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Is pitfall trapping a valuable sampling method for grassland Orthoptera?

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Abstract Common methods to assess diversity and abundance of Orthoptera are sweep netting, transect counts and box-quadrat sampling. Pitfall trapping, by contrast, is rarely used, and the value of this method is still being questioned. In 2008, we studied Orthoptera species richness and abundance in five vegetation types along a gradient of dune succession on the Baltic Sea island of Hiddensee (NE Germany) by comparing transect-count and pitfall-trapping data. Using transect counts, 12 species were detected in the study area. With pitfall traps, three chorto- and thamnobiont Ensifera species (*C. dorsalis*, *M. roeselii* and *T. viridissima*) were not caught at all, and it was only in low-growing and sparsely-vegetated grey dunes that all present species were detected. With pitfall traps, the proportion of present species recorded strongly declined with increasing height and density of the vegetation type. Assuming that transect counts are a good proxy for relative Orthoptera densities, densities ascertained by pitfall traps are strongly biased by vegetation structure and locomotive behaviour of the species. More than 80% of all individuals were caught in sparsely-vegetated grey dunes. Frequency patterns of the species also differed. Using pitfall traps, especially chortobiont species were significantly underrepresented. Qualitative and quantitative sampling of Orthoptera using pitfall traps seems only reasonable in habitats with low and sparse vegetation and a high proportion of geobiont species.

Keywords Heathland · Sampling efficiency · Vegetation structure · Successional stage · Transect count

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Introduction

Orthoptera occur in a wide variety of open terrestrial ecosystems in high diversity, particularly in unimproved grassland and heathland. They are often the main invertebrate consumers in grassland (Curry 1994) and are known to be an important food source for many groups of predators (e.g. birds) (Joern 1986; Samways 1997). Due to their high sensitivity to environmental changes (e.g. grazing, mowing, abandonment) (e.g. Báldi and Kisbenedek 1997; Fartmann and Mattes 1997; Kopetz and Köhler 1991; Samways 1997) they are highly indicative of grassland characteristics. These attributes and the low difficulty of sampling Orthoptera make this insect group very suitable for all kinds of ecological studies and monitoring (Poniatowski and Fartmann 2008).

To assess diversity and abundance of Orthoptera, several sampling techniques are frequently used. Common methods are sweep netting, transect counts and box-quadrat sampling. Pitfall trapping, by contrast, is rarely used (see review by Gardiner et al. 2005). Therefore, little is known about the value and accuracy of pitfall traps for detecting Orthoptera species and ascertaining their abundance (Gardiner et al. 2005; Harvey and Gardiner 2006). Ingrisch and Köhler (1998) indicate that the method provides useful information on species composition, relative abundance and annual activity, particularly for ground-dwelling Gryllidae and Tetrigidae. Indeed, in some surveys pitfall traps were successfully used to sample grassland Orthoptera (e.g. Bieringer and Zulka 2003; Köhler and Weipert 1991; Köhler and Kopetz 1993; Perner et al. 1996). However, in other studies pitfall trapping turned out to be unsuitable for sampling Orthoptera. Using pitfall traps, Siemann et al. (1999) recorded less than half of the species they had found using sweep netting. In tall and unmanaged pastures in the UK, pitfall traps failed to detect any resident Orthoptera (Gardiner and Gouldsmith, unpublished data cited in Harvey and Gardiner 2006). Hence, the efficiency of pitfall trapping may depend on vegetation structure. While low-growing and sparse vegetation can probably be sampled efficiently with pitfall traps, this method seems to be rather ineffective in tall and dense vegetation.

This study aims to compare the efficiency of transect counts and pitfall trapping of Orthoptera along a vegetation-structure gradient to answer the following questions: (i) How do the recorded Orthoptera communities of grassland habitats differ between the two sampling methods?, (ii) are there biases involved in the sampling methods and how does vegetation structure affect capture efficiency of pitfall traps?, (iii) for which habitats might pitfall trapping be a useful method of estimating species richness and abundance of Orthoptera and in which cases is an evaluation of Orthoptera that were (by-)caught in other studies (e.g. of ground beetles, spiders) useful?

Materials and methods

Study area and sampling sites

The study was conducted in 2008 in the coastal heath on the Baltic Sea island of Hiddensee. Hiddensee is located in the very north-east of Germany (Mecklenburg-Western Pomerania) in the national park "Vorpommersche Boddenlandschaft" (Fig. 1). The north–south extent is about 19 km with a maximum width of about 3 km (total area: approx. 16 km^2). Hiddensee is divided into a Pleistocene hilly part in the north (up to 72.5 m a.s.l.) and an adjacent plain in the south, which evolved from Holocene sandy deposits (Möbus 2000). The mean annual precipitation is 547 mm, the mean annual temperature 7.5°C (Reinhard 1962). In comparison with the adjacent mainland, the climate is drier, especially during the growing season (Kliewe 1951). In the centre of Hiddensee, there is an anthropozoogenic coastal heath (total area: approx. 200 ha) consisting of a mosaic of different dune and heath vegetation types: (1) grey dunes (GD, dominated by *Corynephorus canescens*, lichens and mosses), (2) dwarf-shrub heath (HD, *Calluna vulgaris*, *Empetrum nigrum*, *Salix repens*) and (3) grass-encroached heath (HG, *Carex arenaria*, *Deschampsia flexuosa*). Due to the lack of regular land use, several sites are encroached by (4) shrubs (HS, *Betula pendula*, *B. pubescens*, *Prunus serotina*, *Populus tremula* and *Pinus sylvestris*) or even (5) birch forest (BF). In each of these five vegetation types, which represent the main seral stages of dune succession on Hiddensee, three plots (replicates) were chosen. Each of the plots had a homogenous vegetation structure (Sänger 1977) and a size of 500 m^2 (e.g. Behrens and Fartmann 2004; Poniatowski and Fartmann 2008) (Table 1).

Sampling orthoptera

Adults were identified using Bellmann (2006) and Horstkotte et al. (1994); for nymphs we used Oschmann (1969) and Ingrisch (1977). Scientific nomenclature follows Coray and Lehmann (1998).

Transect counts

Relative abundance was estimated by transect counts. Each plot was paced off slowly in loops covering the whole plot. In a band 1 m wide all optically and acoustically observed individuals were counted (total observed area: 70 m^2). Individuals which could not be determined immediately were caught by sweep net or by hand and released after determination. The loops had a distance of at least 5 m to each other to minimize double counting and at least 2 m to the boundaries of the plot to minimize edge effects. Samples were collected at three times during the main activity period of adult Orthoptera in July and August (I. 24–26 July, II. 01–03 August, and III. 25–31 August). The surveys took place under favourable weather conditions (warm, sunny and calm days) between 10:00 and 17:00 h (CET + 1).

Pitfall trapping

In each plot four pitfall traps (Barber 1931) were randomly placed, with a distance of at least 5 m to each other (to minimize interference) and to the boundaries (to minimize edge effects). The traps (6 cm in diameter, 8 cm deep) were buried up to the surface level and filled with ethylenglycol and a few drops of detergent. A 15 × 15 cm plastic transparent roof was placed approx. 10 cm above the trap. The survey started on 15 June; traps were collected every four weeks until 3 October (five emptyings in total). Nymphs were included in the analysis, as habitats of nymphs and adults of the recorded species are relatively congruent (Schirmel, unpublished data).

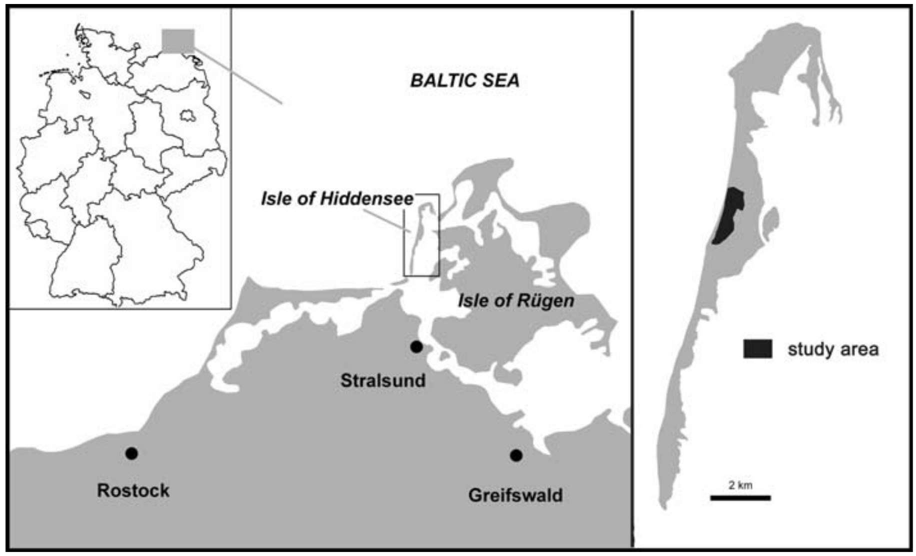

Fig. 1 Position of the Baltic Sea isle of Hiddensee in Germany (*left*) and of the study area (coastal heath) on Hiddensee

Table 1 Characteristics of the five studied vegetation types

No.	Vegetation type	Name	Description
1	Grey dune	GD	Sparsely covering and low-growing vegetation (cover: 10–70%, height: up to 20 cm); dominated by *Corynephorus canescens*, *Carex arenaria*, lichens (*Cladonia* spp.) and mosses
2	Dwarf-shrub heath	HD	Dense vegetation with medium turf height (cover: 80–100%, height: 30–40 cm); dominated by *Calluna vulgaris* and, to a lower extent, *Empetrum nigrum*, *Salix repens* and *Erica tetralix*
3	Heath encroached by graminoids	HG	Dwarf-shrub heath encroached mainly by *Carex arenaria* (cover about 70%) and, to a lower extent, *Deschampsia flexuosa*. Very dense vegetation with medium to high turf (cover: 100%, height: 40–80 cm)
4	Heath encroached by shrubs	HS	Dwarf-shrub heath encroached by bushes (mainly *Betula pendula*). Heterogeneous vegetation with high cover (cover: 90–100%) and turf height (field layer: 40–80 cm, shrub layer: up to 300 cm)
5	Birch forest	BF	*Betula pendula* dominated young forest (about 30–40 years old). *Calluna vulgaris* is very rare. Species-rich field layer with many graminoids, mainly *Molinia caerulea*, *Arrhenatherum elatius* and *Festuca rubra*. Dense or very dense vegetation (cover: 80–100%) with medium to high turf (height: 40–110 cm)

Statistics

Orthoptera species were classified into the life-form types by Rácz (1998) and Nagy et al. (2007). Differing from these studies *Chorthippus biguttulus*, *Decticus verrucivorus* and *Platycleis albopunctata* were classified as geo-chortobiont and *Conocephalus dorsalis* as chortobiont species (cf. Wranik et al. 2009). To assess the completeness of species inventories individual-based species accumulation curves specific to each method were created using the software package PAST (Hammer et al. 2001). Species accumulation curves are a widely accepted way of assessing the sufficiency of a sampling effort for a certain sampling site (Gotelli and Colwell 2001).

To analyse differences in overall species richness among sampling methods the observed number of species were rarefied to the lowest number of specimens recorded (Gotelli and Colwell 2001). In a further step, maximum species richness was estimated using non-parametric estimators Chao 1 (Chao 1984) and ACE (Abundance-based Coverage Estimator, Chao et al. 1993). For an extensive discussion of estimation techniques see Magurran (2004).

Differences in the effectiveness of both methods for total observed and estimated species richness ($n = 15$) and for species richness within each habitat type were compared using Poisson generalized linear models (GLM). To compensate for overdispersion, the standard errors were corrected using a quasi-Poisson GLM model (Zuur et al. 2009). Methods (transect counts, pitfall trapping) and habitat types (GD, HD, HG, HS, BF) were treated as predictors for observed species richness. Differences in the detected individual numbers of species between the two methods were analysed using zero inflated negative binomial models (ZINB). Significance levels were assessed using an Analysis of Deviance (Zuur et al. 2009). All statistical analyses were performed using the software package R 2.9.0 (http://www.r-project.org/).

Results

Species richness

In total, 12 Orthoptera species were recorded, of which 2 were geobiont, 3 geo-chortobiont, 5 chortobiont and 2 thamnobiont (Table 2). Species richness was highest in heath encroached by graminoids (HG) and shrubs (HS) with 9 and 8 species, respectively. The three other vegetation types had species numbers between 5 and 6. While in grey dunes (GD) and dwarf-shrub heath (HD) most species (>80%) belonged to geo- and geo-chortobiont species, in HS and birch forests (BF) the vast majority of the species were chorto- and thamnobiont (88% and 100%, respectively). In HG, species of all life-form types co-occurred with a dominance of geo-chorto- and chortobiont species (together 67%).

Table 2 Frequency of Orthoptera species in the five vegetation types using transect counts (TC) and pitfall traps (PT)

	Vegetation type										*N*	
	GD		HD		HG		HS		BF			
	TC	PT	TC	PT	TC	PT	TC	PT	TC	PT	TC	PT
Geobiont												
Myrmeleotettix maculatus ($F = 0.16$, $P = 0.856$)	239 (74)	418 (92)	45 (58)	16 (55)	12 (5)	14 (28)	–	–	–	–	296 (37)	448 (81)
Oedipoda caerulescens	1 (0)	1 (0)	–	–	–	–	–	–	–	–	1 (0)	1 (0)
											297	449
Geo-chortobiont												
Platycleis albopunctata ($F = 1.24$, $P = 0.307$)	8 (3)	22 (5)	6 (8)	6 (21)	2 (1)	1 (2)	–	–	–	–	16 (2)	29 (5)
Decticus verrucivorus ($F = 4.20$, $P < 0.05$)	1 (0)	2 (0)	13 (17)	7 (24)	18 (8)	5 (10)	–	–	–	–	32 (4)	14 (3)
Chorthippus biguttulus ($F = 6.20$, $P < 0.01$)	72 (22)	12 (3)	12 (16)		60 (25)	1 (2)	2 (1)	–	–	–	146 (18)	13 (2)
											194	56
Chortobiont												
Omocestus viridulus ($F = 4.64$, $P < 0.05$)	–	–	–	–	112 (47)	29 (58)	76 (50)	11 (61)	1 (14)	–	189 (24)	40 (7)
Chrysochraon dispar ($F = 4.11$, $P < 0.05$)	–	–	–	–	19 (8)	–	27 (18)	2 (11)	2 (29)	–	48 (6)	2 (0)
Metrioptera roeselii ($F = 20.12$, $P < 0.001$)	–	–	–	–	9 (4)	–	15 (10)		2 (29)	–	26 (3)	–
Chorthippus albomarginatus	1 (0)	2 (0)					1 (1)				2 (0)	2 (0)
Conocephalus dorsalis ($F = 12.06$, $P < 0.01$)					7 (3)		1 (1)				8 (1)	–
											273	44
Thamnobiont												
Pholidoptera griseoaptera ($F = 2.70$, $P = 0.087$)	–	–	–	–	–	–	26 (17)	5 (28)	1 (14)	1 (100)	27 (3)	6 (1)
Tettigonia viridissima ($F = 14.12$, $P < 0.01$)			1 (1)		1 (0)		5 (3)		1 (14)		8 (1)	–
											35	6
N individuals	322	457	77	29	240	50	153	18	7	1	799	555
N all species	6	6	5	3	9	5	8	3	5	1	12	9
% species completeness		100		60		55		38		20		75

Arrangement of the vegetation types follows a vegetation-height and density gradient (= productivity and biomass gradient) from type 1 to type 5. Assignment of species to the life-form types follows Rácz (1998) and Nagy et al. (2007). GD = grey dune, HD = dwarf-shrub heath, HG = heath encroached by graminoids, HS = heath encroached by shrubs, BF = birch forest. % species completeness = percentage of all recorded species for each vegetation type (= number of species detected by transect counts). Percentage of individuals per species and sampling technique is given in brackets. All comparisons of total individual numbers of species (>2 individuals) were analysed by zero inflated negative binomial model (ZINB)

Observed overall species richness differed between the sampling methods ($F = 9.88$, $P < 0.01$; GLM): Using transect counts, all 12 species detected in the study area were recorded. By pitfall trapping, only 9 species were detected; two chortobiont species (*Metrioptera roeselii*, *Conocephalus dorsalis*) and one thamnobiont species (*Tettigonia viridissima*) were not. Also, rarefied species richness (TC = 11.6, PT = 9.0) and estimated species richness (Chao1: TC = 12.0, PT = 9.0, $F = 7.67$, $P < 0.05$; ACE: TC = 12.7, TC = 9.8, $F = 5.45$, $P < 0.05$; GLM) differed between the methods. The species accumulation curve based on transect-count data nearly approaches an asymptote while those based on pitfall trapping data show a slight slope (Fig. 2).

Species completeness (% of present species) using pitfall traps was significantly negatively correlated with increasing vegetation density and height ($r_s = -1.0$, $N = 5$, $P < 0.05$). While in GD all resident species were caught, in BF only 20% of the five present Orthoptera species were found. Except for GD, in pitfall traps only less than half of the geo-chorto-, chorto- and thamnobiont species were recorded in each of the vegetation types.

Based on transect counts, the mean species richness was highest in HG and HS (Table 3). GD and HD had an intermediate and BF the lowest species richness. Using pitfall traps, species richness was highest in GD and in HG. HD and HS had intermediate positions and BF the lowest species richness by far. Differences in species richness between the two sampling methods were only significant for the two species-richest habitat types HG and HS (HG: $F = 13.71$, $P < 0.05$; HS: $F = 53.4$, $P < 0.01$; GLM) (Table 3).

Relative abundance

In total, 799 individuals were recorded by transect counts and 555 by pitfall traps (Table 2; Fig. 3). Relative densities observed using transect counts were more balanced than those of the pitfall traps. Using transect counts, 40% of all individuals (322) were detected in GD, 30% (240) in HG, 19% (153) in HS and 11% (77) in HD. BF only accounted for 1% of all individuals (7). With pitfall traps, more than 80% (457) of all individuals were found in GD. In BF, only one individual (0.2%) was observed, and in the three remaining types the percentage of individuals was low and ranged from 3 to 9%.

Table 3 Mean number of observed Orthoptera species (±SE) per vegetation type using transect counts (TC) and pitfall trapping (PT)

Vegetation type	Species number		Statistics	
	TC	PT	*F*	*P*
GD	4.0 ± 0.6	4.3 ± 0.3	0.24	0.65
DH	4.0 ± 0.6	2.3 ± 0.7	3.24	0.15
HG	7.3 ± 0.7	3.7 ± 0.7	13.71	0.02
HS	5.7 ± 0.3	2.0 ± 0.0	53.4	0.002
BF	2.0 ± 0.6	0.7 ± 0.3	5.3	0.08

Differences were analysed by generalized linear models (GLM)

By transect counts 37% of all individuals belonged to geobiont, 24% to geo-chortobiont, 34% to chortobiont and 4% to thamnobiont species. Using pitfall trapps 81% were geobiont, 10% geo-chortobiont, 8% chortobiont and 1% thamnobiont. Differences between individual numbers of life-form types detected by the two methods were significant for geo-chortobionts ($F = 7.20$, $P < 0.05$, GLM), chortobionts ($F = 10.05$, $P = 0.01$, GLM) and thamnobionts ($F = 4.65$, $P < 0.05$, GLM). Only for geobionts no significant differences were observed ($F = 0.35$, $P = 0.56$, GLM).

Pitfall traps are more selective in recording Orthoptera species than transects counts are (Table 2). More than 80% of all individuals caught using pitfall traps belonged to the geobiont species *Myrmeleotettix maculatus*. Within the transect-count data set, the species was also dominant, however, it only accounted for 37% of all observed

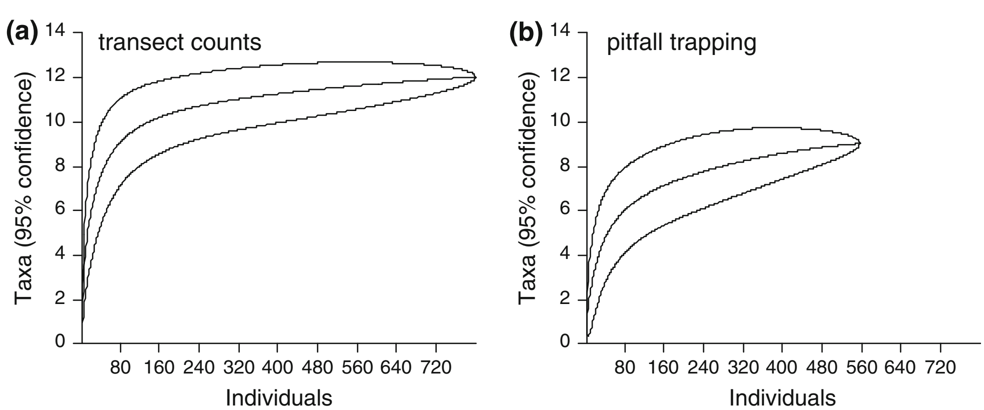

Fig. 2 Individual-based species accumulation curves for data obtained by transect counts **(a)** and pitfall trapping **(b)**

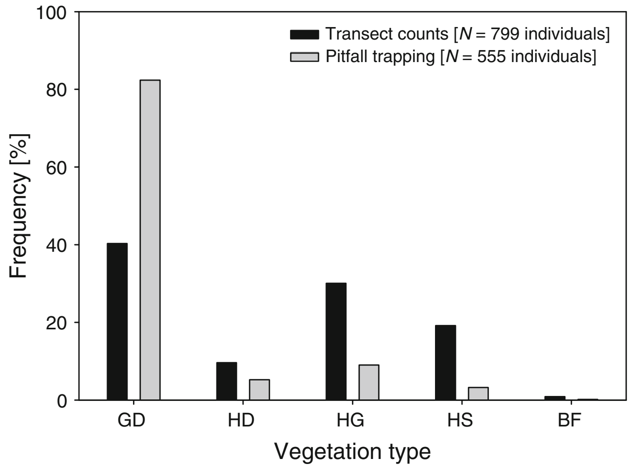

Fig. 3 Frequency of Orthoptera individuals per vegetation type using transect counts and pitfall traps. Sum of individuals per sampling method was set as 100%

individuals. Besides *Myrmeleotettix maculatus* there were two additional species (*Omocestus viridulus* and *Chorthippus biguttulus*) detected in high numbers (24 and 18% of all individuals, respectively). Differences in individual numbers (only species with >2 caught individuals with at least one method) between the two sampling techniques differed significantly for all species except for *Platycleis albopunctata*, *Myrmeleotettix maculatus* and *Pholidoptera griseoaptera* (Table 2).

Discussion

Species richness

Transects counts are a well-established method to survey the presence of Orthoptera (Isern-Vallverdú et al. 1993; Kruess and Tscharntke 2002; Wettstein and Schmid 1999). However, there are differences in the design of the method. Regarding the species accumulation curves and species richness estimators, we suppose that all species present in the study area were detected by transect counts with a combination of acoustic and visual detection. In contrast, the use of pitfall traps failed to detect all species. With respect to sampling effort and detection of the complete species inventory, transect counts are much more effective than pitfall trapping.

Using pitfall traps, the complete species inventory was only recorded in the low-growing and sparsely-vegetated GD. With increasing vegetation height and density, the species completeness observed by pitfall traps decreased significantly. The shift in vegetation structure was accompanied by a shift in Orthoptera species. While earlier seral stages (GD, HD) were dominated by geo- and geo-chortobiont species, later seral stages (HS, BF) were dominated by chorto- and thamnobiont species. However, using pitfall traps, we were only partially able to detect the present geo-chorto-, chorto- and thamnobiont species in each of the vegetation types. The Ensifera species *C. dorsalis*, *M. roeselii* and *T. viridissima* were not caught at all, but this could also be related to their low abundances. In conclusion, transect counts are more sensitive to the detection of rare species than pitfall trapping (cf. Nagy et al. 2007).

Although pitfall trapping is a widespread method for studying epigeal fauna, the study design (e.g. number of traps per plot, diameter of the traps, roofed or unroofed traps) is poorly standardized (Gardiner et al. 2005; Ingrisch and Köhler 1998). Hence, for a proper comparison of species completeness observed in different studies we have to take into account their design and the habitats surveyed. Pitfall trapping in tall and unmanaged pastures in the UK resulted in capturing no species (Gardiner and Gouldsmith, unpublished data cited in Harvey and Gardiner 2006). In oak savannahs and grasslands in Minnesota (US) Siemann et al. (1999) recorded 50 Orthoptera species by using sweep netting; pitfall trapping with four traps per plot provided only 22 species. Our results are very similar to those of Harvey and Gardiner's study (2006) in dune grassland in Essex (UK). They were also unable to detect *C. dorsalis* with pitfall traps, but were highly effective in recording the regionally scarce species *P. albopunctata* and *M. maculatus*. However, there are some studies in which all present Orthoptera species were detected with pitfall traps. In those cases, for example, the Orthoptera assemblage was species poor (Perner et al. 1996) or pitfall traps were exposed for a complete year (Köhler and Weipert 1991). Based on the results of our study, the use of pitfall traps for surveying Orthoptera species composition in grasslands seems to be reasonable only in sparse and low-growing vegetation where geo- and geo-chortobiont species dominate (cf. Nagy et al. 2007).

Relative abundance

As four of the five studied types (HD–BF) had vegetation that was very dense, most of the frequently used and fairly accurate techniques for sampling Orthoptera abundance (e.g. box-quadrat sampling, Gardiner and Hill 2006, Poniatowski and Fartmann 2008) were not applicable. Hence, we used transect counts, as they are easy to conduct and commonly used to estimate Orthoptera abundance (Gardiner et al. 2005). Gottschalk et al. (2003) showed that in *P. albopunctata* standardized transect counts are strongly correlated with population estimates from mark-release-recapture data. Isern-Vallverdú et al. (1993) also found that densities ascertained by transect counts are strongly correlated with real population density in *Aeropus sibiricus*.

Assuming that transect counts are a good proxy for relative Orthoptera densities (Gardiner et al. 2005), densities ascertained by pitfall trapping are strongly biased by vegetation structure and locomotive behaviour of the species. More than 80% of all individuals were caught in the sparsely-vegetated GD. Except for the geobionts, all life-form types differed significantly in frequency patterns between the two methods. This is also true for frequency patterns of single species: all species were significantly underrepresented in pitfall traps, except for the geobiont species *M. maculatus*, the geo-chortobiont species *P. albopunctata* and the thamnobiont species *P. griseoaptera*. For the latter, however, the differences were slightly not significant ($P = 0.087$) which might be explained by the low sample size.

In conclusion, the quantitative sampling of Orthoptera using pitfall traps seems to be reasonable only in habitats with low and sparse vegetation and a high proportion of geo- and geo-chortobiont species (cf. Nagy et al. 2007). As shown by Bieringer and Zulka (2003), in such habitats, predictions of species' relative abundances are reasonable.

Usefulness of pitfall trapping for Orthoptera surveys

Pitfall trapping of Orthoptera assemblages is a valuable sampling method in sparsely-vegetated and low-growing grassland habitats. As pitfall trapping is a destructive sampling method, it should only be applied in suitable habitats, where other methods cannot be used (e.g. military areas, cf. Bieringer and Zulka 2003). The analysis of by-caught Orthoptera from other studies in open habitats, like pitfall trapping of ground beetles and spiders, could provide suitable results for fissuro-, geo- and, to a lower extend, geo-chortobiont species (e.g. Gryllidae, Tetrigidae; Remmert 1978, Ingrisch and Köhler 1998). However, in habitats with high and dense vegetation and a higher proportion of chorto- and thamnobiont species, it is unlikely to detect all present species and to deliver accurate estimates of abundance.

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