Final Research Report

CTPB Project Number: 16-03-OSU

Project Title: Development of IPM strategies for management of slugs on Christmas trees

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Technical report

Introduction

Slugs are one of the most important pests of Christmas trees grown in the Pacific Northwest relative to load rejections in Japan, Hawaii and other Pacific Rim destinations (http://www.oregonlive.com/news/index.ssf/2008/11/hawaii_rejects_oregongrown_chr.html). For example, when a shipment of trees contaminated with *Arion* slugs is discovered in Hawaii officials reject the load, and either ship it back to the Pacific Northwest or have it cleaned up in Hawaii at the shipper's expense. Current strategies for managing slugs focus on a combination of chemical and cultural (e.g. shaking) measures. However, even with these approaches slugs continue to pose a significant economic problem for Christmas tree growers in the Pacific Northwest.

In order to develop effective tools for managing pests it is critical to know what species are infesting the target crop. Surprisingly this information is currently lacking for slugs in Christmas trees thereby making it very difficult to design effective approaches for their management. The objectives therefore of the proposed research were to 1) determine which slug species are present in Christmas Tree plantations and in shipping yards in both Oregon and Washington; 2) determine if these slugs are crawling up into the tree; and 3) identify the most efficacious molluscicides with the ultimate goal of minimizing contamination of exported trees with those slug species that result in shipment rejection.

Methods

Slug communities in Pacific Northwest Christmas tree plantations and shipping yards were determined as follows:

1. At seven Douglas fir (*Pseudotsuga menziesii*) plantations in Oregon and three in Washington five slug refuge traps (50 cm x 50 cm) were randomly placed and secured on the ground underneath trees within the plantations (Figure 1). Modified refuge traps were also wrapped around the trunk of three random trees

(Figure 2) within the plantations to determine if slugs are crawling up into the tree. These traps were checked monthly from November 2017 to December 2018.

2. At three shipping yards in Oregon and three yards in Washington, five slug refuge traps were placed in areas where we suspected slugs were present (e.g. the yard edge, adjacent to areas of debris). These traps were checked every second week during November and December only.

Figure 1. A slug refuge trap used to monitor slug populations in Douglas fir plantations in Oregon and Washington.

Figure 2. A modified slug refuge trap used to monitor slug movement into trees in Douglas fir plantations in Oregon and Washington.

During each collection all slugs were placed into labelled Ziploc® bags and returned to the lab where they were identified using Mc Donnell et al. (2009).

Given that different molluscicides have different efficacies against different pest species e.g. *Deroceras* slugs are more susceptible to metaldehyde than *Arion* slugs (Wedgewood and Bailey 1988), we tested various molluscicides (Table 1) against those species (*A. cirucumscriptus*, *A. subfuscus*, and *A. rufus*) we collected at our field sites that would cause shipment rejection if discovered in Christmas trees at a port of entry in the Pacific Rim. Due to the variable nature of slug collecting, we had to run some tests with a minimal number of slugs. For example we collected adequate *A. circumscriptus*, but *A. rufus* and *A. subfuscus* were much less common in the field, and we were only able to test two products against each of these species (Table 1).

Table 1. List of molluscicides used in laboratory trials.

Treatment	Application Rate	Active Ingredient	Concentration
Slug-Fest	10 oz in 10 gal water per 1000 ft^2	Metaldehyde	25%
Durham 7.5	13 lbs product / acre	Metaldehyde	7.50%
Sluggo	44 lbs / acre	Iron phosphate	1%
Lockout	25 lbs / acre	Metaldehyde	4%
Ferroxx AQ	44 lbs / acre	Iron phosphate	3%
Deadline MPs	40 lbs / acre	Metaldehyde	4%
Bug-N-Sluggo	44 lbs / acre	Iron phosphate; Spinosad	0.97 %; 0.07%
Ferroxx AQ	44 lbs / acre (Three applications)	Iron phosphate	3%
Deadline MPs	40 lbs / acre (Two applications)	Metaldehyde	4%
Bug-N-Sluggo	44 lbs / acre	Iron phosphate; Spinosad	0.97 %; 0.07%
Deadline MPs	40 lbs / acre	Metaldehyde	4%

Trials were conducted in plastic containers (Sterilite; 6 qt) lined with a single wet paper towel. Test slugs were added to a container and baits or sprays (Slug-Fest) were applied. Baits were weighed on a VWR fine balance and applied at labelled field rate. Rates were calculated based on the size of our containers (0.5 ft^2), for example 40 lbs / acre equated to 0.2 grams per container. Single applications were typically made and slug mortality was assessed usually after 24 hours. In several instances we carried out prolonged observations. For example, *A. circumscriptus* were exposed to Deadline M-Ps for two days, *A. rufus* were exposed to both Ferroxx AQ and Deadline M-Ps for five days, and *A. subfuscus* were exposed to Deadline M-Ps for two days.

Results

In total we collected 1451 slugs from eight different species under the ground refuge traps throughout the study. *Arion circumscriptus* (Appendix 1), *Arion subfuscus* (Appendix 2), *Deroceras reticulatum* (Appendix 3), and *Prophysaon* sp. (Appendix 4) were collected in both states and *D. reticulatum* was found at every study site. *Deroceras laeve* (Appendix 5) was collected at three sites in Oregon only while *Ariolimax columbianus* (Appendix 6), *Arion rufus* (Appendix 7) and *Limax maximus* (Appendix 8) were collected at three sites in Washington only.

In Oregon, we collected 799 slugs underneath the ground traps in the plantations (Figure 3) and 467 slugs underneath the traps in the shipping yards (Figure 4). At both location types, *D. reticulatum* was the most abundant species (plantations: 60.6%; yards: 89.0%). Of the other species collected *A. circumscriptus* (plantations: 13.8%; yards: 9.0%), and *A. subfuscus* (plantations: 15.0%; yards: 1.3%) would lead to container rejection if discovered on a shipment of trees destined for Hawaii and other Pacific Rim locations.

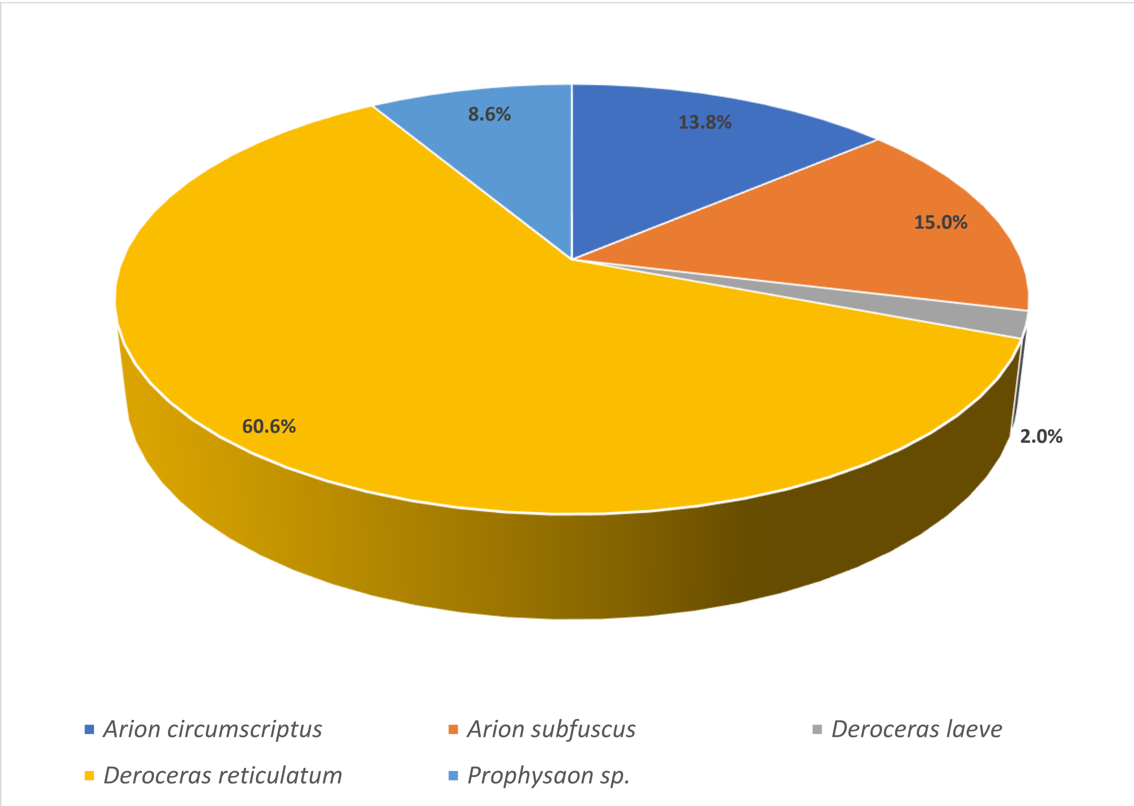

Figure 3. Slug species collected under refuge traps in Douglas fir plantations in Oregon. Percentage values are percentage of total catch (n = 799).

In Washington, we collected 156 slugs underneath the ground traps in the plantations (Figure 5) and 29 slugs underneath the traps in the shipping yards (Figure 6). At both location types, *D. reticulatum* was the most abundant species (plantations: 38.0%; yards: 69.0%). Of the other species collected *A. circumscriptus* (plantations: 10.2%; yards: 3.4%)*, A. subfuscus* (plantations: 21.1%; yards: 10.3%), and *A. rufus* (plantations: 2.4%; yards: 3.4%) would lead to container rejection if discovered on a shipment of trees at a port of entry in the Pacific Rim.

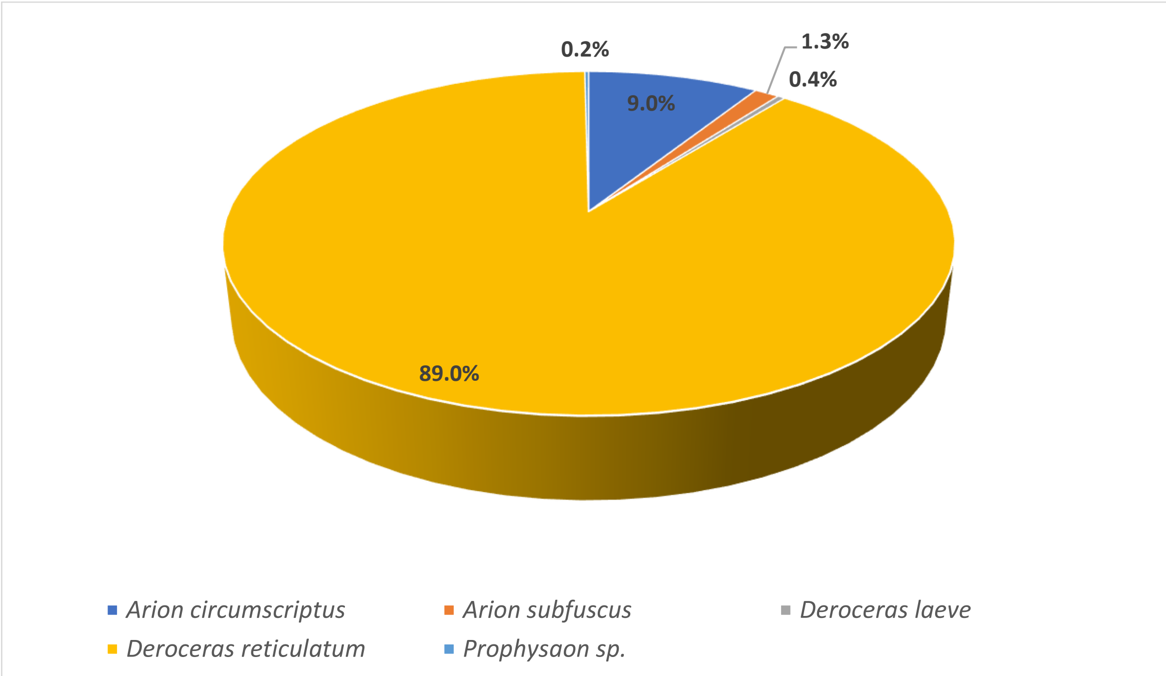

Figure 4. Slug species collected under refuge traps in shipping yards in Oregon. Percentage values are percentage of total catch (n = 467).

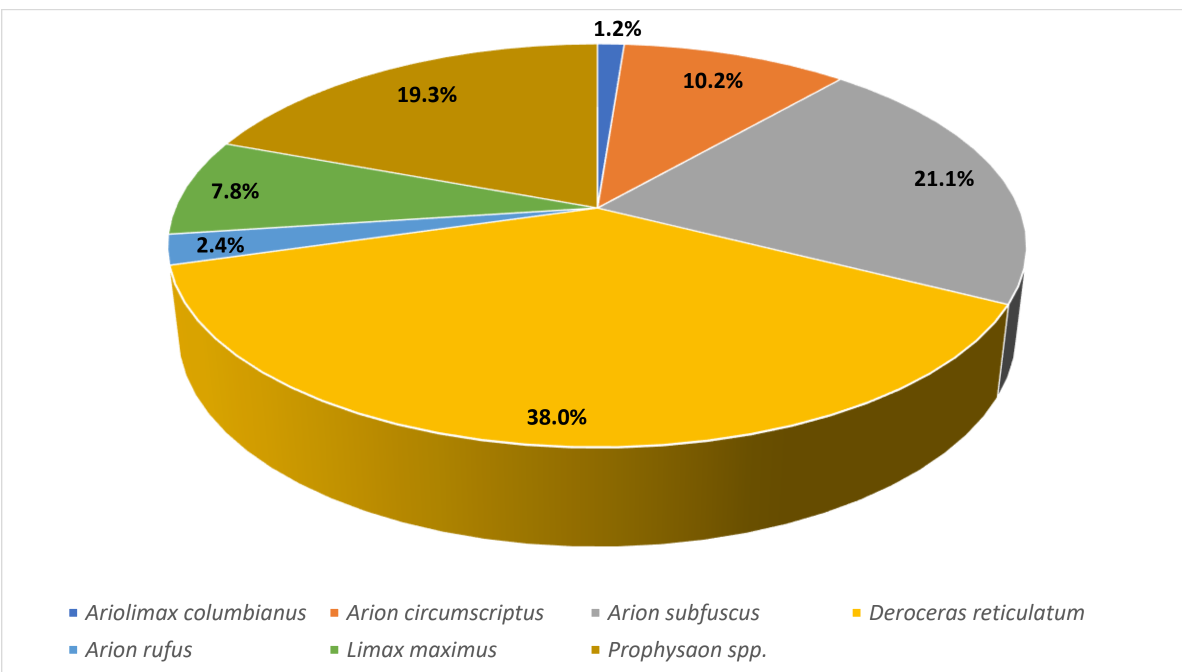

Figure 5. Slug species collected under refuge traps in shipping yards in Washington. Percentage values are percentage of total catch (n = 156).

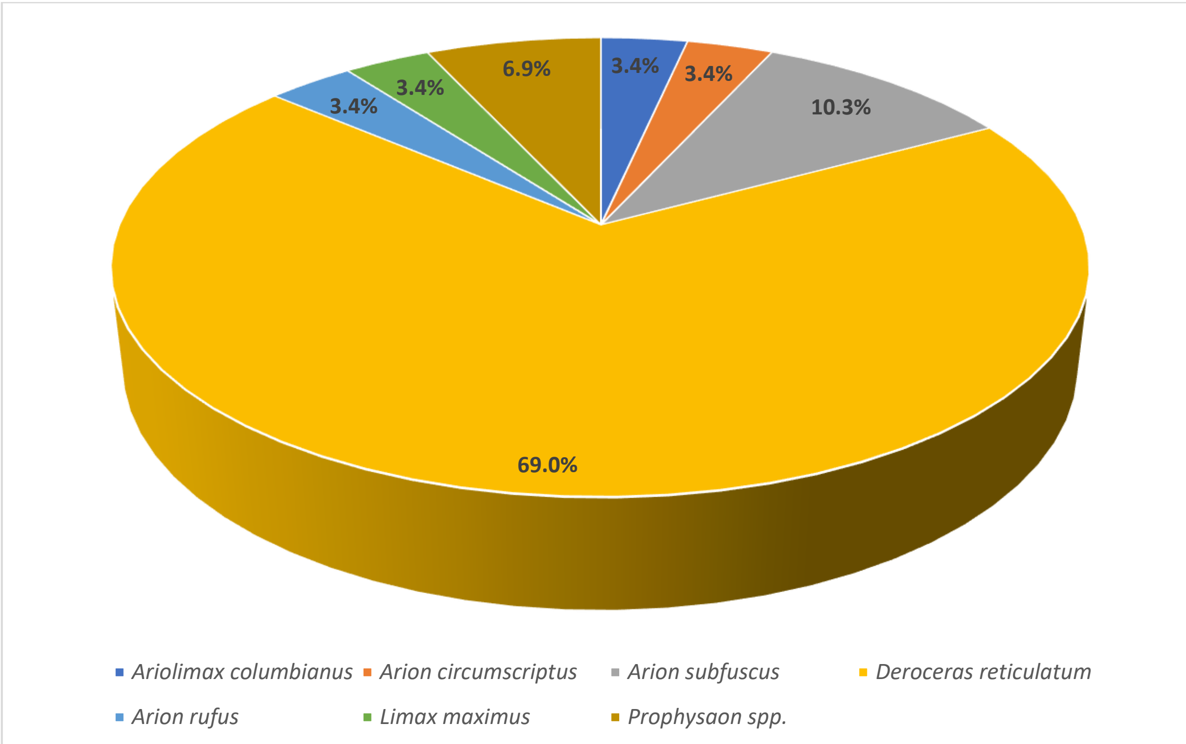

Figure 6. Slug species collected under refuge traps in shipping yards in Washington. Percentage values are percentage of total catch (n = 29).

We collected 28 slugs from five species under the modified blanket traps that were wrapped around the Douglas fir trunks (Table 2). *Deroceras reticulatum* (12 specimens total) and *Arion subfuscus* (11 specimens total) were the most abundant species. Both *D. reticulatum* and *Prophysaon* sp. (3 specimens total) were found in both states. *Arion circumscriptus* (Oregon only) and *L. maximus* (Washington only) were represented by singletons.

Table 2. The abundance of slugs collected under trunk refuge traps in Douglas fir plantations in Oregon and Washington.

	Oregon	Washington	Total
Arion circumscriptus	1	0	1
Arion subfuscus	11	0	11
Deroceras reticulatum	11	1	12
Limax maximus	0	1	1
Prophysaon sp.	2	1	3

For the molluscicide efficacy study, we tested seven different products against *A. circumscriptus*, and given the difficulty in finding *A. subfuscus* and *A. rufus* for the trials a limited number of products were tested against these species (Table 2).

Table 2. Efficacy of different molluscicides on *Arion circumscriptus, Arion rufus* and *Arion subfuscus* in laboratory trials.

Species	**Treatment**	**# Dead**	**# Alive**	**Mortality Rate (%)**
Arion circumscriptus	Slug-Fest	24	0	100
	Durham 7.5	23	1	95.83
	Sluggo	25	5	83.33
	Lockout	21	9	70
	Ferroxx AQ	8	22	26.67
	Deadline MPs	4	26	13.33
	Bug-N-Sluggo	0	30	0
Arion rufus	Ferroxx AQ	6	9	40
	Deadline MPs	4	14	22.22
Arion subfuscus	Bug-N-Sluggo	1	14	6.67
	Deadline MPs	0	15	0

Arion circumscriptus

The most lethal treatments against *A. circumscriptus* were Slug-Fest and Durham 7.5. Slug-Fest caused 100 % mortality, while Durham 7.5 caused 95.8 % mortality (Table 2). Sluggo and Lockout were also effective against this species, causing 83 % and 70 % mortality respectively. Several other products tested against *A. circumscriptus* produced lower levels of mortality. Surprisingly, Ferroxx AQ killed only eight out of 30 slugs (27 % mortality) and Deadline M-Ps (industry standard metaldehyde pellet in Oregon) killed only four out of thirty *A. circumscriptus* (13.3 % mortality). Sluggo, at only 1 % iron phosphate produced three times the mortality of Ferroxx AQ, which has a 3 % iron phosphate content. This again was a surprising result, and may indicate that Sluggo contains a superior attractant. Bug-N-Sluggo did not kill any slugs in these trials.

Arion subfuscus

In comparison to *A. circumscriptus* it was more difficult to collect *A. subfuscus* in the field prior to the molluscicide trials and hence only two products were tested against this species. We tested Deadline M-Ps (industry standard metaldehyde pellet) and Bug-N-Sluggo (a molluscicide with less non-target effects and approved for use in organic production) In order to get representative conventional and organic products. Each was tested against fifteen *A. subfuscus* (Table 2). Deadline M-Ps produced 0 % mortality over 48 hours. Typically if slugs are going to die in the laboratory after exposure to molluscicides, they die within 24 hours. Bug-N-Sluggo produced a 6.6 % mortality rate with one slug out of fifteen dying.

Arion rufus

It was also difficult to collect *A. rufus* and consequently this species was tested with one metaldehyde and one iron phosphate-based product. Four out of fifteen *A. rufus* were killed by Deadline M-Ps (22 % mortality), and six out of fifteen were killed by Ferroxx AQ (40 % mortality). However, after observing low mortality rates in *A. circumscriptus* with these products (see above), we decided to increase the number of applications, making three applications in four days. The Deadline M-Ps mortality rate in Table 2 was the result of using three times the label rate applied in a single dose and even with such a high rate, overall mortality was only 22%. These products do not seem to be effective in controlling *A. rufus*. Bug-N-Sluggo was also tested against fifteen specimens of this species, and it produced no mortality (Table 2).

Discussion

Slugs are an understudied pest of Christmas trees in Oregon and Washington despite being one of the most importance relative to load rejections in Mexico, Japan, Hawaii and other Pacific Rim destinations. For example, when a shipment of trees contaminated with *Arion* slugs is discovered in Hawaii which has zero slug tolerance officials reject the load, and either ship it back to the Pacific Northwest or have it cleaned up in Hawaii at the shipper's expense. Current strategies for managing slugs (e.g. shaking) are unreliable and consequently slugs continue to pose a significant economic problem for Christmas tree growers in the Pacific Northwest. Thus, in order to develop effective tools for managing any pest it is critical to know what species are infesting the target crop and surprisingly this information is currently lacking for slugs in Christmas trees. This knowledge gap makes it very difficult to design effective approaches for their management.

Our results show that eight different slug species infest Douglas fir plantation in Oregon and Washington. Of these, *A. circumscriptus*, *A. subfuscus*, *A. rufus*, *D. laeve*, *D. reticulatum*, and *L. maximus* are European invasive species (Mc Donnell et al., 2009). The remaining two species, *A. columbianus,* and *Prophysaon* sp. are native to the

Pacific Northwest and are generally not regarded as pests. These native taxa are forest dwelling species and thus their presence in Christmas tree plantations is not surprising. Of the eight species that we collected during our surveys, *D. reticulatum* was the most abundant, and accounted for ~70% of the total catch in plantations and yards in both Oregon and Washington. However, given that this species is a widespread global pest and has been recorded in Hawaii and throughout the Pacific Rim, it is not regarded as a quarantine species. On the other hand, the presence of *A. circumscriptus, A. rufus* and *A. subfuscus* in a shipment of Christmas trees would lead to shipment rejection at ports of entry and importantly these species were present in both holding yards and plantations in the Pacific Northwest. Thus, effective management of these species should be a priority for growers.

Our laboratory baiting trials showed that a number of commercial and widely available molluscicides caused high mortality to *A. circumscriptus* and these baits should be used as part of an IPM approach for management of the species. Bait should be broadcast in areas favorable for slugs (e.g. edges of yards, areas of debris, patches of weeds). Furthermore baits should be applied at times when slugs are active and likely to encounter and consume a pellet (e.g. when a spell of rain is followed by dry weather; temperature >50°C). Broadcasting baits during consistent wet weather is not recommended as such conditions result in rapid breakdown of the pellet and reduced efficacy. Spring and Fall applications will also be more effective than Summer and Winter applications.

Although our laboratory bait trials were more limited with *A. rufus* and *A. subfuscus*, these slug species may be more difficult to manage with baits alone and consequently other tools will likely need to be employed including shaking, weed removal, debris and trash removal, and avoiding leaving harvested trees on the ground particularly overnight.

Dissemination of Project Results

Mc Donnell, R.J. (2019) Slime time: Slugs and the development of novel approaches for their control. Pacific Northwest Christmas Tree Association Christmas Tree Short Course. Holiday Inn, Wilsonville, Oregon, February 22 2019.

There were 80 stakeholders in attendance for this presentation.

References

Mc Donnell, R.J., Paine, T.D. and Gormally, M.J. (2009) Slugs: A Guide to the Invasive and Native Fauna of California. University of California Agricultural and Natural Resources Publications. http://anrcatalog.ucdavis.edu/Items/8336.aspx

Wedgwood, M.A., and Bailey, S.E. (1988) The inhibitory effects of the molluscicide metaldehyde on feeding, locomotion and faecal elimination of three pest species of terrestrial slug. Annals of Applied Biology 112:439 – 457.

Appendix 1. *Arion circumscriptus* (© Roy Anderson)

Appendix 2. *Arion subfuscus* (© Roy Anderson)

Appendix 3. *Deroceras reticulatum* (© Rory Mc Donnell)

Appendix 4. *Prophysaon* sp. (© Joshua Vlach)

Appendix 5. *Deroceras laeve* (© Roy Anderson)

Appendix 6. *Ariolimax columbianus* (© Joshua Vlach)

Appendix 7. *Arion rufus* (© Rory Mc Donnell)

Appendix 8. *Limax maximus* (© Rory Mc Donnell)