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An investigation into the response of ground beetles (Coleoptera, Carabidae) to the creation of bare ground within reed bed vegetation at Priory Water NR Leicestershire

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Introduction

Bare ground is an essential component of the habitat of a large number of invertebrate species, some of which are rare and/or in decline (Key, 2000). As bare ground, or exposed soil, is a common feature of the landscape it may be surprising that it is now regarded as a habitat of conservation importance, being designated a UKBAP Priority Habitat in 2008 (Cameron & Leather 2012). Although the designation applies to '*open mosaic habitats on previously developed land*' the presence of bare ground is also an important component of long-established habitats such as heathland, fenland and woodland. Bare ground is generally a transitory habitat, as succession will fairly quickly occur if it is left undisturbed to produce a cover of vegetation. One reason for the increasing rarity of ecologically valuable bare ground is that traditional management of habitats for timber, thatching reeds and livestock, among other things, which created a suitable level of disturbance, has declined substantially and is now generally replicated on a far smaller scale by conservation management. Nevertheless, the value of bare ground is sometimes overlooked or regarded as a negative feature by land managers (Key, 2000).

A number of studies have shown that bare ground or open, sparsely vegetated habitats are important for carabid beetles. In the Brecklands of eastern England the habitat with the greatest carabid species richness was found to be open ground that was disturbed mechanically each year, with only a sparse covering of vegetation (Telfer & Eversham, 1996). At Wicken Fen the activity density, as recorded by pitfall traps, of both common and scarce wetland carabids was positively correlated with low vegetation densities (Martay *et al,* 2011) and the two most abundant scarce species in this study, *Chlaenius nigricornis* and *Oodes helopiodes,* have also been shown to benefit from the more open conditions created by grazing on Welsh peatlands (Holmes *et al,* 1993). At Woodwalton Fen, sites with bare ground had the highest species richness (Tinsley-Marshall & Eversham, 2014) and the authors suggest that exposed mud adjacent to standing water may attract migrating wetland ground beetles.

Bare or open ground has various characteristics that may be beneficial to ground beetles and other invertebrates. The ground surface generally warms up more quickly in open than in vegetated habitats – a feature useful to poikilotherms which often operate most efficiently at temperatures close to, or above, those attained by 'warm-blooded' animals (Key, 2000). *Chlaenius nigricornis*, for instance, was found to have a strong preference for temperatures between 26°C and 29°C in a wet grassland near Kiel in North Germany (Irmler, 2014). Higher temperatures, together with suitable soil texture may also be important for oviposition and the incubation of eggs; many invertebrates, including carabids (Thiele, 1977), lay their eggs in cavities beneath the soil surface. Bare ground may also allow predators that hunt by sight, such as ground beetles and tiger beetles, to find prey more effectively.

Brownfield sites, which include abandoned sand and gravel pits, are known to be valuable habitats for invertebrates, among other groups, and may function as analogues of natural habitats (Eversham *et al*, 1996). Some scarce ground beetles are specifically associated with the shoreline habitats of former sand and gravel pits, which provide conditions similar to those found in marshland or fenland. Buglife suggests that the value of these habitats can be enhanced by ensuring open ground is maintained alongside marginal vegetation (https://www.buglife.org.uk/how-manage-brownfields).

The work described here was stimulated by the published evidence for the important role bare or open ground plays in the distribution of wetland ground beetles and by observations made during a three year survey of ground beetles at Priory Water Nature Reserve, near Melton Mowbray, Leicestershire (Cook & Clark, 2013). Pitfall trapping in reed beds bordering a lake suggested that a number of specifically wetland species, including a few local species, were associated with bare ground that was kept free of vegetation by shading from overhanging shrubs. In this study small areas of vegetation were cleared from the edge of one of the larger reed beds on the reserve to give alternating replicated patches of bare ground and the natural vegetation in order to investigate the influence of bare ground in a reed bed on carabid species richness, species diversity and wetland specificity (see methods below).

Three years' work on reed bed carabids are covered in this paper. In year 1 (2015) the difference between the treatments was investigated using two pitfall traps in each site. In year 2 (2016), the number of traps was increased to six in two of the bare and adjacent vegetated patches in an attempt to address the problem of impedance by vegetation influencing the trap catch and in year 3 (2017) the moss that had accumulated on the bare patches was scraped away down to the soil on two of the patches, leaving the other two moss-covered, to investigate what effect the quality of bare ground had on ground beetles sampled.

Materials and Methods

Study site

Priory Water comprises a complex of lakes of various sizes in abandoned gravel pits, separated by woodland and grassland habitats, in the flood plain of the River Wreake near Kirby Bellars, Leicestershire (SK7118). The site, which was abandoned in the 1970s, was acquired by the Leicestershire Wildfowlers' Association in 1987 and managed as a reserve, principally for wildfowl. The reserve covers an area of 81 hectares, of which 31 hectares are open water. The reed bed used in this study shelved gradually into the largest lake on the site (approximately 20 hectares) and was dominated by *Phragmites australis*. Other species included *Deschampsia caespitose*, *Typha latifolia*, *Juncus inflexus*, *Filipendula ulmaria*, *Stachys palustris*, *Dipsacus fullonum*, *Senecio jacobaea*, *Epilobium parviflorum, Epilobium hirsutum* and *Lythrum salicaria*. The construction of the reed bed was undertaken by the Environment Agency, starting in 2002. This involved the removal of several thousand tonnes of earth to achieve a shelved Lake margin. However, the long dry summer of that year left the area bone dry. After consultation, the lake margin was excavated to a deeper level and finally planted in 2004 with reed (*Phragmites australis*).

Figure 1. One of the cleared plots in the reed bed at Priory Water with pitfall trap positions when two traps were used. To the left and right are vegetated plots.

Preparation of bare ground

In January 2014 four plots (4x4m), alternating with vegetated plots of the same dimensions, were cleared at the edge of the reed bed, down to the water's edge, using a strimmer with all cuttings being removed from the study area (Figure 1). Between January 2014 and March 2015 the open plots were visited on five occasions when any new plant growth was treated with Roundup (glyphosate). Brust (1990) in field studies found no repellent or toxic effects of glyphosate on carabids. In 2016 the sites were maintained as in 2015 i.e. just by spraying. During this period the bare plots became covered with a thin layer of moss (dominated by *Brachythecium rutabulum* and *Amblystegium serpens*). In 2017 the moss cover on two of the bare ground plots was removed to leave bare soil while the remaining two were left moss-covered, to see if this had any influence on the ground beetle fauna.

Trapping method and strategy

Ground beetles were sampled using pitfall traps, which in this study consisted of two parts; a piece of plastic piping, 65mm in diameter and 100mm in length, placed in a hole dug for the trap to form a sleeve, and the trap itself, a plastic pot 70mm deep with a rim 65mm in diameter tapering to a base of 55mm that rested inside the piping with the rim level with the ground surface. The pipe sleeves were put in place in November 2014 well in advance of the first trapping period in March 2015. Digweed *et al* (1995) showed that for carabids a period of less than two weeks was sufficient to eliminate the initial effects of disturbance associated with pitfall trap installation. The traps were covered with 3cm diameter plastic coated chicken wire, anchored with two thin metal pegs, which prevented the capture of small rodents and amphibians but still allowed access to ground beetles (Figure 2). The traps were filled with approximately 30ml of 25% ethanediol (antifreeze) and a few drops of detergent. To prevent the trap filling with rainwater 90mm diameter transparent plastic covers, supported on wooden pegs that could be pushed into the ground, were placed over each trap so as to leave a space of approximately 6cm between the trap and the cover. Bell *et al* (2014) found significantly more carabids in traps with transparent covers than those with opaque or semi-transparent.

Figure 2. Pitfall trap with cover.

Trapping took place over a seven-day period in each month, usually in the third week, from March to October in 2015, from March to July in 2016 and from April to July in 2017. After a trapping period the contents of each trap were emptied into individual containers labeled with plot and trap number, and later sorted in a white tray for carabids. These were stored in individual tubes in 70% isopropyl alcohol. Lids were placed over the plastic pipes to prevent captures during the periods when the traps were not in use.

2015

The aim of the 2015 study was to investigate the difference, if any, in ground beetles sampled on the different treatments. Two traps were set in each cleared plot, on the edge of each cleared plot and in each of the vegetated plots. In all three positions the traps were set approximately 2m apart, one trap close to the water's edge and the other on drier ground away from the water's edge.

2016

Vegetation structure is known to be a possible cause of bias in pitfall trap data when used to compare ground active invertebrates in different habitats. A number of authors (e.g. Topping & Sunderland, 1992; Melbourne, 1999) have shown that vegetation may impede the movement of invertebrates (including ants, spiders and beetles) and thus affect their chance of capture by pitfall traps and the validity of differences seen between, for instance, bare and vegetated ground. To mitigate this problem, and to lend support for the differences found in 2015, the number of traps in two of the bare and adjacent vegetated plots treatments were increased in 2016 from two to six, the rationale being that the effects of impedance would be reduced by increasing the probability of trap encounter. In the six-trap plots the two traps used in the 2015 study were left in place, and the four additional traps were placed on either side of these. This gave three traps near the water's edge and three on drier ground away from the water's edge, all with about a 1m spacing. The remaining bare and vegetated plots were left with two traps in each, as in 2015. All edge traps were removed.

2017

As mentioned above, during the 2016 study the bare plots developed a carpet of moss. To investigate the difference this change in habitat quality made to the ground beetles sampled, the moss was raked away from two of the bare plots to leave bare soil and left untouched on the two other bare plots. Two traps were placed in each of the four plots, with the same pattern used in 2015.

Identification of ground beetles

All carabids collected were identified to species with the aid of a dissecting microscope and keys by Luff (2007) and Lindroth (1974). Voucher specimens of all species recorded were carded and kept for reference in a store box.

Environmental measurements

In 2015 only, temperature and relative humidity was recorded each hour over each seven-day trapping period using a Data Harvest Easy Sense advanced logger. One temperature probe and one relative humidity probe were placed on the surface of the ground in one of the open plots and adjacent vegetated plot. At the end of the recording period data were downloaded onto an Excel spreadsheet. Differences in nocturnal and diurnal relative humidity and temperature were analysed by splitting the data into two twelve hour blocks (06.00h-18.00h & 18.00h–06.00h). A range was calculated for the two parameters for each weekly sampling period in each month. At the end of the eight-month study period monthly ranges for each time block were compared using Wilcoxon Signed-Rank.

Statistical analysis

Analysis of species richness, species diversity, and wetland specificity was carried out on the total number of carabids of each species trapped throughout the sampling period in each of the treatments. Species richness is a simple count of species and is dependent on sample size; the more individuals trapped the greater the expected number of species. Species diversity is an index that provides a more robust comparison of different sites. The Shannon–

Weiner function, an index based on information theory, was used to evaluate diversity. This one of the most frequently used measures of diversity and is usually expressed as

$$H = \sum_{i=1}^{s} pi \ln pi$$

where H= index of diversity, s= number of species, p_i= proportion of the total sample belonging to the *i*th species. The index was calculated for each treatment using Pisces software.

The specificity, or fidelity, of ground beetle species to wetland habitats was assessed by Lott (2003), who rated species according to their dependence on wetlands generally and not only reed beds. For this aspect of the analysis only species with a high fidelity to wetlands, defined as those that are routinely found in wetlands and are likely to be dependent on wetlands to maintain viable populations, were used to compare different treatments.

The statistical significance of differences between the reed bed treatments for the different characteristics was assessed using ANOVA (calculated in Minitab 14) and Wilcoxon signed-rank (calculated online at www.Socscistatistics.com/tests).

Results

Environmental measurements

Both temperature and relative humidity (RH) differed significantly between bare and vegetated ground in the time period 06.00–18.00h, with bare ground having a significantly greater range of both parameters than that covered by vegetation (Wilcoxon Signed-Rank P<0.05). For the time period 18.00-06.00h only temperature had a significantly greater range in bare compared with vegetated ground (Wilcoxon Signed-Rank P<0.05). A comparison of temperature range and RH in bare plots during the two time periods showed they both had a significantly greater range between 06.00-8.00h compared with 18.00–06.00h (Wilcoxon Signed-Rank P<0.05). A similar result was obtained in a comparison of the two parameters between the two time periods in vegetated plots, (Wilcoxon Signed-Rank P<0.05 in both cases).

Species richness

Over the three-year sampling period 55 species were found during the study, with the number of species found in any one year falling from 48 in 2015 to 34 in 2017 (Appendix). Rarer wetland species *Chlaenius nigricornis*, *Dyschirius aeneus*, and *Pterostichus gracilis,* occurred in 2015 although in subsequent years only *C. nigricornis* was found in much lower numbers. Seven species were added to the Priory Water list, four of which are strongly associated with wetlands (*Agonum micans, Bembidion articulatum, B. dentellum* & *D. aeneus*) and were found almost entirely on bare patches (the exception being *A. micans* which also occurred in an edge trap). Although the three other new species (*Bembidion properans*, *Agonum muelleri* and *Notiophilus palustris*) are not confined to wetlands they were found predominantly in bare or edge sites.

In 2015 there was a significantly greater species richness in bare compared with vegetated plots (one way ANOVA, $F = 15.33_{1,7}$ P>0.05). The edges plots fell somewhere in between and were not significantly different from either bare or vegetated plots. In 2016 the differences in species richness were maintained in the six-trap plots (Wilcoxon Signed-Rank P<0.05), but not in the two-trap plots (Wilcoxon Signed-Ranks P>0.05). In 2017 there was no significant difference between bare soil and moss covered bare plots (Wilcoxon Signed-Rank P<0.05).

Diversity

In 2015 there was a significant difference in Shannon–Weiner H values between the plots (one-way ANOVA $F = 5.58_{1,7}$ $P<0.05$). A Fisher *post-hoc* test showed that bare plots had a significantly greater diversity than vegetated plots but the edges, which fell somewhere in between, were not significantly different from either bare or vegetated plots. In 2016 there was a significant difference in the diversity between bare and vegetated plots for the six-trap treatments (Wilcoxon Signed-Rank $P<0.05$), but not for the two-trap treatments (Wilcoxon Signed-Rank $P>0.05$). In 2017 there was no significant difference in diversity between bare soil and moss covered bare plots (Wilcoxon Signed-Rank $P>0.05$).

Wetland specific species

Eighteen species of wetland specific ground beetles were found in 2015 (Table 1). Five of these were only found on bare plots and two on vegetated plots. Overall they showed a significant preference for bare plots (Wilcoxon Signed-Rank $P<0.05$). In 2016 12 wetland-specifics (with no new species) were found, which again showed a significant preference for bare plots (Wilcoxon Signed-Rank $P<0.05$, data pooled from six-trap and two-trap sites) although only two species were confined to bare plots. In 2017 thirteen wetland specifics (no new species) were found but there was no significant difference in their preference for either moss-covered or bare-soil sites, although significantly fewer individuals were found on moss-covered plots (Chi squared, $P<0.05$)

Table 1. Numbers of wetland specific species sampled in 2015 from bare and vegetated plots.

	Bare plots	Vegetated plots
Agonum emarginatum	55	53
A. micans	2	0
A. thoreyi	0	1
A. viduum	4	2
Acupalpus dubius	10	2
Bembidion assimile	39	2
B. articulatum	8	0
B. biguttatum	29	23
B. dentellum	1	0
B. lunulatum	28	3
Chlaenius nigricornis	7	2
Dyschirius aeneus	2	0
Elaphrus cupreus	58	4
Oxypselaphus obscurus	11	45
Pterostichus gracilis	0	1
P. minor	57	23
Stenolophus mixtus	3	0
Trichocellus placidus	0	1

Discussion

The creation of bare areas resulted in a significant increase in the carabid species diversity of the reed bed in the 2015 and 2016 sampling periods, assuming that the vegetated patches represented controls and gave a valid representation of the diversity that would have been found had no bare patches been created. It is possible that the creation of bare areas had an effect on the fairly small adjacent areas of vegetation, as did the trampling that inevitably occurred when traps were set and taken up. These factors may have added structural diversity to the vegetated sites and increased, rather than decreased, diversity. Several authors e.g. Honék (1988), have suggested that larger catches of some species are recorded on bare ground exposed to the sun, due to their thermophilic nature. In this study bare ground had a significantly greater range of temperature and humidity during both 06.00-18.00 and 18.00-06.00h time periods compared with the ground surface covered by vegetation. This variation may have suited particular species and contributed to the greater carabid diversity on bare ground plots.

During a three year survey of the carabids of Priory Water from 2010 to 2013 (Cook & Clark, 2013), three water edge sites were sampled using pitfall traps. Two of the water edge sites were sampled for two years and one (the reed bed used for the present study) for one year (2013). In all sites five pitfall traps were set for a week in every month throughout the sampling period and a combined total of 39 carabid species was recorded. Twenty species were recorded in the reed bed used in the present study. Although not equivalent to the present study, the sampling occurring in different years and at different intensities, this background survey data provides circumstantial evidence that the creation of bare areas in the reed bed resulted in an increase in species richness.

The 55 species for the one wetland site used in this study compares favourably with sites in a survey of Wicken Fen (Tinsley-Marshall & Eversham, 2014) where the most species rich site was Rymes Reed bed with 41 species. Martay *et al* (2011) found a total of 60 species at Wicken Fen with 28 species occurring in the most species-rich site. Species richness *per se* is not necessarily a useful assessment of the conservation value of a site and has often found to be relatively high in recently created, or disturbed, habitats (Riley & Brown, 2011). The modification of the reed bed did, however, result in an increase in a local species (*C. nigricornis*) that had only been found once in the previous three-year survey, although the status of this species has been revised in the recent species status review of Carabidae (Telfer, 2016) and is no longer considered Nationally Scarce. The only NS species found was *P. gracilis*, a single specimen occurring in one of the vegetated sites. *Dyschirius aeneus* is declining (Telfer, 2016) and has only been recorded in 85 national hectads since 1980 but, because of likely under-recording, has not been designated Nationally Scarce. The number of rare or local species in long established sites at Wicken Fen far exceeds the number recorded in the recently created reed bed on which this study was based. Eighteen of the species recorded in this study were high fidelity wetland species, defined by Lott (2003) as species that are routinely recorded from wetlands and mainly dependent on wetlands to sustain viable populations. Again, this compares well with the number found in the two Wicken Fen studies (17 in Tinsley-Marshall & Eversham, *op. cit*.) and 18 in Martay *et al* (2011)), although species data is only given for all species found, not for individual sites. Overall the results obtained from Priory Water suggest that the species richness and diversity of these wetland specialists may be enhanced by the presence of bare ground.

The use of pitfall traps to compare the ground active invertebrates associated with different habitats is clearly open to criticism. Impedance by vegetation and the differing susceptibilities of different species to capture are two of the main reasons why results using pitfall traps must be treated with caution. Direct searching of sites can be used as an alternative, but this is very labour-intensive and open to the same errors – both vegetation density and the habits of different species are likely to influence the results of comparisons. It seems reasonable to conclude that the results of this reed bed study provide some evidence in support of the idea that the value of wetland habitats can be enhanced by ensuring open ground is maintained alongside vegetated areas.

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Appendix

Species lists for Priory reedbed 2015 - 2017

	2015	2016	2017
Agonum emarginatum	✔	✔	✔
A. fuliginosum	✔	✔	✔
A. micans	✔		
A. muelleri	✔	✔	✔
A. thoreyi	✔	✔	✔
A. viduum	✔	✔	
Acupalpus dubius	✔	✔	✔
Amara communis	✔	✔	
A. familiaris	✔		
Badister bullatus			✔
Bembidion aeneum	✔		
B. assimile	✔	✔	✔
B. articulatum	✔		✔
B. biguttatum	✔	✔	✔
B. dentellum	✔		
B. guttula	✔	✔	✔
B. lampros		✔	
B. lunulatum	✔	✔	✔
B. mannerheimii	✔	✔	✔
B. obtusum	✔	✔	✔
B. properans	✔	✔	✔
B. quadrimaculatum	✔		✔
Chlaenius nigricornis	✔	✔	✔
Clivina fossor	✔	✔	✔
Curtonotus aulicus	✔	✔	
Dyschirius aeneus	✔		
Elaphrus cupreus	✔	✔	✔
Harpalus rufipes	✔	✔	✔
Leistus ferrugineus	✔		
L. fulvibarbis	✔	✔	✔
Loricera pilicornis	✔	✔	✔
Nebria brevicollis	✔	✔	✔
Notiophilus biguttatus	✔	✔	✔
N. palustris	✔		
Ophonus rufibarbis	✔		✔
Oxypselaphus obscurus	✔	✔	✔
Patrobus atrorufus	✔	✔	✔
Pterostichus gracilis	✔		
P. macer	✔		
P. madidus	✔	✔	✔
P. melanarius	✔	✔	✔
P. minor	✔	✔	✔
P. niger	✔		
P. nigrita	✔	✔	✔
P. rhaeticus		✔	
P. strenuus	✔	✔	✔
P. vernalis	✔	✔	✔
Poecilus cupreus	✔	✔	✔
Stenolophus mixtus	✔	✔	✔
Stomis pumicatus	✔		
Trechus secalis	✔		
T. quadirstriatus	✔		
T. obtusus	✔		
Trechoblemus micros		✔	
Trichocellus placidus	✔	✔	