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Life History Characteristics of the Rove Beetle, *Dalotia coriaria* (Coleoptera: Staphylinidae) under Laboratory Conditions

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ABSTRACT: Rove beetles (Coleoptera: Staphylinidae) have been reported as predators of animal and human disease vectors and of insect pests associated with field and greenhouse crops including species in the genera *Aleochara*, *Holobus*, *Paederus*, *Dalotia*, *Staphylinus* and *Philonthus*; however, there is limited information on their life history parameters. The rove beetle *Dalotia coriaria* (Kraatz) is a predator of greenhouse pests including fungus gnats. In this study, stage-specific and total development, fecundity, longevity, and sex ratio were investigated under laboratory conditions using growing medium as a substrate, which was designed to simulate what rove beetles would experience under greenhouse conditions. Duration of life stages was 2.2, 7.1, and 7.8 days for egg, larva and pupa respectively, whereas total development time from egg to adult was 17.0 days. Average fecundity was 90.2 eggs per female and the number of adults produced per female was 69.1. In addition, *D. coriaria* male and female adult longevity was 60.3 and 47.8 days. The sex ratio was 1:1 (females:males). These results will be helpful in improving augmentative biological control and mass-rearing.

KEY WORDS: Biological control, bioassays, development, longevity, fecundity, sex ratio

Knowing the biology of a natural enemy is important for the success of any biological control program (DeBach and Rosen, 1991; Gurr *et al.,* 2000). In greenhouses, where augmentative biological control is an important component of pest management (Van Driesche and Heinz, 2004; van Lenteren, 2007; Parrella, 2008) the need to determine life history parameters is imperative in evaluating the performance of natural enemies prior to their introduction (van Lenteren and Manzaroli, 1999).

Studies have documented the potential use of rove beetles (Coleoptera: Staphylinidae) as biological control agents (Fournet *et al.,* 2000; Jandricic *et al.,* 2006; Padmavathi *et al.,* 2008) including the rove beetle, *Dalotia coriaria* (Kraatz) (Carney *et al.,* 2002; Birken and Cloyd, 2007), which is marketed in the USA by several biological control suppliers (Warner and Getz, 2008). *Dalotia coriaria* is a soil-dwelling biological control agent (Meihls and Hibbard, 2009). Both adults and larvae are predators of fungus gnat (*Bradysia* spp.) larvae, and adults may also feed on shore flies (*Scatella* spp.) and thrips nymphs and pupae; all of which are major insect pests of greenhouse-grown crops (Carney *et al.,* 2002; Helyer *et al.,* 2003; Meihls and Hibbard, 2009).

Certain aspects of the biology and feeding behavior of *D. coriaria* have been investigated under laboratory conditions using eggs of *Carpophilus hemipterus* L. and *Musca domestica* L., as a food source (Miller and Williams, 1983); however, there is no information on the life cycle of *D. coriaria* using growing medium as a

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substrate, which is what the rove beetles would experience in greenhouse conditions. Duration of the life cycle from egg to adult was 13, and 11 to 12 days at 27 and 32°C, respectively (Miller and Williams, 1983). In addition, *D. coriaria* development from egg to adult was 21 to 22 days at 25°C (Carney *et al.,* 2002; Helyer *et al.,* 2003). Adult longevity is approximately 21 days while the number of individuals (offspring) in the F_1 generation is 15 rove beetles per female, although this may vary (Carney *et al.,* 2002).

Other rove beetle species have been demonstrated to be potential biological control agents. For example, the rove beetles *Aleochara bilineata* (Gyllenhal) and *A. bipustulata* (L.) have been shown to be effective predators of the cabbage root fly, *Delia radicum* (L.) based on their life history as well as other parameters including the intrinsic rate of increase, host specificity, and host acceptance (Fournet *et al.,* 2000). In addition, predator effectiveness may be associated with synchrony of the prey life cycle (Mackauer, 1976; Fournet *et al.,* 2000). As such, development time of *A. bilineata* and *D. radicum* was found to be similar, which enhanced predation. Another study reported that *Holobus flavicornis* (Boisduval and Lacordaire) development time and adult longevity was 16 and 48 days at 28°C, while fecundity was 186 eggs per female, with 5 eggs produced per female per day (Chen and Ho, 1993). In addition, development time of the rove beetle, *Paederus fuscipes* (Curtis) was 16 days, with duration of egg, larva and pupa stages 5, 7 and 4 days. Male and female longevity was 54 and 72 days while fecundity was 21 eggs per female, and the sex ratio was 0.9:1 (female:male) (Devi *et al.,* 2002). Bong *et al.* (2012) found the development time of the immature stages was 17 to 18 days and fecundity ranged from 121 to 148 eggs depending on the strain of *P. fuscipes*.

Basic studies are essential in assessing the effect of external factors such as growing medium and pesticides on *D. coriaria* survival and development. Moreover, life history studies are useful in developing cost efficient mass-rearing techniques and improving quality control, which may be important in terms of natural enemy production. Therefore, the objective of this study was to determine several *D. coriaria* life history parameters important for population growth with the goal that this information may be useful for improving augmentative biological control programs as well as increasing the efficiency of mass-rearing of this predator.

Material and Methods

A rove beetle, *Dalotia coriaria* colony was maintained in a laboratory in the Department of Entomology (Kansas State University, Manhattan, KS) using Sunshine LC1 Professional Growing Mix growing medium (GM) containing Canadian sphagnum peat moss (73–83%), perlite, and dolomitic lime (Sun Gro Horticulture, Inc.; Bellevue, WA), and raw oatmeal (The Quaker Oats Company; Chicago, IL) as a supplemental food source. In addition, commercially available *D. coriaria* were purchased from a biological control supplier (IPM Laboratories Inc.; Locke, NY) in order to ensure *D. coriaria* availability for the study. Voucher specimens of *D. coriaria* are deposited as accession number 220 in the Kansas State University Museum of Entomological and Prairie Arthropod Research (Manhattan, KS).

Colonies were maintained in 7.8 L Rubbermaid® containers and 1.89 L Gladware® plastic containers. Substrate preparation was as follows: 1.5 L (approximately 500 g) of GM was mixed with 350 mL of water (70 mL water per

300 mL GM) in a 1.89 L Gladware plastic container. Supplemental food was provided by placing approximately 2.0 g of raw oatmeal onto the surface of the GM every 4 to 5 days. In order to maintain constant moisture, approximately 15 mL of water was applied or sprayed every 1 to 2 days on the surface of the substrate using a 946 mL plastic spray bottle (Home Depot; Manhattan, KS). Rove beetle (RB) colonies were maintained under ambient laboratory conditions of 22 to 24°C and 30 to 50% relative humidity (RH), under 0:24 (L:D) hour photoperiod.

Rove beetle adults were collected by sieving the GM using a sieve screen kit (Hubbard Scientific, Co.; Northbrook, IL), with mesh size #5 and #10. Rove beetles were subsequently collected into a 9 mL plastic vial using an aspirator. Mites (species unknown) were present in the colonies and appeared to attack the RB throughout the year, especially from late fall until the end of winter. Mites were observed feeding on RB life stages (eggs, larvae and adults). Mite populations increased rapidly and severely compromised the viability of the RB colony eventually completely depleting the RB population (Echegaray, 2012), which coincides with the observations of Carney *et al.* (2002) under laboratory conditions.

Duration of Life Stages from Egg to Adult

Dalotia coriaria life cycle duration was evaluated under a constant temperature. In order to obtain viable eggs, RB adults, males and females, randomly collected from the main colony, were placed in a 90 × 10 mm Petri dish with approximately 3.0 g of moistened Sunshine LC1 Professional Growing Mix growing medium containing Canadian sphagnum peat moss (73–83%), perlite, and dolomitic lime, and 1 to 2 pieces of raw oatmeal as a supplemental food source. Rove beetles were maintained in an illuminated incubator (Thermo Electron Corporation; Marietta, OH) at 26 ± 3°C and 50 to 60% RH under 12:12 (L:D) hour photoperiod.

Every 24 hr, the GM was carefully examined under a dissecting microscope for the presence of RB eggs. Rove beetle eggs were collected using a moistened, soft fine camel-hair paintbrush. Eggs were then placed individually on a filter paper disk lining the bottom of a 90 × 10 mm Petri dish with a piece of moistened cotton to enhance survival. Petri dishes were placed separately into a 740 ml plastic container. Ten Petri dishes were examined every 12 hr for 2 to 3 min, and the time from oviposition to egg hatch was recorded.

Immediately after egg eclosion, first instar larvae were collected using a moistened soft fine camel-hair paintbrush and individually transferred to a 90 × 10 mm Petri dish with a filter paper disk lining the bottom and approximately 3.0 g of GM. One to 2 pieces of raw oatmeal were placed in the Petri dish near the GM. The GM was examined daily to prevent the growth of mold and fungi. A small piece of moistened cotton was placed inside the Petri dish and replaced every 1 to 2 days to maintain constant moisture. Duration of the larval stage was determined by examining individual larvae every 24 hours from egg hatch until pupation using a dissecting microscope. Likewise, duration of the pupal stage was assessed by evaluating pupae from formation of the pupal chamber until adult emergence. Development time from egg to adult was also determined.

Fecundity

In order to determine female RB fecundity, recently emerged RB adult males and females (<24 hr old) were collected from the main colony into 9 ml vials using an

aspirator, and then placed into a 473 ml polypropylene deli squat container (Fabri-Kal Corp., Kalamazoo, MI) filled with 300 ml of moistened Sunshine LC1 Professional Growing Mix. Approximately ten days after inoculating the GM, third instar RB larvae were collected by sieving the GM using #5 and #10 mesh size sieves. Third instar larvae (head capsule width of 0.34 mm) were then recovered in 9 dram vials using an aspirator and placed separately into a 90 × 10 mm Petri dish with 3.0 g of moistened GM and 1 to 2 pieces of raw oatmeal in order to allow the larvae to pupate. A small piece of moistened cotton was placed in the Petri dish to maintain constant moisture. After one week, the GM was examined for the presence of RB adults.

After emergence, adults were immobilized by collecting them in a 9 ml vial using an aspirator, and then they were transferred into a 12 × 75 mm disposable culture tube (Fisherbrand®; Fisher Scientific, Pittsburgh, PA), which was placed into a 473 ml deli squat container half-filled with crushed ice, for 3 to 4 minutes, before examination under a dissecting microscope to determine gender (male or female). Sex of adults was determined by the shape of the eighth abdominal tergite as described by Klimaszewski and Peck (1998). Subsequently, male and female adults were grouped together to form mated pairs. Males and females were allowed to mate for 24 hr, and then mated pairs were placed separately into a 90 × 10 mm Petri dish containing approximately 3.0 g of moistened GM. One to two pieces of raw oatmeal were placed near the GM. Adults were transferred every three days to a new Petri dish containing moistened GM and raw oatmeal in order to provide enough moisture for survival but prevent growth of mold or fungi. The number of eggs laid per day by each female was determined by examining the GM every 24 hr. In addition, the total number of eggs laid per female was recorded.

Adult Longevity

Rove beetle adult longevity was determined using newly emerged adults (<24 hr old). Longevity was defined as the period (days) from adult emergence until death of RB adults. In order to determine longevity, individual adults were placed in a 90 × 10 mm Petri dish containing approximately 3.0 g of moistened GM and 1 to 2 pieces of raw oatmeal. Rove beetles were transferred every three days into a new Petri dish with moistened GM. The GM was examined daily for the presence of RB and longevity was recorded.

Number of Rove Beetle Adults Produced Per Female (F_1 Generation) and Sex Ratio

Ten mated RB adult pairs were placed separately into a 473 ml deli squat container with moistened GM. To prepare the substrate, 300 ml of GM was measured using a 600 ml beaker and placed into the container. Subsequently, 70 ml of water was added to the container and mixed thoroughly using a spatula. Approximately 3.0 g of raw oatmeal was added to the surface of the GM.

To prevent the RB parental generation (P_1) from mating with their progeny (F_1 adults), every 10 days, each RB pair was collected in a 9 ml vial, using an aspirator, and transferred to a new 473 ml deli squat container with 300 ml of moistened GM, as described previously. Approximately 15 ml of water was sprayed every 1 to 2 days onto the surface of the substrate using a 946 ml plastic spray bottle in order to maintain constant moisture. In addition, 3.0 g of raw oatmeal was added every 4 to 5 days, as a food source, onto the surface of the GM to avoid competition that could

Table 1. Summary of descriptive statistics associated with the rove beetle, *Dalotia coriaria* life history parameters at 26°C and 50 to 60% relative humidity. There were 10 replications for each life history parameter.

Parameters	Mean	Standard error	Minimum	Maximum
Egg (days)	2.20	0.13	2	3
Larva (days)	7.10	0.52	5	11
Pupa (days)	7.80	0.13	7	8
Egg to adult (days)	17.0	0.53	15	21
Male longevity (days)	60.30	3.81	47	86
Female longevity (days)	47.80	4.73	31	81
Fecundity (eggs per female)	90.20	8.93	50	138
Rove beetle adults per female (F_1)	69.10	6.01	39	104

potentially affect survival. The GM in the deli squat containers was examined three times—one, two and three weeks after removing the RB pairs, for the presence of adults (F_1 generation). The number of adults was counted and recorded. Each RB pair was transferred three to four times, each time using a new 473 ml deli squat container until cessation of the oviposition period (approximately 40 days after initiation of the experiment). The total number of adults produced per female (F_1 generation) obtained as the sum of all adults recovered from the deli squat containers was recorded. In addition, gender (male or female) was determined in order to obtain the sex ratio. For a given pair, if only the female was found to be alive, the missing male was immediately replaced by a new male collected from the main colony. Females that lived less than 10 days or failed to lay eggs were discarded.

Statistical Analysis

Data associated with *D. coriaria* life history parameters were analyzed using a statistical analysis software program, SAS for Windows, version 9.2 (SAS Institute, 2002). Differences in longevity (males and females), and fecundity and number of RB per female (F_1 generation) were assessed using a paired *t*-test procedure (SAS Institute, 2002).

Results

Duration of the incubation period (from egg-laying to egg hatch), larval stage (egg hatch to pupation), and pupal stage (pupation to adult emergence) under a constant temperature of 26°C, and 50 to 60% RH are presented in Table 1. The mean duration of the incubation period was 2.2 ± 0.1 (mean ± SEM) days, while duration of the larval and pupal stages was 7.1 ± 0.5 and 7.8 ± 0.1 days, respectively.

Rove beetle adult females initiated egg-laying 1 to 2 days after emergence based on visual observations conducted in the laboratory. Development time from egg to adult was 17.0 ± 0.5 days. There were two generations per month. The shortest development time from egg to adult observed was 15 days while the longest was 21 days. The generation time (time required to complete one generation) from a particular stage to the same stage in the next generation including the preoviposition period was 18 to 19 days.

Female fecundity, adult longevity, and reproductive potential (number of RB adults produced per female) are presented in Table 1. The mean number of adults

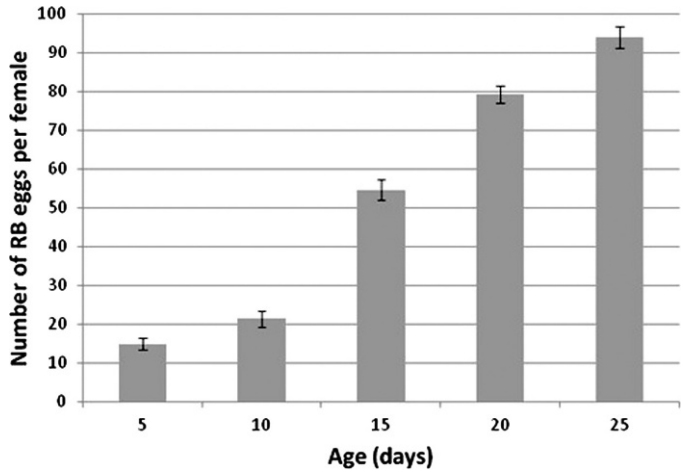

Fig. 1. Total number of rove beetle (RB), *Dalotia coriaria* eggs per female at 26°C, and 50 to 60% relative humidity, using oatmeal as a supplemental food source. There were ten females per age group. Vertical bars represent standard errors of the mean (SEM).

per female in the F_1 generation was 69.1 ± 6.0. The lowest number of adults per female was 39 whereas the highest number was 104. The mean number of males produced was 32.6 ± 3.1 and the mean number of females was 36.5 ± 3.6. Rove beetle females laid 90.2 ± 8.9 eggs with the lowest number of eggs laid 50 and the highest number of eggs laid 138. Rove beetle females laid from 0 to 8 eggs per day throughout their lifespan, although two females laid 10 and 14 eggs in one day. However, in a separate experiment with 10 replications, the mean number of eggs per female was found to be 15.0, 21.4, 54.7, 79.2 and 94.1 after 5, 10, 15, 20 and 25 days (Fig. 1), with the highest number of eggs laid 114. The sex ratio was approximately 1:1 (females:males) based on the total number of RB adults produced per female. Male longevity was 60.3 ± 4.3 with the shortest longevity 47 days and the longest 86 days, whereas female longevity was 47.8 ± 4.7 days with the shortest longevity 31 days and the longest 81 days. Based on a paired *t*-test procedure, there were no significant differences ($t = 2.05$; d.f. = 1, 19; $P = 0.055$) between male (60.3 ± 3.81) and female (47.80 ± 4.73) longevity. In addition, there were no significant differences ($t = 1.95$; d.f. = 1, 19; $P = 0.068$) between the number of eggs (90.20 ± 8.93) and the number of adults produced per female (69.10 ± 6.01). Five males remained alive for 94, 80, 86, 30 and 85 days while two females remained alive for 66 and 80 days.

Discussion

The effect of food source and temperature on *D. coriaria* development has been investigated (Miller and Williams, 1983). However, there is no information available associated with using growing medium as a substrate. Furthermore, *D. coriaria* fecundity and longevity has not been previously documented. In the current study, the development time from egg to adult was approximately four days longer (17.0 vs. 12.5) than that reported by Miller and Williams (1983) at 27°C, which may be due to the use of a different food source [oatmeal vs. live diet (eggs of Nitidulidae)] and GM as a substrate. Moreover, duration of the larval and pupal stages also differed from

that reported by Miller and Williams (1983); in the current study, larval and pupal stage durations were longer (7.1 vs. 4.8 and 7.8 vs. 5.4 days, respectively). However, duration of the egg stage (2.3 days) was similar to that reported by Miller and Williams (1983). Rove beetles that develop under adverse conditions such as low GM moisture content or inadequate food source apparently exhibit extended duration of the larval stage.

First and second instar larvae are extremely active and larvae tend to escape from the Petri dish within one to five days after egg hatching. Minimal mortality was detected, however, when larvae escaped from the Petri dish to the plastic container. Attempts to seal the Petri dish using laboratory film were unsuccessful apparently because high humidity and lack of ventilation inside the Petri dish resulted in larval death. In order to deal with this, 1 tsp of moist GM was placed into the 740 ml plastic container every 1 to 2 days. Larvae were then recovered from the GM into a 9 ml plastic vial using an aspirator and immediately returned to the Petri dish. The overall effect of larval mortality was low. Larval mortality was associated with excessive mold and fungi inside the Petri dish and the mites (described previously). In addition, cannibalism was observed, especially among young larvae and at high larval densities (Echegaray, 2012).

Duration of *D. coriaria* development tends to be reduced with increased ambient temperature (Miller and Williams, 1983) and also may be influenced by soil temperature. In fact, soil temperature affected the development time of *Aleochara bilineata* (Read, 1962). In the current study, females produced 2 to 4 eggs per day during their lifespan and egg deposition was fairly constant throughout the oviposition period, which ended 2, 3, and up to 10 days before termination of the female lifespan. In addition, when commercially available RB were used, females laid 3.7 eggs per day on average after 25 days, which is similar to *Holobus flavicornis* (4.6 eggs per female) (Chen and Ho, 1993). However, results associated with female fecundity as well as the number of RB produced per female (F_1 generation) were highly variable, which corroborates the findings of Carney *et al.* (2002). Therefore, in order to obtain a more consistent mean value (and lower standard error), a higher number of replicates may be necessary.

Female fecundity was obtained by counting the number of eggs in the GM; however, due to their small size, eggs were not easily detected. To deal with this, GM in the Petri dish was examined for three days, which allowed all viable eggs to hatch. After three days, not only the number of eggs but also the number of first instar larvae was counted. Rove beetle females that did not lay eggs or exhibited a short longevity (less than 10 days) were discarded. The number of RB adults per female was lower than the number of eggs per female (69.1 and 90.2, respectively) indicating that mortality in the egg, larva and pupa stages was about 22%. However, mortality during development, for all life stages of *A. bilineata*, was 60% (Fournet *et al.,* 2000). It also appears that the use of sterilized GM substantially reduces survival and reproduction (Echegaray, 2012), which may be associated with the killing of micro-organisms that the RB could use as a food source. This may have forced them to subsist solely on the plant material present in the GM. In addition, the GM may have been less suitable for *D. coriaria* oviposition because of a lack of fissures in the GM that may reduce egg-laying. Differences in GM moisture content, as well as the presence of predaceous mites in the GM, may have influenced RB survival in the deli squat containers. Moreover, differences between the number of eggs and number of

adults produced per female may also be explained by females having a short longevity, and therefore, having a lower oviposition period or fecundity. In the current study, we collected third instar RB larvae. The reason for this was because they are easier to collect from the GM; however, it is possible that this may be too late in the life cycle to begin counts of progeny as mortality to egg, and first and second instars could result in an underestimation of offspring production.

Adult longevity and number of RB produced per female differed from Carney *et al.* (2002) where adult longevity was <21 days with RB producing 15.6 ± 6.4 adults per female, although adult production was assessed assuming female longevity was about three weeks. In the current study, RB adults remained alive for 50 to 60 days, suggesting adults may live longer than three weeks and adult production was 69.1 ± 6.0 per female. Adult longevity was similar to *A. bilineata* at 49 days (Read 1962). In addition, Colhoun (1953) reported longevities of 47 and 49 days for females and males. These findings, however, differed from the results obtained with *D. coriaria*, in which male longevity was more extended compared to the female (60 and 48 days). In the current study, maximum adult longevity was 80 to 90 days, which was lower than both *A. bilineata* and *A. bipustulata* at 126 and 169 days, respectively (Fournet *et al.,* 2000). In addition, Fournet *et al.* (2000) reported a higher number of eggs per day (637) and total fecundity (1139 eggs per female) for both *A. bilineata* and *A. bipustulata*. Differences in food source (oatmeal vs. live diet) and reproductive potential may account for variations between species.

Dalotia coriaria development time and female preoviposition period were comparable to other rove beetle species. However, as with *D. coriaria* adults, *Paederus fuscipes* (Curtis) female longevity was more extended than the males (72 and 54 days) with high variability (40 to 50 days between the shortest and the longest duration) (Devi *et al.,* 2002). However, Bong *et al.* (2012) found that the female and male life span of *P. fuscipes* was very similar (50 and 51 days).

Fecundity is an important measure of reproductive potential in natural enemies; serving as an indicator of the quality of biological control agents (Hohmann *et al.,* 1988). Based on results from the current study, it appears that *D. coriaria* has a lower reproductive potential and fecundity compared to the fungus gnat *Bradysia* sp. nr. *coprophila* (80 to 90 eggs per female for *D. coriaria* compared to 100 to 200 eggs per fungus gnat female) (Gardiner *et al.,* 1990; Cloyd, 2008). This may limit the effectiveness of *D. coriaria* as a biological control agent unless higher numbers of predators are released; however, lower fecundity may not always indicate reduced effectiveness as it is possible that predators with lower fecundity may have higher predation rates thus resulting in their still being effective biological control agents. Fecundity was also lower compared to the shore fly, *Scatella tenuicosta* Collin (710 eggs per female) (Ugine *et al.,* 2007) and *S. stagnalis* Fallen (315 eggs per female) (Vänninen, 2001). However, duration of the life cycle was similar for *D. coriaria* and *B.* sp. nr. *coprophila* (development time from egg to adult of approximately 18 days), which corroborates the findings of Carney *et al.* (2002) based on visual observations under greenhouse conditions. In addition, *D. coriaria* adult longevity (50 to 60 days) may positively affect effectiveness as adults may prey and lay eggs for extended periods of time thus enhancing their ability to regulate fungus gnat larval populations in greenhouses.

In fact, both adult fecundity and longevity have been reported by Syme (1977) as important factors in determining the effectiveness of any natural enemy. In addition,

both the RB adults and larvae may be facultative predators and development times documented appear to be longer compared to other studies involving insect prey. Furthermore, parameters such as predation capacity and searching ability may warrant further investigation, as well as the effectiveness of the RB larval stage. Therefore, knowing the *D. coriaria* life history parameters, fecundity and longevity will be useful in terms of augmentative biological control by providing information that can be used to improve mass-rearing techniques, quality control, and overall effectiveness.

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