Biocontrol Science and Technology

ISSN: 0958-3157 (Print) 1360-0478 (Online) Journal homepage: http://www.tandfonline.com/loi/cbst20

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To cite this article: Rory Mc Donnell, Rico Santangelo, Tim Paine & Mark Hoddle (2016) The feeding behaviour of Rumina decollata (Subulinidae: Gastropoda) raises questions about its efficacy as a biological control agent for Cornu aspersum (Helicidae: Gastropoda), Biocontrol Science and Technology, 26:3, 331-336, DOI: 10.1080/09583157.2015.1111298

To link to this article: http://dx.doi.org/10.1080/09583157.2015.1111298

Accepted author version posted online: 19 Nov 2015.
Published online: 11 Jan 2016.

BIOCONTROL SCIENCE AND TECHNOLOGY, 2016
VOL. 26, NO. 3, 331–336
http://dx.doi.org/10.1080/09583157.2015.1111298

Taylor & Francis
Taylor & Francis Group

RESEARCH ARTICLE

The feeding behaviour of *Rumina decollata* (Subulinidae: Gastropoda) raises questions about its efficacy as a biological control agent for *Cornu aspersum* (Helicidae: Gastropoda)

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ABSTRACT

The facultative predatory snail *Rumina decollata* (L.) has been used as a biological control agent for *Cornu aspersum* (Müller) in Californian citrus orchards for almost half a century despite there being little laboratory and field evidence of its efficacy. We have demonstrated that *R. decollata* can only successfully kill *C. aspersum* that are <13 mm (shell diameter) and if given a choice between a known food plant (carrot roots) and *C. aspersum* within this vulnerable size range, the majority of *R. decollata* (~93%) chose carrots. Adult *R. decollata* will feed on *C. aspersum* eggs and mean total consumption per individual was ~3 eggs over a 7-day period. These experimental results support previous anecdotal suggestions that *R. decollata* may not be an effective snail predator.

ARTICLE HISTORY
Received 27 July 2015
Revised 17 October 2015
Accepted 19 October 2015

KEYWORDS
Rumina decollata; *Cornu aspersum*; biological control; generalist predator; vulnerable prey size range; plant preference

1. Introduction

The use of predatory snails to manage gastropod pests has seldom provided effective control and has often resulted in catastrophic effects on native biodiversity, e.g. the release of *Euglandina rosea* (Férussac) for the biological control of *Lissachatina fulica* (Bowdich) on Pacific and Indian Ocean Islands. Yet generalist snail predators are often still considered as biological control agents and some are even released (Cowie, 2001).

Rumina decollata (L.) is native to the Mediterranean region of Europe and North Africa and is a detritivore, herbivore, and predator of other snails (Tupen & Roth, 2001). It was first reported in the US in 1813 from Charleston, South Carolina, and from California in 1966 (Batts, 1957; Fisher, Orth, & Swanson, 1980), although it is likely to have been intentionally introduced to California in the late 1950s (Fisher & Orth, 1985). The purpose of this deliberate introduction to California is thought to have been to control *Cornu aspersum* (Müller), a widespread snail pest in California citrus orchards. There is a widely accepted perception in California's citrus growing community that *R. decollata* is an effective biological control agent of pest snails. However, it can only be used legally in Fresno, Imperial, Kern, Los Angeles, Madera, Orange, Riverside, Santa Barbara, San Bernardino, San Diego, Ventura, and Tulare counties because of potential negative impacts it poses to native and endangered gastropod species in other counties (California Department of

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Food and Agriculture, 1998). However, *R. decollata* has been recorded in non-regulated counties (Sacramento by RMD, and San Luis Obispo by Tupen & Roth, 2001) suggesting that intentional or accidental introductions into new areas are occurring, possibly putting non-target species at risk.

Although there are many reports of the apparent success of this snail in controlling *C. aspersum* in citrus groves, rarely, if ever, has direct causality been demonstrated experimentally (Fisher et al., 1980; Fisher & Orth, 1985; Sakovich, 1996). As a result, it has been suggested that reports of successful suppression of pest snail populations might be exaggerated (Tupen & Roth, 2001), or that actual evidence of its effectiveness as a biological control agent is weak if control does occur (Cowie, 2001). Furthermore, relatively little is known about the general biology of this predatory snail (Cowie, 2001) and the scientific literature contains many non-specific statements as to the sizes of *C. aspersum* that are vulnerable to predation, e.g. 'specimens that are half grown' (Fisher & Orth, 1985), or 'young *C. aspersum*' (Sakovich, 2002). Also, given that the snail is a known pest of cultivated plants (Fisher & Orth, 1985) and is a generalist malacophage (Barker & Efford, 2002), there are obvious concerns about non-target effects of biological control programmes and unregulated introductions of *R. decollata* into areas of California with native molluscs. These knowledge gaps and concerns provided the incentive for this study in which we aimed to determine the sizes of *C. aspersum* that are vulnerable to predation by *R. decollata*; to ascertain whether *R. decollata* exhibits a preference for *C. aspersum* over a known plant food item; and to assess the vulnerability of *C. aspersum* eggs to predation by *R. decollata*.

2. Materials and methods

2.1. Biological material

All *C. aspersum* and *R. decollata* used in bioassays were collected in the field from various locations in Riverside and San Diego Counties in Southern California. On return to the laboratory, the two species were maintained in separate plastic containers (33 cm × 16.5 cm × 12 cm) containing damp paper towel and a selection of organic vegetables for food. Towels and food were replaced twice weekly. *Cornu aspersum* eggs were collected from laboratory colonies at the University of California Riverside. Prior to bioassaying, test adult *R. decollata* (≥20 mm shell length) were starved for 3 days.

2.2. Laboratory tests

All tests were completed in polypropylene plastic containers (33 cm × 16.5 cm × 12 cm) lined with a single layer of damp paper towel, and observations were made after 24, 48, 72 h and 7 days.

2.2.1. Assessing the size of C. aspersum vulnerable to predation by R. decollata

Choice and no choice tests were used to determine the size of living *C. aspersum* preyed on by *R. decollata*. First, individual adult (i.e. ≥20 mm shell length) *R. decollata* ($n = 27$) were provided with a choice of a small (10–14 mm shell diameter), medium (15–24 mm shell diameter) and large (>24 mm shell diameter) *C. aspersum*. Prey snails were placed at

one end of the container and the predatory snail at the other. All snails began moving within minutes of being placed in the container. Based on the results of these choice tests, a second set of tests was set up in which individual adult *R. decollata* ($n = 9$) were provided with a choice of a small (10–14 mm shell diameter) and a very small *C. aspersum* (<10 mm shell diameter) only. For all choice tests the position of the food snails to each other was randomized for each replicate.

No choice tests ($n = 12$) were then conducted to determine whether they corroborated the results of choice tests. For these bioassays, the small and very small snail size categories were combined so that *R. decollata* were presented with three size classes of *C. aspersum* – small (3–14 mm shell diameter), medium (15–24 mm shell diameter) and large (>24 mm shell diameter).

2.2.2. Assessing preferences for a known plant food item versus C. aspersum

Individual *R. decollata* were given a choice between a small *C. aspersum* (3–13 mm shell diameter) and a piece of carrot root approximately the same weight and size as the prey snail. A total of 30 replicates were completed, i.e. three batches of 10 tests. Carrot is readily consumed by *R. decollata* (Fisher et al., 1980) and is visible in the gut through the shell as an orange mass when individuals have fed. The orange colour of consumed carrot in the gut readily facilitated the identification of specimens that had fed on carrot during these tests.

2.2.3. Assessing predation of C. aspersum eggs by R. decollata

Individual adult *R. decollata* ($n = 10$) were exposed to five fresh (<24 h after being laid) *C. aspersum* eggs placed in a 5 cm diameter plastic Petri dish lined with damp filter paper. The number of consumed eggs was counted after 24, 48, 72 h and 7 days.

3. Results

3.1. Assessing the size of C. aspersum vulnerable to predation by R. decollata

In choice tests with small, medium, and large *C. aspersum*, only small snails (10–13 mm shell diameter) were consumed by *R. decollata* (Table 1). Furthermore, snails were only

Table 1. Number of very small (<10 mm shell diameter), small (10–14 mm), medium (15–24 mm), and large (>24 mm) *Cornu aspersum* killed by starved (3 days) adult *Rumina decollata* in laboratory choice and no choice tests. Data in parentheses are the shell diameters of prey snails killed

		No. exposed	No. consumed				Total consumed
			24 h	48 h	72 h	7 days	
Choice test 1	Small	27	0	1 (12 mm)	0	4 (10, 11, 11, 13 mm)	5
	Medium	27	0	0	0	0	0
	Large	27	0	0	0	0	0
Choice test 2	Very small	9	3 (3, 6, 6 mm)	1 (7 mm)	1 (7 mm)	0	5
	Small	9	0	0	1 (12 mm)	0	1
No choice test	Small[a]	12	1 (9 mm)	1 (8 mm)	0	4 (7, 7, 8, 10 mm)	6
	Medium	12	0	0	0	0	0
	Large	12	0	0	0	0	0

[a]For no choice tests the small and very small categories were combined so that small snails fell into the size range 3–14 mm.

killed in five (18.5%) of the 27 tests. In the second set of choice tests (small versus very small *C. aspersum*) five very small and one small snail were consumed (Table 1). In the replicate in which the small snail was killed, the very small snail was attacked first (48 h earlier). Very small snails were eaten in five (55.6%) of the nine tests.

In the no choice tests, *R. decollata*, only consumed snails in the smallest category and predation occurred in 6 of the 12 replicates. Overall *R. decollata* only killed *C. aspersum* between 3 and 13 mm in size (shell diameter), and attack rates were low.

3.2. Assessing preferences for a known plant food item versus C. aspersum

In these choice tests *R. decollata* displayed a clear preference for carrot over *C. aspersum* with 93.33% (±4.22% [$n = 28$ snails]) of test snails selecting the former, 3.33% (±3.33% [$n = 1$ snail]) selecting *C. aspersum* and 3.33% (±3.33% [$n = 1$ snail]) not making a choice. Of those snails that selected carrot first, nine (32.1%) subsequently fed on *C. aspersum*.

3.3. Assessing predation of C. aspersum eggs by R. decollata

After 7 days, the mean (±SE) percentage of eggs (five available for each of ten snails) consumed per *R. decollata* was 62% (±10.09%), and 90% of *R. decollata* had consumed at least two eggs (Table 2).

4. Discussion

During the tests, we frequently observed *C. aspersum* on the sides and lids of the containers whereas *R. decollata* preferred to remain on the damp paper towel. Such spatial partitioning also occurs in the wild with *C. aspersum* crawling up citrus trunks and *R. decollata* tending to remain on the ground (Fisher et al., 1980). Consequently our results may reflect, in part, an aspect of the spatial partitioning of these snail species in the field and this may have an important impact on encounter rates and on the frequency of predation events.

Table 2. The total number, mean number (±SE) and mean percentage (±SE) of *Cornu aspersum* eggs consumed by 10 individual starved (3 days) adult *Rumina decollata* after 24 h, 48 h, 72 h, and 7 days. Each snail was presented a total of five eggs.

	Cumulative egg consumption			
Decollate snail	24 h	48 h	72 h	7 days
1	1	3	3	3
2	2	4	5	5
3	2	2	2	2
4	0	0	1	4
5	0	0	0	0
6	1	2	2	2
7	2	2	2	2
8	4	5	5	5
9	3	3	3	4
10	2	4	4	4
Total	17	25	27	31
Mean no. ± SE	1.70 ± 0.40	2.50 ± 0.52	2.70 ± 0.52	3.10 ± 0.50
Mean% ± SE	34.00 ± 7.92	50.00 ± 10.44	54.00 ± 10.35	62.00 ± 10.09

Although *R. decollata* is recognised as a non-specific biological control agent, our data demonstrate experimentally that this species, if given a choice in the laboratory, is more likely to select a plant food item (carrot in our tests) over *C. aspersum*. Other reports in the literature support this apparent preference for plants. For example, Frömming (1956) suggested that *R. decollata* prefers to consume living plants to snails. Furthermore, *R. decollata* appears to only successfully overcome and kill prey snails <13 mm (shell diameter). Therefore, individuals larger than 13 mm probably escape predation in nature and, importantly, this category includes reproductively mature individuals that will continue to reproduce. Although the progeny of these snails will be prone to low rates of predation, it is likely that many will develop to reproductive maturity. When *R. decollata* was provided with snails within its preferred size range, predation occurred in <60% of our tests. These data may help, in part, to explain the failure of *R. decollata* to reduce *C. aspersum* populations at some sites in southern California (Fisher & Orth, 1985).

In terms of egg consumption, 10 starved adult *R. decollata*, on average consumed only three eggs each within a 7-day period. However, given that individual egg clutches of *C. aspersum* can contain >150 eggs (Lazaridou-Dimitriadou et al., 1998) and a single individual can lay >695 eggs throughout its life (Fisher & Orth, 1985), a significant number of eggs will probably escape *R. decollata* predation in the field. Furthermore, gravid *C. aspersum* lay their eggs 25–40 mm below the soil surface (Dekle & Fasulo, 2014) and although *R. decollata* can burrow (usually during adverse environmental conditions to aestivate [Batts, 1957]) the frequency with which it encounters subterranean *C. aspersum* egg nests is unknown. Therefore, unless the population of *R. decollata* is overwhelmingly large or predation efficacy is significantly higher in the field than indicated by laboratory tests, this ovicidal pressure is unlikely to be a significant driver of population decline in *C. aspersum*.

The data presented here question strongly the widely held assumption that *R. decollata* is an effective biological control agent of *C. aspersum* in California. Although there are many anecdotal reports of effective biological control of *C. aspersum* by *R. decollata* in citrus orchards, these apparent 'successes' are based on correlative, qualitative, observational data with little or no evidence of actual causality. There is an urgent need for rigorous manipulative field experiments to generate quantitative data to assess the biological control potential of *R. decollata* in California and the likely population level impacts it could have on *C. aspersum*.

Acknowledgements

We are grateful to Robin Veasey for collecting *R. decollata* and *C. aspersum* for our research. We thank William and Holly Stosic for allowing us to collect bucket loads of *C. aspersum* from their garden for these experiments. Thanks also to Christiane Weirauch for assistance with German translation.

Disclosure statement

No potential conflict of interest was reported by the authors.

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