# It's a matter of design – how pitfall trap design affects trap samples and possible predictions

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**Background**. Pitfall traps are commonly used to assess ground dwelling arthropod communities. The effects of different pitfall trap designs on the trapping outcome are poorly investigated however they might affect conclusions drawn from pitfall trap data greatly.

**Methods.** We tested four pitfall trap types which have been used in previous studies for their effectiveness: a simple type, a faster exchangeable type with an extended plastic rim plate and two types with guidance barriers (V- and X shaped). 20 Traps were active for 10 weeks and emptied biweekly resulting in 100 trap samples.

**Results.** Pitfall traps with guidance barriers were up to five times more effective than simple pitfall traps and trap samples resulted in more similar assemblage approximations. Pitfall traps with extended plastic rim plates did not only perform poorly but also resulted in distinct carabid assemblages with less individuals of small species and a larger variation.

**Discussion**. Due to the obvious trait filtering and resulting altered assemblages, we suggest not to use pitfall traps with extended plastic rim plates. In comprehensive biodiversity inventories, a smaller number of pitfall traps with guidance barriers and a larger number of spatial replicates is of advantage, while due to comparability reasons, the use of simple pitfall traps will be recommended in most other cases.

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25    **Summary**

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30    **Methods.** We tested four pitfall trap types which have been used in previous studies for their

31    effectiveness: a simple type, a faster exchangeable type with an extended plastic rim plate and

32    two types with guidance barriers (V- and X shaped). 20 Traps were active for 10 weeks and

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35    pitfall traps and trap samples resulted in more similar assemblage approximations. Pitfall traps

36    with extended plastic rim plates did not only perform poorly but also resulted in distinct carabid

37    assemblages with less individuals of small species and a larger variation.

38    **Discussion**. Due to the obvious trait filtering and resulting altered assemblages, we suggest not

39    to use pitfall traps with extended plastic rim plates. In comprehensive biodiversity inventories, a

40    smaller number of pitfall traps with guidance barriers and a larger number of spatial replicates is

41    of advantage, while due to comparability reasons, the use of simple pitfall traps will be

42    recommended in most other cases.

43        **Introduction**

44

45    Proposed nearly a century ago, pitfall traps remain one of the most commonly applied sampling

46    methods in ecological field studies and are widely used for the assessment of ground dwelling

47    arthropod taxa which are of high importance in modern ecosystem functioning research (Brown

48    & Matthews 2016). Although the limitations of pitfall traps in respect to trait filtering and

49    reflecting diversity and abundances in a habitat appropriately have been intensively discussed,

50    the method is still the best standardized and comparable approach to study ground dwelling

51    arthropods and due to comparative low handling time allows for sufficient replication (Driscoll

52    2010; Kotze et al. 2011).

53    Different features of pitfall trap designs have undergone review and research over the last

54    decades in order to improve and standardize trap designs: colour of traps (Buchholz et al. 2010),

55    the presence and colour of rain covers (Buchholz & Hannig 2009; Császár et al. 2018), sampling

56    intervals (Schirmel et al. 2010), spatial distribution (Ward et al. 2001), different preservatives

57    (Schmidt et al. 2006; Skvarla et al. 2014) as well as pitfall trap diameters and the use of funnels

58    (Császár et al. 2018; Lange et al. 2011). A recent meta-analysis by Brown & Matthews (2016)

59    discussed many pitfall trap parameters (diameter, depth, colour, rain covers, preservatives and

60    the use of funnels) and even proposed a standardized trap design. However, the authors did not

61    consider additions to pitfall trap designs such as extended rim plates or guidance barriers

62    although these have been used in previous studies.

63    In a conventional simple pitfall trap as proposed by the pioneers Dahl (1896), Barber (1931) and

64    Greenslade (1964) which is basically a container sunk in the soil, a large proportion of ground

65    dwelling beetle species occurring in a habitat will not be detected with sufficient certainty as

66  they are comparatively rare in assemblages (Driscoll 2010). To overcome this limitation without

67  increasing the sampling effort and workload, guidance barrier pitfall traps have been introduced.

68  The use of guidance barriers is meant to increase capture efficiency and the number of singletons

69  which are particularly important in conservation studies where complete biodiversity inventories

70  are desired (Hansen & New 2005). However, only few studies investigated the actual effect of

71  guidance barriers on pitfall trap catches and these studies suffered from low sample sizes and

72  unbalanced sampling efforts with a different number of pitfall traps used in the studied pitfall

73  trap designs (Hansen & New 2005; Winder et al. 2001). Moreover, guidance barrier pitfall traps

74  are not commonly used in applied research (but see Hossain et al. (2002) and Schneider et al.

75  (2016)). To our knowledge, the effects of barriers on assemblages or traits have so far not been

76  investigated at all.

77  To reduce handling time in the field as well as the so called 'digging in effects' (Digweed et al.

78  1995; Greenslade 1973), pitfall traps with extended PVC rim plates screwed on top of a pitfall

79  trap glass jar have been designed. With this design, hardly any digging or filling of gaps between

80  the pitfall trap and the surrounding soil is needed in the process of exchanging pitfall trap

81  containers and therefore handling time and the release of soil $CO_2$ are reduced. The latter is

82  known to increase ground dwelling arthropod activity and could therefore affect pitfall trap

83  catches and lead to an overestimation of activity densities (Joosse & Kapteijn 1968; Schirmel et

84  al. 2010). Another advantage of this design is the enhanced standardization of the transition

85  between the pitfall trap and surrounding soil. However, it is unknown how these traps perform in

86  comparison with simple pitfall traps and whether the extended plastic rim plate affects resulting

87  ground dwelling arthropod assemblages.

88    In this study, we investigate the effects of different pitfall trap designs on the catches of the three

89    most commonly studied ground dwelling arthropod taxa (carabid beetles, staphylinid beetles and

90    spiders) and possible effects on assemblage structure and trait filtering in carabid beetles.

91

93      **Materials and methods**

94

95   *Study design*

96   The study was performed on a semi-natural meadow with hedgerows near the Biocenter of the

97   University of Würzburg in central Germany (49.779416° N, 9.973360° E). On this meadow five

98   plots of each four pitfall traps were established. The five plots always consisted of four different

99   pitfall trap designs:

100     i.     Conventional simple pitfall traps (Fig 1 A)

101     ii.    Pitfall traps with a squared extended PVC rim plate screwed on top of the glass jar used

102            as pitfall trap for avoidance of digging in effects and easier exchange (10 x 10 cm²;

103            diameter 7 cm; Fig 1 B)

104     iii.   V-shaped guidance barrier pitfall traps using two 75 cm long metal barriers (height: 7 cm,

105            angle: 90°, proposed by Smith (1976); Fig 1 C)

106     iv.    X-shaped guidance barrier pitfall traps using four 75 cm long metal barriers (height: 7 cm

107            angle: 90°, proposed by Morrill et al. (1990); Fig 1 D)

108   The minimum distance between plots was 45 m while the pitfall traps within a plot were placed

109   in a row and separated from each other by 10 m to minimize possible detrimental effects of

110   neighbouring pitfall traps on pitfall trap catches. All pitfall traps were located 2 m apart from an

111   adjacent hedgerow to make trap samples comparable.

112

113   *Data collection*

114   Pitfall traps were set up at the 13th March 2012 and emptied biweekly until the 22nd May 2012

115   which results in 100 trap samples (5 plots x 4 pitfall traps per plot x 5 sampling intervals). As

116  pitfall trap containers, we used conventional glass honey jars (height: 9 cm, diameter: 7.5 cm,

117  transparent) filled with 200 ml 3 parts water with 1 part ethylene glycol (automobile antifreeze,

118  H. Kerndl GmbH) mixture with odourless detergent as trapping liquid and preservant in each

119  pitfall trap design. Pitfall traps were covered by metal roofs (25 x 25 cm², approximately 10 cm

120  above ground) to protect against flooding. To minimize small vertebrate bycatch, all traps except

121  for the X-shaped guidance barrier type were additionally covered by a wire cross (length: 10 cm,

122  width: 2 mm; Fig 1B).

123  Pitfall trap samples were sorted for carabid beetles (Carabidae), rove beetles (Staphylinidae) and

124  spiders (Araneae). All individuals from these taxa were counted and all carabid beetles were

125  identified to species level following Müller-Motzfeld (2006). Carabid body size was obtained

126  from the online database 'carabids.org' (Homburg et al. 2014).

127

128  *Statistical analyses*

129  All statistical analyses were performed in R 3.3.1 for Windows (R Development Core Team

130  2016).

131  For all analyses the pitfall trap samples of the same plot and pitfall trap design were pooled over

132  all five sampling intervals to account for phenological shifts in the assemblages and reduce the

133  influence of outliers (Kotze et al. 2011; Williams et al. 2010).

134  We used linear mixed effects models (LMER; using 'lmer' from the package lme4 (Bates et al.

135  2015)) to analyse the effects of pitfall trap type on the response variables 'carabid species

136  richness', 'carabid beetle activity density', 'staphylinid beetle activity density', 'spider activity

137  density', the 'proportion of small (< 6 mm) carabid beetles', the 'proportion of large (> 10 mm)

138  carabid beetles' and 'carabid beetle community weighted mean body size'. Activity densities

139    were square root transformed to account for heteroscedasticity. All LMERs contained 'plot ID'

140    as a random effect to account for the nested design and were analysed using the command

141    'anova' (type II sums of squares, Kenward-Roger approximation of denominator degrees of

142    freedom) from the package 'lmerTest' (Kuznetsova et al. 2017) and subsequent Tukey-HSD

143    posthoc tests ('HSD.test' command from the package agricolae (De Mendiburu 2016)). All

144    models met the model assumptions for linear mixed effects models. All response variables were

145    tested for spatial autocorrelation using the 'Moran.I' command from the package ape (Paradis et

146    al. 2004) but no spatial autocorrelation was detected.

147    Additionally, we compared the resulting carabid assemblages (transformed to proportion data) in

148    a NMDS analysis based on Bray-Curtis dissimilarities using the 'metaMDS' command (package

149    'vegan' (Oksanen et al. 2013)). The NMDS fit was tested for significant differences between

150    pitfall trap designs in a PERMANOVA ('adonis' command). To compare the capture efficiency

151    of the different pitfall trap designs we calculated species accumulation curves using the

152    'specaccum' function (including 95% confidence intervals).

153     **Results**

154

155     On the five plots, a total of 655 carabid beetles from 42 species, as well as 626 staphylinid

156     beetles and 4557 spiders were trapped over the course of the five sampling intervals (Tables 1 &

157     2).

158     Activity densities of all three investigated taxa were at least three times higher in the pitfall traps

159     with X-shaped guidance barriers compared to simple pitfall traps and lowest in the pitfall traps

160     with extended PVC rim plate (not significant in carabid beetles; Table 1; Fig. 2). The pitfall traps

161     with V-shaped guidance barriers caught more carabid beetles and spiders than the simple ones

162     but less than the pitfall traps with X-shaped guidance barriers in all three taxa (carabid beetles:

163     LMER: $F_{3,12}$= 69.0, p < 0.001; Fig. 2 A; staphylinid beetles: LMER: $F_{3,12}$= 35.8, p < 0.001; Fig.

164     2 B; spiders: LMER: $F_{3,12}$= 99.7, p < 0.001; Fig. 2 C)

165     The carabid assemblages in the pitfall trap samples of the pitfall trap designs using guidance

166     barriers had approximately twice as many species than the assemblages in the two remainder

167     types (LMER: $F_{3,12}$= 20.6, p < 0.001; Fig. 3 A). The pitfall traps with extended PVC rim plate

168     caught significantly less small species (< 6 mm; LMER: $F_{3,12}$= 12.3, p < 0.001) and more large

169     species (> 10 mm; LMER: $F_{3,12}$= 4.38, p = 0.027) which resulted in a larger community weighted

170     mean body size than in the other pitfall trap designs (LMER: $F_{3,12}$= 69.0, p < 0.001; Fig. 3 B).

171     The NMDS ordination (stress 0.18) showed considerably less variation among the very similar

172     carabid assemblages in the pitfall traps with guidance barriers while carabid assemblages in the

173     pitfall trap designs without guidance barriers showed larger variation between plots. Pitfall trap

174     design influenced the trapped assemblages significantly (PERMANOVA: 9999 permutations,

175    $F_{3,19}$= 2,68, p < 0.001) as the pitfall traps with extended PVC rim plates had rather different

176    assemblages compared to the other pitfall trap types (Fig. 4 A).

177    The species accumulation curves indicated that using one single pitfall trap with X-shaped

178    guidance barriers is approximately as effective as using four to five simple pitfall traps (Fig. 4B).

180    **Discussion**

181

182    We showed that the choice of pitfall trap design affects the final outcome of a study and results

183    in different assemblage approximations even though we tested one habitat which has a finite

184    carabid species pool and a unique assemblage structure. Pitfall trap design might therefore affect

185    conclusions drawn from the study outcome and pitfall trap designs unsuitable for the hypotheses

186    will result in poor results and poor management recommendations.

187    Pitfall traps with guidance barriers proved most effective in our study and showed coherent

188    carabid beetle assemblage structures. These pitfall trap designs have been proposed several times

189    in the past but have seen little use so far (Durkis & Reeves 1982; Hansen & New 2005; Winder

190    et al. 2001). According to our results, the use of few pitfall traps with guidance barriers would be

191    recommended over the use of many simple pitfall traps – especially when comprehensive

192    biodiversity inventories are desired. One single pitfall trap with guidance barriers was

193    approximately as effective as four to five simple pitfall traps in regards of species richness –

194    therefore the use of pitfall traps with guidance barriers could spare handling time in the field and

195    in the laboratory. The guidance barrier designs are (i) more time consuming in the construction

196    with higher payloads in the field and (ii) at least in the X-shaped design traps need to be renewed

197    in each sampling interval in order to exchange the trap container (a problem that could probably

198    be overcome by revisiting the design of the guidance barriers). Nonetheless a reduced overall

199    number of traps and overall reduced handling time subsequently saved in sample processing later

200    on increases the efficiency. However, pitfall traps with guidance barriers need a more or less

201    plain ground: For the study of uneven surfaces (for example rocky ground), simple pitfall traps

202    will be more suitable and efficient. The increased visibility of guidance barrier traps could also

203   result in a higher rate of vandalism which is a problem in pitfall trap studies but might be

204   minimized by using transparent barriers as used by Durkis & Reeves (1982). Moreover, as for

205   now not many studies used pitfall traps with guidance barriers, for means of comparability

206   between studies it will be necessary to use simple pitfall traps in many fields of ecological

207   research.

208   In contrast to Winder et al. (2001), we did not find barrier pitfall trap designs to catch more

209   carabid beetles of a certain size as community weighted mean body size and percentages of small

210   and large carabid beetles remained approximately the same as in the simple pitfall traps. The

211   shape of the guidance barriers only affected total activity densities and not species richness or

212   assemblage composition – therefore, the V-shaped guidance barrier pitfall traps which have a

213   lower impact on ecosystems as their catchment area is only a quarter of those of the X-shaped

214   guidance barrier pitfall traps can be used in biodiversity inventories. This design has also the

215   advantage that the guidance barriers are not covering the pitfall trap container which makes the

216   exchange or collection of pitfall trap samples much easier and faster.

217   Although simple pitfall traps caught less species and fewer individuals as the pitfall traps

218   containing guidance barriers, the resulting carabid assemblages were over all rather similar to

219   those from the pitfall traps with guidance barriers. The remaining differences could probably be

220   compensated by using a higher number of simple pitfall traps in habitats and situations where the

221   use of guidance barriers is not possible.

222   The use of extended PVC rim plates mainly aims at reducing set up time for pitfall traps and

223   digging-in effects. Although this method is – apart from the use of funnels in combination with a

224   two cup system as described in Brown & Matthews (2016) – probably the most efficient in terms

225   of handling time in the field and quite good for standardizing the transition between surrounding

226   soil an pitfall trap, it resulted in low catch rates and considerable alteration of the resulting

227   carabid beetle assemblages in comparison to all other tested pitfall trap designs. Yet, as activity

228   densities were not drastically different from those in the simple pitfall traps, we argue that the

229   'digging in effect' did not boost activity densities essentially in our study.

230   However, trait filtering against small sized carabid species was apparent when using extended

231   PVC rim plates. This effect is completely contrary to the original idea of a more standardized

232   transition between surrounding soil and pitfall trap which should help to catch more small

233   carabid beetles as pitfall trap sampling bias due to the perception of edges is decreasing with

234   increasing body size (Engel et al. 2017; Lang 2000). Carabid beetles most likely avoided the

235   relatively smooth PVC surface and as smaller species would have to cover longer distances in

236   relation to their body size, this effect results in trait filtering. It might be reduced by covering the

237   surface with sand (fixed with spray glue) or other more natural organic substrates. For the

238   moment, due to the reduced and size-biased catches produced by this pitfall trap design, we

239   suggest to refrain from its use.

241      **Conclusions**

242

243   Many studies on ground dwelling predators (carabid beetles, staphylinid beetles, spiders) use

244   pitfall traps to draw conclusions on habitat conservation and ecosystem services including

245   functional traits of species without being aware of the bias of certain pitfall trap designs. We

246   show that pitfall trap design not only affects species richness and activity densities but also the

247   trait composition of the resulting assemblages. For comprehensive biodiversity inventories, we

248   therefore recommend to use a small number of highly effective pitfall traps with overall spared

249   handling time, as the X or V shaped barrier trap designs in our study. However, for most

250   ecological studies the use of simple pitfall trap designs is recommended, to increase

251   comparability to other studies. We hereby recommend to use a nested design of several simple

252   pitfall traps per plot followed by a pooling of the data as suggested by Kotze et al. (2011) in

253   order to get a more conclusive picture of the local assemblages. We can currently not

254   recommend the use of pitfall traps with an extended PVC rim plate, as especially small species

255   tend not to cross such plates.

256

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260

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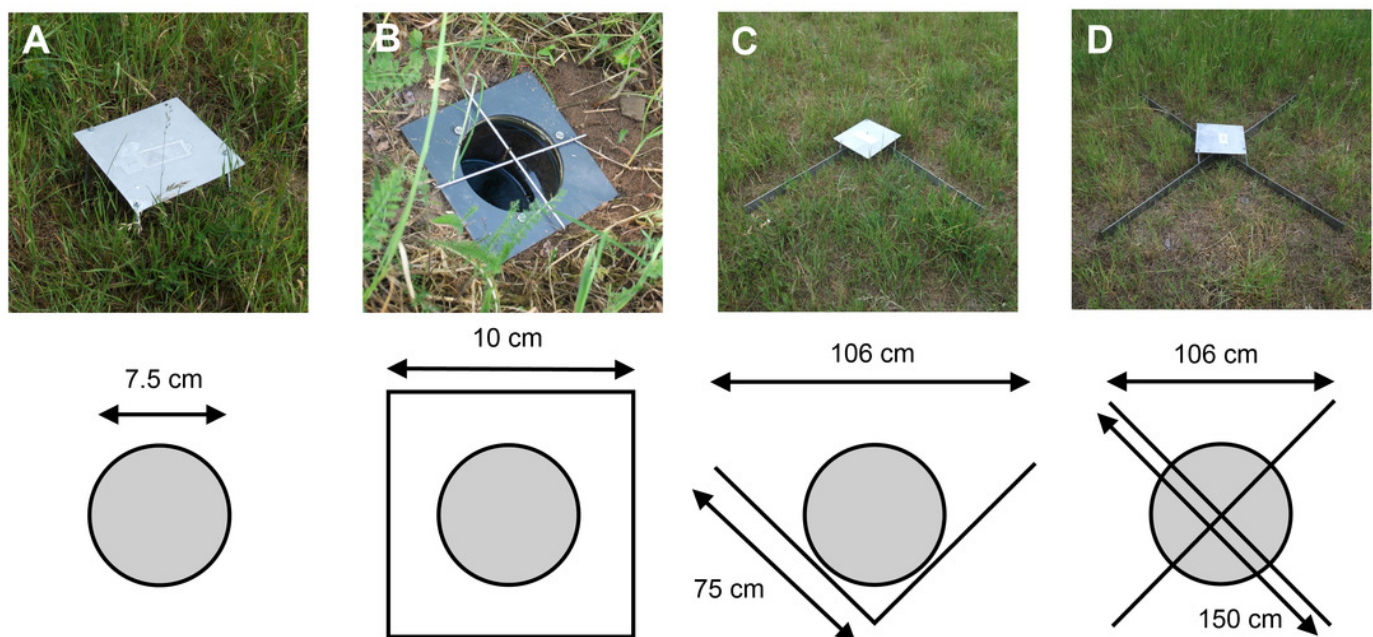
358

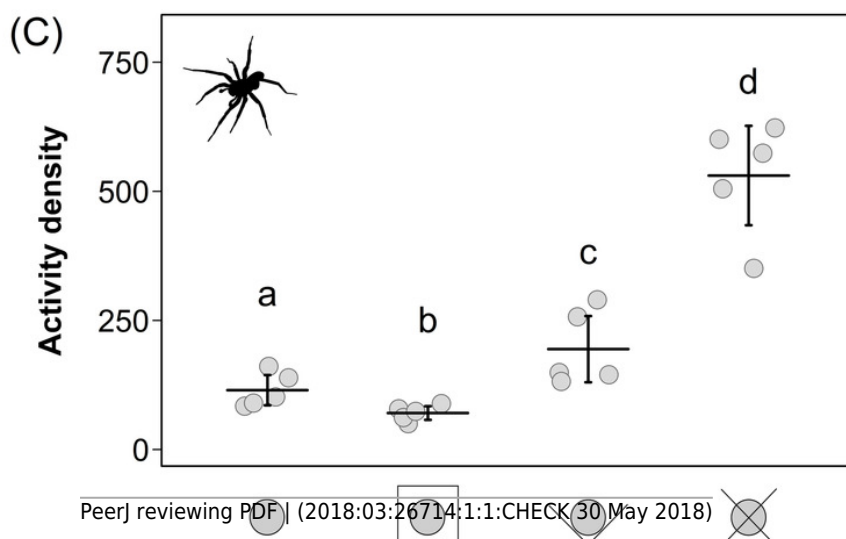
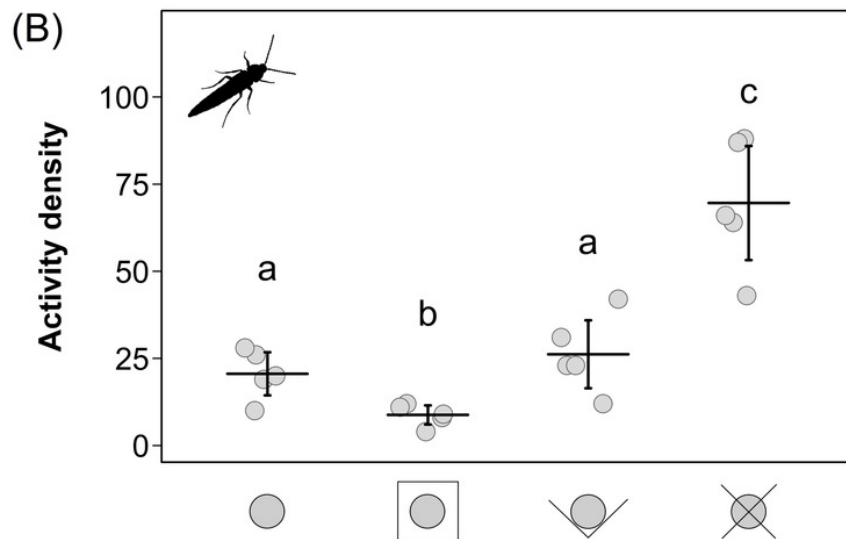
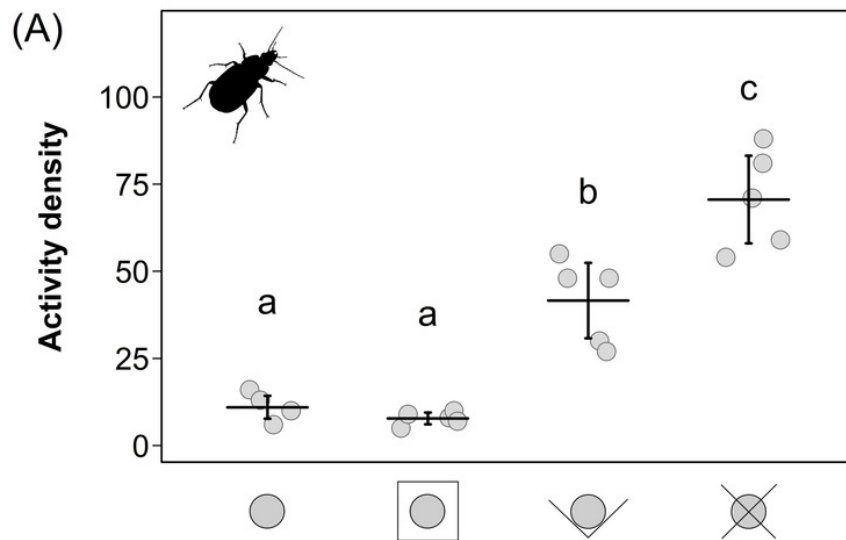
359

# Figure 1

Pitfall trap designs investigated.

**(A)** Conventional pitfall trap, **(B)** pitfall trap with a squared PVC rim (shown without metal roof), **(C)** pitfall trap with V-shaped guidance barriers, **(D)** pitfall trap with X-shaped guidance barriers. Arrows indicate measurements of the corresponding parts.

# Figure 2

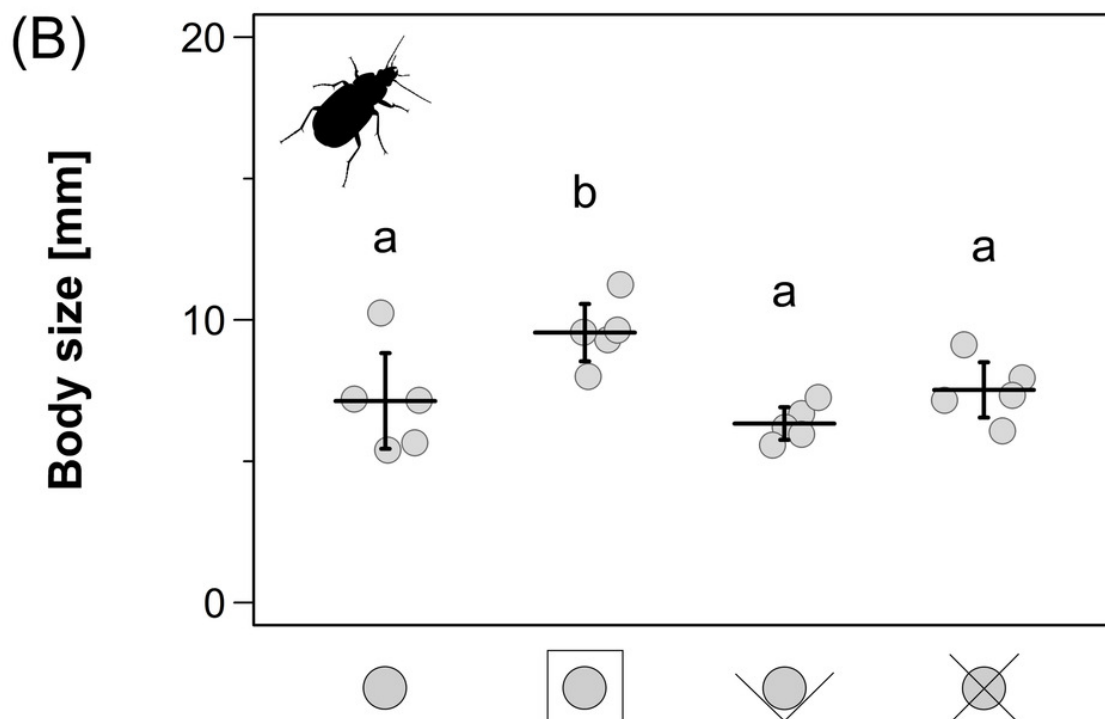
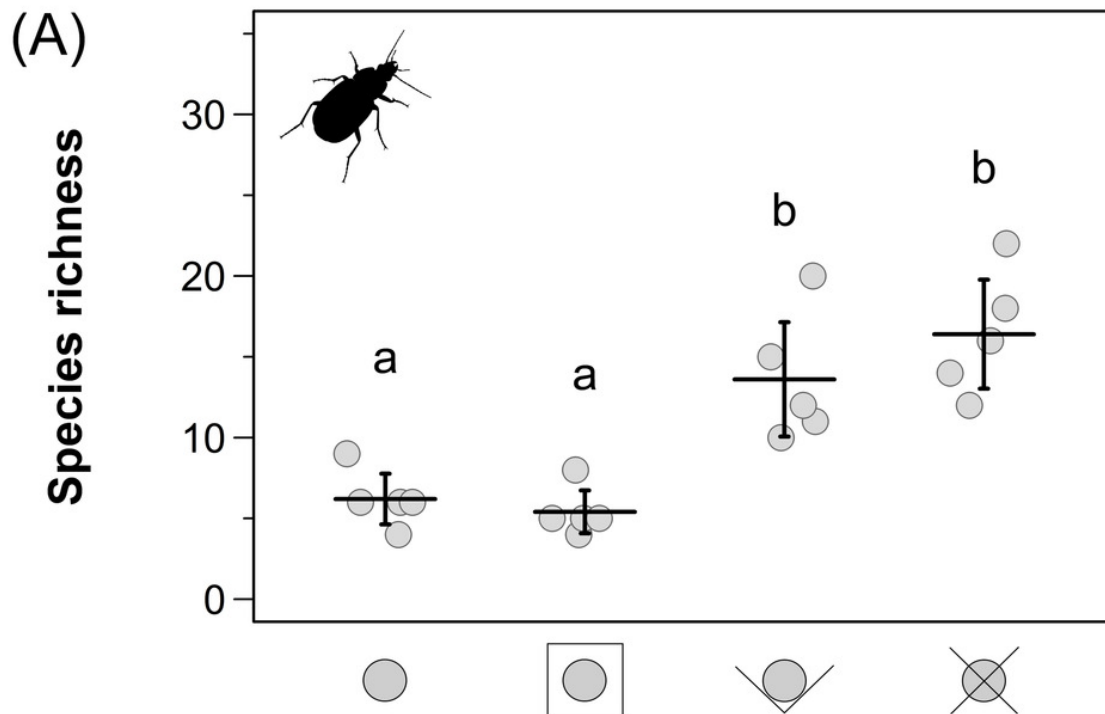
Activity densities (mean ± 95% CI) of carabid beetles (A), staphylinid beetles (B) and spiders (C) for the four different pitfall trap types.

Different letters above indicate significant differences ($p < 0.05$). Pitfall trap designs from left to right: simple type; PVC rim type; V-shaped guidance barrier type; X-shaped guidance barrier type.

# Figure 3

Carabid beetle species richness (A) and community weighted mean body size within the carabid assemblages (B) for the four different pitfall trap types. Means ± 95% CI.

Different letters above indicate significant differences (p < 0.05). Pitfall trap designs from left to right: simple type; PVC rim type; V-shaped guidance barrier type; X-shaped guidance barrier type.

(A)

(B)

# Figure 4

Carabid beetle assemblage characteristics.

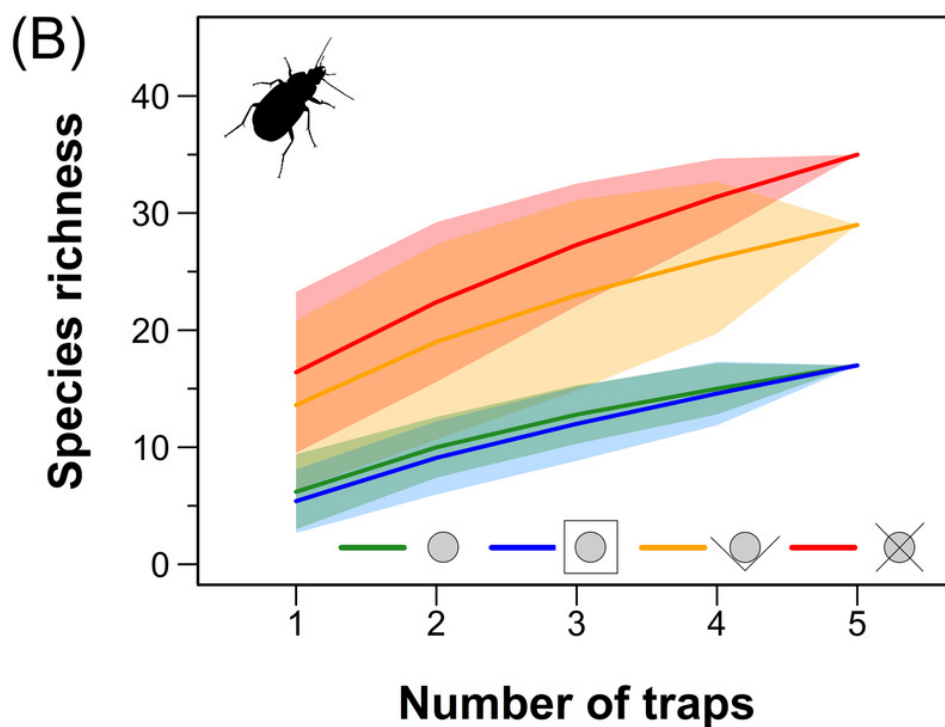
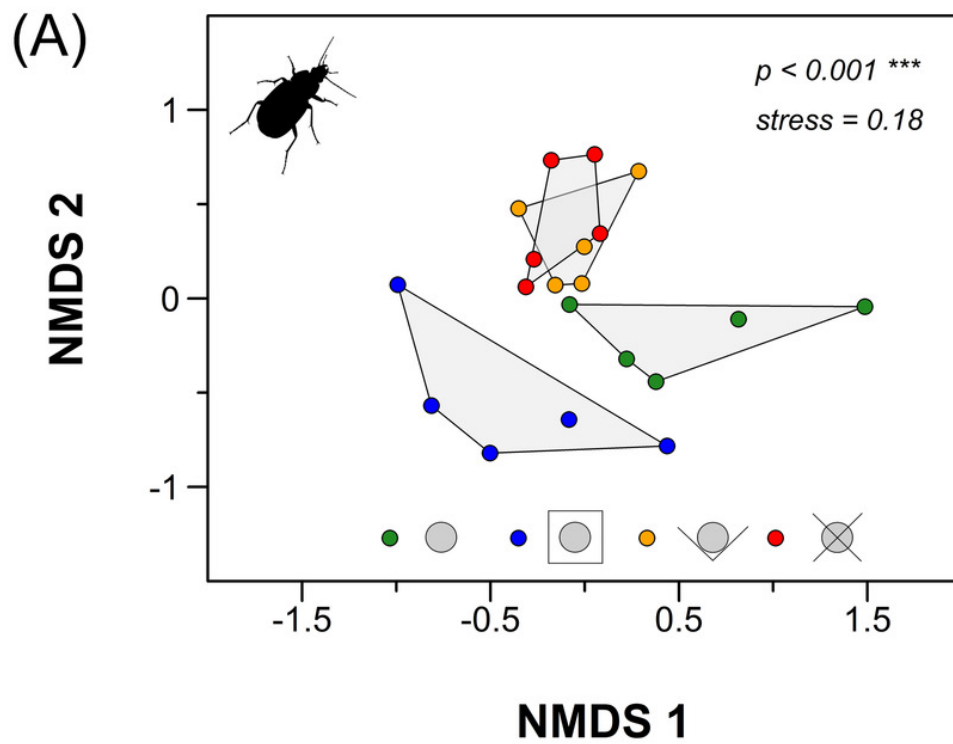
(A) NMDS ordination of the carabid assemblages in the different pitfall trap types. (B) Species accumulation curves (± 95% CI) for the four different pitfall trap types. Colours: green: conventional pitfall trap; blue: pitfall trap with a squared PVC rim; orange: pitfall trap with a V-shaped guidance barrier; red: pitfall trap with a X-shaped guidance barrier. Pitfall trap designs from left to right: simple type (green); PVC rim type (blue); V-shaped guidance barrier type (orange); X-shaped guidance barrier type (red).

Total activity densities and carabid species richness in the different pitfall trap designs over all plots and sampling intervals.

**Table 1:** Total activity densities and carabid species richness in the different pitfall trap designs over all plots and sampling intervals.

| response variable | (i) simple type | (ii) extended PVC rim plate type | (iii) V-shaped barrier type | (iv) X-shaped barrier type |
|---|---|---|---|---|
| *Carabid beetles* | | | | |
| *species richness* | 17 | 17 | 29 | 35 |
| *activity density* | 55 | 39 | 208 | 353 |
| *Staphylinid beetles* | | | | |
| *activity density* | 103 | 44 | 131 | 348 |
| *Spiders* | | | | |
| *activity density* | 576 | 354 | 973 | 2654 |

Carabid beetle species present in the different pitfall trap designs over all plots.

**Table 2:** Carabid beetle species present in the different pitfall trap designs over all plots.

| species | (i) simple type | (ii) extended PVC rim plate type | (iii) V-shaped barrier type | (iv) X-shaped barrier type |
|---|---|---|---|---|
| *Abax parallelepipedus* | | | | 1 |
| *Amara aenea* | 1 | 1 | 14 | 30 |
| *Amara convexior* | 3 | 2 | 4 | 17 |
| *Amara equestris* | | 1 | | |
| *Amara eurynota* | | | 1 | 1 |
| *Amara familiaris* | 1 | | 3 | 3 |
| *Amara lucida* | | | 1 | 3 |
| *Amara lunicollis* | 1 | | 1 | 2 |
| *Amara ovata* | | 1 | 1 | 5 |
| *Amara similata* | | | 3 | |
| *Anchomenus dorsalis* | | | 1 | 4 |
| *Badister bullatus* | 1 | 1 | 1 | 1 |
| *Badister lacertosus* | | | | 2 |
| *Bembidion lampros* | 2 | 1 | 5 | 13 |
| *Bembidion properans* | | | | 2 |
| *Brachinus crepitans* | | | 1 | 6 |
| *Calathus melanocephalus* | 2 | | 3 | 2 |
| *Carabus coriaceus* | 1 | 1 | | |
| *Harpalus affinis* | | 1 | | 1 |
| *Harpalus pumilus* | 3 | 1 | 20 | 32 |
| *Harpalus rubripes* | 5 | 9 | 21 | 62 |
| *Harpalus rufipes* | 1 | 1 | 1 | |
| *Harpalus subcylindricus* | | 2 | 2 | 18 |
| *Harpalus tardus* | 8 | 9 | 27 | 54 |
| *Lebia cruxminor* | 1 | | | |
| *Masoreus wetterhalii* | | | 2 | |
| *Microlestes maurus* | | 1 | 2 | 1 |
| *Notiophilus biguttatus* | | | | 1 |
| *Notiophilus palustris* | | | 2 | 2 |
| *Ophonus laticollis* | | | 1 | |
| *Panagaeus bipustulatus* | 1 | | 2 | 3 |
| *Paradromius linearis* | | | 1 | 2 |
| *Philorhizus notatus* | | | 2 | 1 |
| *Philorhizus sigma* | | | | 1 |
| *Poecilus cupreus* | 4 | 1 | 10 | 11 |
| *Poecilus lepidus* | | 5 | 10 | 25 |
| *Poecilus versicolor* | | | | 1 |
| *Pterostichus strenuus* | | | | 5 |
| *Syntomus foveatus* | | | 7 | 2 |
| *Syntomus truncatellus* | 19 | 1 | 59 | 37 |
| *Synuchus vivalis* | | | | 1 |