 2009).

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Supporting Information

Additional Supporting Information may be found in the online version of this article under the DOI reference: doi: 10.1111/icad.12302:

Table S1. Frequency (%) of plant species in plots with (presence) and without (absence) *Bromus erectus*. Threatened species and habitat specialists are marked with “x”.

Table S2. Frequency (%) of leafhopper species in plots with (presence) and without (absence) *Bromus erectus*. Threatened species, habitat specialists and diet specialists are marked with “x”.

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