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Short communication

Feeding preferences of a predatory beetle (*Pterostichus madidus)* for slugs exposed to lethal and sub-lethal dosages of metaldehyde

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Introduction

Carabid beetles are species rich and abundant in arable habitats worldwide and, due to their predatory polyphagous nutrition, potentially important as natural pest control agents (Kromp, 1999). Diversification of agricultural field margins with techniques such as sowing wildflower mixes can enhance populations of arthropods such as carabid beetles (Asteraki et al., 1995). Management of this type has been shown to reduce densities of pest insects in close proximity to field edges (e.g., Lys & Nentwig, 1994). However, an associated increase of populations of pest species of slug adjacent to sown wildflower margins has been documented (Frank, 1998). Under such circumstances, it has been suggested that chemical protection should be increased at the edges of crops (Friedl & Frank, 1998). This scenario provides slug predators with a range of potential prey items as a consequence of sub-lethal and lethal doses of molluscicides, in combination with unaffected living animals and those that have died from non-chemical causes. Applications of slug pellets to crops have been shown to dramatically depress carabid populations (Purvis & Bannon, 1992), but little is known about effects of molluscicides on arthropod foraging behaviour. Slug pellets are fed on directly by carabids and can even provide good control of some species (Kelly & Martin, 1989). Lack of sensitivity to such baits by other carabids may result from the poor attractiveness of the pellets as food items (Buchs et al., 1989). However, there is a requirement for more knowledge of beetle preferences for slugs that have consumed pellets. Investigations of beetle-slug interactions may be considered timely due to new approaches towards field margin management and the suggestion that carabid beetles such as *Pterostichus* sp. are potential biocontrol agents for slugs (Symondson & Liddell, 1993). This study examines the feeding behaviour of the carabid beetle *Pterostichus madidus* (F.) (Carabidae, Pterostichini), which can reduce densities of slugs in the field (Asteraki, 1993). Laboratory observations of the frequency and duration of beetle attacks on living and dead individuals of the grey field slug (*Deroceras reticulatum* (Muller) Limacidae) are used to assess the influence of lethal and sub-lethal dosages of metaldehyde ingested by the slugs on prey selection.

Materials and methods

Collections of *P. madidus* and adult *D. reticulatum* were made between 15–25 June 1999 in areas untreated with pesticides and stored in incubators (L16:D8; r. h. 60-75%) on a reverse day/night regime. *P. madidus* ($n = 30$) were kept at 20 °C (±1 °C) and fed on tubifex blocks, before the food was removed and subsequently kept for a further 5 days without food. *D. reticulatum* ($n = 120$; of mass 250–350 mg) were fed on grated, organically produced carrot *ad libitum* and kept at 10 °C (±1 °C) in trays (185 × 140 × 70 mm) containing eight individuals. Slugs that were treated with molluscicides were exposed to 0.4 g (ca 20 baiting points) of 6% metaldehyde pellets (a bran-based bait; pbi Agrochemicals, UK) for either 5 days before observations (whereupon dead individuals were used) or 2 days before observations to produce living individuals containing metaldehyde. It was evident from discolouration of the gut that treated slugs had fed on the pellets. After a minimum of 5 days acclimation to the laboratory environment, *P. madidus* individuals were removed from incubators and isolated in petri dishes for *circa* 30 min before observations began. After this ‘settling down’ period, individual *P. madidus* were sequestered in petri dishes (90 mm in diameter) each containing four types of prey item: (1) slugs killed by metaldehyde; (2) slugs in contact with metaldehyde for 48 h but living and mobile; (3) slugs killed by freezing (−18 °C) for 8 h; (4) living slugs. Prey items were matched for size and positioned in separate quadrants, away from the dish edge to take into account the thigmotactic nature of carabids. For observations, beetles were introduced into the centre of petri dishes in a random direction and observed under red lighting for 10 min to record the sequence and duration of contacts by antennae and palps with prey items. Contacts were recorded as occurring with or without feeding. Each beetle/slug was used only once and observations were carried out by several observers over a four hour period at 15 °C (±2 °C). The effects of treatment and status (living/dead) of prey items on feeding behaviours were compared using 2-way ANOVA using log transformed data, where status and treatment were fixed variables and individual was incorporated as a random variable in a repeated measures design (SPSS v.9).

Results

After introduction into petri dishes, starved *P. madidus* rapidly contacted and attacked the slugs. At least one prey item was attacked and fed on in all assays, over 93% of beetles contacted more than one slug before feeding and three or more prey items were investigated in over 60% of the tests. To compare the effects of prey type on beetle feeding preferences, comparisons were made using the amount of time spent feeding, expressed as a mean for all individuals (mean feeding duration). For each prey type, a mean feeding bout duration was also calculated. Since this mean was divided only by the number of individuals that fed on that prey type, the mean bout length was often higher than the feeding duration for the trial (the latter being divided always by the number of trials; $n = 30$).

Overall, *P. madidus* spent most time feeding on dead slugs ($F_{1,87} = 13.332$, $P < 0.001$; Figure 1a) and slugs containing metaldehyde ($F_{1,87} = 11.844$, $P = 0.001$; Figure 1a). However, the duration of feeding bouts was not influenced by the presence of a molluscicide ($F_{1,9} = 0.142$, $P = 0.715$; Figure 1b) or prey status ($F_{1,9}$ 1.156, $P = 0.310$; Figure 1b). There was no significant effect of individual (the repeated measure) on the mean feeding duration ($F_{29,87} = 0.291$, $P > 0.999$) or feeding bout duration ($F_{29,9} = 0.405$, $P = 0.969$). In addition, the combined effects of prey status and treatment did not interact significantly for these measurements (mean feeding duration; $F_{1,87} = 0.003$, $P = 0.958$: feeding bout duration $F_{1,9} = 0.019$, $P = 0.894$).

Examination of the number of contacts *P. madidus* made with prey items revealed no effects of treatment ($F_{1,87} = 0.069$, $P = 0.794$; Figure 1c) or status ($F_{1,87} = 2.713$, $P = 0.101$; Figure 1c). However, there was an interaction between these factors ($F_{1,87} = 4.122$, $P = 0.045$) and significant individual variation in the number of contacts made with prey items ($F_{1,87} = 1.704$, $P = 0.031$). As a consequence, no further ecological consideration of contact frequency is made.

Discussion

Under laboratory conditions, searching *P. madidus* (a generalist feeder) discriminated between molluscine prey items. Preferences in this study were expressed by the time spent feeding on slugs and were most strongly influenced by prey status with more attacks on dead slugs (Figure 1a). This may be expected, since it is well documented that many taxa target dead prey due to the reductions in energy expenditure and handling times compared to attacks on living prey (see Krebs & Davies, 1993). Preferences for dead slugs likely result from the absence of the mucus produced by the dorsal glands as an anti-predatory trait by healthy slugs (Denny, 1989). Such findings are comparable to those of Pakarinen (1994) who stressed slugs in order to reduce mucus secretions. Preferences for dead slugs questions the reliability of *Pterostichus* sp. as a biocontrol agent (in the presence of molluscicides) and necessitates caution in the interpretation of feeding studies using techniques that assess the impact of prey choice based on examination of gut contents (e.g., Symondson & Liddell, 1993). However, dead and dying slugs are rare in the absence of molluscicides (pers. obs.) and, under such circumstances, studies that find high rates of positive identification of molluscine prey items during immunological studies may be considered a good indicator of predation. This situation may change when slug pellets are present, particularly when they are applied at high concentrations (for

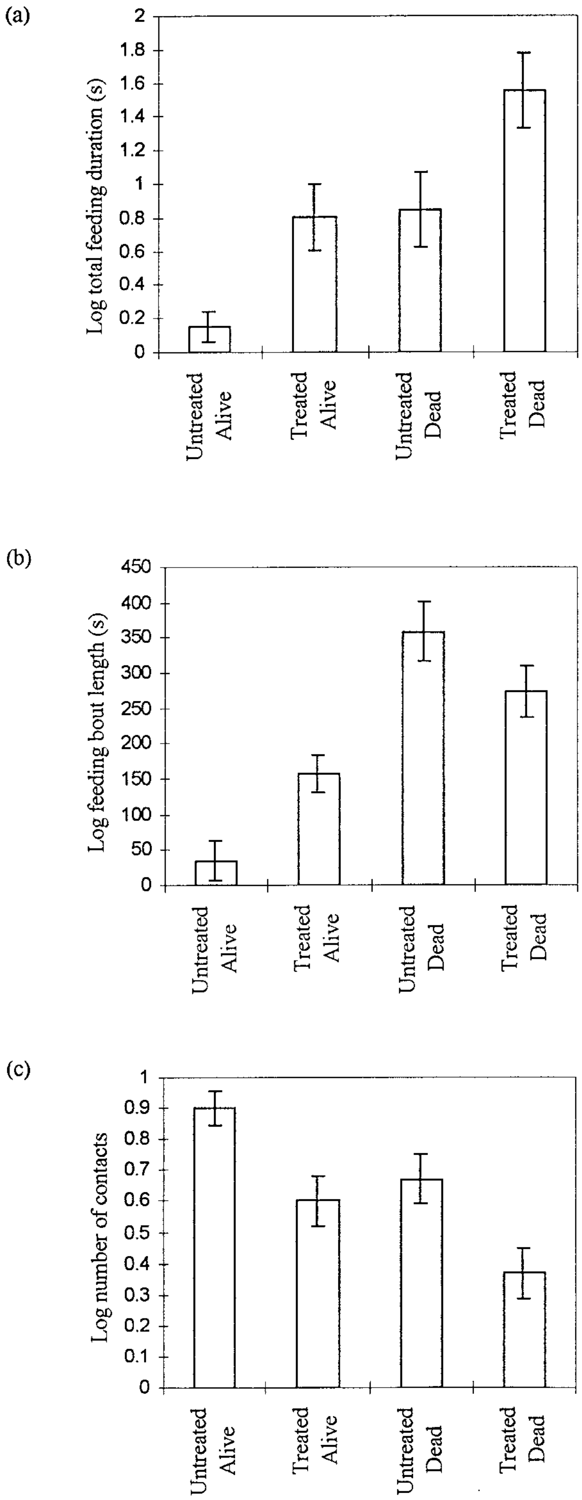

Figure 1. Results of laboratory bioassays (n=30) of feeding preferences of the predatory beetle *Pterostichus madidus* for slugs (*Deroceras reticulatum*) that were treated with metaldehyde (lethal and sub-lethal doseages), killed by freezing or alive. Preferences were measured by (a) the length of feeding bouts, (b) the mean feeding bout duration (based only on those prey items that were attacked), and (c) the number of times slugs were contacted. Log mean values (± s.e.) are shown.

example to field edges; Friedl& Frank, 1998). Interestingly, it has been suggested that the importance of scavenging to the diets of carabids is underestimated (see Kromp, 1999). However, Bohan et al. (2000) found that a related species (*Pterostichus melanarius*) was not opportunistic in its predation of slugs since this species had an associated spatial distribution with slug species including *D. reticulatum.*

It is likely that sub-lethal effects of metaldehyde result in a reduction in the slugs defences against predators, at least after the initial contact with the pellet (which results in copious quantities of mucous being secreted). This may lead to increased predation on slugs containing sub-lethal doses of molluscicide. Searching *P. madidus* prefer physically injured slugs, and often attack and damage the rear end of healthy slugs before engaging in feeding bouts (Pakarinen, 1994). The sub-lethal effects of metaldehyde may be considered to be similar to mechanical injury since beetle predators responded to prey in sub-optimal condition. These findings may provide an insight into why *P. melanarius* were not considered sensitive to metaldehyde/methiocarb (Buchs et al., 1989), yet their numbers in the field were reduced when methiocarb pellets were applied (Purvis & Bannon, 1992). Indeed, methiocarb is a more toxic formulation to carabids (Buchs et al., 1989) and it is feasible that both molluscicides may reach a higher trophic level through scavenging on poisoned slugs.

Differences between the ecology of carabid species, including their feeding behaviour, are documented (e.g. Wheater, 1989; Kielty et al., 1999). However, there is a requirement to determine interspecific differences in responses to prey containing pesticides, particularly for species such as *P. melanarius* which is a larger predator and less of a scavenger than *P. madidus*. Indeed the relative sizes of predators/ prey are of crucial importance to feeding studies in general. The collections and storage of slugs in the current study may have resulted in prey items being collected that are larger than would be targeted in the field by *Pterostichus* sp. This, in turn, could have contributed to the preferences for dead prey items detected in this study. An artifact of experiments of this type is movement of predators and prey to the edge of the arenas used for feeding observations. In the current study, periods of observation were confined to 10 minutes, beetles were observed to move all around the dishes and slugs rarely reached the dish edges. Thigmotactic behaviour by both predator and prey on the few occasions slugs contacted the dish edge could have increased encounters between beetles and living slugs. This may explain why the highest number of contacts occurred with living untreated slugs, since treated living slugs rarely moved during assays. This did not result in more time being allocated to feeding on more mobile prey which may be interpreted as observational evidence that the beetles 'foraged' within the petri dish environment rather than feeding being a consequence of an increased contact frequency with prey. The availability of prey (in terms of size, density and location) and the motivational state of the beetles (in the current study beetles were starved before exposure to prey and exposed to prey for 10 minutes only) may be greatly different in field situations and these factors have a strong influence on feeding behaviour (Wheater, 1987). Indeed it has been shown that *P. madidus* has different behavioural responses depending on many factors such as its motivational state (Wheater, 1991), gender and temperature (Kielty et al., 1999).

We have demonstrated distinct differences in prey choice by predatory beetles in a laboratory environment. Attacks by a generalist predator, *P. madidus*, targeted dead slugs and those (alive and dead) that contained a molluscicide (metaldehyde). Preferences are explained by the reduction in the anti-predatory trait of mucus secretion by slugs as a result of contact with molluscicides. The consequences of beetle feeding preferences for prey items containing molluscicides have implications for the balance between chemical and biological control of slugs in modern farming and gardening systems. Current work is investigating the impact of metaldehyde and methiocarb pellets on the feeding behaviour and growth of several Pterostichini beetles.

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