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Effects of Pitfall Trap Lid Transparency and Habitat Structure on the Catches of Carabid Beetles (Coleoptera: Carabidae) in Tame Pasture

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ABSTRACT Captures of insects in pitfall traps are affected by features of trap design that may confound the interpretation of data. One such feature is a lid suspended over the opening of the trap to exclude debris and rainwater. In this study, we tested whether use of these lids affected captures of carabid beetles by altering the light conditions at the opening to the trap. In one experiment, we examined the effects of lid transparency (opaque, semitransparent, or transparent) on catch rates. In a second experiment, we manipulated the heights (high, medium, or low) of vegetation adjacent to the traps to test for lid transparency and vegetation height interactions. We found that significantly more carabids were captured with use of transparent lids compared with other lid transparencies. Fewest *Agonum cupreum* Dejean, 1831, were captured with use of opaque lids. No other effects were detected. Given these results, we advocate the use of transparent lids, which provide the benefits of traditional opaque lids while minimizing the effects of lid use on light conditions at the opening to the trap.

KEY WORDS ground beetle, trap design, Saskatchewan, sampling method, Byrrhidae

Agricultural practices have intensified over the past century, with movements toward larger-scale farming and livestock operations and an increase in the use of pesticides and nitrogenous fertilizers (Stoate 1996, Vickery et al. 2001). These changes have occurred as part of an effort to meet production demands for an increasing population, and have contributed to a decline in species richness among many arthropods, including grasshoppers (Wingerden et al. 1991), butterflies (Kruess and Tscharntke 2002a,b), true bugs (Di Giulio et al. 2001), and carabids (Rushton et al. 1989, Blake et al. 1996, Pfiffner and Luka 2003). Carabids are a particularly useful indicator of environmental change because they are diverse (Lindroth 1969), are abundant, are easy to collect, have short generation times, and span different trophic guilds. Often used to study the effects of farming practices in agroecosystems (Butts et al. 2003, Floate et al. 2007, Bourassa et al. 2010), carabids also have been instrumental in studies of grassland conservation and management strategy (Eyre et al. 1989, Rushton et al. 1989, Haysom et al. 2004, Grandchamp et al. 2005, Gibb and Cunningham 2010). However, the use of carabid beetles as indicator species for grassland studies relies on accurate sampling methods that allow for comparisons across a range of conditions (Phillips and Cobb 2005).

Pitfall traps are perhaps the most common method used to sample carabid beetles. They are typically open containers dug into the ground, with the opening flush with the substrate, and often covered by an opaque lid to exclude debris and rainfall (Spence and Niemelä 1994, Work et al. 2002). They are inexpensive and easy to install, making them useful in almost any habitat (Phillips and Cobb 2005). Furthermore, they can recover large numbers of surface-active invertebrates to provide rigorous data sets for statistical analyses (Melbourne 1999).

The widespread use of pitfall traps has stimulated efforts to improve their efficiency (Luff 1975, Spence and Niemelä 1994, Melbourne 1999, Koivula et al. 2003). Capture rates depend on the density and activity of epigaeic fauna (Mitchell 1963, Thiele 1977) and trap design characteristics (Spence and Niemelä 1994, Work et al. 2002). Activity levels are influenced by factors that affect the physiological state or behavior of the animal, such as climate, weather, shelter, and hunger (Whicker and Tracy 1987, Honék 1988, Niemelä et al. 1989, Koivula et al. 2003), which in turn can bias estimates of population density (Phillips and Cobb 2005). Characteristics of trap design such as trap diameter (Work et al. 2002, Koivula et al. 2003), soil depth of the trap (Bergeron et al. 2013), preserving agent (Luff 1968, Koivula et al. 2003), and construction material (Luff 1975) can also influence catches.

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Most studies assume that factors influencing pitfall catches are the same across habitats (Melbourne 1999). However, differences in habitat structure in the vicinity of pitfall traps can affect estimates of total arthropod abundance (Greenslade 1964, Melbourne 1999, Phillips and Cobb 2005), species richness (Melbourne 1999), and species composition (Melbourne 1999, Phillips and Cobb 2005). Furthermore, it is important that any observed differences in catch rates and community composition between habitats are representative of the true community and are not artifacts of sampling methods under specific habitat treatments (Phillips and Cobb 2005). Phillips and Cobb (2005) tested and refuted the hypothesis that use of opaque lids in comparisons between forested versus clear-cut sites would provide shade to unevenly affect microhabitats beneath the lids to bias trap captures. However, this concern remains for other types of habitats.

In the current study, we repeated the work of Phillips and Cobb (2005), but in a pasture environment. Because such an environment lacks the vertical structure and buffering effect of the forest canopy, epigeal invertebrates in pastures are subject to greater extremes of temperature and light. Thus, we hypothesized that their capture in pitfall traps would be more susceptible to effects of lid transparency than was observed by Phillips and Cobb (2005) in the forest environment. In addition, the two habitats support different species assemblages with specific preferences and microclimate sensitivities. Hence, pasture and boreal forest communities may perform differently under the same experimental conditions. To test this hypothesis, we compared the abundance, richness, and composition of carabids recovered from pitfall traps with lids that varied in transparency and at sites for which vegetation height was manipulated.

Materials and Methods

Site Description. This study was conducted during the summer of 2012 near the town of Elbow, Saskatchewan (51° 16′ N, 106° 52′ W). The site was mainly a tame pasture with a mixture of alfalfa (*Medicago sativa* L.), crested wheatgrass (*Agropyron cristatum* L. Gaertner), many-flowered aster [*Symphyotrichum ericoides* variety *pansum* (Blake) Nesom], pasture sage (*Artemisia frigida* Willd), Russian wildrye (*Psathyrostachys juncea* L.), and smooth brome (*Bromus inermis* L.) located near the South Saskatchewan River, just below Gardiner Dam. Percent cover of vegetation was estimated in a 2.5-m radius surrounding the trap, and a 1-m^2 subsample was used to determine the plants present and their cover of the area.

Sampling Protocol and Experimental Design. Pitfall traps were constructed from 1-liter round plastic containers (11.2 cm in diameter; Twinpak Inc., Dorval, Canada), with a tight-fitting 0.5-liter inner cup, identical to traps used in other arthropod studies (Spence and Niemelä 1994, Digweed et al. 1995, Phillips and Cobb 2005). Traps were dug into the ground so that the lip of the container was flush with the substrate. They were emptied at ≈14-d intervals and filled with 2–3 cm of silicate-free ethylene glycol each time the trap was emptied. A lid (15 by 15 cm) was elevated 2–5 cm above the trap by two nails placed in opposite corners to keep out debris and excess rainwater (Work et al. 2002). Traps were separated by 20 m to improve independence (Digweed et al. 1995).

We performed two experiments. Experiment 1 used nine traps with three types of lids (opaque, semitransparent, or transparent). Opaque lids (O) were made of plywood, whereas semitransparent lids (ST) were made of plywood with holes to allow 50% transmittance of light and covered with a piece of Plexiglas (Evonik Industries, Essen, Germany). Transparent lids (T) were made of a 0.5-cm Plexiglas. The vegetation height surrounding each trap was ≈0.5 m (unmodified). Traps were operated from 20 June to 4 July and emptied before the alteration in vegetation height. The positioning of traps and their treatments (i.e., lid type and vegetation height) was randomized and arranged in a grid of three rows and nine columns (Phillips and Cobb 2005).

Experiment 2 introduced three vegetation treatments. Based on the method of Melbourne (1999), we clipped vegetation in a 2.5-m radius surrounding each trap to heights of either ≈0.5 (high), 0.25 (medium), or <0.1 (low) m. In combination with the three lid treatments, this generated nine treatment combinations that were replaced three times (n = 27 traps; Phillips and Cobb 2005). Traps for Experiment 2 were operated from 4 July to 18 August, after termination of Experiment 1.

Species Identification. Pitfall samples were sorted and identified to species using the information provided by Lindroth (1969) and Bousquet (2010). In total, 1,520 carabids (28 species), 166 scarabs (3 species), and 12 byrrhids (1 species) were collected (Table 1). Voucher specimens are deposited in the Royal Saskatchewan Museum located in Regina, Saskatchewan, Canada, and the Watershed Security Agency in Saskatoon, Saskatchewan, Canada.

Data Analyses. Catch rates were standardized (total individuals per trap × day) to account for traps that were tampered with or lost. In Experiment 1 (n = 435 beetles), the effect of lid type on catch rate was assessed for the carabid *Agonum cupreum* Dejean, 1831 (42% of total) and the scarab *Diapterna pinguis* Haldeman, for which unexpectedly high numbers were recovered (33.1%). Because data failed to meet the assumptions of normality (Shapiro–Wilk test), Kruskal–Wallis one-way analyses of ranks were used for all data in Experiment 1. Dunn's method of multiple comparison procedures was used to isolate the groups that were significantly different. All data were normal in Experiment 2 (n = 1,263 beetles), and a two-factor analysis of variance (ANOVA) was used to test the effects of lid type and vegetation height on catch rates of the carabids *A. cupreum* (27.5% of total) and *Amara obesa* (Say) (48.4%).

Diversity was measured using Shannon's Diversity Index. ANOVAs were used to test the effects of lid

Table 1. Total catch of carabid species by vegetation height (high, medium, or low) and pitfall lid transparency (opaque, semitransparent, or transparent) for Experiments 1 and 2

Family	Species	Exp 1 no vegetation alteration			Low		Exp 2 medium				High			Total
		O	PT	T	O	PT	T	O	PT	T	O	PT	T	
Carabidae	*A. obesa* (Say 1823)	3	4	6	118	117	48	78	68	43	29	65	50	629
	A. cupreum Dejean, 1831	21	36	64	3	47	49	9	46	6	7	95	85	468
	Syntomus americanus (Dejean 1831)	21	17	46	10	40	9	10	7	10	4	4	20	198
	Poecilus lucublandus Say, 1823	7	1	2	1	16	2	1	3			13	2	48
	Harpalus ventralis LeConte, 1948	11	5	2	2	2	1	3	6	1	1	2	3	39
	Dyschirius planatus Lindroth, 1961	6	2	7	5	2			2	5	1			30
	Amara torrida (Panzer 1797)	1	1	1		1	1	1	1		1	1	12	21
	Carabus taedatus (Fabricius 1787)		1		4	4	3					2	3	17
	Cymindis cribicollis Dejean 1831	1	1			3	2	3	3	1	1		2	17
	Harpalus somnulentus Dejean, 1829			4			1	1	3	1	2		1	13
	Bembidion quadrimaculatum (Linne 1761)	2	2	4		1								9
	Pterostichus femoralis Kirby, 1837	1		1				1			1		1	5
	Chlaenius purpuricollis Randall, 1838		1								1	2		4
	Amara cupreolata Putzeys, 1866	2					1							3
	Bembidion nitidum (Kirby 1837)		1			1								2
	Calathus ingratus Dejean 1828							1				1		2
	Chlaenius sericius (Forster 1771)												2	2
	Cicindela nebraskana LeConte, 1861				1				1					2
	Harpalus opacipennis (Haldeman 1843)						1				1			2
	Amara carinata LeConte, 1848									1				1
	Amara littoralis Mannerheim, 1843			1										1
	Amara quenseli (Schönherr 1806)										1			1
	Carabus maeander Fischer von Waldheim, 1822									1				1
	Cicindela terricola Say, 1824								1					1
	Cymindis neglecta Haldeman, 1843								1					1
	Diplocheila obtusa (LeConte 1848)				1									1
	Harpalus reversus Casey, 1924												1	1
	Piosoma setosum LeConte, 1948						1							1
Byrrhidae	*Porcilonus undatus* (Melsheimer 1869)		2	2			1	1		4		2		12
Scarabeidae	*Diapterna pinguis* Haldeman, 1848	56	47	41	3	1	1	2	1	6		2	3	163
	Trox robinsoni Vaurie, 1955										1		1	2
	Diapterna pinguella Brown, 1929			1										1
	Total species	12	14	14	10	12	14	12	12	11	13	11	15	32
	Total abundance	132	121	182	148	235	121	111	142	79	51	189	187	1,698

type and lid type × vegetation height on the diversity of carabids in Experiments 1 and 2, respectively.

Multidimensional scaling (MDS) was performed to test for possible differences in the effects of lid transparency and vegetation height on species composition. We calculated stress, optimal distance linking metrics (e.g., Bray–Curtis, Euclidean, Mahalanobis, Gowers, and Kulczynski distance metrics), and optimal numbers of dimensions using the vegan and MetaMDS packages for R (version 2.13.1, R Development Core Team 2010). We considered a multidimensional solution acceptable if it had a final stress <0.18; however, we considered our multidimensional solution optimal and with a greater representation of the community structure if it had a final stress <0.10. Selection of a stress value limit between 0.10 and 0.20 allows for adequate representation of two-dimensional MDS solutions, yet optimal solutions for the overall structure are achieved as stress values decrease toward 0.10 (Clarke and Warwick 2001). The closer stress values approach 0.20 or higher, the greater chance the MDS is providing a misleading interpretation of the community structure. Further, we selected the distance linking metric based on the highest nonmetric fit r^2 value between ordination distance and observed dissimilarity. Finally, we evaluated the optimal number of dimensions to achieve an explained variance >85%.

Three stages of analyses were used to examine the effect of vegetation height on the carabid community catch. First, we tested for correlations between vegetation using draftsman's plot. We used a mutual correlation averaging 0.90 as a cutoff, above which data subsets were replaced with a single representative. Second, we calculated Spearman rank correlations (ρ_s) between vegetation and carabid community ordinations. Finally, we used BIO-ENV analysis (Clarke and Ainsworth 1993) to detect whether particular vegetation compositions around each trap matched the distribution patterns of the carabid community for Experiment 1 (but with lid treatment), then for the carabid communities summed through the period of the summer under vegetation and lid treatment. BIO-ENV calculates the correlation coefficients between the biological similarity matrix created when ordinating the data in MDS above and the environmental matrix (vegetation type) derived from the sequential combination of these measured vegetation variables, using the Spearman rank correlation (ρ_s). The combination of variables that best explains the biological ordination is identified as the one with the highest coefficient obtained from all possible combinations (Clarke and Ainsworth 1993). We used global permutation tests (499 permutations) to determine the significance of the BIO-ENV analyses (Clarke et al. 2008). Before our multivariate BIO-ENV analysis, we square-root transformed and normalized our vegetation matrix. All seven species of vegetation identified in this study were included in the analysis. All BIO-ENV analyses, draftsman's plots, and Spearman rank

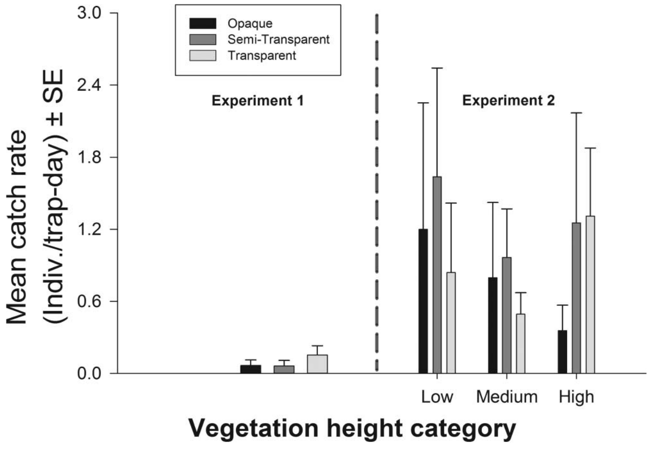

Fig. 1. Mean carabid catch rate ± SE in Experiment 1 (n = 9) and Experiment 2 (n = 3) for each lid transparency and vegetation height category.

correlations were conducted using the Primer software (version 6, PRIMER-E, Plymouth, United Kingdom).

Results and Discussion

The total catch rate of carabids was lowest in traps with opaque lids (Fig. 1), but was only significant (P = 0.011; Table 2) in Experiment 1. Greater catch rates of carabids were obtained using transparent lids and semitransparent lids in Experiments 1 and 2, respectively (Fig. 1). Given their abundance in collections (Table 1), *A. cupreum* and *A. obesa* were used to test the effects of treatment on individual species (Fig. 2). For *A. cupreum*, captures in Experiments 1 (P = 0.011; Table 2) and 2 (P = 0.039; Table 3) were significantly higher in traps using nonopaque lids (Fig. 2). However, captures were highest using transparent lids and semitransparent lids in Experiment 1 and 2, respectively (Fig. 2). Captures of *A. obesa* were not affected by lidtype (Fig. 2; Table 3). There was no effect of lid type or lid type × vegetation height for *D. pinguis* in either experiment (Tables 2 and 3).

Our results identify the use of pitfall trap lids as a factor affecting trap catch. We found that captures of *A. cupreum* were lowest using the opaque lid. This may reflect its diurnal activity (Lindroth 1969, Larochelle and Larivière 2003) and possibly a behavior that favors avoidance of the shadow cast by the lid. Conversely, the shadow cast by the opaque lid may serve to "warn" beetles away from the trap, which relies on the element of surprise. *A. cupreum* was recovered in the study by Phillips and Cobb (2005), but not in sufficient numbers to allow for a species-level analysis. However, this proposed awareness of a shadow beneath opaque lids fails to explain the lack of an effect of lid type on captures of *A. obesa.*

The use of lids is optional, but is desirable in habitats where debris collects in traps and hinders the removal and sorting of samples. Studies comparing the use of uncovered versus covered traps range from no difference in capture efficiency (Buchholz and Hannig 2009) to a greater efficiency in uncovered traps (Spence and Niemelä 1994, Lemieux and Lindgren 1999). However, these studies used lids that altered the light conditions in the trap, which may explain the reported differences between uncovered and covered traps. Based on our results, we propose the use of transparent lids when performing pitfall trap studies in grassland habitats, as they provide the benefits of opaque lids while still allowing light into the trap. Transparent lids also are less noticeable to wildlife which often destroy the traps (Buchholz and Hannig 2009).

The results of the Mahalanobis distance measure for Experiment 1 were a final solution of two dimensions and final stress of 0.08. We had four iterations in the final solution and the proportion of variance explained by these two axes was 99%. Using the Euclidean distance, we measured a final solution of two dimensions and a final stress of 0.03. We had four iterations in the final solution and the proportion of variance explained by these two axes was 99%. Draftsman's plots detected no highly correlated variables ($r > 0.90$). Our BIO-ENV analyses did not detect a significant relationship between vegetation surrounding each trap and the carabid community matrices for either Experiment 1 (ρ_s = 0.473, P = 0.25) or 2 (ρ_s = 0.307, P = 0.22). Furthermore, we found no significant correlation between MDS ordination axes of the carabid community in Experiment 1 (Fig. 3) or carabid community and

Table 2. Summary of Kruskal–Wallis one-way analysis of ranks for the effects of lid transparency on the catch rate of carabids, *A. cupreum*, and *D. pinguis* in Experiment 1

Variable	df	H	P
Catch rate of Carabidae (individuals per trap × day)	2	8.969	0.011
Catch rate of *A. cupreum* (Dejean) (individuals per trap × day)	2	9.006	0.011
Catch rate of *D. pinguis* (individuals per trap × day)	2	0.337	0.845

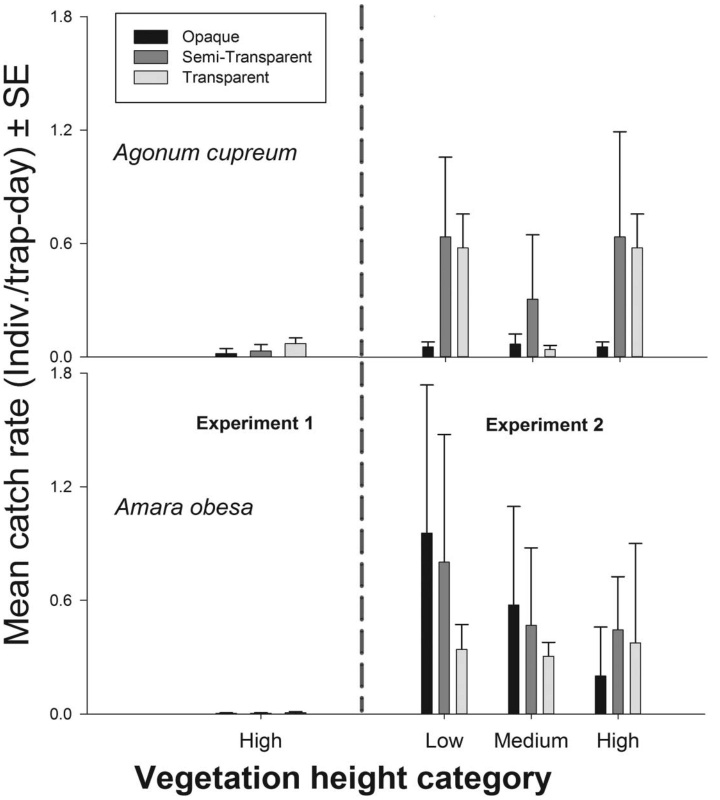

Fig. 2. Mean catch rate ± SE in Experiment 1 ($n = 3$) and Experiment 2 ($n = 9$) for the two most abundant species in each lid transparency and vegetation height category.

any of the vegetation taxa present in Experiment 2 (Fig. 4).

A critical assumption when comparing pitfall catches between habitat types is that biases are the same between locations (Melbourne 1999). This notion is false, as studies have shown that vegetation height surrounding pitfall traps can influence their catches (Melbourne 1999, Phillips and Cobb 2005). In contrast, we found no effects of vegetation structure on pitfall catches, possibly because of the low height of pasture vegetation. The range in height for our vegetation treatments was quite small (0.5–<0.1 m) and may not have influenced the catch rate of carabids.

The species composition was similar to that reported by Pepper (1999), who operated pitfall traps using a salt water preservative on a native pasture in Saskatchewan. The larger number of *D. pinguis* recovered in our study was unexpected. This species disperses by flight, whereas pitfall traps typically target epigaeic species. Similarly, Pepper (1999) recovered a large number of *Onthophagus nuchicornis* L., another species of scarab that disperses by flight. We speculate that captures of these scarabs may reflect an

Table 3. Summary of ANOVA results for the effects of vegetation height (VEG) and lid transparency (LID) on the catch rate of Carabidae, *A. cupreum*, and *A. obesa* for experiment 2

Variable	Source of variation	df	MS	*F*	*P*
Catch rate of Carabidae (individuals per trap × day)	LID	2	0.638	1.421	0.267
	VEG	2	0.5	1.113	0.35
	LID × VEG	4	0.439	0.977	0.444
	Error	18	0.449		
Catch rate of *A. cupreum* (individuals per trap × day)	LID	2	0.327	3.895	0.039
	VEG	2	0.189	2.256	0.134
	LID × VEG	4	0.0665	0.792	0.545
	Error	18	0.0839		
Catch rate of *A. obesa* (individuals per trap × day)	LID	2	0.166	0.765	0.48
	VEG	2	0.306	1.413	0.269
	LID × VEG	4	0.123	0.568	0.689
	Error	18	0.217		

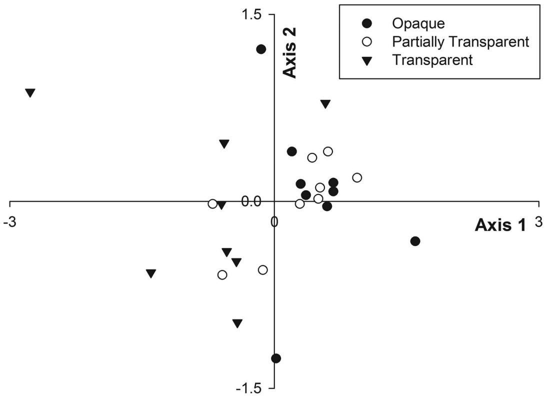

Fig. 3. MDS ordination of trap-level carabid beetle catch rates for lid transparency in Experiment 1.

attraction to moisture associated with the preservative.

Despite the limitations of pitfall traps, they are one of the most useful methods for sampling carabids, and offer advantages such as continuous sampling, large sample sizes, low maintenance, and sampling at multiple locations (Baars 1979, Topping and Sunderland 1992, Spence and Niemelä 1994, Brennan et al. 1999). Considerable efforts by researchers have identified many factors that influence the efficiency of pitfall traps, yet other variables undoubtedly remain. In this study, we showed that pitfall trap lids cause bias in catches among a single species. To improve pitfall trap design, potential effects of the lid should be tested on other species, at additional sites, and across a range of habitats. When interpreting pitfall trap data, it is important to consider the life history and habits of species (Spence and Niemelä 1994, Bergeron et al. 2013), as we have shown with *A. cupreum.* Ultimately, the design of pitfall traps should be modified to prevent structural components from biasing catch results, which may include the use of transparent lids rather than more traditional opaque lids.

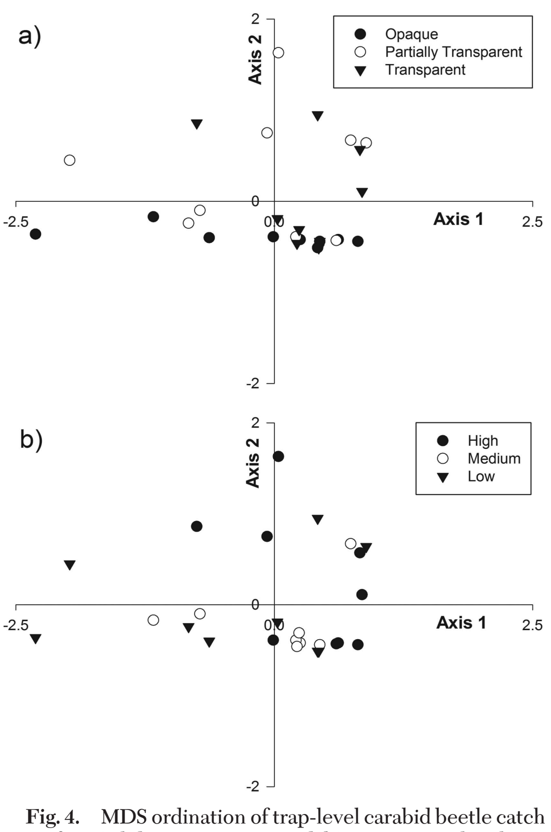

Fig. 4. MDS ordination of trap-level carabid beetle catch rates for a) lid transparency and b) vegetation height in Experiment 2.

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