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Poecilus lucublandus (Coleoptera: Carabidae) and *Pterostichus mutus* Do Not Feed on Hair Fescue, Red Sorrel, and Poverty Oatgrass Seeds

Alexandre M. M. C. Loureiro, Jr.,[1,2,3] G. Christopher Cutler,[1] Vilis O. Nams,[1] and Scott N. White[1]

[1]Department of Plant, Food, and Environmental Sciences, Dalhousie University, Faculty of Agriculture, Truro, Nova Scotia, Canada, [2]Current address: Department of Integrative Biology, University of Guelph, Guelph, Ontario, Canada, and [3]Corresponding author, e-mail: alexandreloureiro13@gmail.com

Abstract

Poecilus lucublandus (Say), *Pterostichus mutus* (Say), and *Harpalus rufipes* (De Geer) are abundant Carabidae in lowbush blueberry fields and may contribute to weed seed predation. We used laboratory no-choice test experiments to determine if these beetles feed on seeds of hair fescue (*Festuca filiformis* Pourr., Poales: Poaceae), poverty oatgrass (*Danthonia spicata* L.), and red sorrel (*Rumex acetosella* L., Caryophyllales: Polygonaceae), which are common weeds in lowbush blueberry (*Vaccinium angustifolium* Ait., Ericales: Ericaceae) fields. *Poecilus lucublandus* and *P. mutus* did not feed on seeds of the test weed species, but *H. rufipes* consumed on average over 30 seeds of each species. There are other weed seeds in blueberry fields that could be palatable to *P. lucublandus* and *P. mutus*, which warrants further research on the granivory potential of these important carabid species.

Key words: granivory, Carabidae, blueberry

Carabidae are important natural enemies in many agricultural systems (Edwards et al. 1979, Westerman et al. 2003, O'Neal et al. 2005, Honěk et al. 2009). Most Carabidae are predators (Lövei and Sunderland 1996) but some are seed consumers, with potential for significant impacts on population dynamics of weeds in agroecosystems (Andersen 1989, Honěk et al. 2003, Honěk and Martinkova 2005, Bohan et al. 2011, Kulkarni et al. 2015). Carabidae community dynamics have been studied in the fields of commercial lowbush blueberry (*Vaccinium angustifolium* Ait.), an important crop in eastern North America (Hall et al. 1979, Prior et al. 1998). Dozens of species of carabids exist in lowbush blueberry fields in Nova Scotia, Canada, and many of the species inhabiting these fields are known seed eaters (Cutler et al. 2012). However, the potential for granivory has not been thoroughly evaluated for many Carabidae.

In early spring, *Poecilus lucublandus* (Say) and *Pterostichus mutus* (Say) are among the more prominent carabids in lowbush blueberry fields (Cutler et al. 2012). Viable overwintered seeds of many weeds can be found in these fields at the same time (Darbyshire and Cayouette 1989, Hoeg and Burgess 2000, White 2018). Although the predatory behavior of these species has been previously studied (Renkema et al. 2013, 2014), little is known of the potential for *P. lucublandus* and *P. mutus* to consume seeds of weeds commonly found in blueberry fields. Others have reported that *P. lucublandus* and *Pterostichus melanarius* (Illiger), a species of

the same genus as *P. mutus*, will consume brassicaceous weed seeds, common dandelion seeds (*Taraxacum officinale* W.), and de-hulled common millet seeds (*Panicum miliaceum* L.) in no-choice and field experiments (O'Rourke et al. 2006, Koprdová et al. 2008, Lundgren et al. 2013, Kulkarni et al. 2016).

We therefore examined whether *P. lucublandus* and *P. mutus* consume seeds of two economically important weeds commonly found in lowbush blueberry fields. Feeding of these species was compared with that of *Harpalus rufipes* (De Geer), a carabid known to feed on seeds (Harrison and Gallandt 2012, Cutler et al. 2016).

Materials and Methods

Beetle Collection and Experimental Designs

From early to mid-July 2016, we collected *P. lucublandus*, *P. mutus*, and *H. rufipes* from two lowbush blueberry fields in Debert (45°25′12″N; 063°30′41″W) and Portapique (45°24′22″N; 063°40′06″W), Nova Scotia, using pitfall traps (Greenslade 1964). Beetles were brought to the laboratory in clear 1-liter plastic containers, and then transferred to sealable plastic cups (120 ml) containing a 50:50 v:v moistened peat and play sand mixture. Beetles were fed cat food (Whiskas; Mars Canada, Canada) until they were needed for the experiments (Cutler et al. 2016). All beetles were collected within 2 wk of the start of an experiment and starved 60 h prior to the experiment. We collected

hair fescue (*Festuca filiformis* P.), poverty oatgrass (*Danthonia spicata* L.), and red sorrel (*Rumex acetosella* L.) seeds from the soil surface of blueberry fields using a hand vacuum (Shark 12 volt hand vac; SharkNinja Operating LLC, USA). Contents were returned to the laboratory for separation of seeds from soil. We determined the quality of hair fescue and poverty oatgrass seeds by soaking them in water, which turns the endosperm orange. We then discarded seeds without endosperms. We only used red sorrel seeds that were fully closed since they have a hard seed coat, which means any seeds that were open had a higher probability of missing the endosperm. It is unlikely that seed quality affected their palatability because our positive control species consumed them readily.

The first experiment was a randomized 2×2 factorial design, where the factors were beetle species (*P. mutus*, *P. lucublandus*) and weed species (hair fescue, poverty oatgrass) with 10 replicates of each factorial combination. The second experiment was a randomized 3×2 factorial design, where the factors were beetle species (*P. lucublandus*, *P. mutus*, and *H. rufipes*) and weed species (hair fescue, red sorrel). We added *H. rufipes* to a second experiment as a positive control since it is known to feed on seeds (Harrison and Gallandt 2012, Cutler et al. 2016), and red sorrel was used due to a shortfall of poverty oatgrass seeds collected from fields. In this second experiment, there was an uneven number of replicates for each factorial combination due to a limited number of *P. lucublandus* and *P. mutus* collected. There were 10 replicates for each combination involving *H. rufipes*, but 8 replicates for both *P. lucublandus* versus red sorrel and for *P. mutus* versus hair fescue, and 7 replicates for the remaining two combinations. We placed a single beetle inside a glass Petri plate (diameter = 9 cm, depth = 2 cm) containing 30 seeds of one weed species in the dish's center and a cotton wick saturated with water on the dish's side. Seeds were replenished when data were collected, and seeds were missing. We kept plates in a growth chamber at 22 (±1)°C and 60% relative humidity in a 16/8 h light/dark cycle.

For the first experiment, the number of seeds consumed (whole seed plus endosperm only) was determined at 2, 8, 12, 24, 36, 48, 60, 72, 96, and 144 h after the start of the experiment. Magnification was not necessary, since all beetles left behind empty seed husks clearly visible to the naked eye. In the second experiment, the number of

seeds consumed was recorded at 2, 6, 18, 30, 42, 54, and 68 h after the start of the experiment. Four *P. lucublandus* died at the end of the first experiment. No beetles died in the second experiment.

Statistical Analysis

In the 2×2 factorial design, we only measured the mean number of seeds eaten at the end of the experiment and calculated the standard error. We analyzed the 3×2 factorial design, which involved combinations between three beetle species and seeds from two weed species, by fitting a general linear model (GLM) with a quasipossion error distribution to the data. This error distribution is used when there is overdispersion, causing the variance to be higher than the mean (Crawley 2013). Here, we also reported the standard error of the mean. To analyze the feeding of *H. rufipes* over time, we fitted a Michaelis–Menten model (Bates and Watts 1988). We modified the model because the original gives a feeding rate of 0 when time approaches infinity, which is biologically meaningless. The modified Michaelis–Menten model is

$$y_i = \frac{x_i \theta_1}{x_i + \theta_2} + K_{fi} x_i + \varepsilon_i$$

where y_i = Mean cumulative number of seeds eaten of weed species i
   x_i = Time of exposure to seeds of weed species i
   θ_1 = Value of y_i at which the model asymptotes
   θ_2 = Value of x_i when $y_i = \frac{\theta_1}{2}$
   K_{fi} = Final consumption rate of weed species i seeds
 ε_i = Error term

We did the nonlinear regression and GLM analyses using the 'nls()' and 'glm()' functions, with the Gauss–Newton algorithm for the nonlinear iterations in R 3.5.0 (Wilke 2015, R Core Team 2017, Wickham 2017).

Results

Seed consumption by *P. lucublandus* and *P. mutus* in the 2×2 experiment was biologically insignificant. The mean cumulative number of seeds consumed of both weed species by both beetle species was < 1 after 144 h (Fig. 1A).

Fig. 1. Mean (± SEM) consumption of (A) hair fescue (*Festuca filiformis*) and poverty oatgrass (*Danthonia spicata*) seeds by *Poecilus lucublandus* and *Pterostichus mutus* after 144 h and (B) hair fescue and red sorrel (*Rumex acetosella*) seeds by *Poecilus lucublandus*, *Pterostichus mutus,* and *Harpalus rufipes* after 68 h in laboratory no-choice experiments.
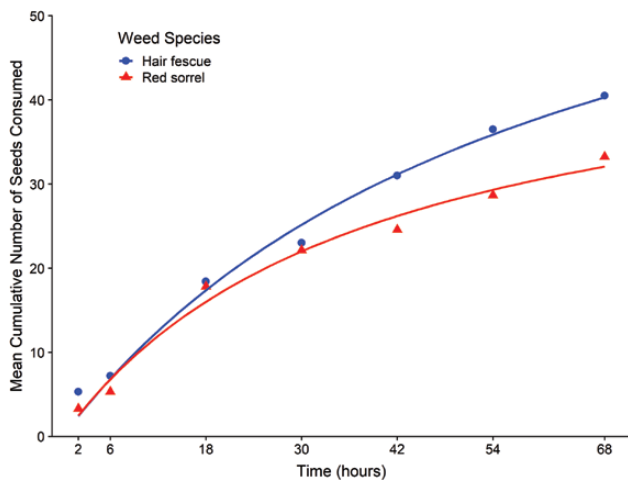
Fig. 2. Mean cumulative hair fescue (*Festuca filiformis*) and red sorrel (*Rumex acetosella*) seeds consumed by *Harpalus rufipes* in a laboratory no-choice experiment fitted with Michaelis–Menten model.

In the 3×2 experiment, beetle species was significant ($F_{2, 44}$ = 57.6, $P < 0.001$). Seeds consumption by *P. lucublandus* and *P. mutus* was again biologically insignificant, but *H. rufipes* readily fed on the seeds (Fig. 1B). *Harpalus rufipes* consumed both species of seeds equally after 68 h (beetle × weed species interaction; $P = 0.55$).

Over time, *H. rufipes* slowed its feeding rate (Fig. 2). The initial feeding rate of *H. rufipes* on hair fescue seeds (K_{0i}) was 1.24 seeds/h, while for red sorrel it was 1.3 seeds/h. The estimated final constant feeding rate on fescue seeds by *H. rufipes* was 0.4 seeds/h. We could not estimate the final feeding rate of *H. rufipes* on red sorrel seeds because the parameter estimate was not significant in the nonlinear regression analysis. The model parameter estimates for hair fescue seed feeding by *H rufipes* were: θ_1 = 76.73 (±11.51) and θ_2 = 61.50 (±16.18). The model parameter estimates for red sorrel seed feeding by *H. rufipes* were: θ_1 = 50.18 (±5.56) and θ_2 = 38.47 (±9.02). Both parameter estimates were significantly lower in the red sorrel model than in the hair fescue one.

Discussion

In the first experiment, *P. lucublandus* and *P. mutus* consumed less than one seed of either weed species. Coupled with the results of the second experiment, where they also consumed less than one seed, it is unlikely that these beetle species contribute to postdispersal consumption of hair fescue, poverty oatgrass, and red sorrel seeds in lowbush blueberry fields. This does not preclude the possibility that *P. lucublandus* and *P. mutus* may feed on seeds of other weed species in lowbush blueberry fields. Others have shown that *P. lucublandus* and other members of the *Ptersotichus* genus will consume de-hulled seeds of common millet (O'Rourke et al. 2006), common dandelion seeds (Lundgren et al. 2013), and three brassicaceous weed species' seeds (rapeseed, *Brassica napus* L.; wild mustard, *Sinapis arvensis* L.; and field pennycress, *Thlaspi arvense* L.) (Kulkarni et al. 2016). De-hulled seeds are softer than hulled seeds, and dandelion seeds are achenes (single-seeded fruits) that in many cases contain large embryos (Tweney and Mogie 1999). Hair fescue, poverty oatgrass, and red sorrel seeds may have been too tough for the beetles to chew on. Additional experiments would be valuable to determine if there are other seeds in blueberry fields that *P. lucublandus* and *P. mutus* consume. Both *P. lucublandus* and *P. mutus* are, however, generally

described as carnivores (Larochelle and Larivière 2003), which may limit potential for these species to contribute to weed seed consumption. *Pterostichus lucublandus* and *P. mutus* do, however, feed on insect pests of lowbush blueberry, including the blueberry spanworm (*Itame argillacearia* Packard) (Lepidoptera: Geometridae) and the blueberry flea beetle (*Altica sylvia* Malloch) (Coleoptera: Chrysomelidae) (Renkema et al. 2013, 2014).

Harpalus rufipes readily consumed both red sorrel and hair fescue seeds, eating on average more than 30 seeds of each weed species over 68 h, with a slowed rate of feeding near the end of the experiment. This reduction in feeding rate was likely due to satiation of the beetles (Honěk et al. 2003). *Harpalus rufipes* reduced its rate of feeding on red sorrel seeds faster than hair fescue seeds, which may have been due to size, nutritional, or chemical differences between seed types (Honěk et al. 2007, 2011). *Harpalus rufipes* is a well-known omnivore which feeds on many different types of seeds (Luff 1980, Jørgensen and Toft 1997, Cutler et al. 2016). Jørgensen and Toft (1997) found that *H. rufipes* thrives on a mixed seed diet, but it does not like seeds that are too hard, or seeds that have small endosperms. Cutler et al. (2016), who did both no-choice and choice tests, found that *H. rufipes* ate less hair fescue seeds than red sorrel in a no-choice test, which is different from what we found. The only substantial difference between our designs was the refrigeration of seeds by Cutler et al. (2016) prior to their experiment. Low temperatures of 13–18°C can have detrimental effects on seed nutrient content during seed development, and temperatures slightly above or below 0°C can damage seeds that are high in moisture content (Delouche 1968, Wolf et al. 1982).

Our experiments show that *P. lucublandus* and *P. mutus* do not consume significant amounts of hair fescue, red sorrel, or poverty oatgrass seeds, whereas *H. rufipes* readily feeds on common lowbush blueberry weed seeds and likely makes greater contributions to weed control through postdispersal weed seed consumption. All three carabid species coexist with and consume insect pests in lowbush blueberry fields (Cutler et al. 2012, Renkema et al. 2014). Therefore, maintaining populations of these carabid species in blueberry fields is desirable.

Acknowledgments

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